MARINE POLLUTION AND ITS CONTROL

Paul L. Bishop, Ph. D.

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Paul L. Bishop, Ph.D.
Professor of Civil Engineering
University of New Hampshire

McGraw-Hill Book Company
New York St. Louis San Francisco Auckland Bogotá Hamburg
Johannesburg London Madrid Mexico Montreal New Delhi
Panama Paris São Paulo Singapore Sydney Tokyo Toronto

This book was set in Times Roman by A Graphic Method Inc.
The editors were Julienne V. Brown and J. W. Maisel;
the production supervisor was Dominick Petrellese.
The drawings were done by Burmar.
Halliday Lithograph Corporation was printer and binder.

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1 2 3 4 5 6 7 8 9 0 HALHAL 8 9 8 7 6 5 4 3 2

ISBN 0-07-005482-7

This book was prepared with the support of NSF grant SER-7900851. Any opinions, findings, conclusions, and/or recommendations herein are those of the author and do not necessarily reflect the view of NSF.

Library of Congress Cataloging in Publication Data

Bishop, Paul L.
Marine pollution and its control.

(McGraw-Hill series in water resources and environmental engineering)
Bibliography: p.
Includes index.
1. Marine pollution. I. Title. II. Series.
GC1085.B57 363.7'394 82-7747
ISBN 0-07-005482-7 AACR2

PREFACE

The public has become increasingly aware of marine pollution and its consequences in the past few years and has responded with demands for remedial action. In many cases regulatory authorities have overreacted to this pressure, and the outcome has been a nearly total prohibition on waste disposal in the marine environment. Only recently has the impact of these actions become apparent. In many instances the alternatives to ocean disposal create more harm to the environment than did the ocean dumping itself. Regulations are now being relaxed to allow use of the assimilatory capacity of the oceans for disposal of waste materials, but it must be remembered that although this capacity represents a vast natural resource, it should not be squandered.

The self-cleansing ability of the oceans must be used widely, or catastrophic, and possibly permanent, damage may result. It falls to the environmental engineer and marine scientist to determine the safe assimilatory capacity of the oceans and to design waste disposal systems which will not overtax this capacity. It is for these engineers and scientists that this book is intended.

Even though millions of tons of waste materials are deposited into the oceans worldwide each year, there is presently no text available which addresses both the causes and the consequences of marine pollution and the methods available to alleviate this problem. The objective of this book is to cover these subjects in enough detail to be of use to both the student and the practicing engineer and scientist involved with the marine environment. Since marine pollution is often a highly volatile subject, this book will attempt to provide as unbiased a view as possible by presenting both sides of the issues and problems to be discussed.

Most environmental engineers are not familiar with the marine environment, and most marine scientists know little about pollution control. Consequently, this book integrates material on marine pollution from the fields of engineering and marine science as well as from other relevant areas and offers a unified approach to controlling the adverse effects of waste disposal in the marine environment. Included are an evaluation of the sources of marine pollutants; the magnitude of the problem created by their discharge; the physical, chemical, and biological effects caused by them; the fates of these materials in the marine environment; and mechanisms for reducing or eliminating adverse effects through proper engineering practice.

The major sources of marine pollution are discussed. These include oil spills and discharge of oily materials to the oceans, discharge of sewage and industrial wastes through ocean outfalls, disposal of shipboard wastes, dumping of sewage sludge and industrial chemicals into the sea, dredging and disposal of dredge spoils, and deposition of radioactive wastes in the oceans.

The material in this text has been presented to the students in my marine pollution control course over the past few years and has been refined and revised as a result. I am most appreciative of the thorough review and criticism of this work provided by Dr. Judith Cappuzzo, Woods Hole Oceanographic Institute, and Dr. James O'Shaughnessy, Northeastern University. Their reviews were most beneficial in preparing the final text. I am also grateful to Mrs. Alice Greenleaf, University of New Hampshire, and Mrs. Isabel Gordon, Heriot-Watt University, Edinburgh, Scotland, for their expert typing of the manuscript and to Dr. Roy Haliwell, Heriot-Watt University, for his valuable assistance and hospitality during the time when much of this book was written. I would also like to thank my wife, Pamela Bishop, for preparing the illustrations for this book. A final word of appreciation is offered to the National Science Foundation, which supported a portion of this work through a grant from the Local Course Improvement Program.

Paul L. Bishop

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THE PROBLEM OF OCEAN POLLUTION

Then God commanded, "Let the water below the sky come together in one place, so that the land will appear"—and it was done. He named the land "Earth," and the water which had come together He named "Sea." And God was pleased with what He saw. . . .

