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PETROLEUM IN THE FRESHWATER ENVIRONMENT

AN ANNOTATED BIBLIOGRAPHY 1946 - 1993

Health and Environmental Sciences Department
Publication Number 4640
March 1997

inland oil spills

DOCUMENT CONTENTS

PETROLEUM IN THE FRESHWATER ENVIRONMENT

AN ANNOTATED BIBLIOGRAPHY 1946 - 1993

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.

THIS DOCUMENT CONTAINS THE NON-EDITABLE VERSION.

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American Petroleum Institute

inland oil spills

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 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 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 transhipment 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, digenesis 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 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. Hrudey, 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.

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 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.

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 ($^{14}CO_2$ - 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 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.

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.

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 CO_2 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 CO_2 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 m^3 of No. 2 fuel oil into Mine Run Creek and approximately 120 m^3 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.

Effects on Rivers, continued

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

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 km^2 (4 mi^2) adjacent to Zeta Creek near its confluence

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 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,

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 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.

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

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.

Effects on Rivers, continued

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 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

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 cylcopoid copepods, copepod nauplii, barnacle nauplii, larvaceans, and larvae of polychaetes, gastropods, and shrimp. There is 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

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

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

densities were lower in oiled sediments (61/m^2) than in sediments without oil (224/m^2). In general, oiled sediments and low densities of nymphs occurred together downstream from industrial and municipal discharges.

Shafer, T.H. and C.T. Hackney. 1987. Variation in Adenylate Energy Charge and Phosphoadenylate Pool Size in Estuarine Organisms after an Oil Spill. *Bulletin of Environmental Contamination and Toxicology.* 38(5):753-761.

After a tanker spill of No. 6 diesel oil into the Cape Fear River in North Carolina, the effects of the spill on adenylate energy charge (AEC) and total phosphoadenylate pool (TPP) were examined for a year. AEC and TPP values of the organisms were compared between contaminated and uncontaminated sites at all seasons. Long-term changes in AEC may result from sublethal stress due to oil pollution in some tidal marsh plants and animals but not in others. TPP is not a more sensitive nor a more universal monitor of stress than AEC.

Smith, A.B., Jr. 1993. Colonial Pipeline Enoree River Oil Spill: A Case History. *Proceedings*, 1993 International Oil Spill Conference, Tampa, FL, March 29-April 1, 1993. API Publication No. 4580. American Petroleum Institute, Washington, D.C. pp. 165-168.

In December 1991 a pipeline ruptured releasing approximately 13,000 barrels of No. 2 fuel oil into Durbin Creek, South Carolina, an inland surface water system. Approximately 12,600 barrels (530,000 gallons) were recovered. The primary factors influencing this rate of recovery were the ability to provide containment at the leak site within 12 hours of the release and to establish containment downstream of the spill in advance of the leading edge of the oil plume.

Snow, N.B. and D.M. Rosenberg. 1975. *The Effects of Crude Oil on the Colonization of Artificial Substrates by Zoobenthos Organisms.* Technical Report No. 551. Fisheries Research Board of Canada, Winnipeg, Manitoba.

Studies were conducted to test the effect of Norman Wells crude oil on colonization of artificial substrates by macroinvertebrates. Oil-soaked and control substrates were deployed in four rivers, representing different flow and suspended sediment regimes.

Snow, N.B., D.M. Rosenberg and J. Moenig. 1975. *The Effects of Norman Wells Crude Oil on the Zoobenthos of a Northern Yukon Stream 1 Year After an Experimental Spill.* Fisheries and Marine Service, Environment Canada.

Effects on Rivers, continued

Physical, chemical and biotic parameters were monitored for 1 year following an experimental spill of Norman Wells crude oil in a Northern Yukon flowing water system. No lasting effects were observed in physical or chemical parameters, or in zoobenthos diversity 1 year after the spill.

Stuber, J.J. and R.K. Zhan. 1985. Biochemical Alterations Induced in Fish by an Acute Kerosene-spillage. *Archives of Hydrobiology.* 103(1):117-127.

This paper reports on the genotoxic consequences in rainbow trout persisting for 3 months following an acute kerosene spill in a river. The exposed fish showed highly increased mixed function oxygenase (MFO) activities and highly significant liver-DNA alternations, measured as single-strand breaks or labilities. This status of DNA alteration of MFO induction is discussed as a possible quasi-steady state equilibrium. The control fish showed the same ratio, though on a much lower level, of DNA alternation to MFO activity.

Travsky, A.L. 1985. Impacts of An Inland River Oil Spill to Terrestrial Wildlife. In R.D. Comer, T.G. Baumann, P. Davis, J.W. Monarch, J. Todd, S. VanGytenbeek, D. Wills and J. Woodling, eds. *Issues and Technology in the Management of Impacted Western Wildlife.* Thorne Ecological Institute. Boulder, CO. pp. 308.

On April 8, 1980, a crude oil pipeline ruptured spilling approximately 8500 barrels of oil into the North Platte River, Wyoming. Mortalities consisted of 355 birds and 33 mammals. An additional 883 birds and mammals were oiled but not captured. Studies through October 1981 compared recovery of the impacted area versus the control area. Some waterfowl and fur-bearer populations remained below pre-spill levels, probably from adult mortality and loss of the year's reproduction.

Wallace, R.R. 1987. A Review of Oil and Biological Community Responses in Northern Rivers. In J.H. Vandermeulen and S.E. Hrudey, ed. *Oil in Freshwater: Chemistry, Biology, Countermeasure Technology.* Pergamon Press, New York. pp. 345-352. *Proceedings* of the Symposium on Oil Pollution in Freshwater. Edmonton, Alberta, Canada. October 15-19, 1984.

This article reviews the use of specific organisms as indicators of stress from oil pollution in fresh waters to be a tool in quantifying the physical or chemical effects of such compounds. Assessments often overlook the interactive responses to oils, by bacterial, algal, and macrobenthic communities. In cold, brown-water rivers, the capability of microorganisms to degrade oil at temperatures as low as 4 C has been established. Field experiments indicate that interactions between components of the micro- and macrobenthic communities may determine the final, observed

responses in macrobenthic indicator organisms.

Weisberg, S.B. and W.H. Burton. 1990. Effects of the PRESIDENTE RIVERA Oil Spill on Young-of-year Striped Bass. *Proceedings*, Oil Spills Management and Legislative Implications Conference, Newport, RI, 15-18 May 1990. American Society of Civil Engineers. pp. 203-214.

On June 24, 1989, approximately 300,000 gallons of No. 6 fuel oil was spilled from the tanker PRESIDENTE RIVERA into the Delaware River. The spill occurred in the center of a striped bass nursery, only six weeks after prime spawning. Toxic effects of the spill on young-of-year striped bass were investigated using *in-situ* bioassay techniques. Despite oil fouling on chambers, no dissolved aromatic hydrocarbons were detected in the water column. Acute mortality was not apparent, with greater than 90% survival at all stations after four days. After 13 days, survival at the station closest to the spill site was about 20% less than at the reference station.

5.0 EFFECTS ON LAKES

Alexander, V., R. Clasby and C. Coulon. 1972. Primary Productivity and Phytoplankton Studies in the Barrow Tundra Ponds. *Proceedings*, 1972 Tundra Biome Symposium. U.S. International Biology Program. pp. 169-173.

A Barrow tundra pond which had oil (type unspecified) introduced in 1970 showed depressed total annual production and changes in phytoplankton species composition and seasonal succession during the following summer. Fertilization with phosphorus stimulated productivity but produced no marked change in species composition or succession.

Atlas, R.M. and M. Busdosh. 1976. Microbial Degradation of Petroleum in the Arctic. *Proceedings*, Third International Biodegradation Symposium. Applied Science, London. pp. 79-85.

Field study to assess distribution of microbes capable of utilizing petroleum hydrocarbons in arctic Alaskan coastal waters (but also in a freshwater pond). *In situ* biodegradation studies in the freshwater and a low saline (3‰) pond were conducted with Prudhoe Bay crude oil; additional treatments included seeding with an oil-degrading bacterium and addition of inorganic and organic fertilizers. Bioassays to evaluate the toxicity of Prudhoe Bay crude oil, fertilizers and seed bacteria to 4 test organisms (amphipods, *Daphnia*, rotifers and fairy shrimp) were done *in situ.*

Barsdate, R.J. 1973. Ecologic Changes in an Arctic Tundra Pond Following Exposure to Crude Oil. (Abstr.). *Proceedings*, Symposium on the Impact of Oil Resource Development on Northern Plant Communities, 1972. Institute of Arctic Biology, University of Alaska, Fairbanks. p. 52.

Physical, chemical and biological changes noted in small tundra pond following application of Prudhoe Bay crude oil in 1970. Massive zooplankton mortality occurred in 1970 and during 1971, the production of phytoplankton, benthic algae and vascular plants, numbers of benthic animals and biomass of chironomid larvae were all low. Preliminary information for 1972 indicated that the pond system was similar to 1971.

Barsdate, R.J., V. Alexander and R.E. Benoit. 1973. Natural Oil Seeps at Cape Simpson, Alaska: Aquatic Effects. *Proceedings*, Symposium on Impact of Oil Resource Development on Northern Plant Communities, 1972. Institute of Arctic Biology, University of Alaska, Fairbanks. pp 91-95.

Abundance and productivity of phytoplankton and numbers of bacteria in arctic

ponds near natural oil seeps were determined. Ponds relatively free of oil and those containing much fresh, low viscosity oil were investigated. Depending upon the level of hydrocarbon stress, stimulation or phytotoxic effects were observed.

Bennett, G.F., G.R. Kunkle, E.J. Tramer, C.E. Stoops, Jr. and R.H. Scheidel. 1984. Oil Spill Focuses Attention on the Problems of a Man-Made Recreational Lake. *Journal of Environmental Systems.* 14(1):31-49.

A runaway railroad engine fell into a turntable pit at maintenance facility and its oil tanks ruptured releasing 4,000 gallons of No. 2 diesel oil. The oil flowed to an agricultural stream that led to an inland, man-made lake. Within two days oil completely covered the water surface. A team of scientists and engineers used a systems approach to evaluate the lake, its water quality, inputs into it, and impact of the oil on it. The results of their study indicated that the oil spill had short term effects only, and there were several other circumstances that contributed to the poor quality of the lake.

Bergstein, P.E. and J.R. Vestal. 1978. Crude Oil Biodegradation in Arctic Tundra Ponds. *Arctic.* 31(3):158-169.

Experimental contamination of enclosed systems containing pond water, water and sediment, and sediment only within natural Arctic tundra ponds. Prudhoe Bay crude oil, oleophilic phosphate or inorganic phosphate fertilizers were added in various combinations to determine whether microbial degradation could be enhanced. Bacteria in water and sediment samples were enumerated (plate counts) and heterotrophic potential was measured, and the presence and activity of oil degraders was inferred from metabolism of radio-labelled hexadecane and naphthalene up to 3-4 weeks following treatment.

Berner, N.H., D.G. Ahearn and W.L. Cook. 1975. Effects of Hydrocarbonoclastic Yeasts on Pollutant Oil and the Environment. In A.W. Bourquin, D.G. Ahearn and S.P. Meyers, eds. *Impact of the Use of Microorganisms on the Aquatic Environment.* EPA-660/3-75-001. U.S. Environmental Protection Agency. Corvallis, OR. pp. 199-219.

Fungi isolated from oil-contaminated environments were introduced into both clean (freshwater lake) and contaminated (refinery drainage) water; both systems were enriched with oil (Louisiana crude or bunker C). The survival and development of seeded and indigenous fungal populations were monitored.

Effects on Lakes, continued

Blunden, D., M. Dale, S. Goudey and J. Hoddinott. 1987. Effects of Oil and Oil-Spill Chemicals on Shoreline Plants of Northern Freshwater Ecosystems. In J.H. Vandermeulen and S.E. Hurdey, eds. *Oil in Freshwater: Chemistry, Biology, Countermeasure Technology.* Pergamon Press, New York. pp. 403-409. *Proceedings* of the Symposium on Oil Pollution in Freshwater. Edmonton, Alberta, Canada. October 15-19, 1984.

The responses of five plant species in northern freshwater ponds to the dispersants Corexit 9600 and Corexit 7664 and dispersed oil were examined. Initial growth and recovery after dormancy were evaluated. The use of these species and other methods for assessing the toxic effects of oil-spill chemicals and crude oil in the development of bioassay methods are considered. The most visible and greatest short term effects of crude oil-spills and dispersant use on shoreline communities will be defoliation and a reduction in above ground plant cover.

Breuil, C. and D.B. Shindler. 1977. Effects of Crude Oil on Bacterial and Fungal Populations in Fresh water Artificial Ponds. *Abstracts of the Annual Meeting of the American Society for Microbiology.* 77:269.

Experiments conducted to determine effects of under-ice oil spills on planktonic microbial populations in subarctic artificial ponds. Microbial populations (total heterotrophs, proteolytic, lipolytic, amylolytic, denitrifying and nitrogen-fixing bacteria, sulfur-oxidizing, sulfur-reducing and methane-producing bacteria, and fungi) were monitored (plate counts, MPN technique) for more than a year following application of Norman Wells and Pembina crude oils.

Bührer, H. 1979. Influence of Hydrocarbons on Ecology of Bacteria in Aerobic Lake Sediment. *Schweizerische Zeitschrift fuer Hydrologie.* 41(2):315-355.

Fuel oil was applied to lake sediment cores at doses of 10 and 100 g/m^2 and microbial populations were monitored (direct counts, isolation and characterization of colonies formed on agar plates) for 21 days. On the basis of cluster analysis of species response, predictions of tolerable hydrocarbon loading to selected lake ecosystems are made.

Busdosh, M. and R. Atlas. 1977. Toxicity of Oil Slicks to Arctic Amphipods. *Arctic.* 30(2):85-92.

Studies were conducted on two species of Arctic amphipods to determine the toxicity of Prudhoe Bay crude oil, Arctic diesel fuel and various other crude oil components. *In vitro* and *in situ* experiments were used to calculate the time

Effects on Lakes, continued

required to achieve 50% and 100% mortality of the test populations.

Caparello, D.M. and P.A. LaRock. 1975. A Radioisotope Assay for the Quantification of Hydrocarbon Biodegradation Potential in Environmental Samples. *Microbial Ecology.* 2(1):28-42.

Laboratory enrichment culture procedures for quantification of bacterial hydrocarbon oxidizing activity in samples from natural environments. The amount of $^{14}CO_2$ evolved from samples inoculated with ^{14}C-hexadecane is used as a relative estimate of the hydrocarbon degradation capability of the microflora. Samples from a variety of locations (freshwater lakes to marine) were tested to assay biodegradation capability.

Cooney, J.J., S.A. Silver and E.A. Beck. 1985. Factors Influencing Hydrocarbon Degradation in Three Freshwater Lakes. *Microbial Ecology.* 11(2):127-137.

Mixed microbial flora of three lakes in Ohio with differing histories of hydrocarbon pollution were examined in relation to the ability to use hydrocarbons. The data indicate that temperature limits hydrocarbon degradation in the winter, except at a site which had been impacted by an oil spill and which received chronic inputs by hydrocarbons and nutrients. Results of temperature and nutrient-addition experiments suggest that different seasonal populations of hydrocarbon users are selected at that site.

Cooper, L.M. and R.K. Hosfeld. 1986. Investigation and Remediation of a Pond Contaminated by Diesel Fuel. *Proceedings,* Annual Meeting of the Association of Engineering Geologists, San Francisco, CA (USA), 5-10 October 1986. p. 47.

Several diesel fuel spills occurred at a truckstop facility located in Ohio and diesel fuel drained from the facility into a pond located 900 feet downstream. The pond became anaerobic, and on at least two occasions the accumulations of diesel fuel were so great that the fuel was burned off the surface of the pond. A total of 7500 cubic yards of fuel-contaminated soil was excavated from the site and hauled to an approved landfill. During the excavation, the pond became completely filled with uncontaminated sediment from the bottom of the pond. This sediment could best be characterized as a highly organic black muck having water content as high as 88% by weight. Because of its condition, the pond was completely filled using in-situ mechanical stabilization to solidify the muck.

Cushman, R.M. and J.C. Goyert. 1984. Effects of a Synthetic Crude Oil on Pond Benthic Insects. *Environmental Pollution.* 33(2):163-186.

Effects on Lakes, continued

The effects of a synthetic crude oil at doses equivalent to 375, 75 and 15 ml oil per cubic meter of pond water on pond benthic insects is described. Total insect abundance and abundance by taxon, total biomass and biomass by taxon, number of taxa, and species diversity based on abundance and biomass were all used as measures of community-level stress. The highest dose caused immediate effects, evident in all indices of stress. Three months after the dosing, there was some recovery of the pond insects even at the highest doses examined. In comparison with indices based solely on numerical abundance, indices of stress incorporating data on biomass of individual organisms did not add appreciably to the understanding of effects.

Dutka, B.J. and K.K. Kwan. 1984. Study of Long Term Effects of Oil and Oil-Dispersant Mixtures on Freshwater Microbial Populations in Man Made Ponds. *Science of the Total Environment.* 35:135-148.

The results of a 19-month investigation of microbial communities subjected to the effects of oil and oil plus dispersant additions in man-made ponds are reported. Microbial biomass estimations by ATP and microscopic procedures using epifluorescence indicated that oil and oil plus dispersants had little or no effect, and any effect noted was stimulatory. Seven days after the oil and dispersant additions to the ponds, no mutagenic or toxic activities to bacteria were noted.

Dutka, B.J., J. Sherry, B.F. Scott and K.K. Kwan. 1980. Effects of Oil-dispersant Mixtures on Freshwater Microbial Populations. *Canadian Research.* 13(5):58-62.

Experiments were conducted on artificial ponds to evaluate effects of Norman Wells crude oil and mixtures of oil and dispersant (Corexit 9527) on planktonic microbial populations. The following parameters were estimated before and following introduction of oil and oil-dispersant mixtures: total bacteria (direct counts), heterotrophic bacteria (plate counts), sulfate-reducing bacteria (MPN), numbers of bacteria capable of utilizing biologically degraded and non-degraded oil as sole carbon sources (spread plates), and numbers of fungi (membrane filtration). In addition, mutagen assays (Ames test) and bacterial toxicity studies (using *Spirillum volutans*) were done.

Edsall, T.A., B.A. Manny, D.W. Schloesser, S.J. Nichols, A.M. Frank, M. Munawar, and T. Edsall. 1991. Production of *Hexagenia limbata* Nymphs in Contaminated Sediments in the Upper Great Lakes Connecting Channels. Symposium on Environmental Assessment and Habitat Evaluation in the Upper Great Lakes Connecting Channels (at) 31. Conference on Great Lakes Research, Hamilton, Ont. (Canada), 1988. *Hydrobiologia.* 219:353-361.

Effects on Lakes, continued

From April through October 1986, researchers sampled sediments and populations of nymphs of the burrowing mayfly *Hexagenia limbata* throughout the connecting channels of the upper Great Lakes to determine if sediment contaminants adversely affected nymph production. Production was high where measured sediment levels of oil, cyanide, and 6 metals were below threshold criteria. At the other locations where sediments were polluted above the criteria, production was markedly lower. This finding indicates that existing sediment quality criteria can be applied to protect *H. limbata* from oil, cyanide, and metals in the Great Lakes and connecting channels. The species fulfills a major role in secondary production and trophic transfer of energy in these areas.

Federle, T.W., J.R. Vestal, G.R. Hater and M.C. Miller. 1979. Effects of Prudhoe Bay Crude Oil on Primary Production and Zooplankton in Arctic Tundra Thaw Ponds. *Marine Environmental Research.* 2:3-18.

Changes in phytoplankton species composition, biomass and primary productivity, and zooplankton mortality were investigated following controlled spills of Prudhoe Bay crude oil in "subponds" established at tundra ponds. Results are compared with data from uncontrolled spills in similar ponds in previous years.

Fremling, C.R. 1981. Impacts of a Spill of No. 6 Fuel Oil on Lake Winona. *Proceedings*, 1981 International Oil Spill Conference, Atlanta, GA, March 2-5, 1981. API Publication No. 4334. American Petroleum Institute, Washington, D.C. pp 419-421.

The impact of an accidental spill of 7400 gallons of No. 6 fuel oil on waterfowl and fish in a Minnesota lake is described.

Giddings, J.M., P.J. Franco, R.M. Cushman, L.A. Hook, G.R. Southworth and A.J. Stewart. 1984. Effects of Chronic Exposure to Coal-derived Oil on Freshwater Ecosystems: II. Experimental Ponds. *Environmental Toxicology and Chemistry.* 3(3):465-488.

Ten 15-m^3 outdoor ponds were treated daily for 8 weeks with a synthetic coal-derived crude oil; ecological effects were monitored for an additional 52 weeks. A gradient of responses was observed across treatment levels. Cladoceran (zooplankton) populations and ecosystem metabolism were affected at the lowest input rate. At the next higher treatment level, effects on zooplankton and ecosystem metabolism were greater and persisted until the oiling ended. Major changes occurred throughout the ecosystem at higher treatment levels. The two highest treatment levels completely disrupted the pond community. The results of this experiment were qualitatively and quantitatively similar to those of a parallel

experiment in pond-derived microcosms and thus substantiated the ability of the microcosms to simulate larger, more natural ecosystems.

Hanna, B.M., J.A. Hellebust and T.C. Hutchinson. 1975. Field Studies on the Phytotoxicity of Crude Oil to Subarctic Aquatic Vegetation. *Internationale Vereinigung fuer Theoretische und Angewandte Limnologie Verhandlungen.* 19(3):2165-2171.

To assess environmental impacts of future oil exploration, plant communities in a subarctic lake were studied in separate microcosms. Primary productivity (^{14}C method), cell numbers and biomass (chlorophyll *a*) were determined for phytoplankton; primary productivity (^{14}C uptake method) and biomass were determined for macrophytes.

Hellebust, J.A., B. Hanna, R.G. Sheath, M. Gergis and T.C. Hutchinson. 1975. Experimental Crude Oil Spills on a Small Subarctic Lake in the Mackenzie Valley, N.W.T.: Effects on Phytoplankton, Periphyton, and Attached Aquatic Vegetation. In *Conference on Prevention and Control of Oil Pollution.* (API Publication 4245). American Petroleum Institute, Washington, D.C. pp. 509-515.

The effects of Norman Wells crude oil on macrophytes, photoplankton, and periphyton in a small subarctic lake were studied in separate microcosms. Species composition, biomass and seasonal succession were examined. Phytoplankton appeared to be unaffected but periphyton showed marked inhibition. One blue-green alga showed considerable growth stimulation. Effects decreased over time. Laboratory studies of cultures of pond algae showed minimal inhibition of growth and photosynthesis under optimal light and temperature conditions. Macrophytes in the lake showed immediate decreases in chlorophyll and, in follow-up studies, significant decreases in biomass.

Horowitz, A. and R.M. Atlas. 1977. Response of Microorganisms to an Accidental Gasoline Spillage in an Arctic Freshwater Ecosystem. *Applied and Environmental Microbiology.* 33(6):1252-1258.

An investigation was conducted of the effects of an accidental spill of leaded gasoline (MOGAS) in an Arctic lake on resident microbial flora (water column and sediments). Total viable heterotrophs, gasoline-utilizing and MOGAS-tolerant microorganisms were enumerated, and respiration rates of sediments exposed to variable amounts of the gasoline were measured up to 6 weeks following the spill. Hydrocarbon degradation potential and gasoline content in sediments were estimated.

Effects on Lakes, continued

Horowitz, A., A. Sexstone and R.M. Atlas. 1978. Hydrocarbons and Microbial Activities in Sediment of an Arctic Lake One Year After Contamination with Leaded Gasoline. *Arctic.* 31(3):180-191.

A site investigation was conducted one year following the accidental spill of leaded gasoline (MOGAS) in an Arctic lake. Analyses of sediment samples were performed to: determine hydrocarbon content; enumeration of heterotrophic, gasoline-utilizing and MOGAS-tolerant microorganisms (plate counts); hydrocarbon biodegradation potential (radio-labelled substrates); and denitrification and nitrogen-fixation potential (acetylene blockage and reduction, respectively).

Hutchinson, T.C. and J.A. Hellebust. 1978. *Vegetational Recovery in the Canadian Arctic after Crude and Diesel Oil Spills.* Canadian Department of Indian and Northern Affairs. QS-8158-000-EE-AL. Ottawa, Canada.

Recovery of aquatic vegetation after low-, medium- and high-intensity Norman Wells Crude oil spills was observed. The degree of recovery was minimal to complete depending upon the intensity of the spill and the type of vegetation studied.

Johnson, B.T. and V.I. Romanenko. 1989. Multiple Testing Approach for Hazard Evaluation of Complex Mixtures in the Aquatic Environment: The Use of Diesel Oil as a Model. *Environmental Pollution.* 58(2/3):221-235.

This study assessed the toxicological hazard of diesel oil, to a model aquatic environment. The immediate impact of diesel oil dosed on a freshwater community was studied in a pond microcosm over 14 days: a 7-day dosage and a 7-day recovery. A laboratory microcosm was designed to monitor the biological effects of diesel oil on water, sediment, plants, and animals. To determine the sensitivity of each part of the community to the contamination and how the community recovered when the oil dissipated, limnological, toxicological, and microbiological variables were considered. The recovery period was characterized by a return to control values. The term 'toxicosm' is proposed to describe this approach and it is a valuable tool for screening aquatic contaminants.

Jordan, M.J., J.E. Hobbie and B.J. Peterson. 1978. Effect of Petroleum Hydrocarbons on Microbial Populations in an Arctic Lake. *Arctic.* 31(3):170-179.

An experimental oil spill (Prudhoe Bay crude) on a small, natural Arctic lake was studied to identify effects on natural microflora. Investigations of microbes in sediments and in the water column (enumeration by direct count, heterotrophic

potential, and hydrocarbon degrading capability) were made one year following the spill.

Kauss, P.B., T.C. Hutchinson and M. Griffiths. 1972. Field and Laboratory Studies of the Effects of Crude Oil Spills on Phytoplankton. *Proceedings of the Institute of Environmental Sciences*. 18:22-26.

Field experiments were conducted in a half-acre pond with cylinders placed to isolate columns of water, to study physical and chemical conditions within and outside the cylinders. Field studies showed that algal species responded quite differently to the oil. Some were inhibited, while others were actually stimulated, and others showed no effect. Laboratory studies showed that aqueous extracts of seven crude oils were inhibitory to the test algae but differed amongst themselves in degree of toxicity. The toxicity appeared to be reduced by volatilization of toxic components.

Kauss, P.B., T.C. Hutchinson, C. Soto, J. Hellebust and M. Griffiths. 1973. The Toxicity of Crude Oil and its Components to Freshwater Algae. *Proceedings*, Joint Conf. on Prevention and Control of Oil Spills, Washington, D.C., March 13-15. pp. 703-714.

Effects of an oil spill on freshwater algae were determined by using laboratory studies and a small, oligotrophic pond. Cylinders were placed into the pond to isolate a water column without significantly changing the physical factors and algal distribution within the pond. Results of the field experiment showed that a variety of responses occurred, that they were largely species specific, and that phytoplankton communities in water of differing nutrient status will likely show different responses because of their floral composition. Laboratory studies showed varying responses of algae to crude oil, depending upon the species.

McComas, T. 1980. *An Evaluation of the Accumulated Environmental Impacts to be Potentially Experienced by the Yukon Territory with Construction of the Foothills Oil and Gas Pipelines.* Appendix D: Effects on Flora. DOE/DFO Task Force, Northern Pipelines Program, Environment Canada, Vancouver.

An annotated bibliography of the literature pertaining to potential impacts of the construction of the Foothills Oil and Gas Pipelines on the Yukon Territory.

McKinley, V.L., T.W. Federle and J.R. Vestal. 1982. Effects of Petroleum Hydrocarbons on Plant Litter Microbiota in an Arctic Lake. *Applied and Environmental Microbiology*. 43(1):129-135.

Study of effects of spills of Prudhoe Bay crude oil, diesel fuel and toluene on Carex litter decomposition. The litter was colonized by natural microbes in an Arctic lake and removed to aquaria for experiments; hydrocarbon effects on activity of the litter microflora were evaluated by measuring the rate of radio-labelled acetate incorporation and by ATP levels. Rates of mineralization of labelled lignocellulose in lake sediments were measured to indicate effects of introduction of the same three petroleum substances and motor oil, gasoline and hexane.

Meyers, P.A. 1987. Chronic Contamination of Lakes by Petroleum Hydrocarbons: The Sedimentary Record. In J.H. Vandermeulen and S.E. Hrudey, eds. *Oil in Freshwater: Chemistry, Biology, and Countermeasure Technology.* Pergamon Press, New York. p. 149. *Proceedings* of the Symposium on Oil Pollution in Freshwater. Edmonton, Alberta, Canada. October 15-19, 1984.

Petroleum hydrocarbons enter lake systems through a variety of processes, most notably land runoff, rivers, and airborne particles, and can become part of the sedimentary record. Distributions of aliphatic and aromatic hydrocarbons in lake sediments do not have the same combination of transport processes. While water transports both, atmospheric inputs are the major pathway for aromatic hydrocarbons. The record preserved in sediments of lakes in North America and Europe parallels the history of petroleum usage in these regions and the chronic contamination of these lakes. Petroleum hydrocarbons can remain in lake sediments even though partial degradation of petroleum components occurs.

Meyers, P.A., J.O. Nriagu and M.S. Simmons. 1984. Petroleum Contaminants in the Great Lakes. In *Toxic Contaminants in the Great Lakes, Advances in Environmental Science and Technology*, Vol. 14. John Wiley and Sons Inc., New York. pp. 147-162.

This discussion of petroleum contaminants in the Great Lakes is divided into four parts - the problem of spilled petroleum, the extent of chronic petroleum contamination, the record of natural petroleum seeps, and the fate of petroleum contaminants. Where appropriate, examples from marine studies are used to augment the limited information about petroleum in these freshwater bodies.

Miller, M.C., V. Alexander and R.J. Barsdate. 1978. The Effects of Oil Spills on Phytoplankton in an Arctic Lake and Ponds. *Arctic.* 31(3):192-218.

Phytoplankton communities of a tundra pond were studied before and after a controlled spill of Prudhoe Bay crude oil. Species composition, biomass and primary productivity were examined along with effects due to changes in grazer (zooplankton) communities.

Miller, M.C., G.R. Hater and J.R. Vestal. 1978. Effect of Prudhoe Crude Oil on Carbon Assimilation by Planktonic Algae in an Arctic Pond. In D.C. Adriano and I. Lehr Brisbin, Jr., eds. *Environmental Chemistry and Cycling Processes: Proceedings of a Symposium, 1976, Augusta, Georgia.* Department of Energy Technical Information Center, Oak Ridge, TN. pp. 833-850.

Primary productivity (measured by ^{14}C bicarbonate assimilation), cell density, biomass and species composition of planktonic algae in a tundra pond were monitored before and after a controlled spill of Prudhoe Bay crude oil. Effects were measured over time to determine toxicity of weathering oil. The literature on effects of crude oil on phytoplankton (and some periphyton) of northern lakes and tundra ponds is reviewed.

Miller, M.C., J.R. Vestal, S. Mozley, M. Butler and J.E. Hobbie. 1977. Effects of Prudhoe Crude Oil Spills on Coastal Tundra Ponds. In *Energy/Environment II.* U.S.EPA-600/9-77-012. pp. 521-529. Available from National Technical Information Service, (703)487-4650 as PB-271506.

Field experiments were conducted on ponds receiving various treatments of Prudhoe crude oil to determine any alterations of phytoplankton and zooplankton composition and reduction in algal productivity and zooplankton reproduction. Toxicity of the crude oil to a variety of aquatic insects and zooplankton was determined in laboratory and field experiments.

O'Brien, W.J. 1978. Toxicity of Prudhoe Bay Crude Oil to Alaskan Arctic Zooplankton. *Arctic.* 31(3):219-228.

Several field and laboratory bioassay studies were conducted to determine the effects of Prudhoe Bay crude oil on Arctic zooplankton. The relative susceptibilities of several species of zooplankton to petroleum are discussed.

Pitts, M.E., V.D. Adams and M.D. Werner. 1987. Compositional Changes of Two Crude Oils Exposed to Weathering Processes in Freshwater Lakes and in Laboratory Aquatic Microcosms. In J.H. Vandermeulen and S.E. Hrudey, eds. *Oil in Freshwater: Chemistry, Biology, Countermeasure Technology.* Permagon Press, New York. pp. 31-41. *Proceedings* of the Symposium on Oil Pollution in Freshwater. Edmonton, Alberta, Canada. October 15-19, 1984.

Wyoming and South Louisiana crude oils were weathered in two Western US freshwater lakes over one year as well as in laboratory three-phase freshwater microcosms over 48 days. The compositional changes in the weathered crude oil samples were investigated at different times. The lake-weathered oils showed a substantial decrease in the more volatile, lighter molecular weight compounds after 7 days, and the oils continued to weather as shown by analysis of samples taken after 100 days. The microcosm oil samples showed little loss of the more volatile compounds because of a closed gaseous phase condition, but showed loss of heavier compounds probably by agglomeration and sedimentation.

Roeder, D.R., G.H. Crum, D.M. Rosenberg and N.B. Snow. 1975. *Effects of Norman Wells Crude Oil on Periphyton in Selected lakes and Rivers in the Northwest Territories.* Technical Report No. 552. Fisheries and Marine Service, Winnipeg, Manitoba.

Oil-treated and untreated artificial substrate samples were placed in three rivers and two lakes in the Northwest Territories to determine the effect of Norman Wells crude oil on periphyton. The community composition on the oil-treated substrates was different from untreated controls, and numbers of species were always equal or greater on the oiled substrates compared to the untreated controls.

Scott, B.F., E. Nagy, B.J. Dutka, J.P. Sherry, W.D. Taylor, V. Glooschenko and J. Hart. 1984. The Fate and Impact of Oil and Oil-dispersant Mixtures in Freshwater Pond Ecosystems: Introduction. *The Science of the Total Environment.* 35:105-113.

Oil and oil-dispersant mixtures were added to the surface waters of a series of man-made ponds. The fate of the oil and dispersant were studied as well as the impact of the added chemicals on the pond ecosystem. Comparisons were made between oil-treated and control ponds as well as oil-dispersant treated and oil and/or control ponds. The addition of dispersant to the oil resulted in a greater amount of oil utilized in the aquatic environment and a greater initial impact on the biota. After one year, with the exception of the filamentous material, recovery was at least comparable to the area where no dispersant was used.

Scott, B.F., E. Nagy, J. Sherry, B. Dutka, V. Glooschenko, N. Snow and P.J. Wade. 1979. Ecological Effects of Oil-Dispersant Mixtures in Freshwater. *Proceedings,* 1979 International Oil Spill Conference, Los Angeles, CA, March 19-22, 1979. API Publication No. 4308. American Petroleum Institute, Washington, D.C. pp. 565-571.

A series of field experiments monitored the effects of Norman Wells crude oil and Corexit 9527 dispersant spilled into artificial freshwater ponds on the changes of biomass of zooplankton, phytoplankton, bacteria and fungi present and on

alterations in dissolved oxygen concentrations.

Scott, B.F. and R.M. Chatterjee. 1975. *Behavior of Oil Under Canadian Climatic Conditions*. Scientific Series No. 50. Canada Center for Inland Waters. Burlington, Ontario.

The effect of freezing weather and ice conditions on the evaporation of the spilled crude oil was studied. A biological examination of the oil-polluted pond was conducted 8 months after the spill.

Scott, B.F. and D.B. Shindler. 1978. Impact of Crude Oil on Planktonic Freshwater Ecosystems. *Proceedings*, Conference on Assessment of Ecological Impacts of Oil Spills. American Institute of Biological Sciences, Arlington, VA. pp. 712-734.

Five oil spills of varied types and amounts were carried out in artificial ponds near Ottawa. Phytoplankton, protozoa, zooplankton and bacteria were monitored for population effects.

Scott, B.F. and V. Glooschenko. 1984. Impact of Oil and Oil-Dispersant Mixtures on Flora and Water Chemistry Parameters in Freshwater Ponds. *Science of the Total Environment.* 35(2):169-191.

Oil or oil dispersant mixtures at concentrations of 100 and 20 ppm respectively were added to a series of artificial freshwater ponds. No discernible short- or long-term effects on phytoplankton were documented for the oil treated system. Both oil-dispersant ponds exhibited fluctuations in the dominant class of algae when oil concentration in the water column was greater than 2 ppm. Periphyton biomass was at least three times greater in mixture-treated compared with oil-treated ponds. Dissolved oxygen values decreased to 4.6 ppm in oil-dispersant treated ponds shortly after treatment, but remained at saturation levels in other systems for six weeks after treatment. High anoxic zones above sediment were detected in mixture-treated ponds in late winter.

Scott, B.F., P.J. Wade and W.D. Taylor. 1984. Impact of Oil and Oil-Dispersant Mixtures on the Fauna of Freshwater Ponds. *Science of the Total Environment.* 35(2):191-207.

Five artificial ponds were treated with crude oil alone or with oil dispersant mixtures to investigate effects on aquatic fauna. Mesozooplankton populations were reduced in the oil-treated pond and eliminated in the ponds receiving the mixture. Species shifts were observed in all treated ponds, with some populations being initially eliminated but reviving in spring. Zooflagellates were not affected by any treatment.

Shindler, D.B., B.F. Scott and D.B. Carlisle. 1975. Effect of Crude Oil on Populations of Bacteria and Algae in Artificial Ponds Subject to Winter Weather and Ice Formation. *Internationale Vereinigung fuer Theoretische und Angewandte Limnologie Verhandlungen.* 19(3):2138-2144.

Report of experiments conducted in artificial ponds near Ottawa. Treatments included "light" application of oil to one pond under ice and a "heavy" spill on top of ice, both with Norman Wells crude oil. Heterotrophic bacterial populations and nutrients were monitored in the treated and control ponds until 6 months after oiling.

Snow, N.B. and G.J. Brunskill. 1975a. *Crude Oil and Nutrient Enrichment Studies in a Mackenzie Delta Lake.* Technical Report No. 553. Department of the Environment, Fisheries and Marine Service. Winnipeg, Manitoba.

Chlorophyll concentrations in water from experimental lake microcosms that were either treated weekly with Pembina crude oil alone, or with nitrogen and phosphorus, or with nitrogen or phosphorus alone were determined. The addition of these nutrients increased phytoplankton abundance 70-fold when no oil was added and 30-40 fold when oil was added, relative to untreated controls.

Snow, N.B. and D.M. Rosenberg. 1975b. *Experimental Oil Spills on MacKenzie Delta Lakes: I. Effect of Norman Wells Crude Oil on Lake 4.* Technical Report No. 548. Fisheries Research Board of Canada, Winnipeg, Manitoba.

A tundra lake was studied for 15 months following a spill of Norman Wells crude oil. Algae and benthic macroinvertebrates were sampled to determine shifts in population levels and community structure due to the spilled oil.

