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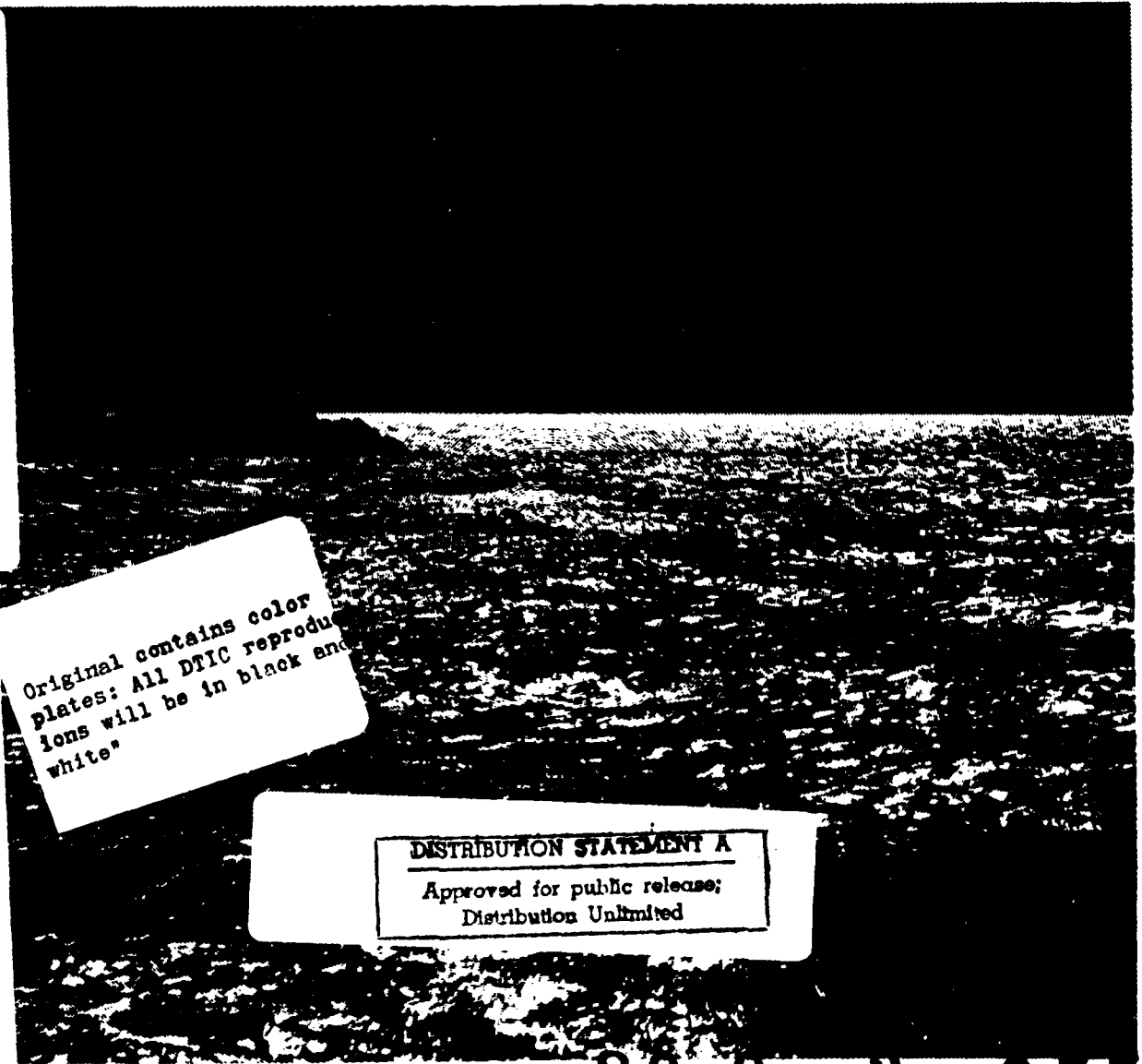
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VOLUME I