Unfortunately, God probably would not be pleased if he were to look at the current state of the oceans. Rivers have become universal sewers that carry away the wastes of people, and the oceans have become the ultimate sink for these wastes.

For many years it was believed that the oceans were so vast that no amount of waste which humans could generate could have other than negligible impact on them. It is now readily evident that this is not the case. Destructive oil spills; marine organisms contaminated by mercury, pesticides, and pathogenic organisms; massive algal blooms caused by nutrients present in sewage discharged into marine waters; and unsightly beaches caused by solid waste and petroleum materials washed up on shore are now widespread. Fortunately, many of these incidents are of short duration. Unfortunately, we do not know what the long-term effects of them may be. We may be permanently despoiling our most essential natural asset.

WHAT IS OCEAN POLLUTION?

There are many pathways by which pollutants enter the oceans (Table 1.1). Sewage and industrial wastes are pumped into coastal waters through marine outfalls; more sewage, as well as garbage and other solid wastes, is dumped by ships plying the seas; solid wastes and sewage sludge are carried to sea aboard barges and dumped into the oceans; harbor dredge spoils must be placed some-

Table 1.1 Potential sources of marine pollution

Dumping of dredge spoils	Oil from tanker cleaning and deballasting
Dumping of industrial wastes	Oil spills from shipping accidents
Dumping of radioactive wastes	Overland flow
Dumping of sewage sludge	Precipitation of airborne pollutants
Dumping of solid wastes	Radioactive wastes in power-plant outfalls
Marine industrial-waste outfalls	River-borne pollutants
Marine sewage outfalls	Sewage from ships
Natural sources	Solid wastes from ships
Ocean mining	Thermal pollution from power plants
Oil from drilling or production platforms	

where and are usually deposited into the sea; radioactive wastes from nuclear power plants, research laboratories, hospitals, and nuclear weapons development are dumped into the oceans in some parts of the world in both liquid and containerized form; runoff from land enters the oceans carrying a myriad of pollutants, including pesticides and chemical nutrients; atmospheric contaminants often precipitate into the oceans; and petroleum products continually contaminate the oceans from offshore drilling platforms, shipping accidents, bilge and oil tank washing, and as a component of sewage, overland runoff, and other liquid wastes. In addition to these sources of pollution, nature itself must be classified as a major source of contaminants. Weathering of the earth's crust, volcanic eruptions, waste products from marine organisms, and natural submarine oil seeps all add to the pollution load the oceans receive.

An international group of experts has divided ocean pollutants into eight categories: halogenated hydrocarbons, nutrients, inorganic chemicals, suspended solids, radioactive substances, thermal waste, petroleum and its derivatives, and other organic chemicals (Anderson and Bissell, 1977). Their list of harmful substances found in the sea is shown in Table 1.2.

The oceans are immense, however. Nearly 71 percent of the earth's surface is covered by oceans. The total volume of the oceans is approximately 3.6×10^{38} gal. The amount of waste material entering the oceans each year is only a miniscule fraction of this amount. For example, it is estimated that the total amount of petroleum hydrocarbon input to the oceans is on the order of 1.8×10^{8} gal/year. This is an enormous volume of oil, but it is infinitesimally small in comparison with the volume of dilution water available in the oceans. Another example is mercury, the cause of the dreaded Minamata disease. An estimated 5000 tons of this highly dangerous material is discharged annually into the oceans. However, spread over the whole ocean this represents a concentration of only 3×10^{-23} mg/L.

With this large a sink for waste dilution, need we be concerned? The answer in many cases is yes. One needs only to look around at the current state of the oceans to see why (Fig. 1.1). In the United States 3 percent of all coastal and estuarine beaches were closed in 1974 because of gross pollution

Table 1.2 Harmful substances found in the sea*

Acetone	Herbicides
Acids and alkalies	Lead
Acrylonitrite	Mercurial compounds
Arsenic	Mercury
Benzene	Military wastes
Cadmium	Naphthentic acid
Carbonate compounds	Nutrients and ammonia
Carbon disulfide	Oil
Chlorobenzene	Organophosphorus compounds
Chloroform	Phenol
Chromium	Phthalate esters
Cresol	Polychlorinated biphenyl compounds
Crotonaldehyde	Pulp and paper wastes
Cumene	Radioactive materials
Cyanide	Solid objects
Detergents	Styrene monomers
o-Dichlorobenzene	Sulfite
p-Dichlorobenzene	Titanium dioxide wastes
Domestic sewage	Toluene
Dredging spoils and inert wastes	Toluene diisocyanate
Epichlorohydrin	Trichlorobenzene
Ethyl alcohol	Vinyl acetate
Ethyl benzene	Vinyl chloride
Ethylene chloride	Xylene
Halogenated hydrocarbons	Zinc
Heat	