Snow, N.B. and B.F. Scott. 1975. The Effect and Fate of Crude Oil Spilled on Two Arctic Lakes. *Proceedings,* 1975 Conference on the Prevention and Control of Oil Pollution, San Francisco, CA, March 25-27, 1975. API Publication No. 4245. American Petroleum Institute, Washington, D.C. pp. 527-534.

Rapid initial evaporation followed by a decrease in evaporation rate was exhibited by Pembina and Norman Wells oil spills on two adjacent lakes. Toxicity to, and extent of physical effects on aquatic organisms depend upon the composition of the crude oil. Organisms using the water surface were the most adversely affected.

Effects on Lakes, continued

Stanley, D.W. 1976. Productivity of Epipelic Algae in Tundra Ponds and a Lake Near Barrow, Alaska. *Ecology.* 57(5):1015-1024.

The biomass and productivity of benthic algae growing on the sediments (epipelic algae) in several tundra ponds and a lake near Point Barrow, Alaska were measured. For one year after an experimental oil spill, epipelic productivity was reduced more than 75% relative to that in surrounding ponds.

Werner, M.D. and V.D. Adams. 1984. Consequences of Oil Pollution on the Decomposition of Vascular Plant Litter in Freshwater Lakes. Part 2. Nutrient Exchange Between Litter and the Environment. *Environmental Pollution.* 34(2):101-117.

A western Wyoming crude oil associated with decomposing *Potamogeton foliosus* was shown to alter nitrogen and phosphorus exchange between the plant litter and its aquatic environment. The crude oil did not affect the nutrient content of the litter at any given stage of decomposition. However, the rate of nutrient loss per initial unit mass of litter was reduced because the oil reduced the rate of litter decomposition. The greatest effect of the oil was to reduce the portion of nutrients which was released to the surrounding water in an inorganic form.

Werner, M.D., V.D. Adams, V.A. Lamarra and N.L. Winters. 1985. Responses of Model Freshwater Ecosystems to Crude Oil. *Water Research.* 19:285-292.

Major responses of model ecosystems (microcosms) simulating two freshwater lakes of the Rocky Mountains to crude oil were: 1) increased rates of oxygen consumption; 2) increased nutrient uptake rates by the decomposer community; and 3) a shift from autotrophic to heterotrophic domination. There were no apparent toxic effects of oil on the overall bacterial community, bacterial populations responded positively to oil addition within seven days. Results indicate that the shift of oiled ecosystems from autotrophic to heterotrophic domination was caused by increased availability of reduced carbon (i.e. oil) to the heterotrophs and by decreased nutrient availability to autotrophs due to nutrient uptake by oil degrading heterotrophs.

ZoBell, C.E. 1973. Microbial Degradation of Oil: Present Status, Problems, and Perspectives. In D.G. Ahearn and S.P. Meyers, eds. *The Microbial Degradation of Oil Pollutants.* Publication No. LSU-SG-73-01. Center for Wetland Resources, Louisiana State University, Baton Rouge, LA. pp. 3-16.

Review of occurrence of hydrocarbon-degrading microbes in nature, hydrocarbons

Effects on Lakes, continued

oxidized and products of oxidation, measurement and rates of degradation activity, environmental variables affecting degradation, and fate of hydrocarbons in natural aquatic systems.

6.0 EFFECTS ON WETLANDS

Alexander, M., P. Longabucco and D. Phillips. 1978. The Ecological Impact of Bunker C Oil on Fish and Wildlife in St. Lawrence River Marshes. *Proceedings*, Conference on Assessment of Ecological Impacts of Oil Spills. American Institute of Biological Sciences, Arlington, VA. pp. 251-267.

The characteristics of a spill of Bunker C oil in the St. Lawrence River and its effects on the fish and wildlife within marshes and bays are described. Changes in fish and wildlife distribution and abundance, and the presence, movements and accumulation of petroleum hydrocarbons were investigated during a 2-year study.

Atlas, R.M. and E. Schofield. 1976. Responses of the Lichens *Peltigera aphthosa* and *Cetraria nivalis* and the Alga *Nostoc commune* to Sulfur Dioxide, Natural Gas, and Crude Oil in Arctic Alaska. *Astarte*. 8(2):53-60.

Nitrogen fixation, carbon dioxide fixation, and oxygen consumption of two lichen and one algal species were measured *in situ* and *in vitro* after exposure to sulfur dioxide, natural gas and Prudhoe Bay crude oil. The crude oil severely inhibited N_2 and CO_2 fixation. The lichens appeared to be less sensitive than the alga.

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.

Burk, C.J. 1977. A 4-year Analysis of Vegetation Following an Oil Spill in a Freshwater Marsh. *Journal of Applied Ecology*. 14(2):515-522.

A 4-year study of the composition of vegetation in a freshwater marsh followed an accidental oil spill. Recovery of perennial vs. annual species and high-, mid- and low-marsh communities was reported.

Crossland, N.O., G.C. Mitchell, P.B. Dorn, and T.W. Lapoint. 1992. Use of Outdoor Artificial Streams to Determine Threshold Toxicity Concentrations for a Petrochemical Effluent. Aquatic Mesocosms in Ecotoxicology, 1992, Symposium on Aquatic Mesocosms in Ecotoxicology, Annual Meeting of SETAC, Toronto (Canada). *Environmental Toxicology and Chemistry*. 11(1):49-59.

Chlorinated ethers from a petrochemical manufacturing chemical plant were applied to three simulated streams at concentrations of 0.5, 1.0, and 2.0 mg/l for 28 days. A fourth stream was treated with 0.25 mg/l for 21 days, and then increased to 4.0 mg/l for a further 7 days. There were no detectable effects of the treatments on macroinvertebrate population densities. There was a marked effect on the drift of macroinvertebrates at a concentration of 2.0 mg/l, but there was no effect at lower concentrations.

Crow, S.A., M.A. Hood and S.P. Meyers. 1975. Microbiological Aspects of Oil Intrusion in Southeastern Louisiana. In A.W. Bourquin, D.G. Ahearn and S.P. Meyers, eds. *Impact of the Use of Microorganisms on the Aquatic Environment.* EPA-660/3-75-001. Environmental Protection Agency, Corvallis, OR. pp. 221-227.

Field study to assess the distribution of hydrocarbonoclastic microorganisms in sediments along an 80-mi transect from salt marsh to freshwater swamp, and including oiled and oil-free habitats. The ratio of hydrocarbon (crude oil)-utilizing microbes (MPN technique) to total heterotrophs was inferred to be an indicator of oil stress in the environment.

Crowell, M.J. and P.A. Lane. 1988. *The Effects of Crude Oil and the Dispersant Corexit 9527 on the Vegetation of a Nova Scotian Salt Marsh: Impacts After Two Growing Seasons.* Lane and Associates Ltd., Halifax, Nova Scotia (Canada).

The effects from Alberta crude oil on three zones of a Nova Scotia salt marsh over two growing seasons, and the impact of application of a dispersant to one of the zones, were investigated. There was little effect on the creek edge zone; the mid-marsh zone was severely impacted and displayed relatively little recovery. The large differences in toxicity between the creek edge and mid-marsh zones appeared to be related to the inability of *Spartina alterniflora* to tolerate the additional stress of oil toxicity. The creek edge recovered within one year and will probably recover from the dispersant treatment within 2 years. The high marsh zone will probably require 3-4 years for full recovery, while the mid-marsh zone will probably require at least 5 years.

Decker, C.J. and J.W. Fleeger. 1984. The Effect of Crude Oil on the Colonization of Meiofauna into Saltmarsh Sediments. *Hydrobiologia.* 118:49-58.

The effect of South Louisiana crude oil on estuarine meiofauna was examined. Oiled and non-oiled controls were established in 45 chambers in a *Spartina alterniflora* marsh in Louisiana. Polychaetes showed delayed colonization and reduced densities while nematode numbers were depressed in the high oiled plots,

but no delay in colonization was noted. One meiobenthic copepod displayed a reaction to the presence of oil, but only in the top 1 cm of sediment. Species diversity of the meiobenthic copepod assemblage showed that diversity was generally lower in the high oil treatment plots than in other plots through day 30.

DeLaune, R.D., C.J. Smith, W.H. Patrick, J.W. Fleeger and M.D. Tolley. 1984. Effect of Oil on Salt Marsh Biota: Methods for Restoration. *Environmental Pollution.* 36:207-228.

South Louisiana crude was applied to replicated plots in a Louisiana *Spartina alterniflora* salt marsh. Various marsh restoration methods were evaluated for mitigating the impact of crude oil on the marsh biota. Oiling the marsh caused no reduction in macrophyte production as compared with the non-oiled plots, thus the cleanup treatment showed no beneficial effects to *Spartina alterniflora.* Likewise, there was no oil-induced mortality for the marsh macrofauna or meiofauna. In Louisiana Gulf Coast salt marshes, which have a low sensitivity to oil as shown in this study, the best response is no cleanup action at all.

Dickman, M. 1971. Preliminary Notes on Changes in Algal Primary Productivity Following Exposure to Crude Oil in the Canadian Arctic. *Canadian Field-Naturalist.* 85(3):249-251.

An oil spill, using naturally weathered (2 mo) Mackenzie Valley crude oil, was simulated on Arctic marsh waters to investigate potential effects of a spill from the proposed Mackenzie Valley pipeline. Primary productivity in natural algal populations was measured (^{14}C methodology) to determine effects.

Finlayson, M. and M. Moser, eds. 1991. *Wetlands.* International Waterfowl and Wetlands Research Bureau, Slimbridge, UK.

This book documents the status of major wetlands throughout the world. Detailed information is presented on wetlands in: Europe and the Mediterranean Basin; North America; Latin America and the Caribbean; Africa; Asia and the Middle East; and Australia and the Oceania.

Fischel, M. 1987. Preliminary Assessment of the Effect of an Oil Spill on a Louisiana Marsh. *Proceedings,* 1987 International Oil Spill Conference, Baltimore, MD, April 6-9, 1987. API Publication No. 4452. American Petroleum Institute, Washington, D.C. pp. 481-494.

This paper assesses the effects of a 300 barrel crude oil spill into a Louisiana

marsh. The effects were assessed through 4 different studies: remote sensing study, vegetation survey, benthic community survey, and analysis of petroleum hydrocarbon concentrations in the sediment.

Freedman, W. and T.C. Hutchinson. 1975. Physical and Biological Effects of Experimental Crude Oil Spills on Low Arctic Tundra in the Vicinity of Tuktoyaktuk, N.W.T., Canada. *Canadian Journal of Botany.* 54:2219-2230.

Effects of simulated crude oil spills on two Low Arctic terrestrial tundra plant communities were examined. Spills of fresh crude oil had a general herbicidal effect, resulting in rapid damage to, and subsequent death of, all aboveground actively growing foliage. Most species were defoliated. However, within several weeks of summer oil spillages, a limited number of relatively tolerant vascular plant species began to develop regrowth shoots. Summer spills were markedly more damaging than winter spills. No increases were seen in active layer depth from spills in summer. However, at one winter spill statistically significant increases in depth of thaw were measured.

Garrity, S.D. and S.C. Levings. 1993. Effects of an Oil Spill on Some Organisms Living on Mangrove (*Rhizophora mangle L.*) Roots in Low Wave-energy Habitats in Caribbean Panama. *Marine Environmental Research.* 35(3):251-271.

Following the discharge of more than 50,000 barrels of crude oil into a tropical, mangrove-fringed estuary, the effects of oiling on the epibiota of mangrove (*Rhizophora mangle*) prop roots were examined. The possible values of four bivalves and one barnacle as indicators of damage from oiling were assessed. Comparisons of abundances at matched oiled and non-oiled sites showed strong indirect evidence of population reductions in six of seven comparisons. However, the shells of only two species persisted long enough on roots (3-6 months) to be useful direct indicators of recent mortality. Population reductions were most striking in brackish streams.

Haines, B.L. and E.L. Dunn. 1985. Coastal Marshes. In Chabot B.F. and Mooney H.A., eds. *Physiological Ecology of North American Plant Communities.* pp. 323-347.

Habitat characteristics, geographic distribution, microtopographic distribution, the environmental stresses of flooding, salinity, low redox potential, and limitations of nitrogen and phosphorus are reviewed for North American coastal marshes. Physiological and morphological responses and adaptations to these stresses are described. The implications of plant ecophysiology for the management of oil spills, heavy metals, biocides, municipal wastes, and dredging are discussed. General

conclusions, a conceptual model of processes controlling production in a southeastern *Spartina alterniflora* dominated salt marsh, and a list of future research needs especially regarding below-ground processes, are provided.

Hanna, B.M., J.A. Hellebust and T.C. Hutchinson. 1975. Field Studies on the Phytotoxicity of Crude Oil to Subarctic Aquatic Vegetation. *Verhandlungen Der Internationalen Vereinigung Fur Theoretisches Und Angewandte Limnologie*. 19:2165-2171.

The application of fresh crude oil to cylinders in a shallow sub-arctic lake at a rate equivalent to a 7,500 barrel spill had the most pronounced effect on the emergent macrophytes of the littoral region. Algal species' composition, numbers, and seasonal fluctuations were not altered by the presence of oil at the specific concentrations applied. An increase in chlorophyll concentration of the submerged shoots of the moss *Scorpidium scorpoides* in oil cylinders may be due to increased chlorophyll content, this compensating for reduced light beneath the oil slick.

Mendelssohn, I.A., M.W. Hester, C. Sasser and M. Fischel. 1990. The Effect of a Louisiana Crude Oil Discharge From a Pipeline Break on the Vegetation of a Southeast Louisiana Brackish Marsh. *Oil and Chemical Pollution*. 7(1):1-15.

A pipeline break in April 1985 near Nairn, Louisiana, resulted in the release of approximately 300 barrels of Louisiana crude oil into a brackish marsh dominated by *Spartina patens*, *S. alterniflora* and *Distichlis spicata*. The major impact was confined to the 50-acre (20-ha) marsh around the pipeline rupture. The oil caused a 64% reduction in live vegetative cover in this marsh 3 months after the spill. Mortality from a low oil dosage (estimated at 0.28 liters/m^2) was probably due to oil contact with a large percentage (about 30-70%) of the photosynthetic leaf surfaces of the vegetation and the penetration of oil into the marsh substrate.

Mendelssohn, I.A., M.W. Hester and J.M. Hill. 1993. Assessing the Recovery of Coastal Wetlands From Oil Spills. *Proceedings*, 1993 International Oil Spill Conference, Tampa, FL, March 29-April 1, 1993. API Publication No. 4580. American Petroleum Institute, Washington, D.C. pp. 141-145.

This study investigated the long-term recovery of a South Louisiana estuarine marsh exposed to an accidental spill of crude oil. Although a pipeline rupture releasing Louisiana crude oil caused the near complete mortality of a brackish marsh dominated by *Spartina patens* and *S. alterniflora*, this marsh completely recovered four years after the spill with no differences in plant species cover between oiled and reference marshes. Remotely sensed imagery of the study site confirmed the relatively rapid recovery demonstrated by the ground-truth data.

Moody, A.I. 1990. *Monitoring of Marsh Vegetation Response to a Jet-fuel Spill at Vancouver International Airport.* AIM Ecological Consultants Ltd., Aldergrove, BC (Canada).

The impact of a jet fuel spill on marsh vegetation at Vancouver International Airport was assessed. On 23 March 1988, an area of estuarine marsh by the Fraser River was affected by a spill of Jet A fuel. Background on the properties of hydrocarbon fuels, impacts on vegetation, physiological response, oil characteristics and plant response, substrate effects, seasonal effects, and recovery, is given. The results indicated that recovery was taking place in the heavily oiled sites. Some recovery appeared transitory, as seedlings were unable to remain viable in the oil-saturated substrates. The communities which existed prior to the fuel spill were replaced by a sparse population of different marsh species.

Obot, E.A., A. Chinda and S. Braid. 1992. Vegetation Recovery and Herbaceous Production in a Freshwater Wetland 19 Years After a Major Oil Spill. *American Journal of Ecology.* 30(2):149-156.

After a major oil spill in a freshwater wetland, the oil was set ablaze as a clean-up measure. Nineteen years later the vegetation structure of the wetland was analyzed for evidence of vegetation recovery. Results indicate that vegetation in the area which received the direct impact of the spill is recovering but vegetation in areas downstream is being degraded due to a slow seepage of persistent crude oil from the spill site. Herbaceous production (including food crops) was negatively correlated with hydrocarbon concentrations in the soil. The results suggest that burning as a clean-up measure is ineffective, at least in wetland ecosystems.

Palm, D.J. 1979. *Damage Assessment Studies Following the NEPCO 140 Oil Spill on the St. Lawrence River.* EPA-600/7-79-256. Industrial Environmental Research Laboratory, Environmental Protection Agency, Cincinnati, Ohio.

Collections of fish, water fowl, amphibians, reptiles and muskrats were conducted for 2 years in control and exposed marshes along the St. Lawrence River following the spill of Bunker C oil from the NEPCO 140 tanker barge.

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.

Vandermeulen, J.H. and J.R. Jotcham. 1986. Long-term Persistence of Bunker C Fuel Oil and Revegetation of a North-Temperate Saltmarsh: Miguasha 1974-1985. *Proceedings*, Ninth Annual Arctic and Marine Oil Spill Program Technical Seminar. Edmonton, Alberta, Canada, June 10-12. pp. 151-166.

This paper documents persistence of stranded eleven-year old Bunker C oil, and the revegetation of marsh areas impacted by the spilled oil. The results of the study indicate that the saltmarsh has generally recovered with few signs that either the oil or any of the cleanup procedures have helped or hindered the revegetation. Sediment samples taken from the initial oiled marsh areas do indicate, however, that the soil retains significant amounts of bunker C derived hydrocarbons primarily in the upper 15 centimeters.

7.0 EFFECTS ON SOILS

Farran, A., J. Grimalt, J. Albaiges, A.V. Botello and S.A. Macko. 1987. Assessment of Petroleum Pollution in a Mexican River by Molecular Markers and Carbon Isotope Ratios. *Marine Pollution Bulletin.* 18(6):284-289.

Sediments sampled within the bed of the Coatzacoalcos River, Veracruz, Mexico were used as geo-accumulators for the assessment petroleum pollution in the river. Stable carbon isotope ratios and the composition of aliphatic and aromatic hydrocarbons were determined to evaluate petrogenic inputs and ascertain their spatial distribution. Molecular markers (acyclic isoprenoid hydrocarbons, steranes, and hopanes) were studied for source identification. High levels of petroleum were found in the whole area, with no defined spatial trends.

Kessler, A. and H. Rubin. 1987. Relationships Between Water Infiltration and Oil spill Migration in Sandy Soils. *Journal of Hydrology.* Amsterdam. 91(3-4):187-204.

This article summarizes a study to predict oil spill migration in sandy soils. Prediction is needed for the design of remedial measures against soil and groundwater contamination. The prediction involves the use of a numerical model to simulate oil spill migration.

Merrill, E.G. and T.L. Wade. 1985. Carbonized Coal Products as a Source of Aromatic Hydrocarbons to Sediments from a Highly Industrialized Estuary. *Environmental Science and Technology.* 19(7):597-603.

Sediments near large urban areas may contain high concentrations of anthropogenic hydrocarbons due to their proximity to source areas. Elizabeth River sediments are contaminated with hydrocarbons from both carbonized coal and petroleum products. Carbonized coal products appear to have point sources associated with creosoting facility sites and are the main source of carcinogenic polynuclear aromatic hydrocarbons in the sediments. Petroleum products appear to have many sources, are highly weathered before reaching the sediments, and are the main source of the unresolved complex mixture. Carbonized coal products may contain compounds in addition to hydrocarbons (such as phenols) that may increase their environmental impact.

Mitchell, W.M., T.E. Loynachan and J.D. McKendrick. 1979. Effects of Tillage and Fertilization on Persistence of Crude Oil Contamination in an Alaskan Soil. *Journal of Environmental Quality.* 8:525-532.

Persistence of Prudhoe Bay crude oil was evaluated with cereal plantings over a four-year period on field plots oiled at 10 and 20 liters/m^2 with tillage and fertilization as treatments. Tilling alone was more effective than fertilization alone in promoting growth. Tillage and fertilization combined resulted in the best plant growth. Greenhouse studies showed that surface-oiled soil produced greater growth from tilled than untilled plots. Conversely, in the 10 to 15 cm layer of oiled soil, greater growth occurred in the untilled than the tilled soil. A significant, negative relationship existed between oil content and moisture in the soil.

Oudot, J. 1990. Selective Migration of Low and Medium Molecular Weight Hydrocarbons in Petroleum-contaminated Terrestrial Environments. *Oil and Chemical Pollution.* 6(4):251-261.

A vertical migration of low and medium molecular weight hydrocarbons is demonstrated in a tropical forest soil heavily impacted by a crude oil spill. An identical pattern of horizontal migration is observed in the lateral zone of the polluted area and in the sediments of a shallow river which received the contaminated water runoff of the forest. The differential migration, attributed to the chromatographic properties of the soil, resulted in the formation of a residual similar in composition to a gas-oil cut. Contamination by this fraction extended far beyond the area initially polluted by the crude oil.

Rogerson, A. and J. Berger. 1981. The Effects of Cold Temperatures and Crude Oil on the Abundance and Activity of Protozoa in a Garden Soil. *Canadian Journal of Zoology.* 59:1554-1560.

Protozoa play an important role in the bacterial decomposition of organic matter, consequently their existence and survival in oil contaminated soil is important. High total populations and rapid excystment rates suggested that significant numbers of protozoa were active on numerous brief occasions throughout the winter months. Oil did not appear to affect seriously either the encysted or trophic protozoa. Protozoa species inhabiting garden loam soil were monitored throughout the winter in undisturbed and crude-oil polluted sites.

8.0 EFFECTS ON ORGANISMS

8.1 Effects on Microorganisms

Baedecker, M.J. 1991. *Comparative Study of Organic Degradation in Selected Hydrogeologic Environments.* FEDRIP Database, National Technical Information Service (NTIS), USGS NR-83-129.

Microbial degradation of hydrocarbons alters the aqueous geochemistry and mineral equilibria. Laboratory experiments with microcosms confirm that specific aromatic hydrocarbons are degraded anaerobically. Organic acids that were not original components of the oil were identified in the microcosms and at a field site in anoxic groundwater. These acids were structurally related to alkylbenzenes which suggests the biological transformation of benzene and alkylbenzenes to organic acid intermediates.

Batterton, J.C., K. Winters and C. Van Baalen. 1978. Sensitivity of Three Microalgae to Crude Oils and Fuel Oils. *Marine Environmental Research.* 1(1):31-41.

Toxic effects of several whole crude and fuel oils, and several water-soluble fractions of the oils on three cultured algae, *Agmenellum quadruplicatum*, *Chlorella autotrophica*, and *Cylindrotheca* sp., were investigated by measuring inhibition of growth and reduction in primary productivity following exposure. Components of the oils were identified and toxicity of major components was tested.

Bennett, D., A.E. Girling and A. Bounds. 1990. Ecotoxicology of Oil Products: Preparation and Characterization of Aqueous Test Media. *Chemosphere.* 21(4-5): 659-670.

This paper presents the results of a study in which aqueous test media of two formulated oil products were prepared and analyzed. The mixing time required to achieve equilibrium between concentrations of constituents in the oil and in an aqueous phase was determined using two methods: total organic carbon analysis and total peak area integration of gas-liquid chromatograms. Individual constituents of the oil products present in the aqueous phases were characterized by gas-liquid chromatography combined with mass spectrometry. The compositions of the aqueous phases were compared with those of solutions of the oil products in dichloromethane. The results illustrate the attainment of equilibrium concentrations of oil product constituents in aqueous phases and differences in the constitution of the aqueous phases compared with the oil products themselves.

Berner, N.H., D.G. Adhearn, and W.L. Cook. 1975. Effects of Hydrocarbonoclastic Yeasts on Pollutant Oil and the Environment. In A.W. Bourquin, D.G. Ahearn and S.P.

Microorganisms, continued

Meyers, eds. *Impact of the Use of Microorganisms on the Aquatic Environment.* U.S. Environmental Protection Agency. EPA-660/3-75-001. Corvallis, OR. pp. 199-219.

Fungi isolated from oil-contaminated environments were introduced into both clean (freshwater lake) and contaminated (refinery drainage) water; both systems were enriched with oil (Louisiana crude or bunker C). The survival and development of seeded and indigenous fungal populations were monitored.

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.

The effect of kerosene on chemoreception was studied on a bacterium from a subtropical, freshwater creek in Florida that had been affected by an oil spill.

Bott, T.L., K. Rogenmuser and P. Thorne. 1976. Effects of No. 2 Fuel Oil, Nigerian Crude Oil, and used Crankcase Oil on the Metabolism of Benthic Algal Communities. *Journal of Environmental Science and Health.* 13(A):751-779.

No. 2 fuel oil, Nigerian crude oil, and used crankcase oil were studied for effects on metabolism of benthic algal communities taken from a low (<0.5 ppt) salinity marsh. Exposure depressed net community primary productivity, with the degree of effect dependent on oil type and concentration. No. 2 fuel oil caused the greatest toxicity. Recovery of community function occurred, although the recolonizing communities were dominated by different genera; notably filamentous blue green algae.

Coffey, J.C., C.H. Ward and J.M. King. 1976. Effects of Petroleum Hydrocarbons on Growth of Freshwater Algae. *Developments in Industrial Microbiology.* 18:661-672.

Two crude (Kuwait, South Louisiana) and No. 2 fuel oils were bioassayed using cultures of five commonly used freshwater algae under light- and temperature-controlled conditions that allowed mixing and gas exchange. Inhibition of growth rate, measured by cell counts (hemocytometer) and indirectly by biomass (colorimetry), was observed in the cultures.

Dennington, V.N., J.J. George and C.H.E. Wyborn. 1975. The Effects of Oils on Growth of Freshwater Phytoplankton. *Environmental Pollution.* 8(3):233-237.

Two different types of phytoplankton (*Euglena gracilis* and *Scenedesmus* *quadricauda*) were exposed to three oil concentrations (0.1%, 1.0%, and 10.0%). Cell numbers were determined at 48-hour intervals by counting on a hemacytometer. Experiments used diesel and lubricating oils. *E. gracilis* cultures containing up to 10% lubricating or diesel oils showed no significant reduction in either population size or growth rate. The growth of *S. quadricauda* was reduced in cultures containing 10% lubricating oil and halted by the presence of diesel oil.

Dickman, M. 1971. Preliminary Notes on Changes in Algal Primary Productivity Following Exposure to Crude Oil in the Canadian Arctic. *The Canadian Field-Naturalist.* 85:249-251.

Algae taken from a marsh near Inuvik, Northwest Territories were exposed to Mackenzie Valley crude oil which had been weathered for 2 months in natural arctic summer conditions. The algae consisted of nearly 80% small flagellates such as *Cryptomonas* spp. and *Chlamydomonas* spp. ^{14}Carbon primary productivity was low in the untreated marsh samples, but the addition of crude oil (0.5 ml per 275 ml marsh water) reduced productivity from 5.12 to 0.59 mgC/m^2/hr. This reduction may have been conservative.

Dutka, B.J., J. Sherry, B.F. Scott and K.K. Kwan. 1980. Effects of Oil-Dispersant Mixtures on Freshwater Microbial Populations. *Canadian Research.* 13(5):58-62.

Experiments conducted on artificial ponds to evaluate effects of Norman Wells crude oil and mixtures of oil and dispersant (Corexit 9527) on planktonic microbial populations. The following parameters were estimated: total bacteria, heterotrophic bacteria, sulfate-reducing bacteria (MPN), numbers of bacteria capable of utilizing biologically degraded and non-degraded oil as sole carbon sources, and numbers of fungi. In addition, mutagen assays and bacterial toxicity studies (*with Spirillum volutans*) were conducted.

Engelhardt, F.R., R.G. Trucco, C.K. Wong and J.R. Strickler. 1982. Effects of Petroleum Hydrocarbons on Trophic Factors of *Daphnia pulex. Proceedings*, Fourth Annual Meeting of the International Society of Petroleum Industry Biologists, September 22-25, 1981, Denver, CO. pp. 297-301.

Total mortality of *D. pulex* resulted at 50 and 100 ppm of particulate (emulsion) fresh Norman Wells (NW) crude oil. The toxic effect of oil emulsions increased with concentration. Effects of paraffin oil, crude oil, weathered oil were examined. Acute toxicity, reproductive potential (percentage of young produced and brood size), metabolic rates and swimming ability were evaluated. Venezuelan (VEN) crude oil emulsions caused more than a doubling in oxygen consumption. Feeding

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behavior changed immediately after addition of 50 ppm NW crude oil emulsion; resulting in a reduced ingestion rate.

Foght, J.M., N.J. Fairbairn and D.W.S. Westlake. 1987. Effect of Oil Dispersants on Microbially-mediated Processes in Freshwater Systems. In J.H. Vandermeulen and S.E. Hrudey, eds. *Oil in Freshwater: Chemistry, Biology, Countermeasure Technology.* Pergamon Press, New York. pp. 252-263. *Proceedings* of the Symposium on Oil Pollution in Freshwater. Edmonton, Alberta, Canada. October 15-19, 1984.

The effect of 15 oil dispersants on the microbial degradation of crude oil was studied. Other ecologically important microbial biochemical processes, such as phosphatase activity, aerobic and anaerobic N fixation, and CH_3 formation in natural waters and sediments were studied with selected dispersants. Several dispersants had slightly stimulatory or no inhibitory effects on oil degradation under laboratory conditions. Other dispersants were toxic or inhibited degradation.

Foght, J.M. and D.W.S. Westlake. 1988. Degradation of Polycyclic Aromatic Hydrocarbons and Aromatic Heterocycles by a *Pseudomonas* species. *Canadian Journal of Microbiology.* 34(10):1135-1141.

Enrichment cultures were established with the aromatic fraction of a crude oil and screened for aromatic-degrading pseudomonads, using a sprayed plate technique. One isolate, *Pseudomonas sp.* HL7b, was chosen for further study because it oxidized several polycyclic aromatic hydrocarbons and aromatic heterocycles without an apparent lag. The bacterium was able to mineralize and/or oxidize a wide range of polycyclic aromatic hydrocarbons (PAHs), S-, N-, and O-heterocyclic analogues, and alkyl PAHs, but not aliphatic hydrocarbons. The isolate displayed two colonial morphologies.

Foght, J.M., P.M. Fedorak and D.W.S. Westlake. 1990. Mineralization of (^{14}C)hexadecane and (^{14}C)phenanthrene in Crude Oil: Specificity Among Bacterial Isolates. *Canadian Journal of Microbiology.* 36(3):169-175.

Bacteria isolated from freshwater, marine, and estuarine samples were tested for the ability to produce $^{14}CO_2$ from n-(1-^{14}C)hexadecane or (9- ^{14}C)phenanthrene added to Prudhoe Bay crude oil. Of 61 hexadecane- and 21 phenanthrene-mineralizing bacteria tested, none mineralized both compounds. Selected isolates and commercially available cultures were tested for mineralization of ^{14}C-labelled mono-, di-, and tri-cyclic aromatics. A hierarchy of degradation was observed: strains mineralizing the mono- and di-cyclic aromatics toluene and naphthalene did not mineralize biphenyl or the tricyclic aromatics anthracene and phenanthrene, whereas those strains that mineralized the tricyclic aromatics mineralized the smaller substrates of the smaller molecular material.

Gaur, J.P. and H.D. Kumar. 1981. Growth Response of Four Micro-algae to Three Crude Oils and a Furnace Oil. *Environmental Pollution.* 25(1):77-85.

Addition of whole crude oils or furnace oil to cultures of four test algae caused reductions in maximum specific growth rate and final yield in a concentration-dependent fashion. *Chlorella vulgaris* and *Selenastrum capricornutum* were the most tolerant and the most sensitive species, respectively. Furnace oil was most toxic and was followed in a decreasing order of toxicity by Assam, UAE, and Bombay high crudes. Differences in chemical composition of oils are apparently responsible for their differential toxicity to different algae. Algal bioassay techniques are suitable for the study of whole crude oils.

Giddings, J.M. and J.N. Washington. 1981. Coal-Liquefaction Products, Shale Oil, and Petroleum. Acute Toxicity to Freshwater Algae. *Environmental Science and Technology.* 15(1):106-108.

Water-soluble fractions of eleven coal-liquefaction products, five shale-oil products, and six petroleum products were tested for acute toxicity to two species of freshwater algae (unialgal cultures of *Selenastrum capricornutum* and *Microcystis aeruginosa*). Inhibition of photosynthesis (measured by ^{14}C bicarbonate uptake) was the toxicity criterion.

Hellebust, J.A., C. Soto and T.C. Hutchinson. 1982. Effect of Naphthalene and Aqueous Crude Oil Extracts on the Green Flagellate *Chlamydomonas angulosa.* v. Heterotrophic Responses. *Canadian Journal of Botany.* 60:1495-1502.

Moderate concentrations of crude oil components dissolved in algal culture media (50% naphthalene-saturated media and 100% aqueous crude oil extract-saturated media) permitted significant rates of acetate uptake and assimilation but inhibited cell division. It is possible that the observed stimulation of acetate uptake was due to hydrocarbon-induced permeability of the cell membrane and/or an increased availability of energy from photosynthetic light reactions owing to decreased CO_2 photoassimilation.

Herman, D.C., W.E. Inniss and C.I. Mayfield. 1990. Impact of Volatile Aromatic Hydrocarbons, Alone and in Combination, on Growth of the Freshwater Alga *Selenastrum capricornutum. Aquatic Toxicology* (Amsterdam). 18(2):87-100.

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Growth of the representative green alga, *Selenastrum capricornutum,* was inhibited due to the restriction of gas exchange, but inhibition was overcome by the addition of $NaHCO_3$ to the growth medium. Relative toxicity of 6 aromatic hydrocarbons was, in order of increasing toxicity, benzene (EC-50 = 41.0 mg/l), toluene (9.4 mg/l), ethylbenzene (4.8 mg/l) and p-, m-, o-xylene (between 3.9-44 mg/l). Examination revealed an additive toxicological interaction between benzene, toluene and m-xylene, indicating that the toxicity of a mixture can be predicted.

Hutchinson, T.C., J.A. Hellebust and C. Soto. 1981. Effect of Naphthalene and Aqueous Crude Oil Extracts on the Green Flagellate *Chlamydomonas angulosa.* IV. Decreases in Cellular Manganese and Potassium. *Canadian Journal of Botany.* 59(5):742-749.

The effects of naphthalene and several aqueous crude oil extracts (British Petroleum Mixed Blend Sour Oil and Bow River Crude) on *Chlamydomonas angulosa* were measured. Neutron activation analysis was used to measure the loss of manganese and potassium from algal cells exposed for different times.

Kabirov, R.R. and R.G. Minibayev. 1982. Effect of Oil on Soil Algae. *Soviet Soil Science.* 14(1):49-55.

To study the effect of oil on soil algae, three series of laboratory experiments were conducted. Unfertilized soil, soil from plots with normal amounts of mineral fertilizers, and soil with large amounts of fertilizers were used. Oil was added to the soil as a water emulsion at concentrations of 0.00015, 0.0015, 0.015, and 0.15 cm^3/g of air dried soil. Overall, crude oil was toxic to most species of soil algae, and reduced the floristic diversity, number, and biomass of the algae.

Kauss, P.B. 1989. Comparative Studies of Hydrocarbon Toxicity in the Genus *Ankistrodesmus. Dissertation Abstracts International B Sciences and Engineering.* 50(1). University of Toronto, Canada.

Nine isolates of the unicellular freshwater green alga, *Ankistrodesmus,* were screened using the aqueous extract of Norman Wells crude oil. Species- and variety-specific growth responses to the extract included inhibition, tolerance and stimulation. The physical, chemical and physiological responses of two *Ankistrodesmus falcatus* varieties of contrasting growth response ie. var. *acicularis* (resistance) and var. *mirabilis* (inhibited), were compared.

Kauss, P.B. and T.C. Hutchinson. 1975a. Studies on the Susceptibility of Ankistrodesmus Species to Crude Oil Components. *Verh. Int. Verein. Limnol.* 19(3):2155-2164.

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Bioassays of Norman Wells crude oil extract and several species of the green algal genus *Ankistrodesmus* were conducted. Toxicity was determined by inhibition of growth (reduced numbers of cells). "Open systems" were used to facilitate gas exchange and evaporation, and to simulate events in a natural environment.

Kauss, P.B. and T.C. Hutchinson. 1975b. The Effects of Water-Soluble Petroleum Components on the Growth of *Chlorella vulgaris* Beijerinck. *Environmental Pollution.* 9(3):157-174.

Toxicity of aqueous extracts of seven crude oils to the green alga *Chlorella vulgaris* determined by changes in numbers of algal cells in bioassay. Effect of aging of oils was examined to determine toxicity after volatile components had evaporated.

Kelley, I. and C.E. Cerniglia. 1991. The Metabolism of Fluoranthene by a Species of Mycobacterium. *Journal of Industrial Microbiology.* 7(1):19-26.

A *Mycobacterium* sp., which was previously isolated from oil-contaminated estuarine sediments, mineralized fluoranthene. When supplemented with an alternative carbon source, the organism was able to mineralize up to 78% of the added (3- ^{14}C) fluoranthene to $^{14}CO_2$ after 5 days of incubation, with relatively little accumulation of intermediate metabolites. Incubation of the *Mycobacterium* sp. with soil and river water, in the presence of fluoranthene, enhanced mineralization of fluoranthene by 92.7% over the indigenous biota.

Kusk, K. 1978. Effects of Crude Oil and Aromatic Hydrocarbons on the Photosynthesis of the Diatom *Nitzschia palea*. *Physiologia Plantarum*. 43:1-60.

The toxicity of crude oil, naphthalene and benzene was determined in bioassays with the diatom *Nitzschia palea* by changes in photosynthesis (measured by oxygen flux) and chlorophyll (acetone extracted).

Larson, R.A., T.L. Bott, L.L. Hunt and K. Rogenmuser. 1979. Photooxidation 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 photooxidation (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 ($^{14}CO_2$ - incorporation).

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Marowitch, J., M.R.T. Dale and J. Hoddinott. 1988. The Effect of Crude Oil and Oil Spill Chemicals on Nitrogen Fixation in the Cyanobacteria, *Nostoc* sp. *Environmental Pollution.* 51:75-83.

The effects of crude oil and three oil spill dispersants (Corexit 9600, 9550 and 7664) on nitrogenase activity in the cyanobacteria *Nostoc* were examined. The addition of oil to *Nostoc* cultures resulted in a catastrophic decline in nitrogenase activity with activity ceasing 7 hours after treatment. The addition of a dispersant with the oil did not ameliorate this effect. Cultures exposed to high concentrations of dispersants showed lower rates of nitrogenase activity than untreated cultures. At the lowest concentration which approximates the manufacturer's recommended application rate, the effects of the dispersant appear to be negligible.

Morrison, S.M. and B.A. Cummings. 1982. *Microbiologically Mediated Mutagenic Activity of Crude Oil.* EPA-600/S3-81-053. 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.