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A Joint Investigation
by the
State of Maryland
Department of Natural Resources,
and
Westinghouse Electric Corporation

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FEB 2 1981

10 William D. Clarke
Chief Scientist and Editor

Lawrence C. Murdock
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PREFACE

The Chester River Study was carried out successfully because of the efforts of the many people working on the project. The State of Maryland Department of Natural Resources portion of the program effort was under the direction of Mr. Lee E. Zeni with assistance from Mr. Frank L. Hamons. The Westinghouse Electric Corporation portion of the program was under the direction of Dr. John C. R. Kelly, Jr. Scientific direction and overall planning were the responsibility of Dr. William D. Clarke, while program management was handled by Mr. Larry C. Murdock. The geological, trace metal, hydrological and meteorological investigations were headed by Dr. Harold D. Palmer, Manager, Aquatic Physical Sciences and he was assisted in these efforts by Dr. Kent T.S. Tzou, Mr. Richard W. Onstenk, Mr. James J. Gugliotti, Ms. Donna M. Dorwart and Mr. Rudy Polak. The biological, chemical and laboratory toxicity investigations were headed by Dr. Thomas O. Munson, Manager, Aquatic Biological Sciences and he was assisted in these efforts by Mr. Joseph M. Forns, Mr. Sidney D. Stillwaugh, Mr. Jerry D. Tasler, Mr. Grey L. Lyons, Ms. Mary J. Saib and Ms. Bethany G. Johnson. Field operations and engineering support were headed by Mr. Al G. Haury, Manager, Aquatic Systems and Operations and he was assisted in these efforts by Mr. Al A. Wyborny, Mr. Charles A. Thurfield, Mr. Olav B. Rasmussen, Mr. John D. McMaster, Mr. Sherman R. Watts, and Mr. Samuel F. Stearns. Considerable assistance was also given during the course of study by Mr. Ranford M. Sapp of the Westinghouse Oceanic Division.

Special thanks go to Ms. Suzanne Stansbury and Ms. Diane E. Koontz for typing the many drafts and final manuscript of this report. Drafting, art work and photographs were prepared by Mr. Skip Nusbaum.

Capt. William M. Nicholson, Mr. Maurice E. Ringenbach and Mr. Anthony J. Goodheart of the National Ocean Survey of the National Oceanographic and Atmospheric Administration (NOAA)

installed and maintained ODESSA environmental monitoring systems for the study of the river. Their participation and assistance during the course of the Chester River Study are gratefully acknowledged.

Cdr. Lawrence Swanson, Mr. Saul C. Berkman, Mr. Donald Dinardi, Mr. Robert Dennis and Mr. Charles B. Taylor also of the National Ocean Survey are thanked for supplying tidal data for the Chester River.

Mr. W. Joseph Moyer, NOAA Climatologist for the states of Maryland and Delaware, supplied climatological summaries for Centreville, Chestertown, Eastern Neck Island, Millington and Rock Hall during the course of the study and in addition provided meteorological information on tropical storm "Agnes".

Mr. Philip Prannebecker, Mr. Wayne B. Solley, Mr. Wayne E. Webb, and Mr. Kenneth R. Taylor of the Water Resources Division of the U.S. Geological Survey furnished stream flow data for the river basin.

Dr. James P. Owens and Dr. Karl Stefansson of the U.S. Geological Survey at Beltsville, Maryland kindly performed clay analyses of sediment samples collected during the study.

Dr. Donald Lear and his staff at the Environmental Protection Agency Field Office at Parole, Maryland are thanked for their help on the program.

The members of the Steering Committee, Dr. Robert Altman, Dr. L. Eugene Cronin, Dr. John C. Geyer, Dr. Donald Pritchard and Dr. Lawrence Jensen are gratefully acknowledged for their guidance and constructive criticism during the course of the study.