**Source:* Anderson and Bissell, 1977.

(Tihansky, 1974). More than 360 mi² of New England coastal waters were closed to shellfishing because of exceedingly high coliform counts in the shellfish (Berg, 1975). Much of the Mediterranean Sea is very sick; beaches are contaminated with sewage and other filth, and fish productivity has dropped to almost zero. Outbreaks of "red tide," the discoloration of seawater produced by large numbers of dinoflagellates which synthesize a toxin that may accumulate in shellfish tissue, are now common all along the Atlantic coast. The cause of this increased incidence of red tide is unknown, but it may be due to increased concentrations of nutrients in coastal waters. Much of the seabed of the New York Bight is considered to be dead because of sludge and dredge spoils dumped into these waters. Large outbreaks of poisonings have occurred in Japan and elsewhere that have been due to consumption of fish and shellfish contaminated with heavy metals. The effects of oil spills are all too obvious to everyone.

The greatest impact of ocean pollution can be seen along the coasts where waste inputs are generally made, but effects are not confined to the coasts. The oceans are very dynamic, and wastes deposited at one point can quickly spread to other locations. The result is a slow, but steady, general increase in contaminant concentrations in the oceans. Elevated levels of heavy metals, such as

Figure 1.1 A plume developing from wastewater discharged into the ocean.

mercury, and of pesticides, such as DDT, have often been found in fish and other marine organisms swimming in deep waters far out at sea.

The United Nations has defined ocean pollution as follows: "Pollution means the introduction by man, directly or indirectly, of substances or energy into the marine environment resulting in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities including fishing, impairment of quality for use of sea water and reduction of amenities." Using this definition we can quite reasonably state that the oceans are indeed becoming polluted, although the degree of pollution is highly variable from place to place.

WHY IS THE OCEAN POLLUTED?

The oceans are immense and theoretically capable of diluting all waste inputs to undetectable levels. However, these waste loads are not uniformly spread over the oceans. Rather, they are almost invariably concentrated along our fragile coastlines, where the potential for damage is the greatest. Considerable damage can be done before oceanic influences can have an effect on these pollutants. A major share of the world's marine fisheries is obtained from coastal waters, and estuaries are essential as breeding grounds for many marine species. The sea now provides half or more of the animal protein consumed by over 2 billion people worldwide (Ketchum, 1971). The concentrated wastes found at a marine disposal point can have a serious impact on these essential resources.

SHOULD ALL MARINE WASTE DISPOSAL STOP?

Given that ocean pollution is occurring and is probably on the increase around the world, should we attempt to prohibit *all* ocean dumping of waste materials? The answer to this question is an emphatic no.

The sea has a great capacity to assimilate and purify waste materials with little or no damage. Biodegradable organic compounds are fairly rapidly decomposed by marine organisms. Indeed, these organic materials, and the nutrients which normally accompany them, are often beneficial, since they serve as a food source for marine organisms and thus increase their productivity. Metals often precipitate to the bottom, where they are incorporated into the sediment, in most cases effectively removing them from any future ecological influence unless disturbed. The oceans *are* vast, and proper waste disposal can result in tremendous dilution and dispersion.

The ability of the seas to accept and purify wastes is a great natural resource which should not be overlooked. It must not be abused either, however. For example, properly done, burial in the ocean may be one of the most promising solutions to the problem of disposal of nuclear waste materials. Improperly done, the resulting damage could be catastrophic and possibly permanent. This is also true for disposal of many other waste materials.

Thus, the oceans can provide a convenient, useful, and, if done properly, ecologically safe location for the disposal of many of our wastes. The challenge we face is to stay within the bounds of the ocean's ability to cleanse itself.

It is the responsibility of the environmental engineer working in the marine environment to assess the cleansing capacity of the sea at a particular site and to ensure that this capacity is not overtaxed. This will require a thorough knowledge of oceanography, as well as of the types of pollutants expected to be encountered, their effects on the marine environment, and methods for their control. Of utmost importance is a knowledge of the fate of any contaminants placed in the sea. Movement of marine waters is extremely complex and highly variable from one location to another. Within these moving waters, the pollutants are continually subjected to physical, chemical, and biological changes, all of which can have an impact on their eventual fate. The only way to assess all these complex impacts adequately is to make a mathematical model of the system. Consequently, the marine environmental engineer must be familiar with modeling techniques.

Unfortunately, or perhaps fortunately, depending on your point of view, decisions concerning marine waste disposal cannot be made purely on a scientific basis. Social, political, economic, and legal implications must also be considered. It is crucial that the environmental engineer working in the marine environment have an intimate knowledge of the law of the sea, a complex and rapidly changing field.