Robichaux, T.J. and H.N. Myrick. 1972. Chemical Enhancement of the Biodegradation of Crude Oil Pollutants. *Journal of Petroleum Technology.* 24:16-20.

Laboratory study of the ability of six surfactants to facilitate the microbial degradation of a weathered, sweet, paraffin-base crude oil. Manometric measures of oxygen consumption were used to measure oil decomposition by inocula of a bacterial culture in both freshwater and seawater samples.

Rogerson, A. and J. Berger. 1981. Effect of Crude Oil and Petroleum-Degrading Microorganisms on the Growth of Freshwater and Soil Protozoa. *Journal of General Microbiology.* 124(1):53-59.

Growth of five species of freshwater ciliates and a soil amoeba using known oil-utilizing bacteria, actinomycetes, and yeast as prey, was studied in the presence and absence of emulsified Norman Wells crude oil.

Rogerson, A. and J. Berger. 1982. Ultrastructural Modification of the Ciliate Protozoan, *Colpidium colpoda*, following Chronic Exposure to Partially Degraded Crude Oil. *Transactions of the American Microscopic Society.* 101(1):27-35.

Ciliate protozoans were chronically exposed to partially degraded Norman Wells crude oil. Cytoplasmic effects were studied using light and transmission electron microscopy. Results showed that protozoa exposed to crude petroleum contained more stained cytoplasmic inclusions than protozoa grown in control cultures. Cells undergo characteristic ultrastructural changes in the presence of crude oil.

Sherry, J.P. 1984. The Impact of Oil and Oil-Dispersant Mixtures on Fungi in Freshwater Ponds. *Science of the Total Environment.* 35(2):149-168.

The impact of crude oil and oil-dispersant mixtures on the mycoflora of a freshwater ecosystem was assessed using artificial ponds. Norman Wells crude oil was added to study ponds alone or in combination with Corexit 9527. After pond treatment, an immediate increase occurred in the number of aquatic fungi in oil-treated systems; an increase, followed by a sharp decrease and a recovery period, occurred in oil-dispersant treated ponds. Fungal enhancement effects were short-term in duration lasting in the range of 7-83 days. No medium- or long-term enhancement effects were documented. No obvious treatment effect was observed on the percentage of fungi capable of growth on non-degraded or biodegraded oil as a sole carbon source.

Soto, C., J.A. Hellebust and T.C. Hutchinson. 1975. Effect of Naphthalene and Aqueous Crude Oil Extracts on the Green Flagellate *Chlamydomonas angulosa* II. Photosynthesis and the Uptake and Release of Naphthalene. *Canadian Journal of Botany.* 53(2):118-126.

Bioassays of naphthalene and aqueous extracts of crude oils (British Petroleum Mixed Blend Sour, Bow River) using *Chlamydomonas angulosa* were conducted to determine effects on photosynthesis (measured by ^{14}C bicarbonate uptake) in open and closed systems. The uptake of labelled naphthalene was studied to determine the persistence of the compound in the algal cells.

Soto, C., J.A. Hellebust, T.C. Hutchinson and T. Sawa. 1975. Effect of Naphthalene and Aqueous Crude Oil Extracts on the Green Flagellate *Chlamydomonas angulosa* I. Growth. *Canadian Journal of Botany.* 53(2):109-117.

The toxicity of naphthalene and aqueous extracts of crude oils (British Petroleum Mixed Blend Sour, Bow River) in bioassays using the green alga *Chlamydomonas angulosa* was determined by changes in growth (numbers of cells). Tests were conducted in both open (allow evaporation and volatilization) and closed systems.

Soto, C., J.A. Hellebust and T.C. Hutchinson. 1977. Effect of Naphthalene and Aqueous Crude Oil Extracts on the Green Flagellate *Chlamydomonas angulosa* III. Changes

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in Cellular Composition. *Canadian Journal of Botany.* 55(22):2765-2777.

Bioassays of naphthalene and aqueous extracts of crude oils (British Petroleum Mixed Blend Sour, Bow River) using *Chlamydomonas angulosa* to determine effects on cellular constituents (alterations in amounts of lipid, protein, carbohydrate, etc.).

Soto, C., T.C. Hutchinson, J.A. Hellebust and R.G. Sheath. 1979. The Effect of Crude Oil on the Morphology of the Green Flagellate *Chlamydomonas angulosa. Canadian Journal of Botany.* 57(24):2717-2728.

Morphological changes of *Chlamydomonas angulosa*, induced by treatment with an aqueous crude oil extract, were compared to normal cells. Oil-treated cells showed an effect on flagellar length, motility, contractile vacuole activity, and granulations, in addition to various other changes. Cells recovered within an 8-day incubation period.

Trzilova, B. and L. Miklosovicova. 1990. Microbial Oxidation of Crude Oil Hydrocarbons in Danube Water. *Archives of Hydrobiology.* 84(1):1-19.

Bacterial degradation of soluble hydrocarbons in water of the Danube River was studied. Total organotrophic bacteria as well as bacteria of various genera survived and grew in hydrocarbon concentrations up to 500 mg/L. Growth rates of bacteria and degradation rates of soluble hydrocarbons were high during the first three days. Due to the changing composition of the bacterial community, respiratory activity of the bacterial cells increased. Bacterial cells became larger in contaminated Danube water.

Tukaj, Z. 1987. The Effects of Crude and Fuel Oils on the Growth, Chlorophyll *a* Content and Dry Matter Production of a Green Alga *Scenedesmus quadricauda* (Turp.) Breb. *Environmental Pollution.* 47:9-24.

The growth of *Scenedesmus quadricauda* algae was examined in the presence of crude oil and fuel oil which were added in the form of a water-soluble fraction (WSF), water extract (WE), and oil-water dispersion (OWD). A decrease in the number of cells, dry matter and chlorophyll *a* production, with respect to the cell population, was observed. The extent of decrease depended on the kind and concentration of the soluble and dispersed hydrocarbon fractions and on the proportions in the culture medium. The water extracts of both oils stimulated dry mass and chlorophyll *a* content which was accompanied by increased size of the algal cells. The WSF, WE, and OWD of fuel oil, had a similar inhibitory effect,

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which points to the dominant role of oil dispersion in the reduction of algal growth.

Vandermeulen, J.H. and Lee, R.W. 1986. Lack of Mutagenic Activity of Crude and Refined Oils in the Unicellular Alga *Chlamydomonas reinhardtii. Bulletin of Environmental Contamination and Toxicology.* 36:250-253.

The study examined the mutagenic potential of the water-soluble fractions of four oils using an unicellular haploid alga. No significant difference was noted in the number of spontaneous streptomycin-resistant mutants in the control plates and those in plates cultured with Kuwait crude, Diesel 25 or Bunker C.

8.2 Effects on Invertebrates

Berry, W.O. 1977. Toxicity of Water-Soluble Gasoline Fractions to Fourth-Instar Larvae of the Mosquito (*Aedes aegypti* (L.)). *Environmental Pollution.* 13(3):229-234.

Static 24-hour acute bioassays were conducted to determine the toxicity of the water-soluble fractions of gasoline to mosquito larvae.

Berry, W.O., J.D. Brammer and D.E. Bee. 1978. Uptake of Water-Soluble Gasoline Fractions and Their Effect on Oxygen Consumption in Aquatic Stages of the Mosquito (*Aedes aegypti* (L.)). *Environmental Pollution.* 15:1-22.

The respiratory response of mosquito larvae and pupae were measured in the laboratory following a 24-hour exposure to one of the components of the water-soluble fraction of gasoline individually, combinations of the components, or all components combined. The uptake of toluene by larvae was measured.

Cajaraville, M.P., G. Diez, I.A. Marigomez and E. Angulo. 1990. Responses of Basophilic Cells of the Digestive Gland of Mussels to Petroleum Hydrocarbon Exposure. *Diseases of Aquatic Organisms.* 9(3):221-228.

A study was conducted on the digestive gland of the mussel *Mytilus galloprovincialis* Lmk. exposed to the water accommodated fraction of 2 crude oils and a commercial lubricant oil (3 different concentrations of each). Mussels were sampled after 21, 35, 77 and 91 day exposures, and the volume density of basophilic cells was determined. Exposure to petroleum hydrocarbons resulted in a significant dose-dependent increase in basophilic cell volume density.

Drewa, G., Z. Zbytniewski, D. Andruszczak, B. Kowalska, V. Korsak, L. Kozica-Raszeja, H. Kozlowska and K. Palgan. 1989. Laboratory Studies of the Effect of an Anionic Detergent and Fuel Oil on the Levels of Chlorophyll, Oxygen and Total Suspended Particulate Matter in Water of the Brda River. *Polskie archiwum hydrobiologii.* 36(1):161-168.

The effect of the anionic detergent, sodium laurylpolyethylene sulphate, and of fuel oil (third fraction of crude oil according to Polish Norm PN-c-960648) on the levels of Chlorophyll *a*, oxygen and total suspended particulate matter (including the biomass of the phytoplankton and zooplankton) in the Brda River was investigated. The detergent and fuel oil increased Chlorophyll *a* and total suspended particulate matter at all concentrations.

Franco, P.J., J.M. Giddings, S.E. Herbes, L.A. Hook, J.D. Newbold, W.K. Roy, G.R. Southworth and A.J. Stewart. 1984. Effects of Chronic Exposure to Coal-derived

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Oil on Freshwater Ecosystems: I. Microcosms. *Environmental Toxicology and Chemistry.* 3(3):447-463.

Freshwater microcosms were treated for 8 weeks with an unrefined coal-oil from 0.03 to 7 ml per week. Phenols were 95% of the water-soluble compounds. At the highest treatment level macrophytes, zooplankton and insects were eliminated, and the ecosystems became anaerobic. Microcosms did not recover to pretreatment conditions within 5 months. At lower dosages there were temporary effects. Community respiration, production/respiration ratio, pH and cladoceran zooplankton numbers, were affected at phenol concentrations below the lowest observable effect concentration of a chronic *Daphnia magna* bioassay.

Franco, P.J., K.L. Daniels, R.M. Cushman and G.A. Kazlow. 1984. Acute Toxicity of a Synthetic Oil, Aniline and Phenol to Laboratory and Natural Populations of Chironomid (Diptera) Larvae. *Environmental Pollution.* 34(4):321-331.

This study compares the responses of larvae of three species of chironomid midges from outdoor ponds and one species from laboratory culture, to a water-soluble fraction of a coal-derived oil and two of its major chemical components, aniline and phenol. The objectives were to determine how representative a laboratory culture is of natural midge populations and to expand the existing toxicity data base for synthetic fuels.

Geiger, J.G. and A.L. Buikema, Jr. 1981. Oxygen Consumption and Filtering Rate of *Daphnia pulex* After Exposure to Water-Soluble Fractions of Naphthalene, Phenanthrene, No. 2 Fuel Oil, and Coal-Tar Creosote. *Bulletin of Environmental Contamination and Toxicology.* 27(6):783-789.

Studies were conducted to determine the effects of No. 2 fuel oil, coal-tar creosote, naphthalene and phenanthrene on the oxygen consumption and filtering rates of *Daphnia pulex.* Values for 48-hour LC_{50}, LC_{30} and LC_{20} were determined.

Goel, P.K., R.K. Trivedy and S.S. Nakate. 1987. Effects of Refined Mineral Oils on Freshwater Phytoplankton. *Environmental Ecology.* 5(3):508-510.

A study on the effects of refined oils on freshwater phytoplankton is discussed in this paper. Response of algae was found to be highly dependent upon algal species, time of contact and the concentration of the oils. Of all the groups studied, green algae were the most susceptible to oil pollution stress.

MacLean, M.M. and K.G. Doe. 1989. *The Comparative Toxicity of Crude and Refined Oils*

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to Daphnia magna and Artemia. Internal Report #33-111. Environmental Protection Directorate, Environment Canada.

This report summarizes the results of acute toxicity tests that were performed using *Daphnia magna* and *Artemia* sp. exposed to 22 different oils, eight pure hydrocarbons, and two reference toxicants. The toxicity results are summarized by ranking the oils from most to least toxic. The *Daphnia magna* appeared to be more sensitive than the *Artemia* to the different oils. The most toxic, as far as affecting the mobility of the two species was unleaded gasoline for the *Daphnia magna* and new automobile lube oil for the *Artemia*. As for lethality, the most toxic to the *Daphnia magna* was furnace fuel oil, and to *Artemia* was leaded gasoline.

Malan, D.E. 1990. Predicted Effects of a Hypothetical Oil Spill on the Saltmarsh Crab *Sesarma catenata*. *Oil and Chemical Pollution* (UK). 6(2):137-159.

The effect of Qatar Light crude oil on the saltmarsh crab *Sesarma catenata* was investigated. These crabs are well adapted to the estuarine environment and mainly occur in the zone dominated by the saltmarsh grass *Spartina maritima*. Static bioassays conducted showed that adult crabs are fairly resistant to the water-soluble fraction (WSF) of the crude oil, but that larval survival is affected at a much lower WSF concentration. Many of the crabs were, however, affected during the bioassays and may be considered as 'ecologically' dead.

Merchant, E.R. and B.T. Walton. 1985. Lethal and Sublethal Effects of Petroleum and Two Coal-derived Oils on the Large Milkweed Bug *Oncopeltus fasciatus* (Dallas) (Hempit., Lygaeidae). *Zeitschrift fur Angewandte Entomologie*. 99:253-260.

Reproduction and longevity of the large milkweed bug *Oncopeltus fasciatus* were examined following topical application of crude oil and two coal-derived synthetic oils. The crude oil was less toxic in all cases than the two synthetic oils. An LD_{50} of 100 mg/g was extrapolated for the crude oil, but daily egg production did not appear to be affected.

Milleman, R.E., S.H. Tumminia, J.L. Forte and K.L. Daniels. 1984. Comparative Toxicities of Coal Derived and Shale Derived Crude Oils and a Petroleum Derived Fuel Oil to the Freshwater Snails *Helisoma trivolvis* and *Physa gyrina*. *Environmental Pollution*. 33:23-38.

The water-soluble fractions (WSFs) of coal-and shale-derived crude oils and a No. 2 diesel oil were tested for acute and chronic toxicity to the pulmonate snails *Physa gyrina* and *Helisoma trivolvis*. Full strength diesel oil WSF did not kill adult snails in 48 hours. Some of the high WSF concentrations significantly delayed hatching of both snail species by about 2 days as compared with the controls. There were no effects of the WSFs on survival of hatched snails. The data suggest that the WSFs may be teratogenic for snail embryos. Comparison of the toxicity of phenol to b-naphthol, naphthalene to phenanthrene, and quinoline to acridine showed that toxicity increased sharply with increasing number of rings.

Miller, M.C., J.R. Vestal, S. Mozley, M. Butler and J.E. Hobbie. 1977. Effects of Prudhoe crude Oil Spills on Coastal Tundra Ponds. in *Energy/Environment II*. U.S.EPA-600/9-77-012. pp. 521-529. Available from National Technical Information Service, (703)487-4650 as PB-271506.

Field experiments were conducted on ponds receiving various treatments of Prudhoe crude oil to determine any alterations of phytoplankton and zooplankton composition and reduction in algal productivity and zooplankton reproduction. Toxicity of the crude oil to a variety of aquatic insects and zooplankton was determined in laboratory and field experiments.

Mozley, S.C. and M.G. Butler. 1978. Effects of Crude Oil on Aquatic Insects of Tundra Ponds. *Arctic*. 31(3):229-241.

Field and laboratory studies were conducted to determine the effects of Prudhoe Bay crude oil on aquatic insects found in tundra ponds. Recovery of tundra pond insect populations and remedial cleanup actions are discussed.

O'Brien, W.J. 1978. Toxicity of Prudhoe Bay Crude Oil to Alaskan Arctic Zooplankton. *Arctic*. 31(3):219-228.

Several field and laboratory bioassay studies were conducted to determine the effects of Prudhoe Bay crude oil on Arctic zooplankton. The relative susceptibilities of several species are described and the relative susceptibilities of zooplankton to petroleum are discussed.

Ramusino, M.C. and D. Zanzottera. 1986. Crude Dubai Oil Toxicity on Some Fresh-water Invertebrates. *Bulletin of Environmental Contamination and Toxicology*. 36:150-158.

Toxicity tests were conducted to evaluate the effects of oil on common invertebrate species in the Po river. The main species tested was *Asellus aquaticus*, a common detritivore, in both the crude oil and its water-soluble fraction. Following treatment with the crude oil an LC_{50} of 14.4 ml/L was obtained. Following

Invertebrates, continued

treatment with the water-soluble fraction an LC_{50} of 11.5 mg/L was obtained. The other species tested showed differing effects depending upon exposure time.

Rao, S.S., R. Sarojini, K. Jayalakshmi and R. Nagabhushanam. 1990. Effect of Diesel on the Ovaries of Freshwater Prawn, *Macrobrachium lamerrii. Journal of Environmental Biology.* 11(4):393-398.

Freshwater prawns were exposed to chronic concentrations of diesel oil for 28 days. This exposure caused a decrease in ovarian index, inhibition of germinative zone, degeneration of oogonial cells and avitellogenic oocytes in immature prawns, whereas in maturing prawns shrinkage of ooplasm, necrotic nuclei lack of distinct nucleus in vitellogenic oocytes was noted.

Rogerson, A., J. Berger and C.M. Grosso. 1982. Acute Toxicity of Ten Crude Oils on the Survival of the Rotifer *Asplanchna sieboldi* and Sublethal Effects on the Fates of Prey Consumption and Neonate Production. *Environmental Pollution.* 29:179-187.

The acute toxicity of ten crude oils to rotifers *Asplanchna sieboldi* varied with the type of crude oil used, and with agitation of the medium. Light crudes (such as Norman Wells, Sweet Mixed Blend, Murban, and Sour Blend crudes) were most toxic; heavy crudes (such as Lloyd Minster, Lagomedio, Alberta, and La Rosa) were least toxic; and intermediate crudes (such as Prudhoe Bay and Bow River crudes) had intermediate toxicity. Agitation sharply increased toxicity.

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

Responses of larval chironomidae to experimental contamination of artificial substrates involving effects of oil and petroleum were studied. A literature review of other related studies was conducted. Communities of *chironomidae* were different during open water periods but were similar over the winter on oiled and unoiled artificial substrates in the Trail River. Greater numbers of species and individuals of Orthocladiinae occurred on the oiled than on the unoiled artificial substrates. The reverse was true for *tanypodinae* and *chironominae.* Ten species showed a positive response, 9 showed a negative response and 10 species were unaffected. Conclusions were that levels of contamination required to cause responses in certain species within the benthic community were difficult to identify and much more research needs to be done.

Invertebrates, continued

Sarojini, R., A.K. Khan and R. Nagabhushanam. 1989. Effect of Petroleum Hydrocarbons (petrol and diesel) on the Physiology of the Crab, *Barytelphusa cunicularis*, Oxygen Consumption. *Journal of Environmental Biology.* 10(4):363-365.

Exposure of the freshwater crabs, *Barytelphusa cunicularis,* to diesel and petrol caused lowering of oxygen consumption at lower exposure period. This indicates not only a change in metabolic rate, but also an increase of stress to the organism. Prolonged exposure, however, brought the respiration back to normal levels.

Tarshis, I. 1981. Uptake and Depuration of Petroleum Hydrocarbons by Crayfish. *Archives of Environmental Contamination and Toxicology.* 19(1):79-86.

Studies were conducted to determine the uptake and depuration rates of the water- soluble fraction of No. 2 fuel oil by crayfish.

Ullrich, S.O., Jr. and R.E. Millemann. 1983. Survival, Respiration, and Food Assimilation of *Daphnia magna* Exposed to Petroleum-and Coal-Derived Oils at Three Temperatures. *Canadian Journal of Fisheries and Aquatic Sciences.* 40:17-26.

Daphnia magna were tested with a No. 2 diesel fuel oil and a coal oil from the H-Coal direct liquefaction process. The coal-derived oil was more toxic than the diesel fuel. Respiration rates of animals exposed to sublethal concentrations of the water-soluble fractions at 10, 20, and 25°C were significantly affected by the water-soluble fraction concentration of the oils and the temperatures. At all temperatures, oxygen consumption rates of animals exposed to the coal-derived oil water soluble fraction decreased with increased concentration.

Warne, M., D.W. Connell, D.W. Hawker and G. Schuurmann. 1989. Prediction of the Toxicity of Mixtures of Shale Oil Components. *Ecotoxicology and Environmental Safety.* 18(2):121-128.

The toxicities of selected oil shale components and of mixtures of these components to a mixed marine bacterial culture was studied. The toxicities of mixtures, whose components were members of the same homologous series, were found to be additive. Even when compounds were structural isomers, synergism was observed. Simple and multiple linear regression equations utilizing measures of toxicity and molecular descriptors were used successfully to predict the enhancement of toxicity due to interaction.

Wong, K.C., J.R. Strickler and F.R. Engelhardt. 1983. Feeding Behavior of *Daphnia pulex* in Crude Oil Dispersions. *Bull. Environ. Contam. Toxicol.* 31:152-157.

Invertebrates, continued

Daphnia pulex were exposed to Norman Wells crude oil to determine what effects the crude oil had on feeding behavior. Feeding behavior changed immediately after crude oil particles were introduced. The frequencies of thoracic appendage movement, mandibular beat, and swallowing decreased while the rates of rejection by both the postabdomen and labrum increased. The resultant a synchrony of the feeding components expresses an early toxicity effect of dispersed petroleum. Metabolism in *Daphnia pulex* was found to increase up to twice normal following exposure to dispersed and water-soluble components of crude oil.

Wong, K.C., F.R. Engelhardt and J. Strickler. 1981. Survival and Fecundity of *Daphnia pulex* on Exposure to Particulate Oil. *Bull. Environ. Contam. Toxicol.* 26:606-612.

The effects of fresh particulate and 24-hr weathered Norman Wells crude oil on the fecundity and survival of *Daphnia pulex* were examined.

8.3 Effects on Plants

Alexander, S.K. and J.W. Webb, Jr. 1987. Relationship of *Spartina alterniflora* Growth to Sediment Oil Content Following an Oil Spill. *Proceedings*, 1987 International Oil Spill Conference, Baltimore, MD, April 6-9, 1987. API Publication No. 4452. American Petroleum Institute, Washington, D.C. pp. 445-449.

Following a spill of light crude oil into the Dickinson Bayou in Galveston, Texas in January 1984, monitoring was conducted to determine the effects of the oil on the smooth cordgrass, *Spartina alterniflora*. Because of low tides and difficulties with boom placement, mechanical cleanup of the marsh was not successful. The results indicated that the heavily oiled sediments had significant reduction of the *Spartina alterniflora* growth, and after 16 months, erosion of the shoreline was evident. This shoreline erosion continued through 32 months post spill. The growth of *Spartina alterniflora* that was only lightly to moderately oiled, was unaffected.

Amakiri, J.O. and A. Onofegharaf. 1984. Effects of Crude Oil Pollution on the Germination of *Zea mays* and *Capsicum frutescens*. *Environmental Pollution*. 35:159-167.

Seeds of *Zea mays* and *Capsicum frutescens* were exposed to crude oil in a number of soaking/germination regimes. Seeds of both varieties showed slowed germination following soaking in the crude oil. Rates of germination were substantially reduced in the *Zea mays* while seeds of *Capsicum frutescens* continued to achieve total germination. The difference was attributed to differences in penetrability of the seed coats.

Baker, J.H. 1970. The Effects of Oils on Plants. *Environmental Pollution*. 1: 27-44.

This is a review article examining crude oil and refinery products. The comparative toxicity of effects of physical properties of oils and effects of environmental conditions are presented. Penetration of oil from plant surfaces, movement of oil in plants, penetration of oils into cells, transpiration, respiration, photosynthesis, translocation, germination and growth, resistance to disease, resistance to oil, and selective effects are summarized.

Baker, J.H. 1971. The Effects of Oils on Plant Physiology. In E.B. Cowell, ed. *The Ecological Effects of Oil Pollution on Littoral Communities*. Institute of Petroleum, London. pp. 88-101.

This article discusses penetration of oil from the plant surface, movement of oil in the plant, transpiration, respiration, photosynthesis, translocation, and resistance to oil. Oils reduce transpiration rate and photosynthesis. Effects on respiration are variable, but respiration tends to increase if the plant is exposed to oil. Oils inhibit

Plants, continued

translocation and the severity of effect depends upon constituents, amount of the oil, environmental conditions, and species of plant.

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 oil 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.

Campbell, W.B., R.W. Harris and R.E. Benoit. 1973. Response of Alaskan Tundra Microflora to Crude Oil Spill. *Proceedings*, Symposium on the Impact of Oil Resource Development on Northern Plant Communities. Occasional Publications on Northern Life No. 1. Institute of Arctic Biology, University of Alaska, Fairbanks, AK. pp. 53-62.

Various concentrations of Prudhoe Bay crude oil were applied on meadow tundra at Barrow, Alaska. Soil respiration rates and characteristics of soil microflora were measured for 2 years following application. Growth of hydrocarbon decomposing flora were stimulated, especially yeasts and several *Pseudomonas* spp., while diatoms and higher fungi were inhibited. Addition of critical levels of inorganic nutrients to the nutrient-poor system is more effective in stimulating oil decomposition than is an inoculation of hydrocarbon decomposers. A clean-up of oil from tundra may produce more grievous problems than leaving it alone.

Ferrell, R.E., E.D. Seneca and R.A. Linthurst. 1984. The Effects of Crude Oil on the Growth of *Spartina alterniflora* Loisel. and *Spartina cynosuroides (L.)* Roth. *Journal of Experimental Marine Biology and Ecology.* 83:27-39.

Greenhouse studies were conducted to examine the effects of crude oil on the

growth of *Spartina alterniflora* Loisel. and *S. cynosuroides* (L.) Roth from North Carolina. The manner in which crude oil contacts plant tissue and/or substratum was an important factor in the responses of both species to oil pollution. Plants recovered from a single application of oil to aerial tissue with relatively little impact on productivity. Observations suggest that decreased productivity and regrowth may have been caused by decreased root and rhizome growth. Regrowth potential of *S. alterniflora* grown in oiled substratum was greater in fine-textured marsh substratum than in sand substratum. terrestrial vegetation, Venezuelan.

Goudey, J.S., M. Dale and J. Hoddinott. 1985. The Effects of Oil Spill Chemicals on Transpiration, Carbon Dioxide Exchange, and Cuticular Structure in *Salix Interior. Canadian Journal of Botany.* 63:2340-2461.

The effects of three oil dispersants (Corexit 9600, 9550, and 7664) on cuticular structure and function in the sandbar willow *S. interior* were assessed. Observations of the leaf surface, measurements of water loss through transpiration, and rates of CO_2 exchange in the light and dark were measured. Although the Corexits coated the leaf surfaces, wax plates (crystals) associated with the cuticle were not visibly altered. Although the dispersants are potent contact poisons, damage to the protective cuticle in *S. interior* does not appear to be a major contributing factor to their toxicity.

Goudey, J.S., M. Dale and J. Hoddinott. 1986. Effects of Oil Spill Chemicals on CO_2 Assimilation by the Fruticose Lichen *Cladina mitis. Environmental Pollution.* 42(1):23-35.

The effects of Corexit 9600, 9550 and 7664 on carbon fixation by the fruticose lichen *Cladina mitis* were examined. Measurements of rates of CO_2 assimilation were obtained and lichen samples were dried, ground, and oxidized. Undiluted dispersant inhibited rates of carbon fixation by 60 to 80%, and bleached portions of the thalli at doses less than 10 mg/g dry weight. The inhibitory effects were not lethal and partial recovery of the lichens was noted within 3 weeks after treatment. Direct application may be detrimental to *Cladina*.

Griffin, W.M. and J.J. Cooney. 1979. Degradation of Model Recalcitrant Hydrocarbons by Microorganisms from Freshwater Ecosystems. *Developments in Industrial Microbiology* 20:479-488.

Laboratory studies of ability of pure and mixed cultures of 35 microbes (21 bacteria, 14 fungi) isolated from freshwater (stream, river and lake) systems to utilize selected hydrocarbons as sole carbon sources or in combination

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(cooxidation). The hydrocarbons tested represented classes resistant to degradation found in crude and/or refined oils: pristine (branched alkane), 1,13-tetradecadiene (olefin), cyclohexane (cycloalkane), and benzene (aromatic). Growth on hexadecane and kerosene was examined.

Heldal, M., S. Norland, T. Lien and G. Knutsen. 1984. Toxic Responses of the Green Algae *Dunaliella bioculata* (Chlorophycea, Volvocales) to Selected Oxidized Hydrocarbons. *Environmental Pollution.* 34(2):119-132.

Hydroperoxides, alcohols, acids, ketones, quinones and epoxides represent classes of compounds likely to form from the photooxidation of crude oil. Representatives of these compounds were tested for toxicity on the green algae *Dunaliella bioculata*. Hydroperoxides and quinones were found to be extremely toxic with 50% effect concentration values ranging from 0.01 to 0.7 ppm. No clear correlation between chemical structure and toxic mode of action was established. The algae showed two major responses: one group of compounds affected growth while the other caused mortality.

Hsieh, Y., M.B. Tomson and C. Ward. 1980. Toxicity of Water-Soluble Extracts of No. 2 Fuel Oil to the Freshwater Alga *Selenastrum capricornutum. Developments in Industrial Microbiology.* 21:401-409.

The water-soluble fraction (WSF) of No. 2 fuel oil and the components of No. 2 fuel oil were bioassayed using cultured *Selenastrum capricornutum*, a green alga. Criterion for toxicity was a reduction in numbers of algal cells in tests with WSF. Aged extracts showed less effect than fresh.

Hutchinson, T.C., P. Kauss and M. Griffiths. 1972. The Phytotoxicity of Crude Oil in Freshwater. *Water Pollution Research Journal of Canada.* 7:52-58.

Field and laboratory studies of toxicity to planktonic algae of crude oil, crude oil-water extracts, selected oil components were conducted. Crude oil spills in a small pond revealed inhibition in growth of some species, no effect on some species, and apparent stimulation in others. Growth was inhibited in laboratory studies of algae and water-soluble fractions of seven crude oils. A decrease in pH, plus other toxic factors which appeared to be volatile, reduced growth.

Hutchinson, T.C. and W. Freedman. 1975. Effects of Experimental Crude Oil Spills on Taiga and Tundra Vegetation of the Canadian Arctic. *Proceedings,* 1975 Conference on Prevention and Control of Oil Pollution, San Francisco, California, March 25-27, 1975. pp. 517-525.

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Experimental oil spills during summer and winter were used to study short-and long-term effects on lichens and mosses. Oil damage was found to be largely as a contact herbicide. Tundra vegetation was affected less severely than that of the boreal-taiga due to the presence of resistant species. Winter spills had a less severe effect than summer spills due to the absence of actively growing foliage at the time of the spill and to the loss or weathering of toxic components. Irrespective of the season of the spill, reproductive ability was severely reduced.

Kershaw G.P. and L.J. Kershaw. 1986. Ecological Characteristics of 35-year-old Crude-oil Spills in Tundra Plant Communities of the Mackenzie Mountains, N.W.T. *Canadian Journal of Botany.* 64(12):2935-2947.

Results are presented from ecological investigations of Canadian alpine tundra where a number of crude oil spills occurred 35 years earlier. The purpose was to determine the substrate and botanical characteristics of these sites and compare them to control sites. In the oiled sites, the oil penetrated up to 60-cm in dry, coarse-textured soil and up to 8-cm in wet, clay-rich soil. Plant cover was substantially lower in oiled sites and in only one community was floristic diversity greater on the oiled site as compared to the control.

King, J.M. and K.S. Coley. 1985. Toxicity of Aqueous Extracts of Natural and Synthetic Oils to Three Species of *Lemna*. In R.C. Bahner and D.J. Hansen, eds. *Aquatic Toxicology and Hazard Assessment, Eighth Symposium.* Special Technical Publication 891 of the American Society for Testing and Materials. Philadelphia, PA. pp. 302-309.

This study observed the acute toxicity of natural and synthetic oils to three species of *Lemna* to determine if growth responses were similar to those for algae. The experiment exposed three species under standard laboratory conditions to two crude oils, a fuel oil, and two coal-liquefaction products. The results showed that the coal-liquefaction products had a greater acute toxicity than the natural oils, which were similar to results obtained with algae. *Lemna* proved to be efficient and effective bioassay organisms.

McCown, D.D. and F.J. Deneke. 1972. Plant Germination and Seedling Growth as Affected by the Presence of Crude Petroleum. *Proceedings,* 23rd AAAS Alaskan Science Conference, Fairbanks, Alaska. pp. 44-51.

The authors were unable to determine the precise way that crude oil contact affected plants, but did draw some conclusions on the potential success of seed germination and growth. Seed germination on freshly oiled soil can be expected

Plants, continued

to be low and although germination on aged soils might occur, subsequent growth and survival would be limited. The longterm result of a terrestrial oil spill may be a shift in species composition.

Singh, A.K. and J.P. Gaur. 1988. Effect of Assam Crude on Photosynthesis and Associated Electron Transport System in *Anabaena doliolum*. *Bulletin of Environmental Contamination and Toxicology*. 41:776-780.

Low concentrations of crude oil stimulated photosynthesis in the alga *Anabaena doliolum* while higher concentrations inhibited photosynthesis. Disruption of phytosystem II activity was found to be the primary action of the oil.

Vandermeulen, J.H., A. Foda and C. Stuttard. 1985. Toxicity vs Mutagenicity of some Crude Oils, Distillates and Their Water Soluble Fractions. *Water Research*. 19:1283-1289.

Two crude oils were tested for mutagenicity and compared to Diesel 25, Bunker C, and used motor oil using Ames tests. Of the oils and their water soluble fractions (WSF), only the used motor oil met the criteria for mutagenicity.

Werner, M.D. and V.D. Adams. 1984. Consequences of Oil Pollution on the Decomposition of Vascular Plant Litter in Freshwater Lakes: Part 1. Decomposition Rates and Dissolved Oxygen Utilization. *Energy Review*. 11(3):83.

Crude oil spills in Rocky Mountain lakes were found to reduce the rate of plant litter decomposition for a period of more than one year. Some groups of microorganisms can not only withstand the toxic effects of oil, but actually have their growth stimulated by the energy source of highly reduced carbons provided by the oil. Other microorganisms are adversely affected. The net effect of a spill would be that oil-damaged, undegraded plant litter would accumulate in the lake system, and the increased biological oxygen demand from the oxygen-requiring biodegradation of petroleum could cause anoxic conditions, especially during ice-covered periods when oxygen could not be replenished from the atmosphere.

8.4 Effects on Birds

Albers, P.H. 1978. The Effects of Petroleum on Different Stages of Incubation in Bird Eggs. *Bulletin of Environmental Contamination and Toxicology.* 19:624-630.

Artificially incubated mallard (*Anas platyrhynchos*) eggs were treated externally with 5 µl of No. 2 fuel oil or 5 µl of Southern Louisiana crude oil at various times during incubation (2, 6, 10, 14, 18, and 22 days). Embryos were most sensitive during the 0 to 10 day incubation period. Southern Louisiana crude oil was more toxic than No. 2 fuel oil. Oil generally did not affect hatching weight, but caused bill abnormalities among embryos exposed to lethal amounts of oil during the first 10 days of incubation. Few external abnormalities were observed in surviving embryos.

Albers, P.H. 1980. Transfer of Crude Oil from Contaminated Water to Bird Eggs. *Environmental Research.* 22:307-314.

Pairs of breeding Mallard ducks were exposed to oiled water at either 100 µm of water surface (high treatment) or 5 µm (low treatment) for 2 days during the first week of egg incubation. Hatching success of ducks exposed to the high treatment was significantly less than controls. Hatching success of ducks exposed to the low treatment was less and incubation temperatures of oiled females were not significantly different from controls. Incubation behavior of females exposed to oiled water and the survival of their ducklings during the first week after hatch was not affected by the oil.

Albers, P.H. and G.H. Heinz. 1983. FLIT-MLO and No. 2 Fuel Oil: Effects of Aerosol Applications to Mallard Eggs on Hatchability and Behavior of Ducklings. *Environmental Research.* 30:381-388.

FLIT-MLO and No. 2 fuel oil are sprayed on wetlands for mosquito control, and the hazard to incubating mallard eggs was evaluated. Normal field applications of FLIT-MLO (9.35 to 46.75 L/ha) or No. 2 fuel oil (2.34 to 4.67 L/ha) do not appear to pose a direct hazard to embryos of birds that are off their nest when spraying occurs. Hatchability of eggs exposed to between 4.67 and 18.7 L/ha of No. 2 fuel oil during early incubation may be significantly reduced.

Averbeck, C. 1992. Haematology and Blood Chemistry of Healthy and Clinically Abnormal Great Black-Backed Gulls (*larus marinus*) and herring gulls (*larus argentatus*). *Avian Pathology.* 21(2):215-223.

The hematological and cholesterol values were compared for healthy gulls and environmentally stressed gulls. The environmentally stressed gulls were either

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oiled, emaciated, infested with endoparasites, had organic abnormalities, or external injuries. The results of the comparison showed that there were significant differences between the healthy and sick birds.

Biderman, J.O. and W.H. Drury. 1980. *The Effects of Low Levels of Oil on Aquatic Birds. A Non-Technical Summary of Research Activities FY76 through FY78.* FWS/OBS-80/16. Fish and Wildlife Service, U.S. Department of the Interior.

Exposure of adult waterbirds or their developing young to slight amounts of petroleum can seriously interfere with the reproductive process. Effects can range from interference with the physiology of reproduction to killing of embryos, developmental defects, stunting of growth, and impairment of survival ability when birds are stressed. Oil can be taken up in food or picked up on their feathers, and can be transferred from the adult to eggs or nestlings. Chronic reduction in reproductive success may be the most significant effect on populations of aquatic birds.

Cavanaugh, K.P. and W.N. Holmes. 1982. Effects of Ingested Petroleum on Plasma Levels of Ovarian Steroid Hormones in Photostimulated Mallard Ducks. *Archives of Environmental Contamination and Toxicology.* 11:503-508.

The rate of ovarian maturation is slowed when photostimulated mallard ducks are given food contaminated with petroleum. Most of the birds will eventually enter the breeding state but when they do start to lay, their patterns of oviposition are erratic and there may be intervals of several days between successive eggs. These effects may be detrimental to reproductive success in the wild. Daily mean concentrations of estradiol and estrone in plasma of laying birds consuming uncontaminated food were significantly higher than for birds eating contaminated food.

Cavanaugh, K.P., A.R. Goldsmith, W.N. Holmes and B.K. Follett. 1983. Effects of Ingested Petroleum on the Plasma Prolactin Levels during Incubation and on the Breeding Success of Paired Mallard Ducks. *Archives of Environmental Contamination and Toxicology.* 12:335-341.

Breeding pairs of mallard ducks consuming food contaminated with South Louisiana crude oil take longer to complete their reproductive cycles than pairs fed uncontaminated food due to an abnormally long period of gonadal maturation. Oil-fed birds produced significantly fewer ducklings per breeding pair than the control groups, and showed qualitatively similar patterns of prolactin level changes throughout the cycle compared to control groups. All oil-fed females laid eggs, but

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low reproductive success among contaminated birds may be due to reduced levels of prolactin during oviposition and incubation.

Cavanaugh, K.P. and W.N. Holmes. 1987. Effects of Ingested Petroleum on the Development Of Ovarian Endocrine Function in Photostimulated Mallard Ducks (*Anas platyrhynchos*). *Archives of Environmental Contamination and Toxicology.* 16(2):247-253.

Female Mallard ducks that had been raised to maturity on a non-stimulatory light regime were divided into two groups and exposed to a stimulatory light regime. The experimental group was given food contaminated with petroleum. The plasma concentrations of hormones in the control birds increased steadily and by the 15th day of photosimulation they started to lay eggs. In the experimental group, plasma concentrations increased more slowly and half started to lay eggs after 21 days. Contaminants derived from ingested petroleum act quickly to interfere with photosimulated ovarian recrudescence and the associated development of ovarian endocrine function.

Coon, N.C. and M.P. Dieter. 1981. Responses of Adult Mallard Ducks to Ingested South Louisiana Crude Oil. *Environmental Research.* 24:309-314.

Morphological, biochemical, and pathological responses of adult mallard ducks to chronic ingestion of South Louisiana crude oil (SLC) were examined. Treatments consisted of untreated duck breeder mash (control), mash containing 1% of a paraffin mixture (used to simulate the aliphatic portion of crude oil), and mash containing either 0.25% or 2.5% SLC. No mortalities were observed in any group, and body weight was not significantly affected. Oil-fed hens laid fewer eggs than those fed the control diet, but hatchability was not affected.

Coppock, R.W., S. Ross, J.D. Reynolds and J.D. Somers. 1990. Observations on PCBs and Mercury in Common Loons (*Gavia immer*) Collected From Southwestern Lake Michigan. *Veterinary and Human Toxicology.* 32(3):257-258.

The death of common loons *Gavia immer* was initially associated with a small spill of Bunker-C oil off the Chicago shoreline of Lake Michigan. Oil was not found on the feathers or in the lungs of the birds. The loons had abundant body fat suggesting they were not debilitated at the time of death. The cause of death could not be directly associated with the spill.

Coulliard, C.M. and F.A. Leighton. 1989. Comparative Pathology of Prudhoe Bay Crude Oil and Inert Shell Sealants in Chicken Embryos. *Fundamental and Applied*

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Toxicology. 13:165-173.

Prudhoe Bay Crude Oil (PBCO), mineral oil and sealing film were applied to chicken eggs and pathological abnormalities were compared between them. The embryos treated with PBCO had more severe pathological changes, but less retardation of growth than the other treatments. Toxic effects of PBCO are due to more than just sealing the shell.

Coulliard, C.M. and F.A. Leighton. 1990a. Sequential Study of the Pathology of Prudhoe Bay Crude Oil in Chicken Embryos. *Ecotoxicology and Environmental Safety.* 19:17-23.

Pathological changes to chicken embryos induced by application of Prudhoe Bay Crude Oil to the shell were examined at sequential times following exposure. Pathological changes, including liver necrosis, renal lesions, and edema were seen two days after exposure and persisted through the prenatal period when the experiment was ended.

Coulliard, C.M. and F.A. Leighton. 1990b. The Toxicopathology of Prudhoe Bay Crude Oil in Chicken Embryos. *Fundamental and Applied Toxicology.* 14:30-39.

Varying doses of Prudhoe Bay Crude Oil were applied to fertile chicken eggs to assess pathological changes. Mortality of the embryos rose in proportion to the dose. Extent of edema and liver necrosis was dose dependent. Additional pathological changes noted were heart distension, spleen enlargement, cellular damage in the kidneys, and hematopoiesis in the liver and spleen.

Couillard, C.M. and F.A. Leighton. 1991a. Critical Period of Sensitivity to Petroleum Toxicity in the Chicken Embryo. *Environmental Toxicology and Chemistry.* 10(2):249-254.

Small amounts of South Louisiana crude oil (SLCO) or Prudhoe Bay Crude Oil (PBCO) were applied to the shell of fertile leghorn chicken eggs on day 8, 8.5 or 9 of incubation. Percent mortality and prevalence of grossly visible lesions were evaluated 96 hours after treatment. The 16-fold decrease in sensitivity of the embryo from day 8 to day 9 of incubation suggests that the chorioallantoic membrane may be important in the toxic action of petroleum oil.

Coulliard, C.M. and F.A. Leighton. 1991b. Bioassays for the Toxicity of Petroleum Oils in Chicken Embryos. *Environmental Toxicology and Chemistry.* 10:533-538.

Birds, continued

This study was conducted to determine if petroleum oils cause liver necrosis in chicken embryos. Six different oils were tested on fertile chicken eggs. Liver necrosis and edema were observed in all cases, and necrosis was evaluated as an endpoint for bioassays.

Crocker, A.D., J. Cronshaw and W.N. Holmes. 1975. The Effect of Several Crude Oils and Some Petroleum Distillation Fractions on Intestinal Absorption in Ducklings (*Anas platyrhynchos*). *Environmental Physiology and Biochemistry*. 5:92-106.

This study was to determine whether crude oils or distillation fractions are quantitatively similar in their inhibitory effects on intestinal absorption mechanisms. All crude oils decreased the adaptive response of the intestinal mucosa for Na^+ and water transfer, but to varying degrees. Inhibition was the least for North Slope, Alaska crude oil, and greatest for South Louisiana and Kuwait oils. When a distillation fraction (from either San Juan Valley (SJV), California or Paradox Basin (PB), Utah crude oil) inhibited the mucosal transfer rates, the potency of this fraction exceeded that of the whole crude oil from which it was derived.

Custer, T.W. and P.H. Albers. 1980. Response of Captive, Breeding Mallards to Oiled Water. *Journal of Wildlife Management*. 44(4):915-918.

Mallards were paired and placed in breeding pens containing sunken water troughs. Experimental troughs were treated with either 100 ml/m^2 (high) or 5 ml/m^2 (low) of Prudhoe Bay Crude Oil for a period of two days. Mallards in the high-oil groups hesitated longer than controls before entering the water. Both sexes made fewer trips to heavily oiled water, and males spent less time per visit in heavily oiled than in untreated water. This study supports field observations that birds attempt to avoid oil after initial contact.

Eastin, W.C. and D.J. Hoffman. 1978. Biological Effects of Petroleum on Aquatic Birds. *Proceedings*, Conference on Assessment of Ecological Impacts of Oil Spills, June 14-17, Keystone, CO. American Institute of Biological Sciences. pp. 561-582.

Microliter applications of crude or refined oil on the surface of fertile eggs of Mallards, common eiders, great black-backed gulls, sandwich terns, Louisiana herons, and laughing gulls were embryotoxic under laboratory and field incubation conditions. Teratogenic effects were observed when oil application was made during the first few days of development. Teratogenicity was increased when oil was supplemented with vanadium, nickel or mercury (metals found in petroleum). Food chain experiments using crayfish, exposed to radio-labelled aromatic compounds, as food for mallards showed that the ducks accumulated most in the

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gall bladder, followed by accumulation in fat, kidney, liver, and blood. Oil spills and oil pollution may pose the greatest threat to developmental and reproductive phases of aquatic birds.

Eastin, W.C., Jr. and H.C. Murray. 1981. Effects of Crude Oil Ingestion on Avian Intestinal Function. *Canadian Journal of Physiology and Pharmacology.* 59:1063-1068.

Effects of dietary ingestion of crude oil on intestinal function in freshwater-adapted mallard ducklings were examined using an *in vivo* luminal perfusion technique. Experiments used a mixture consisting of duck starter mash containing 0.25% or 2.5% Prudhoe Bay crude oil (PBCO) or 2.5% paraffin mixture. There was a significantly lower absorption rate of Na and water in ducklings fed 2.5% paraffin compared with the other groups. Crude oil ingestion may affect the permeability of duckling intestine, but does not directly affect net Na absorption.

Eastin, W.C., Jr., and B.A. Rattner. 1982. Effects of Dispersant and Crude Oil Ingestion on Mallard Ducklings (*Anas platyrhynchos*). *Bulletin of Environmental Contamination and Toxicology.* 29:273-278.

Effects of ingestion of Corexit 9527 on growth and blood chemistries in mallard ducklings were examined. Prudhoe Bay crude oil (PBCO), Corexit, or both were mixed with duck starter mash. Body weight was not affected by treatment. The only significant difference was an increase in plasma alanine aminotransferase activity at week 9 in the dispersant group. No other effects of dispersants were observed, indicating that at prescribed concentrations this chemical is relatively innocuous to waterfowl. When crude oil was fed in combination with dispersant, toxic effects of the oil diminish.

Engel, S.E., T.E. Roudybush, J.C. Dobbs and C.R. Grau. 1978. Depressed Food Intake and Reduced Reproduction in Japanese Quail After a Single Dose of Prudhoe Bay Crude Oil. *Proceedings*, 17th Annual Hanford Biology Symposium, University of California, Davis, California. pp. 27-36.

Experiments were conducted to assess the possible effects of single dose of Prudhoe Bay crude oil (PBCO) on female Japanese quail. Immediately after dose administration, food intake decreased significantly and remained low for one day. Egg production and egg weight returned to normal 3 days after dosing. Hatchability of fertile eggs was not reduced. However, because of decreased egg production and shell quality, reproductive success decreased. Hatching weight was reduced in the oil-treated group. A temporary reduction in food intake

Birds, continued

accounted partially for the adverse effects of a single dose of PBCO on reproductive success of quail.

Frink, L. and B. Crozer-Jones. 1990. Rehabilitation of Oil Contaminated Birds. In D.R. Ludwig, ed. *Wildlife Rehabilitation.* 8:23-34.

This paper discusses emergency responses to oil spills and how oil contaminated birds are rehabilitated. It details the internal and external effects of petroleum contamination to birds and discusses treatment regimes and problems that may inhibit wildlife response from lack of proper equipment and trained personnel to excessive public interest.

Gorman, M.L. and C.E. Simms. 1978. Lack of Effect of Ingested Forties Field Crude Oil on Avian Growth. *Marine Pollution Bulletin.* 9:273-276.

Male domestic chicks (Ross Ranger), mixed sex ducklings (Aylesbury), and Herring gulls (2-10 days old) were used to investigate the effects of ingested Forties Field crude oil on body growth, intestinal absorption of amino-acids and on the entrail loss of plasma proteins. Ingestion of crude oil had no effect upon species growth or on uptake of amino-acids. Large doses of crude oil (10 ml) did not result in structural damage sufficient to cause an increase in the rate of loss of plasma proteins.

Gorsline, J. and W.N. Holmes. 1981. Effects of Petroleum on Adrenocortical Activity and on Hepatic Naphthalene-Metabolizing Activity in Mallard Ducks. *Archives of Environmental Contamination and Toxicology.* 10:765-777.

The hypothesis that hydrocarbons from ingested crude oil may impair the adrenocortical function of contaminated birds was investigated. Mallard ducks were fed food contaminated with South Louisiana crude under conditions consistent with minimal activation of the pituitary-adrenal axis. A progressive decline in naphthalene-metabolizing activities of liver tissue from birds exposed to contaminated food for very long periods of time was due to a decrease in the ability of birds to metabolize the petroleum contaminants.

Gorsline, J. and W.N. Holmes. 1982. Adrenocortical Function and Hepatic Naphthalene Metabolism in Mallard Ducks (*Anas platyrhynchos*) Consuming Petroleum Distillates. *Environmental Research.* 28:139-146.

Reductions in plasma corticosterone concentration and increases in hepatic naphthalene-metabolizing activity that occur when mallard ducks are acutely

Birds, continued

exposed to petroleum-contaminated food are caused by distinct molecular-size classes of compounds in whole crude oil. Data suggest that more than one physiological dysfunction occurs in response to consuming a particular crude oil, the changes may not necessarily be caused by the same compounds. Although a large amount of volatile material may be lost soon after a spill, the toxicity of the residual petroleum may not necessarily diminish. Various fractions of South Louisiana crude oil result in different toxic potencies to mallards.

Gorsline, J. and W.N. Holmes. 1982. Ingestion of Petroleum by Breeding Mallard Ducks: Some Effects on Neonatal Progeny. *Archives of Environmental Contamination and Toxicology.* 11:147-153.

Breeding female Mallard ducks consuming petroleum-contaminated food showed significant increases in naphthalene-metabolizing activities. Food contaminated with 1% South Louisiana crude oil was twice as toxic as uncontaminated food and more potent than food contaminated with Prudhoe Bay crude oil. Irrespective of oil type, greater percentages of oil contained in food induced greater increases in naphthalene-metabolizing activity. Circulating contaminants derived from ingested petroleum are incorporated into eggs of breeding females during yolk deposition.

Grau, C.R., T. Roudybush, J. Dobbs and J. Wathen. 1977. Altered Yolk Structure and Reduced Hatchability of Eggs from Birds Fed Single Doses of Petroleum oils. *Science.* 195:779-781.

Egg production of was significantly reduced on days 1 and 2 following a 200 mg dose of Bunker C oil, and hatchability was significantly reduced on days 1 and 2 but returned to normal on day 4. Oil ingestion was often followed by the formation of thin egg shells that were easily cracked. A 500 mg dose of bunker C oil to chickens *Gallus gallus domesticus* produced yolk structure abnormalities, and a 3 g dose caused cessation of egg production. Yolk structure abnormalities in eggs from Canada geese *Branta canadensis moffitti* were observed after the geese were given 2, 3, or 5 g of bunker C oil.

Gregory, D.G. and W.C. Edwards. 1991. Investigating Oiled Birds From Oil Field Waste Pits. *Veterinary and Human Toxicology.* 33(5):497-498.

Procedures and results of investigations concerning the oiling of inland raptors, migratory waterfowl and other birds are presented. Freon washings from the oiled birds and from the pits were analyzed by gas chromatography and in most instances the source of the oil could be established. The numbers of birds involved (including many on the endangered species list) suggested the need for netting or

Birds, continued

closing oil field waste pits and mud disposal pits.

Hall, R.J. and N.C. Coon. 1988. *Interpreting Residues of Petroleum Hydrocarbons in Wildlife Tissues.* U.S. Fish and Wildlife Service Biology Report. 88(15):7. 8 pp. Washington, DC 20240.

The report discusses how to interpret residues of petroleum hydrocarbons in wildlife tissues, with an emphasis on avian species. Information is presented on sampling and handling of samples, interpretation of results, when analysis should be requested, and how much oil in tissues is harmful to wildlife.

Hartung, R. *Ingestion of Oil by Waterfowl.* Paper presented at the meeting of Papers of the Michigan Academy of Science, Arts, and Letters, University of Michigan (1962).

Different quantities of a radioactively labelled, highly aromatic, low viscosity oil were applied to the breast feathers of black ducks *Anas rubripes.* Radiation levels of the oiled breast feathers indicated that significant amounts of oil were ingested during preening, but ingested oil had not been absorbed and stored internally. The ingestion of a single dose of the cutting oil resulted in a highly significant reduction in mobility of the experimental animal.

Hartung, R. 1965. Some Effects of Oiling on Reproduction of Ducks. *Journal of Wildlife Management.* 29(4):872-874.

After ingestion of 2 g per kg body weight of a relatively nontoxic lubricating oil, one mallard (*Anas platyrhynchos*) and two Pekins stopped laying for about 2 weeks. Very small quantities of mineral oil (2.0 - 35.9 mg) coated on mallard eggs reduced their hatchability to 21 percent compared to 89 percent for unoiled eggs. Experimentally oiled mallards (4 - 5 ml mineral oil applied to breasts and abdomen) continued incubating their clutches, but their eggs did not hatch even though they continued incubation for longer than normal periods.

Hartung, R. and G.S. Hunt. 1966. Toxicity of Some Oils to Waterfowl. *Journal of Wildlife Management.* 30(3):564-570.

A light fuel oil, a diesel oil, two motor lubricating oils, a cutting oil additive, and a cutting oil were tested for their toxic effects on waterfowl. All oils were able to cause lipid pneumonia, gastrointestinal irritation. Lubricating oils caused slight irritation, fatty livers, and adrenal cortical hyperplasia when fed to ducks in single doses. Feeding of a cutting oil and a diesel oil resulted in acinar atrophy of the pancreas. Feeding the cutting oil produced a definite inhibition of cholinesterase

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activity while the diesel oil depressed cholinesterase activity only slightly. Approximate LD_{50} values were determined.

Hartung, R. 1967. Energy Metabolism in Oil-Covered Ducks. *Journal of Wildlife Management.* 31(4):798-804.

Metabolic rates of mallards *Anas platyrhynchos* and black ducks *Anas rubripes* covered with known quantities of oils increased linearly with decreasing ambient temperatures. Comparison of metabolic rates between normal and oiled ducks strongly indicates that metabolism is greatly speeded up in oiled ducks as temperature decreases. A dose-response curve was established for the effects of oiling on the estimated heat conductivity of normal and oiled duck plumages.

Harvey, S., H. Klandorf and J.G. Phillips. 1981. Reproductive Performance and Endocrine Responses to Ingested Petroleum in Domestic Ducks (*Anas platyrhynchos*). *General and Comparative Endocrinology.* 45:372-380.

Oviposition rates and shell thickness of eggs laid by Khaki Campbell ducks fed a daily diet of 5 ml crude oil/100 g chicken pellets were greatly reduced as compared to experimental controls. Plasma levels of prolactin and corticosterone in the oil-fed birds were less than in the control birds, suggesting that the reduction in oviposition rates and shell thickness of eggs from the oil-fed birds was not due to impaired gonadal hormone secretion or from stress-induced increases in adreno-cortical activity. Increases in plasma thyroxine concentrations were only observed after the reproduction effects were observed.

Harvey S., P.J. Sharp and J.G. Phillips. 1982. Influence of Ingested Petroleum on the Reproductive Performance and Pituitary-Gonadal Axis of Domestic Ducks (*Anas platyrhynchos*). *Comparative Biochemistry and Physiology.* 72(C):83-89.

Chronic ingestion of a sublethal dose (5%) of dietary North Sea crude oil delayed the onset of lay in adult Khaki Campbell ducks and greatly reduced the rate of oviposition and quality of the eggs subsequently laid. These detrimental effects could not be satisfactorily explained by changes in gonadotropin secretion or in plasma calcium levels. However, the reduced rate of lay was accompanied by low gonadal steroid levels.

Hoffman, D.J. 1978. Embryotoxic Effects of Crude Oil in Mallard Ducks and Chicks. *Toxicology and Applied Pharmacology.* 46:183-190.

Microliter quantities of South Louisiana crude oil were applied to the surfaces of

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fertile mallard *Anas platyrhynchos* and white leghorn chicken *Gallus gallus* eggs. Early embryo lethality was greater in mallard than in chick embryos, but later embryo lethality was more prevalent in chick embryos. The overall incidence of embryo lethality was similar in both species. Teratogenic defects were more frequent in chick embryos (≥ 1 µl) than in mallard embryos (5 µl). External application of a mixture of paraffin compounds present in crude oil had virtually no embryotoxic effects in either species.

Hoffman, D.J. 1979. Embryotoxic Effects of Crude Oil Containing Nickel and Vanadium in Mallards. *Bulletin of Environmental Contamination and Toxicology*. 23:203-206.

The effects of crude oil with and without added nickel and vanadium on embryonic development in mallards *Anas platyrhynchos* was studied by comparing survival rates, embryonic weights, crown-rump lengths, bill lengths, and external, soft tissue, and skeletal defects. Treatment with crude oil or crude oil containing vanadium or nickel resulted in considerable and significant embryonic mortality compared with untreated controls. In the presence of either metal, the percentage of surviving embryos that were abnormal was significantly greater than with crude oil alone. All three treatments resulted in a significant incidence of abnormal survivors.

Hoffman, D.J. 1979. Embryotoxic and Teratogenic Effects of Petroleum Hydrocarbons in Mallards (*Anas platyrhynchos*). *Journal of Toxicology and Environmental Health*. 5(5):835-844.

Application of ≥5-µl of the aromatic hydrocarbon mixture significantly reduced embryo survival and mean weights. The aliphatic mixture did not cause death, stunted growth, or abnormal survivors. Of the aromatic hydrocarbons tested, pyrene caused a small but significant decrease in survival. Monocyclic and thiopheno aromatics caused significantly shorter bill lengths. Addition of 0.5% chrysene to the aromatic mixture even at half the original concentration (26% aromatics by weight) resulted in considerable enhancement of embryo toxicity.

Hoffman, D.J. and P.H. Albers. 1984. Evaluation of Potential Embryotoxicity and Teratogenicity of 42 Herbicides, Insecticides, and Petroleum Contaminants to Mallard Eggs. *Archives of Environmental Contamination and Toxicology*. 13:15-27.

Results are reported for the embryotoxicity of environmental contaminants applied externally to mallard (*Anas platyrhynchos*) eggs. Many petroleum products were embryotoxic and moderately teratogenic. The most toxic was a commercial oil used for control of road dust followed by South Louisiana crude oil, Kuwait crude,

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No. 2 fuel oil, Bunker C, and industrial and automotive waste oil. Prudhoe Bay crude, unused crankcase oil, aviation kerosene, and aliphatic hydrocarbon mixtures were less toxic and less teratogenic.

Holmes, W.N., K.P. Cavanaugh and J. Cronshaw. 1978. The Effects of Ingested Petroleum on Oviposition and Some Aspects of Reproduction in Experimental Colonies of Mallard Ducks (*Anas platyrhynchos*). *Journal of Reproduction and Fertilization.* 54:335-347.

Unmated mallard ducks fed South Louisiana crude showed an 84% decline in the daily rate of oviposition and a 33% decrease in egg-shell thickness as compared to untreated controls. In mated birds, normal patterns of oviposition, fertilization, and hatchability were restored after removal of petroleum from the diet. The addition of Kuwait crude oil to diets had no effect on the rate of oviposition, the incidence of fertility, or the hatchability of the fertilized eggs at low doses. A diet of 3 ml Kuwait crude oil/100 g dry food completely abolished oviposition; normal oviposition was restored when the concentration of crude oil was decreased. However, the incidence of fertilization remained low and none of the fertilized eggs gave rise to viable ducklings. Kuwait crude oil had no effect on eggshell thickness.

Holmes, W.N. and K.P. Cavanaugh. 1990. Some Evidence for an Effect of Ingested Petroleum on the Fertility of the Mallard Drake (*Anas platyrhynchos*). *Archives of Environmental Contamination and Toxicology.* 19(6):898-901.

This paper describes a study where male and female of monogamous pairs of mallard ducks were housed separately on each side of a removable wire-mesh partition and each bird was fed either uncontaminated food or food that had been contaminated with South Louisiana crude oil. The partition was removed and the birds were allowed to interact. When the male consumed contaminated food, the ability of the male to fertilize eggs was significantly reduced. When the female consumed contaminated food, ovarian development was slowed significantly. Ingested petroleum contaminants may impair the development of photostimulated gonadal endocrine function.

Hooper, T.D., K. Vermeer and I. Szabo. 1987. *Oil Pollution of Birds: An Annotated Bibliography*, Technical Report Series No. 34. Canadian Wildlife Service, Pacific and Yukon Region, British Columbia.

An extensive annotated bibliography of 606 citations concerning effects of oil pollution on birds.

Birds, continued

Hughes, M.R., C. Kassera and B.R. Thomas. 1990. Effect of Externally-applied Bunker Fuel on Body Mass, Body Temperature, Plasma Concentration and Water Flux of Glaucous-winged Gulls, *Larus glaucescens*. In *Thirteenth Arctic and Marine Oil Program Technical Seminar, Edmonton (Canada), 6-8 June 1990*. pp. 219-229.

The effects of severe external Bunker C contamination on adult gulls were evaluated. Oiled gulls showed markedly reduced food intake, lost body mass, and decreased water efflux and plasma concentration. The decrease in plasma concentration is likely due to ion loss not balanced with ion intake, although oil contamination may affect the renal and/or extrarenal salt excreting systems. Freshwater rehabilitative therapy, derived largely from studies of domestic ducks and nestling seabirds, may be inappropriate for oiled adult birds. Reduced drinking might diminish the rate of elimination of toxic metabolites or oil derivatives.

Hunt, G.S. 1961. *Waterfowl Losses on the Lower Detroit River Due to Oil Pollution.* Publication No. 7. Great Lakes Research Division, Institute of Science and Technology, University of Michigan.

Loss of waterfowl due to oil pollution in the lower Detroit River is discussed, and laboratory experiments on the effects of exposure of waterfowl to No. 5 and No. 2 fuel oils are described.

Jenssen, B.M. 1989. Effects of Ingested Crude and Dispersed Crude Oil on Thermoregulation in Ducks (*Anas platyrhynchos*). *Environmental Research.* 48:49-56.

Crude oil and crude oil mixed with a dispersant were administered to domestic ducks *Anas platyrhynchos* by stomach tube to examine effects on thermoregulation. No significant differences were seen in heat production or thermal conductance or skin temperature, at low temperatures. The body temperatures of all treated ducks were significantly higher than those of controls.

Jenssen, B.M. and M. Ekker. 1989. Rehabilitation of Oiled Birds: A Physiological Evaluation of Four Cleaning Agents. *Marine Pollution Bulletin.* 20(10):509-512.

This paper discusses the need to develop more efficient detergents for cleaning birds. The properties of four different cleaning agents were tested to remove oil from plumage and to restore the water repellent and insulative properties of the feathers of domestic ducks *Anas platyrhynchos* and of common eiders *Somateria mollissima*. By using more efficient detergents, the cleaning time was reduced by approximately half. Results show that these detergents are efficient at restoring the

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insulative properties of the cleaned plumage. The water repellent properties of the plumage were not re-established before the plumage was dry, and cleaning oiled birds using cold water resulted in hypothermia.

Jenssen, B.M. and M. Ekker. 1991a. Effects of Plumage Contamination With Crude Oil Dispersant Mixtures on Thermoregulation in Common Eiders and Mallards. *Archives of Environmental Contamination and Toxicology*. 20(3):398-403.

Thermoregulatory effects of plumage-oiling with Statfjord A crude oil (SACO), or of SACO mixed with the dispersants Finasol OSR-5 or OSR-12 were studied by measuring the rate of metabolic heat production of common eiders *Somateria mollissima* and mallards *Anas platyrhynchos*. The study suggests that oil-dispersant mixtures are more potent than crude oil alone, and that common eiders are more sensitive to crude oil-dispersant mixtures than mallards. The species differences are probably due to specific differences in plumage structure, i.e., birds possessing an air-filled plumage, with high insulative properties, are probably more vulnerable than species with a plumage which does not offer so much resistance to heat loss.

Jenssen, B.M. and M. Ekker. 1991b. Dose Dependent Effects of Plumage-oiling on Thermoregulation of Common Eiders *Somateria mollissima* Residing in Water. *Polar Research*. 10(2):579-584.

Thermoregulatory effects during the first hours after plumage-oiling were studied by measuring the metabolic heat production of common eiders *Somateria mollissima* which were resting in water for up to three hours. The ducks were exposed to 10-70 mL Statfjord A crude oil. The study demonstrated a dose-and time-dependent effect of plumage oiling on metabolic heat production during the first three hours after contact with the oil. The results indicate that the immediate, short-term effects following initial contact with oil at sea are lesser in scale than those which occur after the birds have preened the oil into a greater part of their plumage.

Jones, B. 1985. Removal of Oil from a Peregrine Falcon. *Wildlife Rehabilitation*. 4:73-74.

This paper discusses the removal of oil from a peregrine falcon entangled in ropes on an oil drilling vessel. The ropes were covered with a graphite based grease used to protect metal fittings from corrosion. The falcon was not only oiled, but appeared to have ingested some of the grease. The paper tells how the falcon was cleaned, nursed to good health, and released.

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Lambert, G., D.B. Peakall, B.J.R. Philogene and F.R. Engelhardt. 1982. Effect of Oil and Oil Dispersant Mixtures on the Basal Metabolic Rate of Ducks. *Bulletin of Environmental Contamination and Toxicology.* 29:520-524.

Basal metabolic rates (BMR) of adult mallards (*Anas platyrhynchos*) exposed for one hour to Prudhoe Bay Crude Oil (PBCO), Corexit 9527, and a mixture of oil and dispersant were measured. Birds exposed to Corexit 9527 showed signs of loss of buoyancy, but no significant increase in BMR. Exposure to PBCO alone caused a modest (approximately 13%) but significant increase in BMR; the effect lasted through 8 to 14 days post-exposure. Exposure to PBCO and Corexit resulted in a significant increase in BMR observed through 8 to 14 days post-exposure.

Lawler, G.C., J.P. Holmes, B.J. Fiorito, J.L. Laseter and R.C. Szaro. 1978. Quantification of Petroleum Hydrocarbons in Selected Tissues of Male Mallard Ducklings Chronically exposed to South Louisiana Crude Oil. *Proceedings,* 1978 Conference on Assessment of Ecological Impacts of Oil Spills, Keystone, Colorado, June 14-17, 1978. pp. 583-612.

Heart, liver, and kidney tissues from male mallard ducklings that had ingested commercial duck starter containing South Louisiana crude oil from hatch to 8 weeks were analyzed for 55 saturated and aromatic oil hydrocarbons. Data suggest that the ducklings metabolized the low molecular weight saturated hydrocarbons at a faster rate than the high molecular weight saturates.

Lawler, G.C., W. Loong and J.L. Laseter. 1978. Accumulation of Aromatic Hydrocarbons in Tissues of Petroleum-Exposed Mallard Ducks (*Anas platyrhynchos*). *Environmental Science and Technology.* 12(1):51-54.

Mallard drakes were dosed with South Louisiana crude oil were examined for aromatic petroleum hydrocarbons. Petroleum aromatics were found in every tissue analyzed from oil-dosed mallards. Skin and underlying adipose tissue accumulated more aromatic hydrocarbons than other tissues, which included: liver, breast muscle, heart muscle, brain, uropygial gland, and blood. The detection of aromatic hydrocarbons in brain tissue suggests they may contribute to observed sublethal effects of petroleum on the nervous system of mallards.

Lawler, G.C., W. Loong and J. Laseter. 1978. Accumulation of Saturated Hydrocarbons in Tissues of Petroleum-Exposed Mallard Ducks, (*Anas platyrhynchos*). *Environmental Science and Technology.* 12(1):47-51.

Tissue analysis by gas chromatography and mass spectrometry was performed on

Birds, continued

adult mallard ducks following 14 days of treatment (feeding) with 5 ml/day of South Louisiana crude oil. Oil was found in every tissue except the brain; the highest concentrations were found in the skin and underlying adipose.

Lee, Y.-Z, P.J. O'Brien, J.F. Payne and A.D. Rahimtula. 1986. Toxicity of Petroleum Crude Oils and Their Effect on Xenobiotic Metabolizing Enzyme Activities in the Chicken Embryo in Ovo. *Environmental Research.* 39:153-163.

Crude oil applied to fertile chicken eggs was found to significantly increase embryo mortality, induce cytochrome P450 levels and increase mixed-function oxidase activities. Administration of disulfiram in dioxane prior to application of oil was found to mitigate toxicity.

McEwan, E.H. and A.F.C., Koelink. 1973. The Heat Production of Oiled Mallards and Scaup. *Canadian Journal of Zoology.* 51:27-31.

Heat loss of heavily oiled mallards and scaup was 1.7 to 2 times greater than their normal values, respectively. Oiling increased basal heat production and shifted the lower critical temperature from 12 to 25°C. Scaup were more sensitive to the oiling than were the mallards and attempts to rehabilitate the scaup were rarely successful.

McEwan, E.H. and P.M. Whitehead. 1980. Uptake and Clearance of Petroleum Hydrocarbons by the Glacous-Winged Gull (*Laras glaucescens*) and the Mallard Duck (*Anas platyrhynchos*). *Canadian Journal of Zoology.* 58:723-726.

Glacous-winged gulls and mallard ducks fed tritiated crude oils, showed a rapid uptake of labelled hydrocarbons into tissues and plasma. Results showed that petroleum hydrocarbons ingested by the birds were distributed in various body tissues and fluids but detoxification mechanisms existed for the removal of these hydrocarbons.

Nwokolo, E. and L.O.C. Ohale. 1986. Growth and Anatomical Characteristics of Pullet Chicks Fed Diets Contaminated With Crude Petroleum. *Bulletin of Environmental Contamination and Toxicology.* 37:441-447.

Pullet chicks fed varying amounts of crude oil gained less weight and experienced greater mortality as the amount of oil in their diet increased. In addition, organ weights were lower in chicks fed higher amounts of oil, with lesions on the liver, pancreas and spleen.

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Olsen, G.H., J.M. Nicolich and D.J. Hoffman. 1990. A Review of Some Causes of Death of Avian Embryos. *Proceedings,* Annual Conference of the Association of Avian Veterinarians. Orlando, FL. pp. 106-111.

This paper discusses what factors can reduce hatchability of birds. Petroleum and crude oils have be found to reduce hatching rates of eggs. In mallard duck eggs, a very small exposure will kill 50% of the embryos while the other 50% have malformations. The most toxic oil to birds is commercial road dust control oil.

Rattner, B.A. and W.C. Eastin Jr. 1981. Plasma Corticosterone and Thyroxine Concentrations During Chronic Ingestion of Crude Oil in Mallard ducks (*Anas platyrhynchos*). *Comparative Biochemistry and Physiology.* 68C:103-107.

Mallard ducks were exposed to various dietary quantities of crude oil for 18 weeks. At 6, 12, and 18 weeks, blood samples were taken and plasma corticosterone and thyroxine. were measured. Results of the study showed that ingestion of crude oil appeared to reduce the plasma concentration of corticosterone in growing mallard ducks. This observed alteration in corticosterone concentration could reduce tolerance to temperature and dietary functions in the environment. Crude oil did not appear to affect the plasma thyroxine concentration in mallard ducks.

Rocke, T.E., T.M. Yuill and R.D. Hinsdill. 1984. Oil and Related Toxicant Effects on Mallard Immune Defenses. *Environmental Research.* 33:343-352.

Mallards *Anas platyrhynchos* were dosed with crude oil, Bunker C fuel oil, and an oil dispersant, separately and in mixtures. They were then exposed to the avian cholera pathogen to evaluate resistance to infectious disease. Although the ability of the exposed mallards to produce antibodies was not affected by exposure, their ability to resist disease was significantly lower.

Speich, S.M., D.A. Manuwal and T.R. Wahl. 1991. The Bird/Habitat Oil Index - A Habitat Vulnerability Index Based on Avian Utilization. *Wildlife Society Bulletin.* 19(2):216-221.

This paper describes a bird oil index (BOI) that quantifies aspects of species behavior, biology, distribution, and abundance as they relate to potential exposure to oil on the water surface. The BOI was used to evaluate the relative importance of oil pollution to waterbirds in different habitat areas of Puget Sound, Washington. The application of the BOI process allows comparisons on the local scale as well as on the larger, continental scale.

Birds, continued

Stickel, L.F. and M.P. Dieter. 1979. *Ecological and Physiological/Toxicological Effects of Petroleum on Aquatic Birds.* FWS/OBS-79/23, PB80-127285. U.S. Fish and Wildlife Service, Biological Services Program. Laurel, MD. pp.1-14.

Birds were fed an oil contaminated diet to determine the effects on physiological condition, reproduction, and survival; and the accumulation of oil in body tissues. Very small quantities of oil applied to bird eggs caused embryo mortality. Adult birds were able to adapt to and tolerate high concentrations of petroleum hydrocarbons in their diet, when not otherwise stressed. Young birds showed subtle biochemical and behavioral changes. Accumulation of oil in mallard ducks when fed oil contaminated crayfish was greatest in the gall bladder, followed by fat, kidney, liver, and blood.

Stubblefield, W.A., G.A. Hancock, W.H. Ford and R.K. Ringer. 1994. An Evaluation of the Toxic Properties of Naturally Weathered Exxon Valdez Crude Oil to Surrogate Wildlife Species Part 1: Acute and Subchronic Toxic Properties. *Environmental Toxicology and Chemistry.*

The acute and subchronic toxic properties of naturally weathered EXXON VALDEZ cargo oil were assessed in tests using Mallard ducks and European ferrets. The results indicated that acute exposures of ducks and ferrets to weathered EXXON VALDEZ cargo oil using dietary concentrations as high as 100,000 mg oil/kg diet, (10%) and oral doses of up to 5,000 mg/kg body weight, respectively, posed no significant risks to the survival potential of these species.

Szaro, R.C. 1979. Bunker C Fuel Oil Reduces Mallard Egg Hatchability. *Bulletin of Environmental Contamination and Toxicology.* 22:731-732.

Mallard duck eggs were exposed to Bunker C fuel applied to the air cell end of the eggs and allowed to spread freely. Six-day survival and hatchability were significantly reduced in all oil treatment groups. As little as 5 µl of Bunker C fuel oil was sufficient to reduce hatching success to 36 percent.

Szaro, R.C. and P.H. Albers. 1977. Effects of External Applications of No. 2 Fuel Oil on Common Eider Eggs. In D.A. Wolfe, ed. *Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms.* Pergamon Press, Inc., New York. pp. 164-167.

Studies were conducted with common eider eggs exposed to No. 2 fuel oil in amounts of 5 µl and 20 µl; eggs were also tested with 20 µl of propylene glycol, a neutral blocking agent. Hatching success was 96% for the eggs treated with

propylene glycol and 92 percent for eggs treated with 5 µl oil. Only 69% of the eggs treated with 20 µl oil survived. The level of oil used to demonstrate lethality in eider eggs is believed to be well below that encountered in the environment.

Szaro, R.C., N.C. Coon and W. Stout. 1980. Weathered petroleum: Effects on Mallard Egg Hatchability. *Journal of Wildlife Management.* 44:709-713.

Mallard duck eggs were exposed to weathered oil and water-soluble fractions of Prudhoe Bay crude oil and No. 2 fuel oil. There was no evidence that Prudhoe Bay crude oil became less toxic during 10 days of weathering. There was a pronounced dose effect on the hatching success of eggs treated with both oils in the fresh indoor- and outdoor-weathered groups. The toxicity of crude and refined oils was ameliorated following weathering.

Szaro, R.C., G. Hensler and G.H. Heinz. 1981. Effects of Chronic Ingestion of No. 2 fuel Oil on Mallard Ducklings. *Journal of Toxicology and Environmental Health.* 7:789-799.

No. 2 fuel oil was fed to mallard *Anas platyrhynchos* ducklings to assess the effects during early development. Five growth parameters (body weight, wing length, ninth primary length, tarsal length and bill length) were depressed in birds receiving a diet containing 5% fuel oil. There was no oil related mortality, but avoidance behavior was impaired. Liver hypertrophy and splenic atrophy were gross evidence of pathological effects in birds in the 5.0% oil diet. More subtle effects included biochemical lesions that resulted in the elevation of plasma alanine aminotransferase and ornithine carbamoyltranferase activity.

Szaro, R.C., P.H. Albers and N.C. Coon. 1978. Petroleum: Effects on Mallard Egg Hatchability. *Journal of Wildlife Management.* 42(2):404-406.