THE MARINE ENVIRONMENT

We must not be concerned only with the impact of waste disposal in the open ocean. In fact, most of the damage done occurs within a few miles of shore, principally within estuarine waters. Consequently, this book is concerned with waste disposal in all marine waters—whether it be an estuary, bay, harbor, coastline, sea, or open ocean.

CHAPTER
TWO

PRINCIPLES OF OCEANOGRAPHY

INTRODUCTION

The vast majority of the earth is covered with water. The world's oceans cover over 70 percent of the earth's surface, averaging 12,200 ft in depth. By contrast, the average height of land on earth above mean sea level is only 2760 ft, so the oceans are much deeper than the land is high. The ocean floors are also much more irregular than the topography of land, with numerous large mountains and deep trenches. Because of the immensity of the oceans, their inhospitable environments, and their large variability from place to place, it is said that there is more known about the surface of the moon than about the topography of the seas.

This chapter will present the essential highlights of oceanography, the science of the oceans, with particular reference to knowledge needed by environmental engineers working in the marine environment. The subjects of physical oceanography, geological oceanography, chemical oceanography, and biological oceanography will be covered separately. This separation is really artificial, however, as all of these are interrelated. These interrelations will be pointed out as we go along.

GENERAL CHARACTERISTICS OF THE OCEANS

Ocean basins and continents are unevenly distributed over the earth's surface (Fig. 2.1). Although all the major bodies of water on earth are interconnected into what is really one large ocean, they are usually divided into five oceans: Atlantic, Pacific, Indian, Arctic, and Antarctic. Many oceanographers dis-

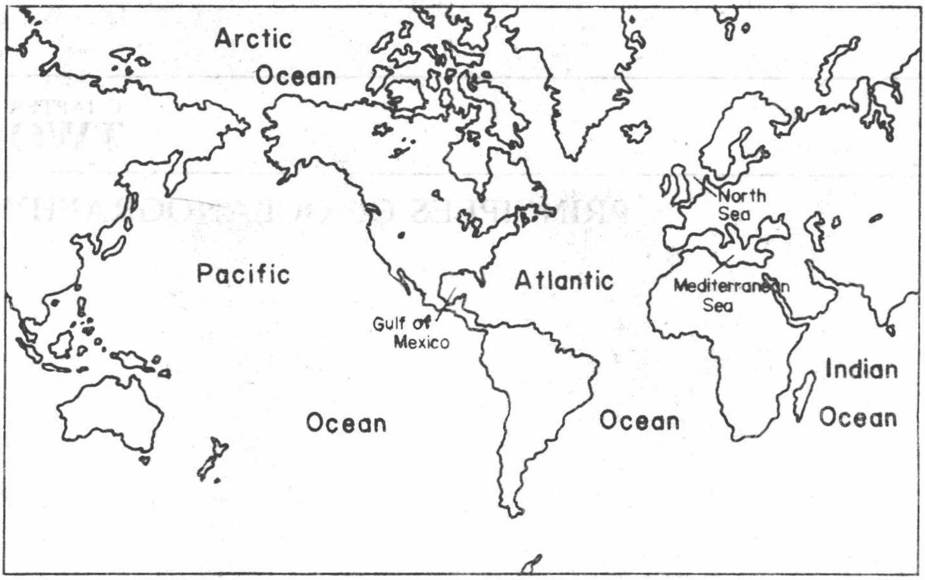

Figure 2.1 Major oceans and seas of the world.

agree, though, and prefer to consider that there are only three or four oceans: Atlantic (including the Arctic Sea), Pacific, and Indian.

The Pacific Ocean is the largest and deepest and covers one-third of the earth. The Atlantic is a relatively narrow ocean. Several large but shallow seas, including the Mediterranean, Baltic, and Caribbean seas and the Gulf of Mexico, are generally considered part of the Atlantic Ocean. Most of the earth's surface is located in the northern hemisphere (67 percent), while the southern hemisphere is mostly water (about 80 percent). Table 2.1 presents physical data on the oceans of the world.

Table 2.1 Areas, volumes, and depths of oceans

	Area		Volume		Mean depth	
Ocean	$10^6 km^2$	$10^6 mi^2$	$10^6 km^3$	$10^6 mi^3$	km	mi
Pacific	181	70	714	172	3.94	2.45
Atlantic	94	36	337	81	3.58	2.22
Indian	74	29	285	69	3.84	2.39
Arctic	12	5	14	3	1.12	0.70
Total, or mean, depth	362	140	1350	325	3.73	2.32

Source: Menard and Smith, 1966.