Survival, hatching success and growth of embryos were studied after mallard duck eggs were treated with South Louisiana crude, Kuwait crude and No. 2 fuel oils during various developmental stages.

Szaro, R.C., M. Dieter, G. Heinz and J. Ferrell. 1978. Effects of Chronic Ingestion of South Louisiana Crude Oil on Mallard Ducklings. *Environmental Research.* 17(3):426-436.

Studies were conducted on mallard ducklings to determine the effects of chronic exposure by ingestion to South Louisiana crude oil. Growth, behavior, biochemical and histological abnormalities were assessed.

Birds, continued

Vangilder, L.D. and T.J. Peterle. 1980. South Louisiana Crude oil and DDE in the Diet of Mallard Hens: Effects on Reproduction and Duckling Survival. *Bulletin of Environmental Contamination and Toxicology.* 25:23-28.

Mallard hens were fed South Louisiana Crude Oil (SLCO) and dichlorodiphenylchloroethane (DDE) to determine effects on reproduction and duckling survival. Data showed that SLCO or DDE fed to mallard hens produced two effects in their ducklings: 1) a greater proportion failed to initiate maintenance of a functional body temperature in response to temperature stress; and 2) the metabolic rate of ducklings that did maintain a functional body temperature was increased.

Vangilder, L.D. and T.J. Peterle. 1981. South Louisiana Crude Oil or DDE in the Diet of Mallard Hens: Effects on Egg Quality. *Bulletin of Environmental Contamination and Toxicology.* 26:328-336.

The effects of two environmental pollutants, crude oil and dichlorodiphenylchloroethane (DDE), on the size and composition of mallard *Anas platyrhynchos* eggs was studied. It was concluded that any pollutant-induced changes in the physical characteristics of the egg as well as physiological changes in the embryo induced by the presence of pollutants in the egg would probably interact to produce reductions in egg hatchability, thermoregulatory ability and survival of ducklings.

Vangilder, L.D. and T.J. Peterle. 1983. Mallard Egg Quality: Enhancement by Low Levels of Petroleum and Chlorinated Hydrocarbons. *Bulletin of Environmental Contamination and Toxicology.* 30:17-23.

Mallard hens were assigned to receive diets containing either, 0.5% South Louisiana crude oil (SLCO), 5 ppm DDE, 0.5% SLCO + 5ppm DDE, or a control diet. There was a significant interaction between the two pollutants in their effect on egg hatchability. Hatchability of eggs fed SLCO alone was significantly less than that of eggs laid by hens fed any other diet. Overall results showed that pollutant-induced effects may be positive or negative depending upon dose level; life history stage of the organism, and interactions with other pollutants.

Welte, S. and L. Frink. 1991. *Rescue and Rehabilitation of Oiled Birds.* U.S. Fish and Wildlife Service, Fish and Wildlife Leaflet. No. 13.2.8. Washington, DC.

Oiled bird rehabilitation is an intensive, crisis-oriented response that requires an experience, specialized medical expertise, stockpiles of special equipment, and

Birds, continued

human resources. This article summarizes the internal and external effects of oil on birds, handling of waterfowl and seabirds, and the key components of an effective oil spill response.

White, J. 1990. Protocol for the Rehabilitation of Oil-Affected Waterbirds. *Proceedings*, Annual Conference of the Association of Avian Veterinarians. Orlando, FL pp. 153-163.

This paper summarizes rehabilitation of an oil-contaminated waterbird. The author discusses life-threatening medical problems to be addressed before a bird can be cleaned. The author discusses cleaning, nutritional support, and release criteria for cleaned birds, and the importance of re-waterproofing.

Whiteley, P.L. and T.M. Yuill. 1991. Interactions of Environmental Contaminants and Infectious Disease in Avian Species. In B.D. Bell, R.O. Cossee, J.E.C. Flux, B.D. Heather, R.A. Hitchmough, C.J.R. Robertson and M.J. Williams, eds. *Proceedings*, Acta XX Congressus Internationalis Ornithologici, Vol. 4. Christchurch, New Zealand December 2-9, 1990. pp. 2338-2342.

This paper discusses how contaminants can decrease birds' resistance to viral and bacterial infections which is critical to note in the conservation and management of wild bird populations. How environmental contaminants attack the immune system is discussed.

8.5 Effects on Fish

Al-Sabti, K. 1985. Frequency of Chromosomal Aberrations in the Rainbow Trout, *Salmo gairdneri Rich.*, Exposed to Five Pollutants. *Journal of Fish Biology.* 26:13-19.

Rainbow trout *Salmo gairdneri* were exposed to a number of industrial chemicals, including crude oil. Chromosomal aberrations in tissues from the kidneys and gills were observed in 31.6 to 40.7% of the fish exposed to crude oil.

Brannon, E.L., T.P. Quinn, R.P. Whitman, A.E. Nevissi, R.E. Nakatani and C.D. McAuliffe. 1986. Homing of Adult Chinook Salmon After Brief Exposure to Whole and Dispersed Crude Oil. *Transactions of the American Fisheries Society.* 115(6):823-827.

Adult chinook salmon *Oncorhynchus tshawytscha* that had returned to a hatchery were exposed for one hour to either whole Prudhoe Bay crude oil, a chemical dispersant, or chemically dispersed oil in freshwater. Neither frequency of homing (72% overall) nor days to return to the hatchery (mean = 3.2 days) were affected by the treatments. Retention of some treated fish at the hatchery determined that longevity was sufficient to prevent significant bias in estimates of homing. Homing speed increased and longevity decreased, but homing frequency remained relatively constant.

Cotta Ramusino, M., P. Dellavedova and D. Zanzottera. 1984. Effects of Crude Dubai Oil on *Salmo gairdneri Rich.* and *Carassius auratus L. Bulletin of Environmental Contamination and Toxicology.* 32:368-376.

In April 1980 a pipeline burst along the Po River in Italy, releasing 663 tons of crude oil. Laboratory tests were conducted to determine the lethal concentration and calculate the concentration threshold value, below which mortality does not occur (safety dose). This report discusses the results of the test on two different organisms; the *Carassius auratus L.* and the *Salmo gairdneri Rich.* The report also discusses the various disorders that the fish experience after being exposed to oil, including disorientation and restlessness.

Cotta Ramusino, M. and D. Zanzottera. 1986. Crude Dubai Oil Toxicity on Some Fresh-water Invertebrates. *Bulletin of Environmental Contamination and Toxicology.* 36:150-158.

In April, 1980, following a pipeline burst along the Po River in Italy, where 663 tons of crude oil were spilled, laboratory toxicity tests were conducted to determine if behavioral changes occurred in the fish exposed to oil. This report discusses the mortalities that occurred after certain exposures, and the various dysfunctions that

Fish, continued

resulted from exposure to the oil, including limited mobility and disorientation.

Engelhardt, F.R., M.P. Wong and M.E. Duey. 1981. Hydromineral Balance and Gill Morphology in Rainbow Trout *Salmo gairdneri*, Acclimated to Fresh and Sea Water, as Affected by Petroleum Exposure. *Aquatic Toxicology.* 1(3,4):175-186.

Laboratory studies were conducted to determine the effects of crude oils (Norman Wells, Venezuelan) on ion balance, osmolality, cortisol balance and gill morphology in rainbow trout *Salmo gairdineri.*

Glubokov, A.I. 1990. Growth of Three Species of Fish During Early Ontogeny Under Normal and Toxic Conditions. *Journal of Ichthyology (English Translation of Voprosy Ikhtiologii).* 30(2):51-59.

Coho salmon, Siberian sturgeon and masu salmon were exposed to toxic petroleum products, phenol, DDT, trichlorform, mercury, cadmium, and copper. Growth was evaluated by studying the rate of length and weight increases and the changes in weight as a function of increasing length. In higher concentrations, the toxicants cause death without disturbing the growth processes; in lower concentrations growth is stimulated, and in intermediate concentrations, growth is retarded.

Hellou, J. and J.F. Payne. 1986. Effect of Petroleum Hydrocarbons on the Biliary Bile Acid Composition of Rainbow Trout (*Salmo gairdneri*). *Comparative Biochemistry and Physiology.* 84C:257-261.

Venezuelan crude oil and olive oil were administered orally to rainbow trout *Salmo gairdneri.* Effects on biliary bile acid composition and volume were compared.

Hodgins, H.O., W.D. Gronlund, J.L. Mighell, J.W. Hawkes and P.A. Robisch. 1977. Effect of crude oil on trout reproduction. *Proceedings,* Symposium on Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. Seattle, WA, November 10-12, 1976. Pergamon Press, New York. pp. 143-150.

The effects of long-term petroleum exposure on the reproductive success of salmonid fish was studied by incorporating Prudhoe Bay crude oil into the diet of adult rainbow trout *Salmo gairdneri* during sexual maturation. There was no significant impairment of hatching success related to the petroleum exposure. Test and control males were virtually identical in fertility. Mean survival from hatching to swim-up fry stage of development was 76% for test and 91% for control fish. No gross morphological or histological abnormalities were observed in offspring of

Fish, continued

petroleum-fed fish, but there were histological abnormalities of eye lenses and livers in adult fish exposed to the oiled food.

Jardine, C.G. and S.E. Hrudey. 1988. Threshold Detection Values of Potential Fish Tainting Substances from Oil Sands Wastewaters. *Water Science Technology.* 20(8/9):19-25.

This paper discusses fish tainting testing that was conducted to determine if chemicals found in oil sand extraction were detected in walleye at varying concentrations. Detection threshold values appear to be related to the molecular weight and vapor pressure of the tainting compounds. To determine whether a compound will cause tainting of fish, however, its concentration in water and the bioconcentration factor for the compound with each particular species of fish will have to be considered.

Khan, R.A. 1987. Crude Oil and Parasites of Fish. *Parasitology Today.* 3:99-100.

Effects of crude oil exposure on parasites of fish are reviewed in this paper. Gut parasites are reduced following exposure to crude oil while gill and blood parasites are increased. Impairment of the mucous and immune defense mechanisms may be responsible for the increased parasitism.

Khan, R.A. 1991. Influence of Concurrent Exposure to Crude Oil and Infection with Trypanosoma murmanensis (*Protozoa: Mastigophora*) on Mortality in Winter Flounder, *Pseudopleuronectes Americanus. Canadian Journal of Zoology.* 69(4): 876-880.

A study was conducted to determine the influence of concurrent exposure to crude oil and a hemoprotozoan parasite on mortality in winter flounder. Juvenile and adult flounder were infected and exposed to sediment contaminated with various concentrations of oil. Mortality occurred earlier and was greater in juvenile fish exposed to crude oil than in adults. However, a larger percentage of oil-treated infected adult flounder died after exposure at the highest concentrations. At the highest concentrations, organ somatic indices and blood values in surviving flounder were affected more in the infected, oil-treated fish than in controls.

Koning, C.W. and S.E. Hrudey. 1992. Sensory and Chemical Characterization of Fish Tainted by Exposure to Oil Sand Wastewaters. *Water Science Technology.* 25(2):27-34.

This paper outlines a study that was conducted to see if fish were tainted when

Fish, continued

exposed to oil sand-extraction wastewaters. The results showed that the fish were tainted after a period of 24 hours, and the phenol levels detected in the fish tissue were well above reported odor threshold levels.

Kurelec, B., A. Garg, S. Krca, S. Britvic, D. Lucic and C. Gupta-Ramesh. 1992. DNA Adducts in Carp Exposed to Artificial Diesel-2 Oil Slicks. *European Journal of Pharmacology, Environmental Toxicology and Pharmacology.* 228:(1):51-56.

Liver DNA adducts were analyzed by ^{32}P-postlabeling carp *Cyprinus carpio* exposed to slicks prepared from No. 2 diesel oil/water emulsions. A similar adduct pattern was found in the liver DNA of carp exposed to crude oil-polluted water. These results indicate that diesel oil can cause extensive DNA damage in carp *in vivo* and the damage accumulates proportionately with time of exposure.

Landrum, P.F. 1987. Photoinduced Toxicity of Polycyclic Aromatic Hydrocarbons to Aquatic Organisms. In J.V. Vandermeulen and S.E. Hrudey, eds. *Oil in Freshwater: Chemistry, Biology, and Countermeasure Technology.* Pergamon Press, New York. p. 304. *Proceedings* of the Symposium on Oil Pollution in Freshwater. Edmonton, Alberta, Canada. October 15-19, 1984.

This paper discusses how polycyclic aromatic hydrocarbons (PAHs) are not normally considered acutely toxic to aquatic organisms because of their low water solubility. Studies have illustrated that anthracene is acutely toxic (100% mortality) to juvenile bluegill sunfish at certain dosages in less than 9 hours. These dramatic effects occur as a result of the interaction of bioaccumulated parent PAH and light, not the action of externally formed photodegradation products.

Leung, S-Y. T. 1977. *Effects of Crude Oil on the Developmental Stages of Japanese Medaka (Oryzias latipes).* M.S. Thesis. Iowa State University, Ames, Iowa.

The sensitivity of various life stages of the freshwater Japanese medaka *Oryzias latipes* to several crude oils were studied. Medaka eggs were extremely resistant. Hatching time was accelerated in eggs exposed to crude oil. Significant mortality was observed with larvae exposed to the crude oil, indicating that newly hatched larvae were more susceptible. Results of subadult tests showed no mortality, and quick recovery when transferred to clean water.

Lindstrom-Seppe, P. 1988. Biomonitoring of Oil Spill in a Boreal Archipelageo by Xenobiotic Biotransformation in a Perch (*Perca fluviatilis*). *Ecotoxicology and Environmental Safety.* 15(2):162-170.

Fish, continued

The effect of the accidental fuel oil spill (250 tonnes) in a boreal archipelago (Gulf of Bothnia, Finland) on xenobiotic metabolism of local perch was monitored for 1.5 years. The monooxygenase and conjunction activities of perch liver were determined from control areas and those areas where oil had spilled. Only a slight induction in monooxygenase activities was seen in perch caught near the spill four months after the accident. The induction of monoxygenase activities in laboratory experiments was quite clear: after a single dose, the activity rose rapidly and then quickly disappeared.

Lockhart, W.L., R.W. Danell and D.A.J. Murray. 1987. Acute Toxicity Bioassays with Petroleum Products: Influence of Exposure Conditions. In J.H. Vandermeulen and S.E. Hrudey, eds. *Oil in Freshwater: Chemistry, Biology, Countermeasure Technology.* Pergamon Press, New York. pp. 335-344. *Proceedings* of the Symposium on Oil Pollution in Freshwater. Edmonton, Alberta, Canada. October 15-19, 1984.

Forty-eight hour-LC_{50} values were obtained with young rainbow trout exposed to water-soluble fractions (WSF) of a range of crude and refined oils. The results suggest that toxicity of the water-soluble fractions is associated largely with the substituted benzenes and naphthalenes. The LC_{50} values were highly dependent on the particular exposure conditions. Aeration of test containers virtually eliminated toxicity. These results are discussed in terms of the design of bioassays relevant to ice-covered environments and to other situations where volatilization may be low or reduced.

Martin, D.J., C.J. Whitmus, A.E. Nevissi, J.M. Cox and L.A. Brocklehurst. 1989. *Effects of Petroleum-contaminated Waterways on Migratory Behavior of Adult Pink Salmon, Final Report, 1987-1989.* Dames and Moore, Seattle, WA. Available from National Technical Information Service, (703)487-4650 as PB90-120478/XAB.

This report describes the effect of oil-contaminated water on the migratory behavior of adult pink salmon during migration through Jakalof Bay in Alaska. The study found that: 1) migrating salmon do not appear to avoid oil-contaminated water with hydrocarbon concentrations at levels of 1 to 10 ppb, but do experience disorientation; 2) disorientation behaviors include searching and negative rheotaxis (retreat); and 3) disorientation temporarily disrupts migration, but salmon eventually return to the home stream. These findings suggest that salmon exposed during migration retreat to re-establish orientation.

Martin, A.N., H. Babich, D.W. Rosenberg and E. Borenfreund. 1991. *In Vitro* Response of the Brown Bullhead Catfish Cell Line, BB, to Aquatic Pollutants. *Archives of*

Fish, continued

Environmental Contamination and Toxicology. 20(1):113-117.

Established cell lines from brown bullhead catfish (BB) and rainbow trout (RTG-2) and primary cultures of cells derived from gill, fin, and gonad tissues from brown bullhead catfish were evaluated for use as bioindicators in the neutral red cytotoxicity assay. The BB and RTG-2 cells were compared after exposures to chlorinated pesticides and various polycyclic aromatic hydrocarbons.

McKeown, B.A. and G.L. March. 1978a. The Acute Effect of Bunker C Oil and an Oil Dispersant on: 1 Serum Glucose, Serum Sodium and Gill Morphology in Both Freshwater and Seawater Acclimated Rainbow Trout (*Salmo gairdneri*). *Water Research.* 12(3):157-163.

Physiological stress testing using Bunker C oil and an oil dispersant on rainbow trout acclimated to freshwater and saltwater was performed. Both compounds tended to reduce the serum glucose levels of the fish. The freshwater group experienced a significant decrease in sodium levels, and the saltwater group experienced an increase in serum sodium levels when treated with the dispersant. Microphotographs of gill filaments and lamellae showed severe damage.

McKeown, B.A. and G.L. March. 1978b. The effects of Bunker C Oil and an Oil Dispersant: Part 2. Effects on the Accumulation of Chlorine-Labelled Bunker C Oil in Various Fish Tissues. *Marine Environmental Research.* 1:119-123.

Laboratory study of differential tissue accumulation of Bunker C oil and a Bunker C oil/Oilsperse 43 (1:1) mixture in the rainbow trout. Accumulation of hydrocarbon was significantly higher in muscle, liver and kidney tissues (but not gill tissue) when exposure was in conjunction with the dispersant.

Middaugh, D.P., M.J. Hemmer and E.M. Lores. 1988. Teratological Effects of 2,4-dinitrophenol, "Produced Water" and Naphthalene on Embryos of the Inland Silverside Menidia Beryllina. *Diseases of Aquatic Organisms.* 4(1):53-65.

Embryos of the inland silverside *Menidia beryllina* were exposed to 3 teratogens: 2,4-dinitrophenol, (2,4-DNP), produced water (PW), and naphthalene (NPH). A severity-index based upon craniofacial, cardiovascular, and skeletal terata was used to rank responses each day. The compounds caused teratogenic expressions in embryos and larvae. Survival in control embryos and larvae was generally unaffected.

Mitchell, D.M. and H.J. Bennett. 1972. The Susceptibility of Bluegill Sunfish, *Lepomis*

Fish, continued

macrochirus and Channel Catfish, *Ictalurus punctatus*, to Emulsifiers and Crude Oil. *Proceedings of the Louisiana Academy of Sciences.* 35:20-26.

Static bioassays were conducted on bluegill sunfish, channel catfish, *Daphnia pulex* and the diatom *Cylindrotheca lusiformis* to determine their response to crude oil and four oil dispersants. (UL, ODH, ODR and MC). Tests with crude oil, dispersants, and mixtures of both were conducted on fish, and the effects of the water-soluble fraction were determined for the fish, *Daphnia pulex* and the diatom.

Moles, A., S.D. Rice and S. Korn. 1979. Sensitivity of Alaskan Freshwater and Anadromous Fishes to Prudhoe Bay Crude Oil and Benzene. *Transactions of the American Fisheries Society.* 108:408-414.

Studies were conducted to determine the sensitivity of the eggs, alevins, fry, freshwater residents, and out migrants of several species of freshwater and anadromous fishes to the water-soluble fractions of Prudhoe Bay crude oil and benzene. Salmonids were consistently the most sensitive species tested. Threespine sticklebacks were consistently the most tolerant. Out-migrants of pink salmon, sockeye salmon and Dolly Varden acclimated to seawater were about twice as sensitive as out-migrants tested in freshwater.

Nakatani, R.E., E.L. Brannon, A.E. Nevissi, M.L. Landolt, D.G. Elliott, R.P. Whitman, S.P. Kaluzny and T.P. Quinn. 1987. *Effects of Crude Oil and Chemically Dispersed Oil on Chemoreception and Homing in Pacific Salmon.* API Publication No. 4445. American Petroleum Institute. Washington, DC.

An experiment was conducted using Prudhoe Bay crude (PBC) oil, chemically dispersed PBC oil, and chemical dispersant to study : 1) the homing ability of adult chinook salmon, 2) longevity of salmon, and 3) acute toxicity to adult coho salmon. The results indicate that short exposure to oil or chemically dispersed oil did not significantly effect the homing capabilities of the pacific salmon.

Nava, M.E. and F.R. Engelhardt. 1980. Compartmentalization of Ingested Labelled Petroleum in Tissues and Bile of the American Eel (*Anguilla rostrata*). *Bulletin of Environmental Contamination and Toxicology.* 24(6):879-885.

Experiments on the fate of crude oil hydrocarbons in exposed fish were conducted by feeding American eels crude oil, then chemically analyzing various tissues and bile. The buildup and release of hydrocarbons over several weeks was monitored.

Ogata, M., Y. Miyake, S. Kiva, K. Matsunnaga and M. Imanaka. 1977. Transfer to Fish

Fish, continued

of Petroleum Paraffins and Organic Sulfur Compounds. *Water Research.* 11:333-338.

The accumulation of petroleum-related compounds in the flesh of freshwater eels, resulting from exposure to Arabian light crude oil, was determined by gas chromatographic analyses.

Payne, J.F., J. Hellou, L.L. Fancey, J. Kiceniuk and U. Williams. 1988. Fish Bile: Potential for Assessing Petroleum Hydrocarbon Pollution. *Aquatic Toxicology* (Amsterdam). 11(3-4):413.

This project investigated the potential of using primary or secondary bile acids as indicators of hydrocarbon stress and the feasibility of using hydrocarbon metabolites in bile to assess the bioavailability of PAHs in petroleum contaminated sediment. Using rainbow trout exposed to Venezuelan crude oil, it was determined that neither volume of bile nor bile acid was affected by petroleum exposure. Using winter flounder exposed to sediments contaminated with Venezuelan crude oil, it was found that most of the biological indices used displayed little or no change even at the highest exposure levels.

Poirier, A., F.B. Laurencin, G. Bodenned and C. Quentel. 1986. Experimental Poisoning of the Rainbow Trout, *Salmo gairdneri* Richardson, By Engine Diesel-Oil: Mortalities, Hematological Changes, History. *Aquaculture.* 55(2):115-137.

This study examined the effect of diesel oil-contaminated water on rainbow trout. Hematological and histological studies were performed on surviving specimens following a 96-hour exposure. Hemodilution, hyperglycemy, lymphopenia, as well as lesions of the gills, gastric glands and exocrine pancreas, were observed and related to a stress reaction to the pollutant. Anaemia and leucopenia were still observed a week after exposure; they may be caused by the toxic effect of the hydrocarbons.

Prasad, M.S., P. Prasad and D. Singh. 1987. Some Hematological Effects of Crude Oil on Freshwater Catfish, *Heteropneustes fossils* (Bloch). *Acta Hydrochimica Hydrobiologie.* 15(2):199-204.

The exposure of catfish *Heteropneustes fossils* to crude oil extract resulted in a number of hematological changes. The hematological effects shown by the crude oil resembled partly those kept in severe hypoxic conditions and partly to the fishes poisoned by heavy metals (Cu and Zn).

Fish, continued

Prasad, M.S. 1987. Toxicity of Crude Oil to the Metabolism of Freshwater Minor Carp, *Puntius sophore. Bulletin of Environmental Contamination and Toxicology.* 39(2):188-193.

The respiration rate in vitro and overall oxygen quotient *in vivo* of a freshwater minor carp *Puntius sophore* was measured after exposing the fish to the lethal and sublethal doses of crude oil extracts for varying periods. Maximum inhibition in the respiratory rate occurred at the gills. This sensitivity may be related to the mode of uptake of petroleum fractions to the fish. Results differ from using petroleum hydrocarbons, in which oxygen consumption increases in exposed fish.

Prasad, M.S. and K. Kumari. 1987. Toxicity of Crude Oil to the Survival of the Fresh Water Fish *Puntius sophore* (ham.). *Acta Hydrochimica Hydrobiologie.* 15(1):29-36.

The exposure of the freshwater fish, *Puntius sophore,* to different concentrations of crude oil (200-4000 ppm) revealed that 4000 ppm was acutely lethal to the fish. Mortality did not occur at exposure of less than 500 ppm at 21 C for up to 15 days. The formation of coagulated mucous film over the body and gills was a factor causing mortality among the experimental fish.

Prasad, M.S. 1988. Sensitivity of Branchial Mucous to Crude Oil Toxicity in a Freshwater Fish, *Colisa fasciatus. Bulletin of Environmental Contamination and Toxicology.* 41:754-758.

A study was undertaken to provide a better understanding of the pathogenic effects of crude oil on the branchial mucous of a freshwater fish. The assessment is based on the histochemical observations of mucous cells in the epithelia of gill rakers and filaments. Results suggest that the mucous cells try to attenuate the stress, but this physiological adjustment seems transient when the stress is further increased.

Prasad, M.S. 1989. Localization of Branchial Enzymes and Their Significance in the Detection of Crude Oil Toxicity in *Colisa fasciatus. Acta Hydrochimica Hydrobiologie.* 17(1):95-100.

The effect of crude oil on the histochemical localization of branchial enzymes was investigated in *Colisa fasciatus.* The activity of all enzymes decreased when treated with the lethal solutions of crude oil, except the enzyme LDH which showed an increasing trend throughout the experiment. The results suggest that crude oil is capable of impairing the enzyme activity. The increased level of enzymes may be used as an indicator for assessing the toxicity of oil pollutants.

Fish, continued

Prasad, M.S. 1991. SEM Study on the Effects of Crude Oil on the Gills and Air Breathing Organs of Climbing Perch, *Anabas testudineus*. *Bulletin of Environmental Contamination and Toxicology*. 47(6):882-889.

This investigation observed the morphological changes occurring in the epithelia of gills and air breathing organs of climbing perch at the SEM level. As the concentration of oil increased, exposed fish showed swelling of the epithelial cells, increased mucus formation coating gill filaments and lamellae, lesions in the epithelial layer, hypertrophic mucous cells and sloughing of the epithelial layer and vacuolization in the substances of the gill lamellae.

Ramusino, M.C., P. Dellavedova and D. Zanzottera. 1984. Effects of Crude Dubai Oil on *Salmo gairdneri* Rich. and *Carassius auratus* L. *Bulletin of Environmental Contamination and Toxicology*. 32:368-376.

Dubai crude oil and its water soluble fraction were tested to determine the lethal concentrations to *Salmo gairdneri* and *Carassius auratus*. *Carassius auratus* treated with crude oil resulted in a 48-hour LC_{50} of 19.89 ml/L. Three different sizes of trout were tested (egg sac, swim-up, and 5 cm size). LC_{50} results were not able to be calculated for any of the three sizes but mortality and growth impairments were observed. It was concluded that *Salmo gairdneri* were very sensitive to the oil.

Rice, S.D. 1973. Toxicity and Avoidance Tests with Prudhoe Bay Oil and Pink Salmon Fry. *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. 667-670.

Values of the median tolerance limit of pink salmon fry exposed to Prudhoe Bay crude oil in both seawater and freshwater were determined. The concentration of crude oil that elicited an avoidance response by the fry was determined for both seawater and freshwater.

Rice, S.D., D.A. Moles and J.W. Short. 1975. The Effect of Prudhoe Bay Crude Oil on Survival and Growth of Eggs, Alevins, and Fry of Pink Salmon, *Oncorhynchus gorbuscha*. *Proceedings*, Conference on Prevention and Control of Oil Pollution, San Francisco, CA, March 25-27, 1975. API Publication No. 4245. American Petroleum Institute, Washington, D.C. pp. 503-507.

Laboratory bioassays were conducted on the eggs, alevins and fry of pink salmon (*Oncorhynchus gorbuscha*) to determine the effects of Prudhoe Bay crude oil on

Fish, continued

their survival and growth.

Saha, M.K. and S.K. Konar. 1986. Chronic Sublethal Effects of Crude Petroleum on Fish. *Environmental Ecology.* 4(3):494-499.

This paper examined the chronic effects of crude petroleum on fish in an effort to help explain a declining fish population in the Hooghly River in India. Ninety-day exposure of sublethal concentrations of crude oil reduced activity, growth rate, maturity, fecundity and survival of fish, *Tilapia mossambica*. Respiration of fish was significantly affected at all concentrations. Thus hydrocarbon discharge into lower part of the Ganges (Hooghly river) may be one of the factors for declining trend of fish production in the river.

Steadman, B.L., W.A. Stubblefield, T.W. LaPoint, H.L. Bergman and M.S. Kaiser. 1991. Decreased Survival of Rainbow Trout Exposed to No. 2 Fuel Oil Caused by Sublethal Preexposure. *Environmental Toxicology and Chemistry.* 10(3):355-363.

Rainbow trout were exposed for 21 days to sublethal levels of No. 2 fuel oil. Following exposure, the ability of the trout to survive acutely lethal levels was observed. Preexposure decreased survival of rainbow trout.

Steadman, B.L., A.M. Farag and H.L. Bergman. 1991. Exposure-Related Patterns of Biochemical Indicators in Rainbow Trout Exposed to No. 2 Fuel Oil. *Environmental Toxicology and Chemistry.* 10(3):365-374.

Several biochemical indicators were evaluated as monitoring techniques in rainbow trout exposed to No. 2 fuel oil for their ability to predict the exposure concentration. The principal factor affecting the response was the length of exposure not the exposure concentration. Two patterns of response were observed, depending on the length of exposure. There was no observation of a dose-dependent response in any of the biochemical responses which suggests that toxicity was responsible for the lack of concentration dependence.

Tagatz, M.E. 1961. Reduced Oxygen Tolerance and Toxicity of Petroleum Products to American Shad. *Chesapeake Science.* 2:65-71.

The effects of reduced oxygen content on the toxicity of gasoline, diesel fuel and Bunker fuel to American shad were studied. The toxicity of each of these petroleum products was determined for both normal and low oxygen levels.

Thomas, R.E. and S.D. Rice. 1987. Effect of Water-soluble Fraction of Cook Inlet Crude

Fish, continued

Oil on Swimming Performance and Plasma Cortisol in Juvenile Coho Salmon (*Oncorhynchus kisutch*). *Comparative Biochemistry and Physiology.* 87C:177-180.

Juvenile Coho salmon *Onorhunchus kisutch* exposed to the water soluble fraction (WSF) of Cook Inlet crude oil demonstrated significantly reduced swimming performance and significantly higher plasma cortisol levels. Coho salmon smolts and jacks exposed to WSF of Cook Inlet crude oil were compared for sensitivity to the oil, uptake of aromatic hydrocarbons, and mixed function oxidase activity. Smolts accumulated aromatic hydrocarbons more quickly and at much greater level than the jacks. The jacks were better able to metabolize accumulated aromatic hydrocarbons.

Thomas, R.E., S.D. Rice and S. Korn. 1987. Reduced Swimming Performance of Juvenile Coho Salmon (*Oncorhynchus kisutch*) Exposed to the Water-soluble Fraction of Cook Inlet Crude Oil. In W.B. Vernberg, A. Calabrese, F.P. Thurberg and F.J. Vernberg, eds. *Pollution Physiology of Estuarine Organisms.* University of South Carolina Press, Columbia, SC. pp. 127-137.

Juvenile coho salmon *Oncorhynchus kisutch* exposed to the water soluble fraction (WSF) of crude oil demonstrated reduced swimming capacity. Degree of effect depended on concentration of oil and on length of exposure. Swimming capability was returned to normal following depuration.

Thomas, R.E., S.D. Rice, M.M. Babcock and A. Moles. 1989. Differences in Hydrocarbon Uptake and Mixed Function Oxidase Activity Between Juvenile and Spawning Adult Coho Salmon (*Oncorynchus kisutch*) Exposed to Cook Inlet Crude Oil. *Comparative Biochemistry and Physiology.* 93C:155-159.

This study compared juvenile and adult salmon exposed to oil. The juvenile salmon accumulated up to 30 times more hydrocarbon in their liver and gut than the adult salmon, which may be due in part to their higher fat content. The aryl hydrocarbon hydroxylase (AHH) activity continually increased in the juvenile salmon over the 12 days of exposure during the testing, while, in the adult salmon, the AHH activity peaked after two days and remained high.

University of Washington School of Fisheries. 1986. *Influence of Crude Oil and Dispersant on the Ability of Coho Salmon to Differentiate Home Water [(HW)] From Non-home Water [(NHW)].* American Petroleum Institute Publication No. 4446. American Petroleum Institute. Washington, D.C.

This study examined the ability of the coho salmon to differentiate home water

from non-home water when in the presence of crude oil and dispersant. It was concluded that both oil and dispersed oil masked the ability of the salmon to detect home water odor cues.

Vandermeulen, J.H. 1990. Time and Dose Response of Aryl Hydrocarbon Hydroxylase in Fingerling Trout (*salvelinus fontinalis*) Under Small Experimental Oilslicks. *Comparative Biochemistry and Physiology C Comparative Pharmacology and Toxicology*. 95(2):169-175.

This paper discusses an experiment where fingerling brook trout *salvelinus fontinalis* were exposed to small slicks of Kuwait crude and Bunker C fuel. The purpose of the experiment was to monitor changes in the liver aryl hydrocarbon hydroxylase, (AHH), activity. The results indicate that AHH activity is proportional to slick dosage. At higher concentrations of hydrocarbon exposure, the AHH activity increased rapidly, indicating that the trout's system can respond rapidly to even small increases in environmental contamination.

Vignier, V., J.H. Vandermeulen and A.J. Fraser. 1992. Growth and Food Conversion by Atlantic Salmon Parr During 40 Days' Exposure to Crude Oil. *Transactions of the American Fisheries Society.* 121(3):322-332.

This paper presents the results of a study where Atlantic Salmon juveniles were exposed to sublethal concentrations of Hibernia oil-water mixtures. Results indicated that the oiled juveniles showed reduced growth for 14 days before growth rates approached those of the controls. Reduction in growth coincided with reduced food conversion efficiency, rather than reduced food intake. Low concentrations of oil may have transitory effects on juveniles, but chronic oiling may impair growth and influence the timing of length-dependent smoltification.

Wong, M.P. and F.R. Engelhardt. 1984. Disruptive Effects of Petroleum Hydrocarbons on Ion-dependent Adenosine Triphosphatase Activities. *Proceedings*, Second International Symposium on Responses of Marine Organisms to Pollutants Held at Woods Hole Oceanographic Institution, Massachusetts, USA, 27-29 April 1983. *Marine Environmental Research.* 14(1-4):492.

This study was undertaken to investigate the ion-dependent adenosine triphosphatases (ATPases). Trout *Salmo gairdneri* were exposed to crude oil dispersions and to selected petroleum hydrocarbons. The activities of a range of ATPases were found to vary in accordance with the in vivo ion imbalance in exposed fish. Generally, exposure to aromatic hydrocarbons resulted in inhibition of enzyme activities. The effects correlated with the observed ionic dysfunction of

Fish, continued

hydrocarbon-exposed fish. This evidence suggests that the toxic mode of action of petroleum hydrocarbons on ion balance has a biochemical basis.

Woodward, D.F., R.G. Riley, M.G. Henry, J.S. Meyer and T.R. Garland. 1985. Leaching of Retorted Oil Shale: Assessing the Toxicity of Colorado Squawfish, Fathead Minnows, and Two Food-chain Organisms. *Transactions of the American Fisheries Society.* 114(6):887-894.

Development of a large shale-oil industry in Colorado, Utah, and Wyoming would result in disposal of large volumes of restored shale. Water percolating through these wastes could leach toxicants into the upper Colorado River system. In 96-hour exposures, undiluted leachate was not toxic to fathead minnows *Pimephales promelas* or Colorado squawfish *Ptychocheilus lucius*, and was only slightly toxic to the mayfly *Hexagenia bilineata* and to *Daphnia magna*.

Woodward, D.F., P.M. Mehrle and W.L. Mauck. 1981. Accumulation and Sublethal Effects of a Wyoming Crude Oil in Cutthroat Trout. *Transactions of the American Fisheries Society.* 110(3):437-445.

Studies were conducted on cutthroat trout to determine the effects of long term (90-day) exposure to crude oil. Effects on growth, survival, morphology and hydrocarbon accumulation were documented.

8.6 Effects on Mammals and Other Vertebrates

Coulliard, C.M. and F.A. Leighton. 1993. *In Vitro* Red Blood Cell Assay for Oxidant Toxicity of Petroleum Oil. *Environmental Toxicology and Chemistry.* 12(5):839-845.

An *in vitro* assay using rabbit red blood cells and rat liver enzymes was developed to determine the level of oxidant damage to red blood cells caused by petroleum oils. The formation of methemoglobin was used as an indicator of oxidant damage to red blood cells. In comparison of oils and naphthalene, naphthalene caused the greatest methemoglobin production in red blood cells, whereas whole oil induced significantly less methemoglobin.

Engelhardt, F.R. 1984. Environmental Effects of Petroleum on Mammals. *Reviews in Environmental Toxicology.* 1:319-337.

This book provides a comprehensive review of the toxicity of crude oil to mammals. Included are discussions on external contact, adhesion of oil, skin reaction, eye effects, heat loss, inhalation, ingestions, and uptake, metabolism and clearance.

Haim, A. and A. Kalir. 1986. Enzymatic Activity in Crude Oil Contaminated Rats. *Comparative Biochemistry and Physiology.* 85C:103-105.

White laboratory rats were exposed to Suez crude oil via tube feeding. Enzymatic activity was markedly affected 96 hours after the first dose, but activity levels measured 96 hours after a second dose were much closer to those of the controls.

Haim, A., B. Nicolaisen and N.A. Oritsland. 1984. Crude Oil--its Impact on the Rat's Heat Balance. *Comparative Biochemistry and Physiology.* 78A:259-261.

Rats ingesting Midale crude oil showed no significant increase in heat production. Those contaminated by coating the skin showed a significant initial increase in heat production and a significant initial decrease in respiratory quotient.

Hedtke, S.F. and F.A. Puglisi. 1982. Short-term Toxicity of Five Oils to Four Freshwater Species. *Archives of Environmental Contamination and Toxicology.* 11:425-430.

The toxicity of five oils (waste oil, No.1 and No. 2 fuel oil, and two crude oils) to four freshwater species (the American flatfish *Jordanella floridae*, the Fathead minnow *Pimephales promelas*, larvae of the wood frog *Rana sylvatica*, and larvae of the spotted salamander *Ambystoma maculatum*) were determined. LC_{50} values depended on the species, the oil type, different batches of the same oil, the form of the oil when added to the test system, the test type, duration of exposure, and the oil-water contact time. The influential variable was the method of introducing the oil.

Khan, S., A.M. Rahman, J.F. Payne and A.D. Rahimtula. 1986. Mechanisms of Petroleum Hydrocarbon Toxicity: Studies on the Response of Rat Liver Mitochondria to Prudhoe Bay Crude Oil and its Aliphatic, Aromatic and Heterocyclic Fractions. *Toxicology.* 42:131-142.

Isolated liver mitochondria from rats were subjected to DMSO extracts of Prudhoe Bay crude oil and its fractions. Mitochondrial respiration and enzyme activities were measured. It was concluded that the aromatic components of PBCO inhibit mitochondrial respiration and oxidative phosphorylation.

Khan, S., M. Irfan and A.D. Rahimtula. 1987. The Hepatotoxic Potential of a Prudhoe Bay Crude Oil: Effect on Mouse Liver Weight and Composition. *Toxicology.* 46:95-105.

Mice fed Prudhoe Bay crude oil (PBCO) had significantly increased liver weights. Biochemical changes were observed in the liver following exposure to crude oil. These results indicate that PBCO may induce hepatoxicity by altering the intermediary metabolism of biochemical constituents.

Khan, S., M. Codner, J.F. Payne and A.D. Rahimtula. 1989. Effect of a Prudhoe Bay Crude Oil on Hepatic and Renal Peroxisomal B-oxidation and Mixed-function Oxidase Activities in Rats. *Carcinogenesis.* 10:269-272.

Prudhoe Bay crude oil fed to rats resulted in significant decrease in body weight gain and increased liver and kidney weights. Increased hepatic and renal microsomal cytochrome P450 levels and mixed-function oxidase activities were observed.

McBee, K. and J.W. Bickham. 1988. Petrochemical-Related DNA Damage in Wild Rodents Detected by Flow Cytometry. *Bulletin of Environmental Contamination and Toxicology.* 40(3):343-349.

Two species of wild rodents (*Peromyscus leucopus* and *Sigmodon hispidus*) living at a dump site contaminated with complex mixtures of oil, grease, organic chemicals and metals have significantly higher frequencies of chromosomal aberrations than did animals from control sites. The study concludes that changes in DNA content through flow cytometric analysis may provide indication of the action of mutagens.

Mammals and Other Vertebrates, continued

McEwan, E.H., N. Aitchison and P.E. Whitehead. 1974. Energy Metabolism of Oiled Muskrats. *Canadian Journal of Zoology.* 52(8):1057-1062.

Heavy oiling (approximately 40 g crude oil) resulted in about a 120% increase in heat production immediately following oiling; by day 3, no effects were noted. The authors conclude that had these animals been exposed to water, as in natural conditions, moderate oiling would have killed them.

Pyastolova, O.A. and M.N. Danilova. 1986. Growth and Development of *Rana Arvalis* in Conditions Imitating Oil Contamination. *Soviet Journal of Ecology.* 17(4):209-214.

The influence of crude oil on embryonic and larval development of the sharp-snouted frog was investigated. Even the lowest concentrations of oil unfavorably influence the early stages of ontogenesis of *Rana arvalis* Nilss. This is reflected in reduced survival, change in tempos of growth, development, and fatness, and the appearance of anomalies and deformities. An ecological evaluation of the consequences of oil contamination of the aquatic environment and various types of bottoms is provided.

Smith, L.H., W.M. Haschek and H. Witschi. 1981. Acute Toxicity of Selected and Crude and Refined Shale Oil and Petroleum-derived Substances. In W.H. Griest, M.R. Guerin and D.L. Coffin, eds. *Health Effects Investigation of Oil Shale Development.* Ann Arbor Science, Ann Arbor, MI. pp. 141-160.

General information was obtained on the toxicity of selected samples of crude Paraho Shale oil and some of its derivatives, some crude petroleums, and three refined petroleum products. Species tested were rats, guinea pigs, mice and rabbits. Results showed that, when ingested, crude shale oil was slightly toxic and all other samples were practically non-toxic. Compared with petroleum and some of its derivatives, shale oil and its derivatives appear to have low toxicity.

Tabata M., J. Suzuki and S. Suzuki. 1986. Metabolic Enzyme Induction in the Rat by Organic River Sediment Pollutants. *Bulletin of Environmental Contamination and Toxicology.* 37(2):180-186.

The activities of mixed-function oxidases in the liver of fish can be a tool for monitoring oil pollution. Because fish are difficult to sample uniformly, the authors attempted to evaluate the enzyme inducing ability of river sediment organic matter using the laboratory rat.

Wolfe, J.L. and R.J. Esher. 1981. Effects of Crude Oil on the Swimming Behavior and

Mammals and Other Vertebrates, continued

Survival in the Rice Rat. *Environmental Research.* 26:486-489.

Swimming behavior and survival at low temperatures were observed with wild-caught rice rats. Two types of crude oil were applied to the water surface at two concentrations (South Texas Crude, and Empire Crude). Application rates were 200 and 20 ml of oil to the surface of the water in the experimental tanks. Both concentrations of the oils significantly inhibited crossings per night. Both oils at high concentrations produced a significant mortality within 3 hours. The effects of the low concentrations were not significant.

8.7 Multiple Organisms

Albers, P.H., A.A. Beslisle, D.M. Swineford and R.J. Hall. 1985. Environmental Contamination in the Oil Fields of Western Pennsylvania. *Oil and Petroleum Pollution.* 2:265-280.

A study was conducted to determine the effects of chronic exposure to oil field discharges on freshwater wildlife. There were significantly higher concentrations of hydrocarbons in crayfish, fish, and small mammals from areas with oil extraction activity than from areas without oil extraction activity. Estimates of total petroleum in invertebrates, trout, and suckers averaged between 200 and 280 ppm for areas with oil extraction sites and between 8 and 80 ppm for areas without oil extraction activity. It appears that oil and wastewater discharges in oil fields may disrupt the composition of the community and cause a reduction in stream productivity.

Das, P.K. and S.K. Konar. 1988. Acute Toxicity of Petroleum Products, Crude Oil and Oil Refinery Effluent on Plankton, Benthic Invertebrates and Fish. *Environmental Ecology.* 6(4):885-891.

This paper discusses the toxicity of petroleum products, refinery effluents, and crude oil on plankton, benthic invertebrates, and fish. Abnormal behavior such as erratic movements was most prominent in organisms exposed to petroleum products. Diesel oil caused the highest acute toxicity in cladoceran zooplankton and chironomid larvae while cyclohexane caused the highest in the mollusc. In the fish studied, the highest acute toxicity was caused by crude oil.

Milleman, R.E., W.J. Birge, J.A. Black, R.M. Cushman, K.L. Daniels, P.J. Franco, J.M. Giddings, J.F. McCarthy and A.J. Stewart. 1984. Comparative Acute Toxicity to Aquatic Organisms of Components of Coal-derived Synthetic Fuels. *Transactions of the American Fisheries Society.* 113:74-85.

In acute toxicity tests, green algae, diatoms, adult snails, juvenile cladocerans, larval midges, adult amphipods, juvenile fathead minnows, and embryo-larva stages of rainbow trout and largemouth bass were exposed to 2 phenols, 2 azaarenes, and 2 polycyclic aromatic hydrocarbons present in coal-derived oils. Median lethal or median effective concentrations are provided. Generally, toxicity increased with increasing carbon ring number. There was a relationship between increases in toxicity and increases in the calculated octanol-water partition coefficients of the compounds.

Panigrahi, A.K. and S.K. Konar. 1989. Acute Toxicity of Some Petroleum Pollutants to Plankton, Fish and Benthic Organisms. *Environmental Ecology.* 7(1):44-49.

Multiple Organisms, continued

Plankton, fish and benthic organisms were exposed to different petroleum pollutants over a 96-hour period for acute toxicity testing. Benthic organisms seemed the least effected by petroleum pollutants. Toluene was most toxic to zooplankton. Gear oil was most toxic to gastropods. Kerosene oil and n-hexane were most toxic to chironomid larvae.

Scheier, A. and D. Gominger. 1976. A Preliminary Study of the Toxic Effects of Irradiated vs. Nonirradiated Water-Soluble Fractions of No. 2 Fuel Oil. *Bulletin of Environmental Contamination and Toxicology.* 16(5):595-603.

Studies were conducted to determine the effects of ultraviolet radiation on the toxicity of No. 2 fuel oil to five freshwater and marine species (grass shrimp, sheepshead minnow, mummichog, channel catfish and bluegill sunfish).

Woodward, D.F., E.E. Little and L.M. Smith. 1987. Toxicity of Five Shale Oils to Fish and Aquatic Invertebrates. *Archives of Environmental Contamination and Toxicology.* 16(2):239-246.

The chemical composition and toxicity of three shale crude oils, and a refined shale oil were assessed to determine the potential hazards to organisms posed by accidental spills. Colorado squawfish *Ptychocheilus lucius*, fathead minnow *Pimephales promelas*, cutthroat trout *Salmo clarki*, and colonies of aquatic invertebrates were exposed to the water-soluble fractions of the shale oils for 96 hr to determine LC_{50}. The cutthroat trout was less tolerant of shale oil exposure than the other species tested. Exposure to concentrations of 1/2 to 1/8 those causing mortality reduced the swimming capacity. The genera *Baetis* and *Isoperla* were most sensitive to shale oil exposure; significant mortality occurred at the lowest concentration tested for each shale oil.

8.8 Toxicity of Spill Chemical Countermeasures

Akintonwa, A. and A.G. Ebere. 1990. Toxicity of Nigerian Crude Oil and Chemical Dispersants to *Barbus* Sp. and *Clarias* Sp. *Bulletin of Environmental Contamination and Toxicology.* 45(5):729-734.

The toxicity of crude oil and two dispersants; Conco-k and Teepol were examined on two types of fish: *Barbus* fingerlings and *Clarias* eggs. Teepol was found to be the most toxic to *Barbus* fingerlings with a 24-hr LC_{50} of 7- 8 µl/L. Teepol and Conco-k were more toxic to the fingerlings than the crude oil. The crude oil alone was toxic to fingerlings, but combinations of crude oil and dispersants were more toxic than any of the three alone.

Albers, P.H. 1979. Oil Dispersants and Wildlife. *Proceedings,* 1979 U.S. Fish and Wildlife Service Pollution Response Workshop, St. Petersburg, Florida. Fish and Wildlife Service, U.S. Department of the Interior. pp. 67-72.

The advantages and disadvantages of the use of dispersants, and the effect of dispersants on hatching rates of mallard duck eggs are discussed.

Albers, P.H. and M.L. Gay. 1982. Effects of a Chemical Dispersant and Crude Oil on Breeding Ducks. *Bulletin of Environmental Contamination and Toxicology.* 29:404-411.

The effects of the dispersant Corexit 9527 and Prudhoe Bay crude oil (PBCO) on breeding mallard ducks and their eggs were evaluated. There was no significant difference in hatchability between the control and dispersant or oil groups. Percentage of each duck brood dying before 1 week of age, the number of eggs laid, and number of eggs lost were not significantly different.

Barnett, J. and D. Toews. 1978. The Effects of Crude Oil and the Dispersant Oilsperse 43 on Respiration and Coughing Rates in Atlantic Salmon (*Salmo salar*). *Canadian Journal of Zoology.* 56(2):307-310.

The toxicity of 1:1 emulsions of crude oil and an oil dispersant (Oilsperse 43) was investigated in acute and chronic 96-hour bioassays using Atlantic salmon acclimated to fresh water. A 96-hour LC_{50} of 99 mg/L was determined and sublethal effects (respiration, coughing) were studied.

Belkhir, M. and M. Hadj Ali Salem. 1986. Oil Spill Dispersant Toxicity to Fish and Molluscs. *FAO Fisheries Reports.* 334(Suppl.):11-14.

A study was conducted to determine if the oil spill dispersant, Dispolene 32S, was

toxic to fish and molluscs. The results of the study indicated that the dispersant was quite toxic, especially to the fish. The molluscs seemed much more resilient when exposed to the dispersant.

Chadwick, H.K. 1960. Toxicity of Tricon Oil Spill Eradicator to Striped Bass (*Roccus saxatilis*). *California Fish and Game.* 46:371-372.

Laboratory studies were conducted on striped bass to investigate the toxicity of Tricon oil spill eradicator to fish. The response to 0.001%, 0.005% and 0.05% solutions was determined in static tests.

Dowden, B.F. 1962. Toxicity of Commercial Waste Oil Emulsifiers to *Daphnia magna. Journal Water Pollution Control Federation.* 34(10):1010-1014.

The toxicity of crude oil and crude oil with each of two different types of emulsifiers was determined in bioassay with *Daphnia magna*; 24-, 48- and 72-hour median tolerance limits are reported.

Giddings, J.M., B.R. Parkhurst, C.W. Cehrs and R.E. Millemann. 1980. Toxicity of a Coal Liquefaction Product to Aquatic Organisms. *Bulletin of Environmental Contamination and Toxicology.* 25(1):1-6.

Acute toxicity tests of water-soluble fractions of a coal-liquefaction product (No. 6 fuel oil) and two petroleum-based oils (No. 2 diesel fuel, No. 6 fuel oil) were conducted with two freshwater algal species (*Selenastrum capricornutum, Microcystis aeruginosa*) and a freshwater crustacean (*Daphnia magna*). Toxicity criteria included change in photosynthesis rates (measured by ^{14}C-bicarbonate) for the algae and immobilization for the daphnid.

Hébert, G.W. and R.H. Kussat. 1972. *A Laboratory Evaluation of the Toxicity of Certain Oils and Chemical Oil Dispersants to Juvenile Coho Salmon and Staghorn Sculpins.* Canada Department of the Environment, Technical Report 1972-1976.

Standard static bioassays were conducted using freshwater juvenile coho salmon and marine staghorn sculpin to determine the 96-hour median tolerance limits of 10 oil dispersants and 6 types of oil. Bioassays were conducted using oil-dispersant mixtures. The Pour Point and Viscosity Rating for the oils were related to their toxicity to fish.

Heldal, M., S. Norland, T. Lien and G. Knutsen. 1978. Acute Toxicity of Several Oil Dispersants Towards the Green Algae *Chlamydomonas* and *Dunaliella.*

Chemosphere. 3:247.

The acute toxicity of several (maximum of 31, not all dispersants used in all tests) dispersants to the freshwater green alga *Chlamydomonas reinhardti* and the marine green alga *Dunaliella marina* was determined. Dispersants were tested alone, as water extracts of mixtures of Ekofisk crude oil and dispersant, and as 1:1 mixtures of Ekofisk crude oil and dispersant. LC_{50} values and lethal (99.5% dead) concentrations are reported.

Merlin, F., C. Brocard, R. Cabridenc, J. Oudot and Vindimian. 1991. Toward A French Approval Procedure For the Use of Dispersants In Inland Waters. *Proceedings*, 1991 International Oil Spill Conference, San Diego, CA, March 4-7, 1991. API Publication No. 4529. American Petroleum Institute, Washington, D.C. pp. 401-404.

Two short-term exposure on three aquatic species using light Arabian crude and domestic fuel oil were conducted. The fuel oil was twice as toxic as the crude. The effectiveness tests of 17 dispersants showed that water quality influences the effectiveness and not all dispersants should be used in freshwater. Recommendations included: 1) application procedures should be developed for inland waters; 2) testing should be performed on freshwater in real river conditions; and 3) open sea test data cannot be used for freshwater applications.

Nagy, E.B., F. Scott and J. Hart. 1981. *The Fate of Oil and Dispersant Mixtures in Freshwater.* Environmental Protection Service Technical Development Report. EPS 4-EC-81-3. Environment Canada.

Manmade ponds were used to compare the fate, distribution and composition of oil/dispersant mixtures. Oiled and controlled conditions were established using Norman Wells Crude oil and Corexit 9527. The surface, water column, sediment, liner and attached biota were sampled systematically for 1 year.

Norland, S., M. Heldal, T. Lien and G. Knutsen. 1978. Toxicity Testing with Synchronized Cultures of the Green Alga *Chlamydomonas. Chemosphere.* 7(3):231-245.

Bioassay of an oil dispersant, Corexit 9527, using synchronous cultures of the green alga *Chlamydomonas* is presented. Toxicity determined by changes in cell growth, which was measured by weighted cell volumes.

Oda, A. and P. Eng. 1968. *A Report on The Laboratory Evaluation of Five Chemical Additives Used for the Removal of Oil Slicks on Water.* Paper No. 2019. Division of Research, Ontario Water Resources Commission.

Laboratory examination of five oil dispersants was conducted to evaluate their effectiveness as oil dispersants, biological treatability, toxic effects on freshwater fishes and effects on the palatability of water. Recommendations for the use of oil dispersants are made.

Quaife, L.R., C.H. Peabody, H.M. Brown and R.H. Goodman. 1986. Freshwater Oilspill Research Program - Field Trial. *Proceedings*, 9th Annual Arctic and Marine Oilspill Program, Technical Seminar. Conservation and Protection, Environment Canada. pp. 601-621.

This report summarizes an experiment conducted to assess the usefulness and toxicity of dispersants on a freshwater oil spill. Generally, neither the application of dispersant-alone, oil-alone, nor the oil-and-dispersant mixture caused any beneficial or bad effects. The microtox system showed that there was no significant toxicity of the dispersed oil mixture or the oil-alone mixture.

Rehwoldt, R., L. Lasko, C. Shaw and E. Wirhowski. 1974. Toxicity Study of Two Oil Spill Reagents Toward Hudson River Fish Species. *Bulletin of Environmental Contamination and Toxicology*. 11(2):159-161.

Studies were conducted to determine the toxicity of fuel oil, a collecting agent (Herder), and a dispersant, alone or in combination, on several freshwater species of fish. Median lethal tolerance values were determined for banded killifish, striped bass, pumpkinseed, white perch, American eel and carp.

Rogerson, A. and J. Berger. 1981. The Toxicity of the Dispersant Corexit 9527 and Oil-Dispersant Mixtures to Ciliate Protozoa. *Chemosphere*. 10:33-39.

The toxicity of Corexit 9527 to ciliate protozoa was determined on the basis of growth rate. Species growth rate remained constant with increasing Corexit concentrations until an acutely toxic threshold was obtained (100 ppm for the most sensitive species). Although the dispersant was found to be toxic, results showed that chemically dispersed oil was more toxic than either the dispersant or crude oil alone.

Saxby, J.D. 1978. Comparison of Crude Oils and Their Alteration Products. *Geochimica et Cosmochimica Acta*. 42(2):215-217.

Comparisons of source materials, migration mechanisms and alteration processes within reservoirs are made using GC data from high-molecular-weight saturated fractions of crude oil. A simple method for utilizing this data is described.

Sprague, J. and W. Carson. 1970. *Toxicity Tests with Oil Dispersants in Connection with Oil Spilled at Chedabucto Bay, Nova Scotia*. Technical Report No. 201. Fisheries Research Board of Canada. St. Andrews, N.B.

Studies were conducted on the American lobster, winter flounder and par stage of Atlantic salmon, to determine the toxicity of Bunker C oil and several oil dispersants. Four- and seven-day median lethal concentrations of dispersants and oil, alone and in combination, were determined.

Tracy, H.B., R.A. Lee, C.E. Woelke and G. Sarborn. 1969. Relative Toxicities and Dispersing - Evaluations of Eleven Oil-Dispersing Products (in the Pacific Northwest). *Journal of the Water Pollution Control Federation.* 41(12):2062-2069.

To provide information on oil dispersants to organizations involved in oil-spill control in the Pacific Northwest, a series of *in situ* and laboratory studies were performed on eleven oil-dispersing products. Each dispersant was awarded a score of one (high performance) to four (low performance).

Vindimian, E., B. Vollat and J. Garric. 1992. Effect of the Dispersion of Oil In Freshwater Based on Time-Dependent *Daphnia magna* Toxicity Tests. *Bulletin of Environmental Contamination and Toxicology.* 48(2):209-215.

Time dependence of the acute toxicity of oil and dispersants on the freshwater organism *Daphnia magna* was investigated using a French crude and a gas oil, free of volatile substances after being equilibrated with the atmosphere. Two commercial dispersants, British Petroleum Enersperse 1037 and Dasic Freshwater, were evaluated. The Dasic Freshwater dispersant was less toxic than the Enersperse especially for short term exposure. Crude oil was far more toxic than gas oil. Gas oil essentially had the same toxicity as the dispersant. The differential toxicity of the dispersants was strongly time dependent. Oil toxicity was considered the most important variable.

Westlake, D.W.S., J. Foght and F.D. Cook. 1983. *Effect of Dispersants on the Biodegradation of Norman Wells Oil.* Interim Report (unpublished) to the Hudson's Bay Oil & Gas Co., Calgary, Alberta.

Laboratory study of the effects of 14 commercially available oil dispersants on the growth and degree of hydrocarbon decomposition shown by a mixed culture of oil-degrading bacteria in the presence of Norman Wells crude oil. Viable cell counts (spread plates) of bacteria and the extent of oil degradation (gas chromatography) were determined at periodic intervals to evaluate whether

dispersants inhibited or facilitated oil decomposition processes relative to "weathered" (i.e., abiotic) controls, in the presence and absence of nutrient (nitrogen and phosphorus) additions.

9.0 CLEANUP

9.1 Mechanical Equipment

Anonymous. 1971. Vacuum Unit Helps Clean Up Local Oil Spill. *American City Magazine.* 86(7):12.

The VAC-ALL Unit is usable on lake surfaces and in storm sewers for oil spill cleanup.

Anonymous. 1972. Oil Cleanup. *World Ports.* 34(3):29.

An oil spill cleanup machine which pumps oil-contaminated water into eight separation tanks in series is described.

Anonymous. 1976. Oil Slick Removal System. *Mechanical Engineering.* 1976:62.

An oil recovery device is described which uses water jets and pumping action. It is useful in waves up to 2.3 ft (0.7 m) high. It is reported that 98% of an oil slick measuring 500 m2 and 2 cm thick can be removed each hour regardless of viscosity.

Beach, R.L. and D.W. Durfee. 1976. *Development of a Streaming Fiber Oil Spill Control System. Stage II.* Report No. CG-D-4-77. U.S. Coast Guard, Office of Research and Development, Washington, D.C.

Seaward International, Inc. has developed the streaming fiber oil spill control concept into a large scale model, and tested it successfully under simulated field conditions. The streaming fiber concept utilizes long, continuous fibers oriented parallel to the water flow. The fibers function by slowing down and thickening the incoming oil, so that recovery by conventional means can be performed.

Beach, R.L. and D.W. Durfee. 1979. *Development of a Streaming Fiber Oil Spill Control System. Stage II. Modifications to Large Scale Model.* Report No. CG-D-05-79. Prepared for the U.S. Department of Transportation. U.S. Coast Guard, Office of Research and Development, Washington, D.C.

The large scale model of the Streaming Fiber fast current oil skimmer was modified to improve performance in waves and viscous oils. Modification included a sorbent foam belt rotating beneath the fiber array to intercept and collect any oil escaping from the fibers, and separate flotation for the fiber array to improve wave conformance by decoupling the array motions from the skimmer vessel.

Mechanical Equipment, continued

Cohen, S.H. and W.T. Lindenmuth. 1979. *Design, Fabrication and Testing of the Air-Jet Oil Boom.* EPA 600/7-79-143. U.S. Environmental Protection Agency, Cincinnati, OH.

This report describes the design, fabrication and testing of the Air-Jet Boom; a novel boom which has the capability to divert oil slicks under wave and current conditions that normally preclude the deployment of conventional booms.

Fuller, H.I. 1971. The Use of Floating Absorbents and Gelling Techniques for Combating Oil Spills on Water. *Journal of the Institute of Petroleum.* 57(553):35.

A consideration of criteria for the use of floating absorbents is presented. Supply, storage, transportation, application, harvesting, and disposal are addressed. Absorbents are rated based on reported experience.

Garrett, W.D. and W.R. Barger. 1970. Factors Affecting the Use of Monomolecular Surf Films to Control Oil Pollution on Water. *Environmental Science Technology.* 4(2):123-127.

Several monolayer-forming materials with varying surface chemical properties were examined for their ability to survive at an air/water interface and contain oil films. Monolayer properties relevant to oil pollution control which were determined were: the monolayer spreading velocity, the ability to resist spread against wind, and the thickness of an oil lens supportable by a particular monolayer.

Getman, J.H. and L.A. Schultz. 1976. Tests of Oil Recovery Devices in a Broken Ice Field. *Proceedings*, 8th Annual Offshore Technology Conference, Vol. III, May 3-6, 1976. Houston, TX.

As part of its Arctic pollution response program, the United States Coast Guard recently completed a two-phase testing program of oil spill recovery devices operating in a broken ice field at below freezing temperatures.

Grace, J. and A. Sowyrda. 1970. The Development and Evaluation of a Pneumatic Barrier for Restraining Surface Oils in a River. *Journal of the Water Pollution Control Federation.* 42(12):2074-2093.

This report deals with the development and evaluation of a pneumatic barrier for restraining surface oils in the Buffalo River. A perforated tube is placed below the surface of the water and air is injected through the tube. The current produced by the rising plume of bubbles causes a local region of decreased density.

Mechanical Equipment, continued

Institute of Petroleum. 1975. *Mechanical Systems for the Recovery of Oil Spilled on Water.* Applied Science Publishers, Ltd., England.

This report deals with the techniques and equipment involved in the mechanical recovery of spilled oil on water. It does not consider the cleanup techniques of dispersion, sorption or sinking.

Krause, M. 1986. Development of Mobile Plants for the Cleaning of Oil Polluted Sands. (Entwicklung Mobiler Anlagen zur Aufbereitung von Oelverschmutzten Sanden.) Available from the National Technical Information Service at (703)487-4650 as TIB/A92-00625/XAB.

In the laboratory oil polluted 'synthetic' North Sea sand could be cleaned by a washing process. For use in the field, two semi-mobile pilot plants have been developed and tested. From a version consisting of an attrition cell connected with an upstream washer for the oil-sand separation, 95% of the oil could be separated from the sand, yielding an optically pure sand. The oil-loaded wastewater could be regenerated and recycled in such a velocity that the overall process, sand cleaning plus water regeneration, can continuously be carried out. The efficiency of the plant has been demonstrated for the purification of coarse-grained natural North Sea sand, although oil-polluted North Sea mud-soil could not.

Lam Lau, Y. and J. Moir. 1979. Booms Used for Oil Slick Control. *Journal of Environmental Engineering Division.* American Society of Civil Engineering. 105(EE2):369-382.

Laboratory experiments confirm that oil containment by a boom is not possible when the Froude number is greater than about 0.5. Tests on diversion of oil by an angled barrier were used to establish an empirical relationship between the maximum angle for the barrier and a densimetric Froude number based on boom draught.

Littlejohn, L.A., K.F. Kruk, R.E. Williams and T.F. Bailey. 1986. *Method and Apparatus Employing Oleophilic Brushes for Oil Spill Clean-up.* Patent No. US 4575426, 11 March 1986.

A method is described for removing oil from non-oleophilic surfaces including: a waterbody, a subtidal sea floor, a riverbed, a shoreline, or a beach. The method sweeps the surface with flexible, oleophilic bristles such that the oil is adsorbed on the bristles and drawn into the interstitial spaces between the bristles. The bristles comprise at least one brush so that the sweeping of the surface may be easily controlled, and the removal of the oil will be continuous and even without leaving behind streaks of the oil. Oil is removed from the bristles and the interstitial spaces between the bristles by suction and deposited in a collection tank.

Meikle, K.M., H. Whittaker and F. Laperiere. 1985. An Experimental High Pressure Waterjet Barrier. *Proceedings*, 1985 International Oil Spill Conference, Los Angeles, CA, February 25-28, 1985. API Publication No. 4385. American Petroleum Institute, Washington, D.C. pp. 7-11.

This paper discusses a barrier that uses an array of high pressure waterjets that has been developed to contain or deflect floating oil. Preliminary experiments have demonstrated that oil can be controlled effectively with this technique even in the presence of waves. Trials using an experimental prototype have established that it is stable, has good mobility, and is able to maintain position as a deflector or as a collector in currents approaching 2 knots.

Nash, J.H. 1984. *Field Manual for Plunging Water Jet Use in Oil Spill Cleanup*. Ecology Research Service, U.S. Environmental Protection Agency. Washington, DC.

This illustrated manual provides practical information on the principle of plunging water jet operation, rapid fabrication of the equipment (from readily available materials), and use in the field. Water jets carry entrained air into the water column. The expansion of air generates a horizontal surface current which carries the floating pollutant laterally relative to the direction of stream flow. This lateral motion can be used in a diversionary manner to carry the floating pollutant into naturally occurring regions of the low flow, where conventional equipment works efficiently. This systems is relatively unaffected by waves and works well in currents up to at least 6 knots.

Nyroenen, T. and P. Selin. 1985. Some Applications of the Use of Peat in Environmental Problems. *Proceedings*, Peat and the Environment '85, Swedish National Peat Committee, Hasselforg Elmia AB, Joenkoeping (Sweden), Symposium on Peat and the Environment, Joenkoeping, Sweden, September 17, 1985. pp. 395-400.

Slightly humified (Sphagnum) peat is a multi-purpose natural product which does not cause a new waste problem after use. Application is based on the mechanical, biological and chemical filtering capability. Thermally treated peat is an efficient, oil absorbing material that can remove oil from stones and vegetation.

Punt, M. 1990. The Performance of a Water Jet Barrier in a River. *Spill Technology Newsletter*. 15(1):1-4.

This paper discusses the effectiveness of a water jet barrier in a river environment. With the current design, the water jet barrier can not be held in a position to allow it to contain oil in a current greater than 0.5 m/s. It is believed that water jet barrier concept is still feasible for containing and aiding in the combustion of oil, but the configuration of the system must be changed to allow it to operate effectively in currents greater than 0.5 m/s.

Pomonik, G.M. 1973. *Vacuum Desorption Concept for Removing Oil from Water.* Project No. 4305, Prepared for Department of Transportation, U.S. Coast Guard Headquarters, Washington, D.C. Mechanics Research Inc., Los Angeles, CA.

A prototype working model was developed of a unique oil/water separator for the removal of oil from bilge and ballast water aboard ships and tanks. The concept involved desorption of gas from the water by means of a vacuum. The bubbles thus formed aided the separation process by forming on particles in the water and rapidly raising them to the surface.

Roberts, A.C. 1973. *Using Five Streams with a Self-Propelled Oil Spill Skimmer.* EPA-R2-73-181. Office of Research and Monitoring, Environmental Protection Agency, Edison, New Jersey.

This report results from field tests and operations conducted in the fall of 1972. The objective was to develop tactics for operation of a fire boat in conjunction with a self-propelled oil skimming boat for oil spill cleanup with minimum use of booms.

Schatzberg, P. and K.V. Nagy. 1971. Sorbents for Oil Spill Removal. *Proceedings*, Joint Conference on Prevention and Control of Oil Spills. API Publication No. 4117. American Petroleum Institute, Washington, D.C. p. 221.

Laboratory studies of oil and water sorption capacity, oil retention capacity, buoyancy with and without absorbed oil, effect of petroleum product variation, and sorbent/oil coherence were conducted. On average, inorganic and natural organic materials exhibited lower sorption capacities.

Shaw, S.H., R.P. Bishop and R.J. Powers. 1978. *Development of a Sorbent Distribution and Recovery System.* EPA-68-032138. Office of Research and Development, Environmental Protection Agency, Cincinnati, OH.

This report describes the design, fabrication, and test of prototype system for the recovery of spilled oil from the surface of river, estuarine, and harbor waters. The system utilizes an open cell polyurethane foam in small cubes to absorb the floating oil, is highly mobile, and can be transported in two pickup trucks.

Swift, M.R., B. Celikkol, G. Le Compagnon and C.E. Goodwin. 1992. Diversion Oil Booms in Current. *Journal Waterway Port Coastal Ocean Engineering.* 188(6):587-598.

This paper discusses diversion booming, and develops, calibrates and validates a mathematical model relating mooring points, boom parameters, and current. The model is applied, to the design of a boom configuration for the Northeast Petroleum terminal on the Piscataqua River in New Hampshire. Trial configurations are evaluated employing the model and using a leakage criterion of 0.31m/s (0.6 knots) for the maximum normal component of current.

Thomas, F.B. 1971. Method of Removing Floating Contaminant from Streams. Patent No. 3,563,380. *U.S. Patent Office Gazette.* February 16, 1971.

The author patents a method of removing oil, grease and other floating contaminants from a stream. The method includes floating a barricade, extending above the surface of the water, in a stream and positioning this barricade at an acute angle to the direction of flow. The contaminants collect on the upstream face of the barricade and periodically are removed from the surface of the stream.

Toms, A.W. 1978. Removing Free Oil from Waste Streams. *Processing.* 24(2):58-59.

A separator device is described that uses gravity flow to feed water through a lightweight porous medium. Free oil can be separated from water to reach concentrations of less than 15 ppm.

Tsang, G. 1975. *Ice Conditions and the Proposed Containment and Removal of Spilled Oil on St. Clair and Detroit Rivers.* Scientific Series No. 56. Inland Waters Directorate, Canada Center for Inland Waters, Burlington, Ontario.

This paper presents the probability of winter oil spills, effects of ice on winter oil spillage, and containment and recovery of spilled oil under winter conditions. The study shows that oil and ice may be separated and a floating boom (or booms) that is properly designed and deployed can contain the oil. Equations for designing and laying the boom are derived. Large-volume surface pumping seems to be the most effective means of final oil recovery.

Urban, R.W., D.J. Graham and S.H. Schwartz. 1978. *Performance Tests of Four Selected Oil Spill Skimmers.* EPA-600-2-78204. Environmental Protection Agency, Cincinnati, OH.

Mechanical Equipment, continued

Performance tests were conducted at the U.S. Environmental Protection Agency's OHMSETT test facility with four selected oil spill pickup devices (skimmers). Each skimmer was tested for two weeks with high and low viscosity oils.

Vadekar, M. and H.S. Wilson. 1977. Process for Removing Oil from Oily Waste Water Streams. Patent No. 4,008,160. *U.S. Patent Office Gazette.* 955(3):937.

This article describes a process for removing oil from oily waste water streams, particularly where oil is present as a stable oil-in-water emulsion. The process comprises passing the stream over a particulate bed of an unprocessed, vinyl chloride containing polymer including PVC and its copolymers.

Van den Bussche, H.K.J. 1973. Oil Scrubbers for Inland Waters. *Oil and Gas Journal.* 71(8):108-110.

An oil spill cleanup device designed for use on inland waterways and bays (where wave heights are small) is described. An endless belt of porous, synthetic polymer is continuously squeezed to remove the oil it picks up.

9.2 Methods and Approaches

Adams, J.K., A.J. Heikamp, Jr. and R.P. Hannah. 1983. Method for Ranking Biological Resources in Oil Spill Response Planning. *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. 159-164.

The authors developed a scheme for identifying and ranking freshwater and marine habitat types for the purpose of the Louisiana Offshore Oil Port spill contingency planning. Values are assigned to the following criteria to determine protection and cleanup priorities: habitat recovery, persistence of oil, cleanup damage, important species, and habitat rarity.

Brown, M. 1989. Clean-up Technology. In J. Green and M.W. Trett, eds. *The Fate and Effects of Oil in Freshwater.* Elsevier Applied Science. London, England and New York, USA. pp. 215-226.

This chapter discusses various cleanup technologies for freshwater spills. Among them are mechanical means, including diversionary and collection booming and weir skimmers. Underflow or oil-retaining dams are discussed. Chemical and biological cleanup technologies are covered as well as incinerating, land-farming and landfills.

Cox, G.V. and E.B. Cowell. 1979. Mitigating Oil Spill Damage--Ecologically Responsible Cleanup Techniques. In *The Mitigation Symposium: A National Workshop on Mitigating Losses of Fish and Wildlife Habitats.* General Technical Report RM-65. Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Ft. Collins, CO. pp. 121-128.

The need for planning experience and recognition of ecological, social and political demands in oil spill cleanup is stressed. A review of commonly used cleanup methods and their effects in marine and freshwater habitats is presented.

Cox, G.V. and J. Lindstedt-Siva. 1979. Super Fund -- An Ecologist's Dilemma. *Proceedings*, Ecological Damage Assessment Conference. Society of Petroleum Industry Biologists. pp. 379-388.

Superfund legislation would require ecological damage assessment and ecological restoration in the event of oil and hazardous material spills. The authors contend that ecologists lack the methods and information to assess ecological damage or evaluate ecosystem restoration.

Methods and Approaches, continued

Dalton, T.F. 1971. Management of Industrial Oil Spills. *Industrial Water Engineering.* 8(7):28-30.

This article reviews the numerous methods of removing oil spilled in and around plant operations - from chemicals which will disperse, thicken, or gather the oil, to sinking agents and materials for harvesting the oil.

Foget, C.R., E. Shrier, M. Cramer and R. Castle. 1979. *Manual of Practice for Protection and Cleanup of Shorelines, Vol. R, Decision Guide, Vol. II. Implementation guide.* U.S. Environmental Protection Agency. Industrial Environmental Research Laboratory, Cincinnati, OH.

A guide for on-site use in deciding and implementing the most effective protection and cleanup techniques for specific oil spill situations.

Fussell, D.R., H. Gödjen, P. Hayward, R.H. Lilie, A. Marco and C. Panisi. 1981. *Revised Inland Oil Spill Cleanup Manual.* CONCAWE, The Hague, Netherlands.

The manual presents various methods that may be used in the cleanup of oil spills in soils, groundwater and surface water, and general instructions on equipment deployment and use. Guidance in the selection of techniques to control spills in certain general environmental categories is given.

Hubbard, E.H. 1974. Inland Oil Spill Clean-Up. In *Transactions from the 9th World Energy Conference, Vol. 3, Div. 2, Technical Papers, Environment and the Energy Supply.* United States National Committee of the World Energy Conference. September 23-27, 1974. Detroit, Michigan. pp. 392-412.

This summary paper covers prevention, contingency planning, containment, removal, storage and disposal methods for spilled oil on inland waters and land.

Jerbo, A. 1973. Two Types of Oil Spills in Swedish Inland Waters: Tests of New Materials, Ideas, and Methods. *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. 559-567.

Cleanup of an oil spill was discussed in relation to standard methods and the development of new methods and materials. Saneringsull, an adsorption material, was used for cleanup. The oil content in fish and in water downstream of the impacted area were monitored.

Methods and Approaches, continued

Moir, M.E. and D.C. Yetman. 1993. The Detection of Oil Under Ice by Pulsed Ultraviolet Fluorescence. *Proceedings*, 1993 International Oil Spill Conference, Tampa, FL, March 29-April 1, 1993. API Publication No. 4580. American Petroleum Institute, Washington, D.C. pp. 521-523.

While detection of oil spills on water is relatively straightforward, spills under ice present a unique challenge. Freshwater and synthetic sea ice were grown and crude oil was introduced under the ice and irradiated. The returning fluorescence signal greater than 450 nm was measured with a simple, rugged photodiode detector. Calculations suggest that oil can be detected under freshwater ice and sea ice up to 100 cm and 80 cm thick respectively. Discontinuities in the ice limit the detectability of oil and even a modest snow covering defeats detection.

Nadeau, R.J. 1979. Priority Scheme for Cleaning Up Inland Oil Spills. *Proceedings*, 1979 U.S. Fish and Wildlife Service Pollution Response Workshop. Fish and Wildlife Service, U.S. Department of the Interior. p. 101.

This publication presents a structured decision-making guide to enable the user to assess the threat to the environment and human welfare of an oil spill and to coordinate and evaluate the flow of information between various interest groups and those responsible for the spill cleanup.

Punt, M., G. Choryhanna and A. Martin. 1991. Solvent Extraction and Recovery of Petroleum-derived Hydrocarbons from Soil. In *14th Arctic and Marine Oil Spill Program Technical Seminar, Vancouver, B.C. (Canada); 12-14 June 1991.* pp. 469-481.

Methods of removing petroleum hydrocarbons from soil and shoreline material using solvent extraction is investigated. Solvent extraction is a technology which has been used effectively in industry for several decades, but it has only been recently that the technology has been used in the soil remediation field. Many of the existing soil remediation units use proprietary solvents which, in many cases, result in higher operating costs.

Rural Electrification Administration. 1981. *Design Guide for Oil Spill Prevention and Control at Substations.* REA Bulletin 65-3. U.S. Department of Agriculture. Washington, D.C.

Oil spill prevention and control from power facilities and electrical equipment containing oil are addressed. Detailed information on oil retention systems, spill prevention techniques, and oil containment, removal and disposal is given.

Teal, A.R. 1985. Innovative Response Techniques for Major River Systems. *Proceedings*, 1985 International Oil Spill Conference, Los Angeles, CA, February 25-28, 1985. API Publication No. 4385. American Petroleum Institute, Washington, D.C. pp. 173-175.

Topics discussed in this paper include spill response techniques, logistics, deployment, and safety. Development of innovative response techniques to challenging conditions on the Mackenzie River in Canada, including boom anchor deployment by helicopter, mid-river channel recovery deployment, shoreline deflection and recovery deployment, and under-ice recovery are detailed.

Viraraghavan, T., G.N. Mathavan and S.M. Rana. 1987. Use of Peat in Wastewater Treatment. *Proceedings*, Symposium '87 Wetlands/Peatlands, Canadian Society for Peat and Peatlands, Dartmouth, NS (Canada). pp. 225-232.

Horticultural peat from Saskatchewan was assessed for its potential to remove pollutants from sanitary wastewater and to remove oil from oily waters. It was found that the oil-binding capacity of the peat was 7.5 to 7.8 times its weight. The percentage removal of oil from oil-in-water emulsions ranged from 30 to 95%, depending on the type of emulsion. Batch kinetic studies showed that equilibrium was reached in 1-3 hours. Isotherm analysis showed that the Branaur-Emmett-Teller isotherm generally fits the adsorption pattern. Column studies showed that peat filters are capable of removing up to 90% of the oil from oil-in-water emulsions.

Volkman, J.K., D.G. Holdsworth, G.P. Neill and H.J. Bavor, Jr. 1992. Identification of Natural, Anthropogenic and Petroleum Hydrocarbons in Aquatic Sediments. *Science of the Total Environment.* 112(2-3):203-219.

There are complex distributions of hydrocarbons in aquatic sediments that originate from various sources. Petroleum-derived residues are common in coastal and estuarine areas, particularly those near urban or industrial centers. This contamination is readily seen in capillary gas chromatograms of the alkanes as an unresolved complex mixture (UCM). The source of the oil can often be deduced from characteristic distributions of biomarker steranes, rearranged steranes, hopanes and methyl hopanes determined by capillary gas chromatography-mass spectrometry. Methyl hopanes are major polycyclic alkanes in oils from carbonate source rocks, such as those from the Middle East, but are uncommon in Australian oils. GC-MS fingerprinting techniques show that lubricating oils are a major source of hydrocarbon pollution in many estuaries and coastal areas around Australia.

9.3 Biodegradation

Anonymous. 1972. Destroy Oil Sludge by Biological Process. *Hydrocarbon Processing*. 51(11):19.

A brief summary of an 18-month study conducted by Shell Oil and EPA is provided. Soil cultivation, a method of putting microbes to work to dispose of various oil sludge wastes, was found to be better than incineration. Through microbial digestion, oil is transformed into harmless substances such as CO_2 and water, and this process is greatly accelerated by the addition of fertilizers.

Atlas, R.M. 1977. Stimulated Petroleum Biodegradation. *CRC Critical Reviews in Microbiology*. 5:371-386.

Review of methods proposed and tested to enhance microbial degradation of crude oil, refined oils and oily wastes. Approaches to seeding of slicks with hydrocarbonoclastic microbes, nutrient amendment, environmental modification and substrate modification are assessed.

Atlas, R.M. 1985. Effects of Hydrocarbons on Microorganisms and Petroleum Biodegradation in Arctic Ecosystems. In F.R. Engelhardt, ed. *Petroleum Effects in the Arctic Environment*. Elsevier Applied Science Publishers, London and New York. pp. 63-99.

This review article focuses on the impact of arctic oil spills upon microorganisms and the hydrocarbon biodegradative capacities of microorganisms in arctic terrestrial and aquatic habitats. Compared to more temperate ecosystems, the impact of petroleum hydrocarbons on microorganisms and microbial activities in arctic ecosystems appears to be more variable. Factors other than the presence of contaminating hydrocarbons appear to determine the response of microorganisms to oil contamination. In most cases the composition of the microbial community changes following contamination with hydrocarbons; generally numbers of hydrocarbon degraders increases and species diversity declines. In contrast to temporal zones, however, the increase in numbers of hydrocarbon degraders in arctic ecosystems may take months or years.

Bourquin, A.W., D.G. Ahearn and S.P. Meyers, eds. 1975. *Impact of the Use of Microorganisms on the Aquatic Environment*. U.S. Environmental Protection Agency. EPA-660/3-75-001. Corvallis, OR.

An EPA-sponsored symposium to determine the possible impact of microbial insect control agents or oil-degrading agents into the aquatic environment is summarized. The use of microorganisms to clean up oil spills in aquatic environments is considered, with emphasis on the use of hydrocarbonoclastic microorganisms in special environments, such as Arctic regions and Louisiana salt marshes.

Okpokwasili, G.C. and L.O. Odokuma. 1990. Effect of Salinity on Biodegradation of Oil Spill Dispersants. *Waste Management.* 10(2):141-146.

Biochemical oxygen demand and river water biodegradation tests of oil spill dispersants were determined at NaCl concentrations of 0, 20, and 40 g/L, and at ambient temperature. Surfactant concentration was monitored by infra red spectroscopy. Results indicate that microbial degradation of all the dispersants used in the study decreased with increasing salt concentration.

Olivieri, R., P. Bacchin, A. Robertiello, N. Oddo, L. Degen and A. Tonolo. 1976. Microbial Degradation of Oil Spills Enhanced by Slow-Release Fertilizer. *Applied and Environmental Microbiology.* 31(5):629-634.

The improved cleanup of marine oil spills by stimulating biodegradation through the use of a slow-release fertilizer is reported. A paraffin-supported fertilizer containing Mg NH_4 PO_4 as an active ingredient was developed and evaluated in laboratory and field experiments using quantitative infrared spectrometry and chromatographic techniques.

Olivieri, R., A. Robertiello and L. Degen. 1980. Method for Depolluting Freshwater and Saltwater Bodies from Crude Oil, Petroleum Products and Their Derivatives. Patent No. 4,230,562. In *U.S. Patent Office Gazette.* 999(4):1536.

A method for cleaning oil by spreading compounds which contain phosphorus and slow-release nitrogen is described. The nutrient compounds are applied onto the water surface in a form which can be assimilated by aquatic microorganisms that are capable of metabolizing hydrocarbons.

9.4 Chemical Countermeasures

Anonymous. 1970. Using Chemicals for Cleaning Up Oil Spills. *Ocean Industry.* 5(8):35-40.

A brief summary is presented with comprehensive coverage of sorbants, dispersants, oxidation and biodegradation.

Anonymous. 1976. Oil Dispersal Compound. *Chemical Engineering World.* 11(12):88.

Coast Guard-6 is a compound used to disperse oil spills without foaming or forming undisposable oil sludge residues.

Anonymous. 1991. Chemical-biological Approach to Oil Spills. *Chemical & Engineering News.* 69(13):28.

A chemical treatment for oil-spill cleanup was developed by the International Science Center, Bubendorf, Switzerland, that converts the oil carpet, on salt or freshwater, into a non-toxic, water-soluble microemulsion using special emulsion agents. Biological treatment consists of microbes that degrade the oil.

Bahloul, S.K., A.A. Donatelli, W.W. Bannister and J.W. Walkinshaw. 1979. Gelants for Control of Petroleum Spills on Water. *Ind. Eng. Chem. Prod. Res. Dev.* 18(4):364-367.

Gelation is a promising method for the control and cleanup of hydrocarbon liquid spills on water. The hydrocarbon is converted into a gel when a solution consisting of 70% Amine D, 15% ethyl alcohol, and 15% benzyl alcohol by volume is added to the liquid and subsequently reacted with carbon dioxide. Spills on water were simulated with substances such as no. 2 fuel oil, Avgas 145, pentane, isooctane, and cyclohexane, and for each case the organic phase was converted successfully into a gel. Gel strength increased with decreasing gelation temperature and was affected slightly by saltwater.

Brown, H.M. and R.H. Goodman. 1989. Dispersants in the Freshwater Environment. In *ASTM Special Technical Publication, 1989, 1018 (Oil Dispersants: New Ecol. Approaches 61-0 (Water))* pp. 31-40.

This article discusses the effect of oil and dispersants on a freshwater ecosystem using laboratory and field experiments. The purpose was to select a suitable dispersant for a field trial and to develop monitoring techniques capable of detecting chronic and sublethal effects in selected freshwater species. The field trial demonstrated that a spill of light oil covering 5-10% of the surface of a small

shallow freshwater lake had no long-term measurable effects and application of a dispersant ameliorated some short-term effects in this low energy system.

Brown, H.M., J.S. Goudey, J.M. Foght, S.K. Cheng, M. Dale, J. Hoddinott, L.R. Quaife and D.W.S. Westlake. 1990. Dispersion of Spilled Oil in Freshwater Systems: Field Trial of a Chemical Dispersant. *Oil and Chemical Pollution.* 6:37-54.

The impacts of oil and dispersed oil on freshwater ecosystems were examined. In July 1985, 3 m^3 of crude oil were spilled on two fen lakes. The slick on one lake was treated with the dispersant Corexit 9550. The dispersant was effective in removing the oil from the water surface even though wave energy was very low. The results suggest that the best response to oil contamination in isolated fen lakes is no action at all. However, floating oil or oil washed ashore could pose a significant threat to indigenous wildlife or its habitats. Under these conditions, chemical dispersion may prove to be an effective alternative when conventional control and recovery measures are not feasible.

Canevari, G.P. 1977. Chemical Oil Dispersing Agents and Their Feasibility for Use. In P.L. Fore, ed. *1977 Oil Spill Response Workshop.* Publication No. NSW/OBS/77-24. Fish & Wildlife Service, Washington, D.C. pp. 83-94.

Chemical dispersants can minimize damage from oil spills. Self-mix dispersant systems are effective but need to be further evaluated as to dilution and resultant toxicity of dispersed oil.

Castle, R.W. and E. Schrier. 1979. Chemical Dispersion of Oil. *Ecolibrium* 8(3):15-19.

The authors present some guidelines for selecting a chemical dispersant for a given environment and type of oil. They also indicate when nothing should be done with dispersants.

Cowell, E.B. 1978. Ecological Effects of Dispersants in the United Kingdom. In L.T. McCarthy, Jr., G.P. Lindblom and H.F. Walters, eds. *Chemical Dispersants for the Control of Oil Spills.* ASTM STP 659. American Society for Testing and Materials, Philadelphia, PA. pp. 277-292.

The problems associated with the toxicity of dispersants at the time of the TORREY CANYON disaster are described together with subsequent developments to reduce toxicity. The problems of laboratory bioassay and its limitations in ecological prediction are reviewed in relation to dispersant concentrations that are reached under field use. Problems of the use and ecological effects of dispersants

in shore cleaning are described in association with practical aspects of safe application.

Hellman, H. and F.J. Bruns. 1970. Application and Comparative Examination of Chemical Agents for the Dispersion of Crude Oil on Water Surfaces. *Erdol und Kohle, Erdgas, Petrochemie vereinigt mit Brennstoffchemie.* 26(9):513-517.

A suitable procedure developed on the basis of laboratory and outdoor tests, is proposed for chemical dispersal agents. The procedure aims primarily at testing the dispersing and emulsifying capacity of the products.

Nagy, E.B., B.F. Scott and J. Hart. 1984. The Fate of Oil and Oil-dispersant Mixtures in Freshwater Ponds. *Science of the Total Environment* (Netherlands). 35(2):115-133.

The fate, distribution and composition of Norman Wells oil and oil-dispersant (Corexit 9527) mixtures were studied in a series of five, lined, inground ponds containing sandy gravel sediment and mesotrophic water. Final distribution calculations revealed that about 45% of the oil had degraded in the oil-dispersant-treated ponds during the one year study, while only 23% could not be accounted for in the oil pond. Changes in the oil composition during the experiment were similar in all ponds, with no evidence to suggest that the dispersant affected oil composition in any special manner.

Nelson-Smith, A. 1978. Effects of Dispersant Use on Shore Life. In L.T. McCarthy, Jr., G.P. Lindblom and H.F. Walter, eds. *Chemical Dispersants for the Control of Oil Spills*. ASTM STP 659. American Society for Testing and Materials. Philadelphia, PA. pp. 253-265.

Field and laboratory studies of the effects of dispersants on organisms are reviewed.The author concludes that spilled oil should be removed mechanically whenever possible; dispersants are wholly undesirable in the coastal environment on their own, but can be recommended around colonies of birds and for removal from hard surfaces in regions of importance. Heavy oils must be removed mechanically.

Nichols, J.A. and H.D. Parker. 1985. Dispersants: A Comparison of Laboratory Tests and Field Trails with Practical Experience at Spills. *Proceedings*, 1985 International Oil Spill Conference, Los Angeles, CA, February 25-28, 1985. API Publication No. 4385. American Petroleum Institute, Washington, D.C. pp. 421-427.

This paper discusses how laboratory tests can demonstrate the effectiveness of

dispersants fairly easily, but it is far more difficult to assess their effectiveness during field conditions. Because timeliness is critical for dispersant application, it is necessary to study their use in field trials and actual incidents. It is important to study the methods of application, the period after release into the sea during which dispersants remain effective, the influence the sea conditions, and the temperature have on dispersant effectiveness.

Westlake, D.W.S., J. Fought, J.S. Goudey, M. Dale and J. Hoddinott. 1986. The Biological Component of the Freshwater Oil Spill Research Program. *Proceedings*, Ninth Annual Arctic and Marine Oil Spill Program Technical Seminar, Edmonton, Alberta, Canada, June 10, 1986. pp. 628-634.

A major concern in establishing dispersants as a viable response technique in freshwater is the potential for shoreline damage. A program was designed to monitor the effects of a freshwater oil spill treated with Corexit 9550. Three freshwater sloughs were used for the experiment.

9.5 *In-situ* Burning

Anonymous. 1970. Cellular Glass Nodules Can Burn Away Oil Spills on Fresh and Salt Water. *Oil and Gas Journal.* 68(9):88.

Combustion of spilled oil on water is achieved by use of cellulated textured glass beads (¼ inch in diameter), which become covered with oil by capillary action and then can be ignited.

Day, T., D. Mackay, S. Nadeau, and R. Thurier. 1979. Emissions from *in situ* Burning of Crude Oil in the Arctic. *Water Air and Soil Pollution.* 11(2):139-52.

The results of an exploratory study of the effects of *in situ* burning on air quality in the Beaufort Sea region of the Arctic are presented. Estimates are made of the likely emissions of soot, CO, SO_2 and metals based on literature and some experimental work. It is concluded that burning may be a method of substantially reducing the adverse environmental impact of oil spills in the Arctic.

Sheppard, E.P., R.A. Wells and P.E. Georghiou. 1983. The Mutagenicity of a Prudhoe Bay Crude Oil and its Residues from an Experimental *in situ* Burn. *Environmental Research.* 30:427-441.

Fresh and weathered Prudhoe Bay crude oil as well as combustion residues were tested for mutagenicity using strain TA98 in the Ames *Salmonella typhimurium*/liver microsome test. Mutagenic effects were clearly visible at very low concentrations, with precipitated plume having the greatest activity followed by the burn residue, the weathered oil, and fresh crude, respectively. The most polar components of the neutral fraction of the samples displayed the greatest mutagenicity.

Summerfield, M. 1993. Radiative Evaporation of Oil Spills on Seas or Rivers. 1993. *Proceedings*, International Oil Spill Conference, Tampa, FL, March 29-April 1, 1993. API Publication No. 4580. American Petroleum Institute, Washington, D.C. p. 849.

Because of the drawbacks of *in-situ* oil burning as a means of removing spilled oil, a similar technique, evaporation of the oil by absorbed heat, may be used instead. Oil spilled can be collected by a boom floating in the water, and gathered in a catenary-like contour, deep enough to absorb the beam of radiation near the apex of the catenary. Circulation in the gathered oil layer would serve to assure the minimum of heat conduction (loss of heat) to the water below. The efficiency of the overall process, from the standard heat of combustion to the radiation beam emitted, is about 40 percent.

9.6 Case Studies

Audet, A. 1993. Response to the RIO ORINOCO Incident: A Small-scale Incident that Lasted a Whole Year. *Proceedings*, 1993 International Oil Spill Conference, Tampa, FL, March 29-April 1, 1993. API Publication No. 4580. American Petroleum Institute, Washington, D.C. pp. 209-212.

When the tanker RIO ORINOCO ran aground in the Gulf of St. Lawrence near Anticosti Island, approximately 200 metric tons, or 200,000 liters, of fuel oil were spilled. Most of the pollution drifted onto the shores of Anticosti Island, which is considered a hunting and fishing paradise. The Salvage Plan could not be carried out due to bad weather, and all five attempts made in the weeks that followed were unsuccessful. Mechanical cleanup operations on the shoreline continued while the salvage attempts were being made, with about a hundred men deployed over more than 60 kilometers. On December 21, 1990, winter caused the discontinuation of attempts at salvaging the wreck of the RIO ORINOCO. Cleanup and restoration were also discontinued for the winter. In June 1991, restoration and cleanup work on the shoreline resumed and this was completed in late July. The wreck of the RIO ORINOCO was removed on August 6, 1991.

Burns, R.C. 1988. Cleanup and Containment of a Diesel Fuel Spill to a Sensitive Waterbody at a Remote Site Under Extreme Winter Conditions. *Proceedings*, 11th Arctic and Marine Oil Spill Program Technical Seminar, June 7-9, 1988, Vancouver, B.C. EP, Environment Canada. pp. 209-220.

This paper summarizes the cleanup of a 59,000 liter diesel oil spill that occurred in Warwick Lake in January 1983. Warwick Lake is 165 kilometers north of Red Lake, Ontario and was covered with snow and ice at the time of the spill. Temperatures ranged between -35 and -50 C. Collection trenches were cut in the ice and contaminated snow and recovered oil were burned on the site. Subsequent inspections of the area showed no significant damage to the environment.

Chen, E.C. 1972. *Arctic Winter Oil Spill Test.* Technical Bulletin 68. United States Coast Guard, Inland Waters Branch, Department of Environment. Washington, DC.

The oil spill test discussed in this report was a supplemental experiment of a summer test conducted previously. Its purpose was to investigate the physical properties of crude oil spilled in an Arctic winter environment.

Environmental Protection Agency. 1975. *Environmental Effects of Schuylkill Oil Spill II, June 1972.* EPA/430/9-75-019. Environmental Protection Agency, Washington, D.C.

Case Studies, continued

The fate and effects of a spill of six to eight million -gallons of waste crankcase oil re-refined sludge into the Schuyl kill River, Pa., in June 1972 have been studied. No direct permanent effects were noted.

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, 1975. API Publication No. 4385. American Petroleum Institute, Washington, D.C. pp. 319-323.

In June 1982, two oil barges were lost on the Arkansas River when their tow boat lost power. One barge was impaled by ice breakers on Lock and Dam No.4, 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 major adverse environmental effects were observed.

Jorgenson, M.T., L.W. Krizan and M.R. Joyce. 1991. Bioremediation and Tundra Restoration After an Oil Spill in the Kuparuk Oilfield, Alaska, 1990. *Proceedings*, 14th Arctic and Marine Oil Spill Program Technical Seminar, Environment Canada, Publication EN 40-11/5-1991. pp. 149-154.

This paper discusses cleanup, bioremediation, and tundra restoration in an oilfield in Alaska. Following a 300 to 600 barrel crude oil spill into a coastal tundra area, cleanup was initially conducted by flushing, raking, and swabbing. Aerobic and anaerobic biodegradation was promoted by controlling water levels and surface moisture and by fertilizing and aerating. The cleanup efforts caused significant damage to the vegetation. However, due to the preservation of the subsurface roots and stems, partial recovery and revegetation occurred within a year.

Kemerer, J.A., N. Hendrickson and R. Mullinaux. 1985. A Case History: Oil Spill Onto the Prado Flood Control Basin, a Freshwater Wetlands Cleanup. *Proceedings*, 1985 International Oil Spill Conference, Los Angeles, CA, February 25-28, 1985. API Publication No. 4385. American Petroleum Institute, Washington, D.C. pp. 325-330.

During January and February 1983, EPA conducted a cleanup of several thousand gallons of crude oil spilled onto the Prado Flood Control Basin California. A number of environmental factors and physical constraints affected the cleanup operation. The basin is a forested wetland supporting a wide variety of wildlife, including migratory waterfowl. The oil was concentrated at the center of the basin in thick willow brush. Removal of the oil had to be performed for the most part manually, with small, recreational-type aluminum boats that provided the only access to the contaminated area. The safety of workers in debris-laden boats had to be considered on several occasions during unfavorable weather conditions.

Lamp'l, H.J. 1973. Lake Champlain: a Case History on the Cleanup of No. 6 Fuel Oil Through Five Feet of Solid Ice at Near-Zero Temperatures. *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, DC. pp. 579-582.

Cleanup and recovery operations following the spill of 44,000 gallons of heated No. 6 fuel oil into the frozen lake are described.

Miller, A.J. and G.L. Ott. 1985. *Major Oil Spill on the Delaware River, September 1985.* Geological Survey Water Supply Paper (US) 2300 1986. pp. 47-48.

On September 28, 1985, the tanker GRAND EAGLE ran aground on a rocky shoal in the Delaware River. This paper discusses the spill and cleanup that followed. More than 435,000 gallons of crude oil was spilled and ultimately spread over a 25-mile stretch of the river, impacting wetlands, waterfowl, recreational facilities, boat docks, and commercial river traffic. A computer program specifically designed for such incidents was used to prepare initial trajectories for the movement of the oil.

Mitchell, N., P.D. Holmes, B. Pyburn and W.J. Syratt. 1985. An Estuarine Oil Spill Incident in the United Kingdom. *Proceedings*, 1985 International Oil Spill Conference, Los Angeles, CA, February 25-28, 1985. API Publication No. 4385. American Petroleum Institute, Washington, D.C. pp. 341-348.

In September 1983, the crude carrier SIVAND collided while berthing at the River Humber in England. As a result of the collision, about 6,000 tons of Nigerian light crude oil was released. A combination of fast currents and southeasterly winds carried the oil over a wide area of the estuary, polluting dock areas and river creeks and threatening a number of sensitive areas. Four hundred tons of oil was recovered from docks, rivers, creeks, and inlets using disc and vacuum skimmers. A further estimated 2,000 tons was dispersed chemically using boats and aircraft. Information on the effects of the oil and cleanup on the estuary has so far indicated that the impact was considerably less than originally feared.

Case Studies, continued

Mullins L. 1987. Oil Pollution -- The Problem. In *3rd Annual International Conference: Lake, River and Coastal Pollution - Can it Be Contained?* 5-6 November 1987. pp. 57-60.

This paper describes the pollution caused by the wrecking of the KOWLEEN BRIDGE bulk ore carrier near Baltimore, County Cork, in November 1986. Clean-up operations used sorbents and high powered water jets. Details are given of application to rock, shingle, slipways, piers and walls. The Reno Mattress dune protection system is discussed.

Noel, M.R. and K.A. Ebbot. 1992. Remediation of a 115,000-gallon Petroleum Pipeline Leak. In *5th National Outdoor Action Conference on Aquifer Restoration, Groundwater Monitoring, and Geophysical Methods.* Las Vegas, NV. May 11-13, 1992. pp. 275-289.

A rupture in a buried pipeline in June 1988 released 115,000 gallons of diesel fuel, contaminating soil and groundwater at a site in Milwaukee, Wisconsin. Emergency and interim response actions resulted in the recovery of over 70,000 gallons of product from the ground surface, a nearby creek, and recovery trenches. The most cost effective and technically feasible remedial alternative included low temperature thermal desorption for treatment of the impacted soils, and recovery of impacted groundwater with discharge to a sanitary sewer. The implementation of the thermal desorption process was the first application of its type in the State of Wisconsin.

Owens, E.H. and C.R. Foget. 1982. A Small River Oil Spill: A Large Step Back to Cleanup Technology. *Spill Technology Newsletter.* 7(1):3-10.

Authors reviewed the cleanup of a No. 6 fuel oil spill. Methods included physical removal of contaminated material from marshes which was more deleterious to vegetation than the oil itself.

Pontasch, K.W. and M.A. Brusven. 1987. Periphyton Response to a Gasoline Spill in Wolf Lodge Creek, Idaho. *Canadian Journal of Fisheries and Aquatic Sciences.* 44(9):1669-1673.

A post-impact study on a 94,438 liter unleaded gasoline spill into Wolf Lodge Creek in northern Idaho was undertaken to determine the temporal and spatial response of periphyton following the spill. Periphytic biomass and chlorophyll *a* concentrations were determined above and below the spill. Downstream areas were mechanically agitated to release substrate-trapped hydrocarbons 35 days after the spill. Periphyton samples were taken 26 days after the spill indicated that

periphytic biomass, especially of the heterotrophs, was greater in the impacted than unimpacted areas. The Autotrophic Index, which is a ratio of the biomass to chlorophyll 'a', was up to 30 times greater in the impacted reach. Two months after the spill and 1 month after stream cleaning, the Autotrophic Index was approximately the same in reference and impacted areas.

Smith, A.J. 1973. Successes and Failures with Oil Spills in Southeastern Inland Waters. *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, DC. pp. 583-588.

Five unique cases of spill occurrence, containment or removal in the southeastern states are described. Information gained from successful and unsuccessful cleanup attempts is highlighted.

Wiltshire, G.A. and L. Corcoran. 1991. Response to the PRESIDENTE RIVERA Major Oil Spill, Delaware River. *Proceedings*, 1991 International Oil Spill Conference, San Diego, CA, March 4-7, 1991. API Publication No. 4479. American Petroleum Institute, Washington, D.C. pp. 253-258.

On June 24, 1989, a Uruguayan tanker grounded and spilled 300,000 gallons of "high pour" No. 6 oil downstream of Marcus Hook on the Delaware River. Recovery and cleanup efforts were limited. Non-traditional cleanup methods, such as clamshell bucket dredges, hopper barges, dedicated mucker boats, overpowered boats, net boom, and high sea booms towed down-current, were found to be more effective than conventional methods. There was a minimal impact on fish; most affected wildlife were swimming and wading birds and fur-bearing animals.

9.7 Environmental Effects

Baca, B.J., C.D. Getter and J. Lindstedt-Siva, 1985. Freshwater Oil Spill Considerations: Protection and Cleanup. *Proceedings*, 1985 International Oil Spill Conference, Los Angeles, CA, February 25-28, 1985. API Publication No. 4385. American Petroleum Institute, Washington, D.C. pp. 385-390.

Oil spills occur in freshwater environments are unique and require different considerations for protection and cleanup as compared to marine spills. This paper focuses on cleanup of freshwater marshes and swamps. Spills in marshes are generally the most destructive, especially when marshes have little or no flushing. The return of the marsh or swamp to its original state is dependent upon the amount and type of oil, the amount of flushing, the type of vegetation and the potential for revegetation, and the type of cleanup conducted. Spills occurring in marsh and swamp habitats of rivers are much less destructive based on the water movement in those systems. Various case studies are presented to illustrate the impacts of freshwater spills.

Baker, J.M., J.A. Bayley, S.E. Howells, J. Oldham and M. Wilson, 1989. Oil in Wetlands. In B. Dicks, ed. *Ecological Impacts of the Oil Industry.* John Wiley and Sons, Chichester and New York. pp. 37-59.

Wetlands include a variety of bog, fen, reed-swamp and saltmarsh communities. A number of oil-pollution case histories have been investigated, and field experiments have been carried out with cleanup and rehabilitation in mind. The behavior of oil in wetlands is described in relationship to tidal and water-table movements. Clean-up techniques including dispersant treatment, cutting and burning are discussed. Some species can grow in sediments with high concentrations of weathered oil and have been successfully used in the rehabilitation of oiled sites.

Baker, J.M., 1995. Net Environmental Benefit Analysis For Oil Spill Response. *Proceedings*, 1995 International Oil Spill Conference, Long Beach, CA, February 27-March 2, 1995. API Publication No. 4620. American Petroleum Institute, Washington, D.C. pp. 611-614.

This paper discusses the Net Environmental Benefit Analysis (NEBA) from an ecological viewpoint, examining the advantages and disadvantages of different spill responses with regard to flora and fauna and their habitats, compared with no response at all. Of particular concern was nearshore dispersant spraying and shoreline cleanup. Scientific case histories and experimental evidence is reviewed. For shoreline cleanup, consideration is given both to the shore itself and to any potentially interacting systems that might be affected in various ways depending on the spill response.

Environmental Effects, continued

Berkner, A.B., D.C. Smith and A.S. Williams. 1977. Cleaning Agents for Oiled Wildlife. *Proceedings*, 1977 International Oil Spill Conference, New Orleans, LA, March 8-10, 1977. API Publication No. 4282. American Petroleum Institute, Washington, DC. pp. 411-415.

Advantages and limitations of detergents and solvents in the removal of oil products from contaminated wildlife (birds and aquatic mammals) are discussed with respect to oil type, animal type and cleaning procedures and facilities. Twenty-two commercial detergents are evaluated for removal of eight oil types from feathers; toxicity data for selected detergents are given.

Cairns, J., Jr. and A.L. Buikema, Jr. 1984. *Restoration of Habitats Impacted by Oil Spills*. Butterworth Publishing, Stoneham, MA.

This book provides a comprehensive narrative on how various habitats are restored after being impacted by an oil spill. It starts by discussing oil and what happens after it is spilled. Restoration of rocky shores, sandy beaches, tidal flats, seagrass ecosystems, salt marshes, mangroves, coral reefs, tundra, taiga, and fisheries is discussed. The book is the product of a workshop that was held to discuss habitat restoration.

Clayton, J.R., Jr., G.H. Farmer, J.R. Payne, G.D. McNabb, Jr., P.C. Harkins, J.S. Evans, N.P. Rottunda, C.R. Phillips and M.L. Evans. 1989. Effects of Chemical Dispersant Agents on the Behavior and Retention of Spilled Crude Oil in a Simulated Streambed Channel. In *ASTM Special Technical Publication 1018 (Oil Dispersants: New Ecological Approaches 61-2 (Water))*. San Diego, CA. pp. 4-24, 46, and 51.

Field experiments were performed to obtain estimates of the effects of selected chemical dispersants on the behavior and retention of spilled crude oil in a shallow freshwater streambed environment in Alaska. Comparisons between experiments, with and without pre-spill additions of dispersants to the oil, imply that the use of chemical dispersants in freshwater streambeds must include an understanding of the interplay between variables related to the type of oil and the specific streambed environment.

Vandermeulen, J.H. and C.W. Ross. 1993. *Oil Spill Response in Freshwater Environments: Impact on the Environment of Cleanup Practices*. API Publ. No. 4567. American Petroleum Institute, Washington, D.C.

This review provides information on the impact and potential ecological effects of oil spill cleanup methods used in freshwater habitats. Effectiveness of cleanup actions is not included, but rather, results from toxicity tests of petroleum and various products to freshwater organisms. The report focuses specifically on the

impacts of cleanup methods employed in a number of oil spills in freshwater environments.

Wardley-Smith, J., ed. 1976. *The Control of Oil Pollution on the Sea and Inland Waters.* Graham and Trotman Ltd., London.

This is a detailed treatment of the effects of oil spills on marine and freshwater environments and cleanup methods.

Westree, B. 1977. Biological Criteria for the Selection of Cleanup Techniques in Salt Marshes. *Proceedings*, 1977 International Oil Spill Conference, New Orleans, LA, March 8-10, 1977. API Publication No. 4284. American Petroleum Institute, Washington, DC. pp. 231-235.

Vegetational and environmental characteristics of salt marsh types are described. Cleanup methods that will not cause further unnecessary destruction of marshes following oil spills are recommended.

10.0 USE OF MODELS

Bartell, S.M. 1985. Comparison of Model Forecasts with Measured Effects of a Synthetic Oil in Pond Ecosystems. *Proceedings*, Workshop on Environmental Modeling for Priority Setting among Existing Chemicals, Munchen-Neuherberg (FRG), 11 November 1985.

Comparisons were made between the ecological effects of phenolic compounds measured in experimental ponds and the effects forecast by aquatic ecosystem models. The Standard Water Column Model (SWACOM) was used to extrapolate acute toxicity data to estimated changes in production of phytoplankton, zooplankton, and forage fish in relation to oil exposure. Replacement of SWACOM by POND, a model structurally more similar to the ponds, resulted in more accurate forecasts of the observed patterns of change in biomass production of algae and forage fish, and the observed pattern of change in nutrient concentration. The combination of toxicity data measured for the water-soluble fraction of the oil, the measured concentrations of total phenolic compounds, and the POND model provided the most accurate forecasts of effects.

Bennett, J.R., D.J. Schwab, E.W. Lynn and B.B. Parker. 1986. Pathfinder: An Interactive Model for Trajectory Prediction in the Great Lakes. *Proceedings*, Applications of Real-Time Oceanographic Circulation Modeling Symposium, Laurel, MD (USA), 23 May 1985. pp. 59-68.

A series of computer programs has been developed to assist in forecasting the movement of oil spills, floating and submerged debris, or other objects in the open waters of the Great Lakes. A numerical circulation model is used to calculate the lake currents based on observed winds for the previous day and wind forecasts for following days. Another program predicts the trajectories of the particles and allows the user to examine particle locations at a given time, or the trajectory of a single particle. The system is intended to be used primarily by NOAA and the U.S. Coast Guard for guidance in operational spill response and search and rescue operations in the open water areas of the lakes, where the currents are due mainly to large-scale wind-driven circulation.

Brown, H.M. and P. Nicholson. 1991. The Physical-Chemical Properties of Bitumen in Relation to Oil Spill Response. *Proceedings*, Fourteenth Arctic and Marine Oil Program Technical Seminar. Vancouver (British Columbia), Canada. June 12-14, 1991.

Viscous bitumen from Alberta must be diluted with gas condensate before it can be transported by pipeline to export markets. If a spill of this material (called Dilbit) occurs, its properties will change rapidly as the condensate fraction evaporates.

Use Of Models, continued

Laboratory measurements were made of Dilbit evaporation rates and the changes which occur in Dilbit's viscosity, density, and flash point. Two oil spill models, which use different approaches to describe evaporation, were run to determine if they could predict the measured Dilbit evaporation rates based on the known initial material properties. Both models appeared to predict the Dilbit evaporation characteristics if appropriate input parameters were used.

Camara, A.S., F.C. Ferreira, J.E. Fialho and E. Nobre. 1991. Pictorial Simulation Applied to Water Quality Modeling. In T. Barnwell, P.J. Ossenbruggen, and M.B. Beck, eds. *Proceedings*, Second International Conference on Systems Analysis in Water Quality Management, Durham, New Hampshire, USA, 3-6 June 1991. *Water Science Technology.* 24(6):275-281.

Pictorial simulation models considering pictorial entities and operations are introduced. Pictorial entities are defined by their shape, size, color and position. Pictorial operators include reproduction (copy of a pictorial entity), mutation (expansion, rotation, translation, change in color), fertile encounters (intersection, reunion) and sterile encounters (absorption). Pictorial simulation is applied to two water quality management problems to illustrate its potential applications: oil spills and waste stabilization ponds.

Cronk, J.K., W.J. Mitsch and R.M. Sykes. 1990. Effective Modelling of a Major Inland Oil Spill on the Ohio River. *Ecological Modelling.* 51(3-4):161-192.

A model of the large 2700 cubic meter inland oil spill on the Monongahela River was developed to estimate the fate and transport time of the oil for 600 km downstream. Emphasis was on developing an effective modelling procedure that balances accuracy with simplicity, is user friendly, and is easily applicable to future spills. Model calibration with oil concentration data suggests that loss of oil due to sedimentation was important. After calibration, the model estimates that 1400 m^3 or 52% of the spilled oil ended up in the sediments, most of it in the first few reservoir polls along the river. Both the model and field data agree on similar peak concentrations of oil of between 1.0 and 2.5 ppm (by volume) in the river pools between 130 and 240 km downstream of the spill. The model further considers travel time, resuspension, storms and exposure time.

French, D.P. 1991. *Estimation of Exposure and Resulting Mortality of Aquatic Biota Following Spills of Toxic Substances Using a Numerical Model. Proceedings,* Symposium on Aquatic Toxicity and Risk Assessment. San Francisco, CA, April 22-24, 1990. American Society of Testing and Materials (ASTM), STP 1124 (14th Vol.). Philadelphia, PA. pp. 35-47.

Use Of Models, continued

This paper discusses a numerical model developed for natural resource damage assessment. The exposure and toxicity models allow estimation of mortality of fish, invertebrates, eggs, and larvae and lost production of lower trophic levels that result from acute exposures to toxic concentrations in aquatic environments. The biological effects model is used to interpret the impacts of the losses by using population and food web models.

Herbes, S.E. and G.T. Yeh. 1985. A Transport Model for Water-soluble Constituents of Synthetic Oil Spills in Rivers. *Environmental Toxicology and Chemistry.* 4(2):241-254.

A numerical model was developed to predict dissolved aqueous concentrations of phenolic contaminants resulting from spills of synthetic oil into a river. The model (termed SOPTRAN, for synthetic oil pollutant transport) simultaneously solves algorithms for slick spreading, oil evaporation, phenolics dissolution, advection and dispersion using an implicit integrated compartment method. Predictions were compared with measurements of phenolics dissolution into underlying water following application of a coal-liquefaction product to two small ponds. The means of measured concentrations during phenolics dissolution was 84% of predicted values. With minimal calibration, SOPTRAN adequately described differential rates of dissolution of phenol and C_1- to C_4 -alkylphenol isomer groups. The model was used to simulate a hypothetical 300m^3 (80,000-gal) accidental release of a coal liquid from a barge into a large navigable river under both instantaneous and non-instantaneous (i.e., leakage) spill scenarios.

MacKay, D. and S. Paterson. (No Date). *The Physical Properties of Fresh and Weathered Crude Oils. Special Report.* Department of Chemical Engineering, University of Toronto, Ontario.

A computer program which could predict the physical properties of crude oils as a function of temperature and extent of evaporation was written. The program developed could not successfully be applied to predict the physical properties of Marine Diesel and Bunker C oil.

Palczynski, R.J. 1987. Model Studies of the Effect of Temperature on Spreading Rate of a Crude Oil on Water. In J.H. Vandermeulen and S.E. Hrudey, ed. *Oil in Freshwater: Chemistry, Biology, Countermeasure Technology.* Permagon Press, New York. pp. 22-30. *Proceedings* of the Symposium on Oil Pollution in Freshwater. Edmonton, Alberta, Canada. October 15-19, 1984.

This paper discusses the one-dimensional, viscous-surface tension spreading rate

of oil slicks on calm water. The spreading rates of different crude oils at various temperatures increased with temperature at the rate of .011/degree C. The increase in temperature of crude oils decreases their viscosity, density, surface and interface tensions while their spreading rate increases. Data are given for changes with temperature in viscosity, surface tension, water-crude interfacial tension, and density of crude samples. The pour point of samples is discussed.

Puskas, J., E. McBean and N. Kouwen. 1987. Behavior and Transport of Oil Under Smooth Ice. *Canadian Journal of Civil Engineering/Revue Canadienne de Genie Civil.* 14(4):510-518.

This paper discusses mathematical and physical models that are used in studying transport of oil slicks beneath ice in the presence of an ambient water current. The mathematical expressions for the relevant forces are developed by utilizing basic boundary layer theory and considering the physical properties of the oils. The models are verified by the laboratory experiments where three different crude oils are tested beneath freshwater ice under various flow conditions.

Reed, M., D. French, S. Feng and W. Knauss. 1990. A Three-dimensional Oil and Chemical Spill Model and Coupled Geographical Information System. *Proceedings,* Seventh Technical Seminar on Chemical Spills, Edmonton (Canada), 4-5 June 1990. pp. 1-16.

A three-dimensional model for natural resource damage assessments is applicable to the Great Lakes environments, including connecting channels. It is designed to simulate fates of pure hazardous substances, crude oils, and petroleum products. Crude oil and petroleum products are simulated by 4 components (2 aromatic components, an insoluble volatile component, and an insoluble nonvolatile fraction). The model can simulate continuous releases of a contaminant, with representation of complex coastal boundaries, variable ecosystem habitats. A graphic interface gives the user complete and facile control of the dynamic transport and biological submodels, as well as the ability to display elements of the underlying geographical information system data base.

Reed, M. and D. French. 1991. A Natural Resource Damage Assessment Model and Geographical Information System for the Great Lakes. In *Environment Canada Chemical Spills, 8th Technical Seminar, Vancouver, BC, Jun 10-11, 1991.* Applied Sciences Association, Narragansett, RI. pp. 1-10.

A coupled geographical information system is the basis for a model of the physical transport, biological consequences, and economic effects of an oil or chemical

spill. The model, which accommodates various biological habitats, hydrological regimes, and wind-driven hydrodynamics common to lakes and shorelines, has been applied to the Great Lakes and associated rivers, but is applicable to any freshwater or marine environment. For use on a personal computer, the model will be incorporated into the US federal regulatory framework.

Schwab, D.J., J.R. Bennett and E. Lynn. 1985. Pathfinder - An Interactive Model for Trajectory Prediction in the Great Lakes. *Proceedings*, 28th Conference on Great Lakes Research, Milwaukee, WI, 3-5 June 1985. p. 63.

A series of computer programs have been developed to assist in forecasting the movement of oil spills, floating or submerged debris, or other objects in the open waters of the Great Lakes. A numerical circulation model is used to calculate the lake currents based on observed winds for the previous day and wind forecasts for following days. The system is intended to be used primarily by NOAA and Coast Guard for guidance in operational spill response and search and rescue operations in the open water areas of the lakes where the currents are due mainly to the large-scale wind-driven circulation.

Shen, H.T. and P.D. Yapa. 1988. Oil Slick Transport in Rivers. *Journal of Hydraulic Engineering.* 114(5):529-543.

This paper discusses a two-dimensional computer model that simulates oil movement in rivers for both open water and ice-covered conditions. This tool is useful for determining the appropriate cleanup measure based on the spill movement and for assessing likely environmental impacts of possible spills.

Shen, H.T., P.D. Yapa and M.E. Petroski. 1986. Simulation of Oil Slick Transport in Great Lakes Connecting Channels. Vol. 2. User's Manual for the River Oil Spill Simulation Model. Available from the National Technical Information Service at (703)487-4650 as AD-A213 709/9/XAB.

Two computer models named as ROSS and LROSS are developed for simulating slick transport in rivers and lakes, respectively. The slick transformation processes in these models include advection, spreading, evaporation and dissolution. These models can be used for slicks of any shape from instantaneous or continuous spills in rivers and lakes with or without ice covers. Although developed for the need of the connecting channels in the upper Great Lakes, these models are site-independent and can be used for other rivers and lakes. The programs are written in FORTRAN programming language to be compatible with FORTRAN77 compiler. The models are designed to be used on both mainframe and microcomputers.

Shen, H.T., P.D. Yapa and M.E. Petroski. 1986. Simulation of Oil Slick Transport in Great Lakes Connecting Channels. Vol. 3. User's Manual for the Lake-River Oil Spill Simulation Model. Available from the National Technical Information Service at (703)487-4650 as AD-A213 710/7/XAB.

In this study, two computer models are developed for simulating slick transport in rivers and lakes, respectively. The slick transformation processes in these models (ROSS and LROSS) include advection, spreading, evaporation, and dissolution. These models can be used for slicks of any shape from instantaneous or continuous spills in rivers and lakes with or without ice covers. Although developed for the need of the connecting channels in the upper Great Lakes, these models are site-independent and can be used for others rivers and lakes. The programs are written in FORTRAN language to be compatible with FORTRAN77 compiler. The models are designed to be used on both mainframe and microcomputers.

Shen, H.T., P.D. Yapa and M.E. Petroski. 1991. Simulation of Oil Slick Transport in Great Lakes Connecting Channels. User's Manual for the River Spill Simulation Model (ROSS). Available from the National Technical Information System at (703)487-4650 as AD-A247 845/1/XAB.

The computer model, ROSS, was developed for simulating oil slick transport in rivers. The oil slick transformation processes considered include advection, spreading, evaporation and dissolution. These model can be used for slicks of any shape originating from instantaneous or continuous spills in rivers with or without ice covers. Although developed for the connecting channels in the upper Great Lakes, including the Detroit River, Lake St. Clair, the St. Clair River and the St. Mary's River, the models is site-independent and can be used for other rivers and lakes. The programs are written in FORTRAN programming language to be compatible with the FORTRAN77 compiler. In addition, a user-friendly, menu-driven program with graphics capability was developed for the IBM-PC AT computer, so that the model can easily assist the cleanup action in the connecting channels should an oil spill occur.

Shen, H.T., P.D. Yapa, D.S. Wang and X.Q. Yang. 1991. *A Mathematical Model for Simulating Fate and Transport of Oil in Rivers*. Report No. 91-1. Department of Civil and Environmental Engineering, Clarkston University, Potsdam, New York.

This report discusses a model that has been developed specifically for oil spills on rivers. The model takes into account advection, mechanical spreading, turbulent diffusion and mixing, evaporation, dissolution, emulsification, shoreline deposition and sinking. A case study is presented and how the model works is explained.

Use Of Models, continued

Suflita, J.M. 1975. *Sequential Continuous Culture Systems as Simulatory Models for the Fate of Oil in Aquatic Ecosystems.* N.Y. State Assembly Scientific Staff, Albany, N.Y. Engineering and Applied Science, National Science Foundation. Washington, D.C.

The degradation of diesel oil in sequential continuous flow culture systems was investigated, including the effects of nitrogen, phosphorus and surfaces on degradation. Oil degradation in field experiments was studied and a tentative predictive model for the fate of oil in aquatic ecosystems was constructed.

Yang, W.C. and H. Wang. 1977. Modeling of Oil Evaporation in Aqueous Environment. *Water Research.* 11(10):879-888.

Development of a numerical model to predict short-term oil weathering when the evaporation process dominates. Temperature, wind speed and slick size for two crude oils and a No. 2 fuel oil were considered.

Yapa, P.D., D.S. Wang, H.T. Shen, X.Q. Yang and J.B. Perry. 1991. Integrated Model for Fate and Transport of Oil in Rivers. Hydraulic Engineering. *Proceedings*, 1991 National Conference, American Society of Civil Engineers, New York, 1991. pp. 638-643.

An integrated oil-spill model for microcomputers was developed for simulating fate and transport of spilled oil in rivers. This model can simulate the oil-slick transformation in transient flow conditions with varying wind and air temperature. The model consists of: 1) a menu-based interface for preparing interactive data, assigning fixed data files, and executing all modules; 2) an unsteady flow module to simulate the flow conditions along the river as a function of time; 3) a 2-dimensional 2-layer model that can simulate advection, horizontal diffusion, spreading, evaporation, dissolution, vertical mixing, emulsification, and shoreline deposition; and 4) a graphics interface for visualizing the results from the oil spill model. The model is completely integrated and user-friendly, so that the tasks of data preparation, running the flow model, and visualization of the model output can all be performed by following the step-by-step menus provided.

Yapa P.D., S.F. Daly, S.C. Hung and H.T. Shen. 1991. Oil Spill Simulation in Rivers. *Proceedings*, 1991 International Oil Spill Conference, San Diego, CA, March 4-7, 1991. API Publication No. 4529. American Petroleum Institute, Washington, D.C. pp. 593-600.

This paper discusses computer models developed for simulating oil-slick transport in rivers, including the connecting channels of the Great Lakes, the upper St. Lawrence River, and the Allegheny-Monongahela-Ohio River system. A Lagrangian discrete-parcel algorithm is used to determine the location and concentration distribution of the oil as well as the deposition of oil on the shore. The model for the Great Lakes connecting channels (ROSS) is a two-dimensional surface slick model which considers advection, spreading, horizontal diffusion, evaporation, dissolution, and shoreline deposition. The model is applicable to both open water and ice-covered conditions. Models for the St. Lawrence River and the Ohio River System are developed based on a two-layer scheme (ROSS2) which considers vertical mixing and emulsification processes in addition to the processes considered in the surface slick model.

Yapa, P.D., H.T. Shen, M. Karamouz, G.R. Baumli and W.J. Brick. 1987. A Computer Model for Oil Slick Transport in Rivers. In *Water Forum '86: World Water in Evolution, Vol. 1, Long Beach, CA, 4 August 1986*. pp. 1815-1822.

A computer model for simulating oil-slick transport in rivers is presented. In the model the effects of advection, spreading, evaporation, and dissolution on the transformation of an oil slick are considered. The model can be used to simulate instantaneous or continuous spills, and has been applied to simulate the fate of oil spills in the Great Lakes connecting channels.

Zeller, K.F. and A.T. Amr. 1985. An Evaluation of Jubail Meteorological Data to Provide Wind Parameters for Oil Spill Movement Predictions. *Proceedings,* Symposium/Workshop on Oceanographic Modelling of the Kuwait Action Plan (KAP) Region, 1985. pp. 315-328.

Surface oil-spill movement is dependent upon wind turbulence, wind speed and wind direction. Oil-spill models require a wind parameter as input for computations. Computing surface wind fields over sea from sparse measurements obtained at coastal and inland stations has to be done with great care because of the differences in surface roughness. This paper evaluates selected 5-minute meteorological data obtained at Jubail during homogeneous wind turbulence periods. Data from one of the coastal sites are compared with data from the inland 90 m tower site. Values of the friction velocity, roughness length, coefficient of friction, and power law exponent are investigated. Wind speeds from these selected data periods are then correlated for subcategories of bulk Richardson number, vertical temperature lapse rate and wind direction.

REFERENCES

These references were used in the Introduction

Hoffman, E.J., J.S. Latimer, G.L. Mills and J.G. Quinn. 1982. Petroleum Hydrocarbons in Urban Runoff From a Commercial Land Use Area. J. Wat. Pollut. Control Fed. 54:1517-1525.

Hoffman, E.J., G.L. Mills, J.S. Latimer and J.G. Quinn. 1983. Annual Input of Petroleum Hydrocarbons to the Coastal Environment via Urban Runoff. Can. J. Fish. Aquat. Sci. 40 (Suppl. 2):41-53.

MacKenzie, M.J. and J.V. Hunter. 1979. Sources and Fates of Aromatic Compounds in Urban Stormwater Runoff. Environ. Sci. Technol. 13:179-183.

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

Van Vleet, E.S. and J.G. Quinn. 1977. Input and Fate of Petroleum Hydrocarbons Entering the Providence River and Upper Narragansett Bay From Wastewater Effluents. Environ. Sci. Technol. 11:1086-1092.

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

Appendix A

INDEX OF SOURCES

List of Journal Abbreviations

Acta Hydrochim. Hydrobiol.	Acta Hydrochimica Hydrobiologie
Annu. Rev. Microbiol.	Annual Review of Microbiology
Appl. Environ. Microbiol	Applied and Environmental Microbiology
Aquat. Toxicol.	Aquatic Toxicology
Arch. Environ. Contam. Toxicol.	Archives of Environmental Contamination and Toxicology
Arch. Hydrobiol.	Archives of Hydrobiology
Avian Pathol.	Avian Pathology
Bacteriol. Rev.	Bacteriological Reviews
Bull. Environ. Contam. Toxicol.	Bulletin of Environmental Contamination and Toxicology
Calif. Fish Game	California Fish and Game
Can. Field-Nat.	Canadian Field-Naturalist
Can. J. Bot.	Canadian Journal of Botany
Can. J. Fish. Aquat. Sci.	Canadian Journal of Fisheries and Aquatic Sciences
Chesapeake Sci.	Chesapeake Science
Can. J. of Chem. Eng.	Canadian Journal of Chemical Engineering
Can. J. Zool.	Canadian Journal of Zoology

Journal Abbreviations continued

Can. Res.	Canadian Research
Canada Dept. Environ. Tech. Rept.	Canada Department of the Environment Technical Report
Comp. Biochem. Physiol.	Comparative Biochemistry and Physiology
Comp. Biochem. Physiol. C Comp. Pharmacol. Toxicol.	Comparative Biochemistry and Physiology C Comparative Pharmacology and Toxicology
Contrib. Mar. Sci.	Contributions in Marine Science
CRC Crit. Rev. Microbiol.	CRC Critical Reviews in Microbiology
Dept. of Indian and Northern Affairs	Department of Indian and Northern Affairs
Dev. Ind. Microbiol.	Developments in Industrial Microbiology
Dir. Fish. Res. Aquat. Environ. Monit.	Directions in Fisheries Research and Aquatic Environmental Monitoring
Dis. Aquat. Org.	Diseases of Aquatic Organisms
Diss. Abst. Int. Pt. B - Sci. & Eng.	Dissertation Abstracts International Part B Sciences and Engineering
Ecotoxicol. Environ. Saf.	Ecotoxicology and Environmental Safety
Energy Rev.	Energy Review
Environ. Contam. Toxicol.	Environmental Contamination and Toxicology
Environ. Lett.	Environmental Letters
Environ. Pollut.	Environmental Pollution
Environ. Res.	Environmental Research
Environ. Sci. Technol.	Environmental Science Technology
Environ. Toxicol Pharmacol.	Environmental Toxicology and Pharmacology

Journal Abbreviations continued

Service. Tech. Devel. Rept.	Environment Canada, Environmental Protection Service Technical Development Report
Environmental Pollution. Ser. A	Environmental Pollution, Series A
Estuar. Coast. Shelf Sci.	Estuarine and Coastal Shelf Science
Eur. J. Pharmacol.	European Journal of Pharmacology
Fish. Mar. Serv. Environment Canada	Fisheries and Marine Service, Environment Canada
Fish. Res. Board Can.	Fisheries Research Board of Canada
Geochim. Cosmochim. Acta	Geochimica et Cosmochimica Acta
Ind. Eng. Chem. Prod. Res. Dev.	Industrial Engineering and Chemical Production Research and Development
Ind. Env. Res. Lab.	Industrial Environmental Research Laboratory
Ind. Water Eng.	Industrial Water Engineering
Int. J. Miner. Process.	International Journal of Mineral Processing
Int. Ver. Theor. Angew. Limnol. Verh.	Internationale Vereinigung fuer Theoretische und Angewandte Limnologie Verhandlungen
J. Appl. Ecol.	Journal of Applied Ecology
J. Can. Petrol. Tech.	Journal of Canadian Petroleum Technology
J. Environ. Eng.	Journal of Environmental Engineering
J. Environ. Eng. Div.	Journal of Environmental Engineering Division
J. Environ. Sci. Health.	Journal of Environmental Science and Health
J. Exp. Mar. Biol. Ecol.	Journal of Experimental Marine Biology and Ecology
J. Fish. Res. Bd. Can.	Journal of the Fisheries Research Board of Canada

Journal Abbreviations continued

J. Gen. Microbiol.	Journal of General Microbiology
J. Hydrol.	Journal of Hydrology
J. Ichthyol (Engl. Transl. Vopr. Ikhtiol.)	Journal of Ichthyology (English Translation of Voprosy Ikhtiologii)
J. Ind. Microbiol.	Journal of Industrial Microbiology
J. Inst. Petroleum.	Journal of the Institute of Petroleum
J. Petrol. Technol.	Journal of Petroleum Technology
J. Res. U.S. Geol. Survey	Journal of the U.S. Geological Survey
J. Sediment. Petrol.	Journal of Sedimentary Petrology
J. Wat. Pollut. Control Fed.	Journal Water Pollution Control Federation
J. Waterway Port Coastal Ocean Eng.	Journal Waterway Port Coastal Ocean Engineering
J. Wildl. Manage.	Journal of Wildlife Management
Limnol. Oceanogr.	Limnology and Oceanography
Mar. Chem.	Marine Chemistry
Mar. Environ. Res.	Marine Environmental Research
Mar. Pollut. Bull.	Marine Pollution Bulletin
Mar. Tech. Soc. Journ.	Marine Technical Society Journal
Microb. Ecol.	Microbial Ecology
Microbiol. Rev.	Microbiology Review
Muench. Beitr. Abwasser-Fisch.-Flussbiol	Muencher Beitrage Zur Abwasser-, Fischerei-, und Flussbiologie
New Zeal. Entomol.	New Zealand Entomology
Oil Chem. Pollut.	Oil Chemical Pollution

Journal Abbreviations continued

Oil Gas J.	Oil and Gas Journal
Physiol. Plant.	Physiologia Plantarum
Proc. Louisiana Acad. Sci.	Proceedings of the Louisiana Academy of Sciences
Prog. Ind. Microbiol.	Progress in Industrial Microbiology
Prog. Water Technol.	Progress in Water Technology
Schweiz. Z. Hydrol.	Schweizerische Zeitschrift fuer Hydrologie
Sci. Total Environ.	Science of the Total Environment
Spill Technol. Newsl.	Spill Technology Newsletter
Trans. Am. Microsc. Soc.	Transactions of the American Microscopical Society
Undersea Technol.	Undersea Technology
Verh. Int. Verein. Limnol.	Verhandlungen Der Internationalen Vereinigung Fur Theoretisches Und Angewandte Limnologie
Vet Hum Toxicol.	Veterinary and Human Toxicology
Water Pollut. Res. J. Can.	Water Pollution Research Journal of Canada
Water Air Soil Pollut.	Water, Air and Soil Pollution
Water Res.	Water Research
Water Resour. Bull.	Water Resources Bulletin
Wildl. Rehab.	Wildlife Rehabilitation
Wildl. Soc. Bull.	Wildlife Society Bulletin

Appendix B

SUBJECT INDEX

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Subject Index (Continued)

Subject Index (Continued)

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Appendix C

PRIMARY AUTHOR INDEX

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Primary Author Index (continued)

Primary Author Index (continued)

Primary Author Index (continued)

American Petroleum Industry

Petroleum in the Freshwater Environment

An Annotated Bibliography

Manual for the Electronic Version

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Introduction

This Diskette Product includes Folio® Bound Views 3 search software and the complete text and graphics of *Petroleum in the Freshwater Environment* as an accompanying Folio® Views infobase. Using this software, you may search the complete text of *"Freshwater"* for words or combinations of words and find the information for which you are looking. Every word in the volume is already indexed, so searches are very quick. Any annotations you place in the text are immediately indexed and separately searchable.

Minimum System Requirements

PC:	486 or better; 16 MB of RAM: VGA monitor: Windows 95
Macintosh:	68020 or better: 6 MB of RAM: System 7 or higher

Installation Instructions

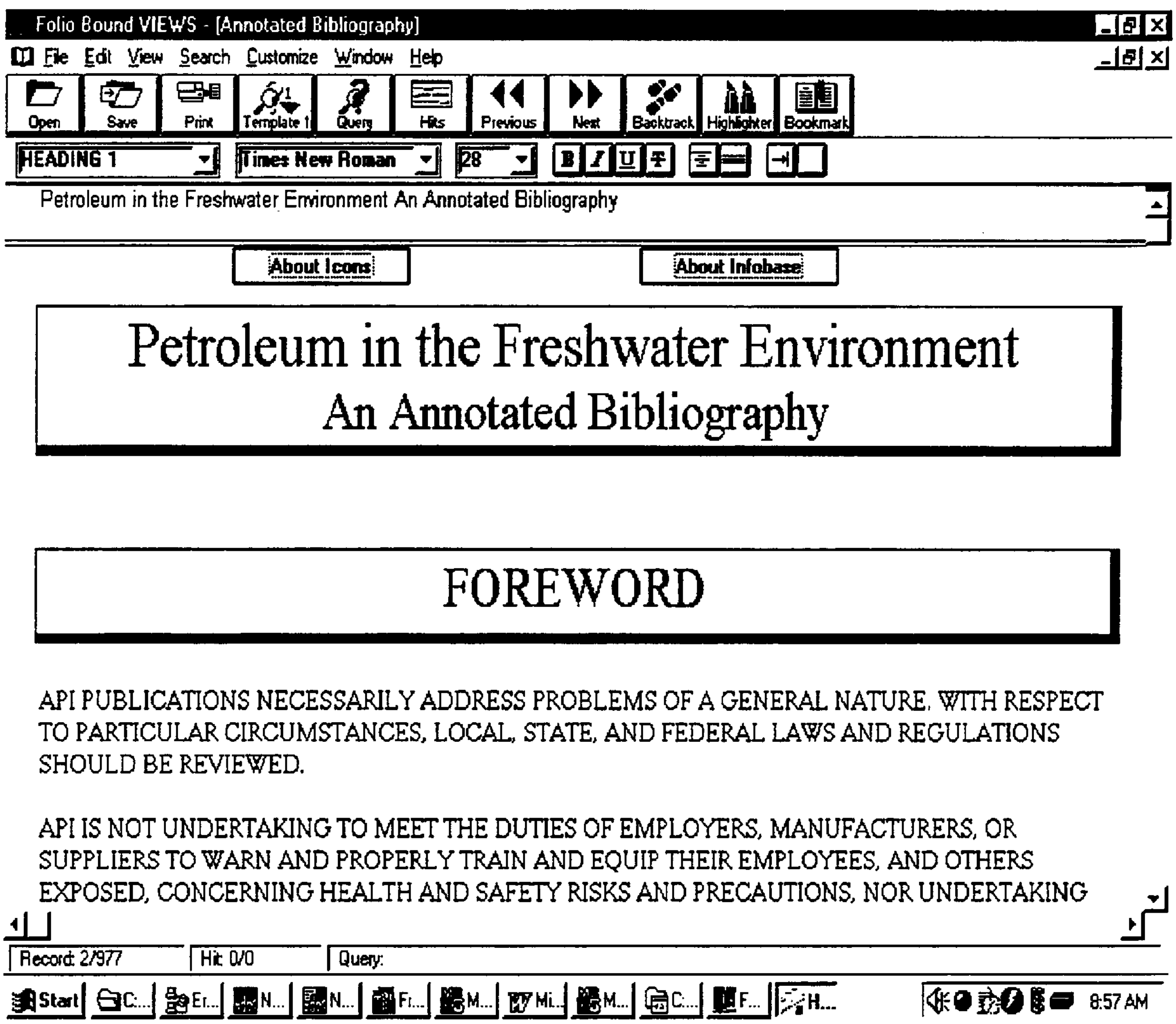
Window's Install

To install the Product, from the File Menu in Windows select Run. In the box type A:\Setup, then follow the menu instructions.

Mac Install

To begin the install procedure, insert the diskette in its drive, click on the installer icon from the MAC folder on the diskette.

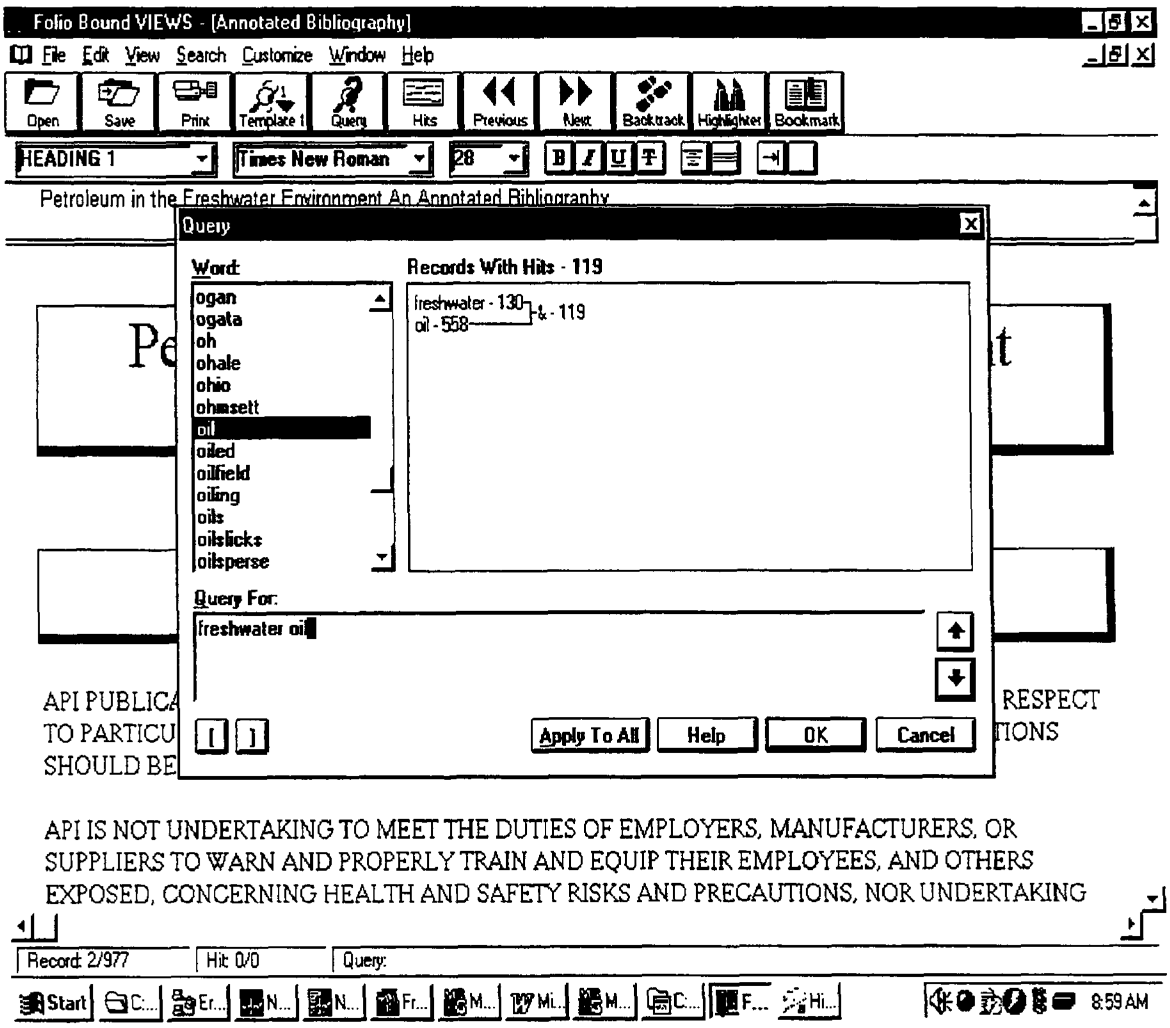
After your installation, click on the Freshwater Icon and the following screen will appear.



Searches

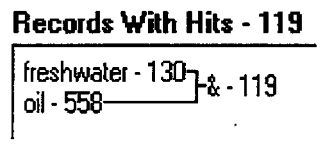
Searches are record based. In this infobase, records are paragraphs. When you perform a search, VIEWS reports the number of records which contain matches to your query. VIEWS does not report the number of times a word appears in the infobase; rather, it reports the number of records in which the word appears.

All queries (searches) are entered into the Query dialog. The dialog performs two primary functions: one, it provides a place for you to enter the queries; and two, it provides feedback on your query through the Records with Hits results map.

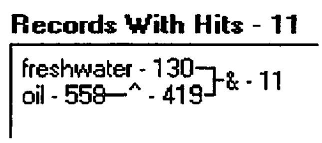


To initiate a search, open the Freshwater infobase and press F2 or click on the Query button. Searches are not case sensitive. Do not include punctuation in search terms. To perform a simple search, type the word or words you want to locate. Press OK to be taken to the first hit. Press F3 for the next hit and F4 to return to a previous hit. You may also use the Next and Previous buttons for this purpose.

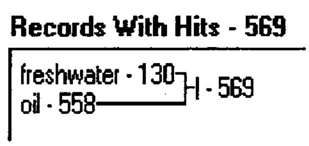
Search operators: **AND** (optional), **OR, NOT**.



Freshwater **and** oil- all paragraphs that include both words.



Freshwater **not** oil- all paragraphs that include one but not the other word.



Freshwater **or** oil- all paragraphs that include at least one of these words.

Wildcards:

? replaces any single letter.

***** replaces multiple characters.

For example: B??l will pick up bell, bill, and bull. Fresh* will pick up Fresh, Freshly, Freshwater and Freshwaters.

Phrase and Proximity Searches:

Place phrases in quotes, e.g., "Freshwater oil". Phrases are not indexed, so phrase searches take longer.

Ordered:

"Freshwater oil"/5 returns all occurrences of Freshwater followed by oil within 5 words.

Unordered:

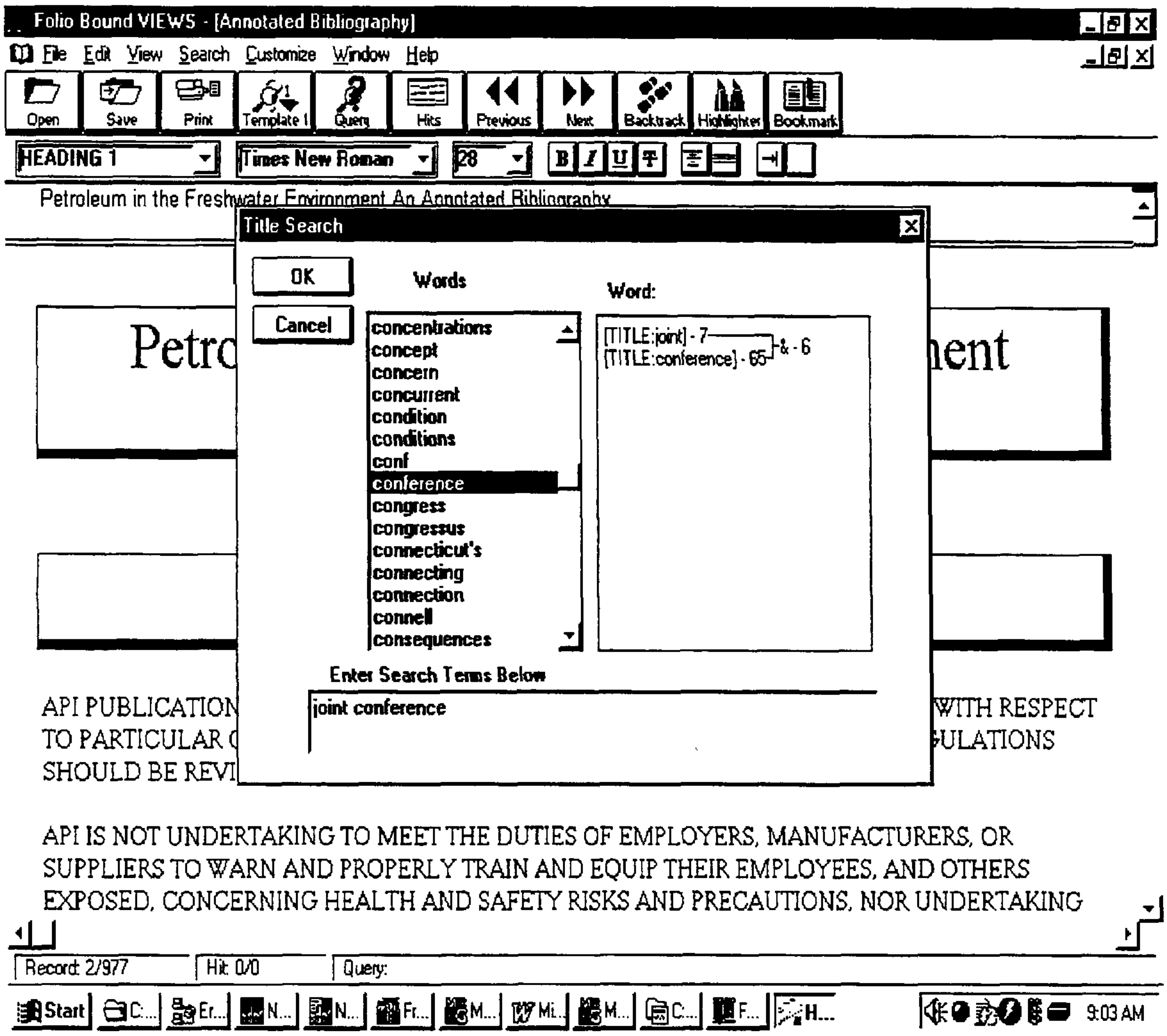
"Freshwater oil"@5 returns all occurrences of Freshwater and oil within 5 words regardless of which word occurs first.

Press F1 when the query dialog is open for a comprehensive review of all commands available during queries.

Query Template

The Query Template is a specialized query that allows you to find a particular word (or words) in the title portion of each entry.

Click on the query template icon on the Button bar.



A query for the words JOINT CONFERENCE yeilds 6 results. One example follows:

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.

Follow the **About Icons** button to see more about the button bar icons.

Navigating

Navigation is the process of moving through an infobase to find the information you need. VIEWS uses the standard navigational keystrokes available on each supported platform for basic navigation: **PAGE UP, PAGE DOWN, HOME, END**, and the arrow keys. Other navigational tools are specific to VIEWS. These include Jump Links and the Contents window.

Jump Links take you from one point in the infobase to another. Double clicking on text that is colored and underlined will take you to a related portion of the infobase. Press **F5** to return to the previous location. The examples below are Jump Links to specific parts of the Freshwater publication.

TABLE OF CONTENTS

Use the Contents window to quickly browse the table of contents of an infobase. An infobase table of contents is expandable and collapsible, so you can see as much or as little information as you need. In addition, every heading in the table of contents is linked automatically to the corresponding record in the document window. To use the Contents window: Choose Table of Contents from the View menu. (Pressing **CTRL+T** also opens the Contents window.) Double click a plus sign to expand a branch of the table of contents. Double click a minus sign to collapse a branch of the table of contents. After performing a query, move to the Table of Contents Window. You may want to narrow the view to Headings with hits or Words around hits using the view menu. These settings will stick. In later sessions you may want to change them back to view the entire table of contents.

Valuable Short Cut Key Strokes

F1 - Context sensitive Help. Specific to screen or dialog box in view. Use it early and often to gain mastery of the software.

F2 - Query: Opens the Query dialog to search the infobase.

F3 - Next: Advances the cursor to the next query hit.

F4 - Previous: Returns the cursor to the previous query hit.

F5 - Backtrack: Backs you through searches you have performed and the links you have followed.

CTRL+T - Table of Contents: Opens the Contents window for the infobase.

Using Search Results

To print or save text to a file you must first select the target text. Insert the cursor (click the mouse once) on the text you want to use. Press **F6** to tag the text. From the File menu select Print or Save As, then follow the menu options. From the Edit menu, select Clear All Tags before beginning a new selection.

Shadow Files - for VIP Users Only

Shadow Files - Shadow files allow you to store changes to an infobase without directly affecting the original information in the master infobase. Anything which you can do in an infobase may be done in a shadow file.

To create a shadow file, the master infobase must first be opened. From the menu select File, then New. Specify Folio® Shadow as the file type. Name the file and keep the .SDW extension associated with it. Make sure the path specifies a subdirectory on a writable drive. Press OK. The word "Shadow" will appear as part of the title at the screen top. The infobase view is unchanged, but any annotations placed in the file will be retained in the shadow file. In subsequent sessions users may open the shadow file directly. Begin Folio® Views, then select File, Open. Specify Folio® Shadow as the file type. Double click on the file name to open and use the shadow file again. If a master file is already open users may close it, then select File, Open, Shadow.

Personal Annotations - for VIP Users

Users may only annotate an infobase if it is on a writable drive.

Bookmarks hold your place in an infobase from session to session. If you find information of interest, add a bookmark so you can find the information later. Each bookmark may be up to 127 characters long, allowing you to describe the place you are holding with great detail. VIEWS allows up to 1000 bookmarks in the same infobase. Insert the cursor where you wish to place a bookmark. (Do not place bookmarks inside words.) Press **CTRL+M**, type your bookmark descriptions and press OK. Later to return to your bookmark, press **CTRL+M**, select the bookmark and press OK.

Notes allow you to place notes in the margin. Each paragraph in the infobase may have one note, if desired. The text of the note appears in a popup window. When you are not viewing the text of the note, the note appears as a small icon next to the paragraph where it was placed. Press **CTRL+N**, type the text of your note. Press Escape to close the note, then press Save.

Highlighter allows you to highlight sections of an infobase as you might do with a highlight pen and printed text. To create a highlight style, press **CTRL+H**. Enter a descriptive name for your highlight. Select Character. To make a yellow highlighter, next select Background, double click on Yellow. Follow the dialog options to save your selection and return to the text. Now select the text you want to highlight. (Hold down the left mouse button and move the cursor along the text.) Press **CTRL+H**, double click on your highlight selection and return to your text. Click once to deselect the text and view the result.

Popups are similar to notes but are attached to text or objects. To create a popup, select some text as you do to create a highlight. From the customize window, select Popup, enter your personal annotation, press Escape and save the result. Double click on the selected text to view the popup.

Notes, Popups and Highlights are immediately indexed and separately searchable. Refer to the Searches section of this manual for the proper query syntax.

Technical Support

Should you have problems installing or using the software, telephone technical support is provided by API's software developer, ProInfo Corporation. ProInfo may be reached at (202) 289-3893 weekdays 8 to 5 PM Eastern time.

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