Many others who assisted us in this study are cited in the appropriate sections of Volume II.

CONTENTS

1. Findings in Brief and Recommendations	1	3. Chlorinated Hydrocarbons	10
1.1 Pollutants Examined are not at Hazardous Levels	1	3.1 Distribution of Chlorinated Hydrocarbons	12
1.2 Pollutants Examined do Affect Shellfish Stocks	1	3.2 Laboratory Toxicity Studies	17
1.3 Pollutants Examined Enter River from Bay	1		
1.4 Pollutants Examined are Carried Primarily on Fine Sediments	1	4. Trace Metals	22
1.5 Shore Erosion is Serious and Protective Methods Largely Inadequate	2		
1.6 Recommendations	2	5. Shore Erosion	25
2. Introduction	4		
2.1 Reasons for Study	4	Appendix	31
2.2 Selection of Study Area	6		
2.3 Description of Study Area	8	Glossary	37
2.4 Study Approach and Methods	8		
2.5 Report Organization	9		

1. FINDINGS IN BRIEF AND RECOMMENDATIONS

1.1 Pollutants Examined are not at Hazardous Levels

• Shellfish and finfish from the Chester River are presently safe for human consumption with respect to concentrations of hard chlorinated hydrocarbon type insecticides and polychlorinated biphenyls (PCB's)¹.

• The insecticides, DDT, DDD, DDE, chlordane, and PCB's (primarily Aroclor 1242) were found routinely in biological samples and sediment samples from the Chester River, but at levels far below those considered hazardous to humans.

• Other agriculturally used insecticides such as lindane, aldrin, dieldrin, endrin, and toxaphene were not found routinely in samples.

• The U.S. Food and Drug Administration, partly as a direct result of this study, has re-examined its stringent environmental standard for chlordane levels in shellfish, suggesting an interim standard more in line with other existing standards and thereby removing the threat of closure of the shellfisheries in Chesapeake Bay.

1.2 Pollutants Examined do Affect Shellfish Stocks

• The ultimate body tissue concentration of the insecticide chlordane varies from one species of shellfish to the next, oysters concentrating this compound at levels roughly five times higher than soft-shelled clams when exposed to the same environmental levels.

• Soft-shelled clams are more adversely affected than oysters by the same chlordane exposure level.

• Low concentrations of chlordane (parts per trillion) affect the shell structure of oysters, modifying the crystals of the prismatic layer.

• After high-level exposures of chlordane, soft-shelled clams and oysters will purge themselves of the accumulated chlordane when removed from the high exposure environment.

• Both soft-shelled clams and oysters concentrate relatively more chlordane in their tissues at low environmental exposure levels than at high exposure levels, i.e., the concentration factor is not a constant.

• The discovered variability of the concentration factor is an important parameter in establishing water quality criteria for shellfish stocks.

• It has not been established that present environmental levels are completely harmless to shellfish stocks.

1.3 Pollutants Examined Enter River from Bay

• Most of the measured chlorinated hydrocarbon pollutants are entering the Chester River from the upper Bay rather than from the river drainage area itself.

• The amounts of insecticides and PCB's in sediments and organisms decrease in the upstream direction from the mouth of the river to the farthest upstream sampling station.

• The fine sediments carpeting the bottom of the river are derived in large part from the upper Bay based on mineralogical composition and the presence of a unique clay type not common in the sediments drained by the river.

• The Susquehanna River is the main source of sediments to the upper Bay.

1.4 Pollutants Examined are Carried Primarily on Fine Sediments

• Both trace metals and the insecticides and PCB's are carried on the surfaces of sediments, there being an inverse relationship between the amount of these materials and the mean grain-size of the sediments.

• The finer-sized sediments carry greater amounts of pollutant materials and these sediments are more easily transported by water currents.

• The lower Chester River is a two-layered system much of the year with water flowing downstream in the surface layers and upstream in the bottom layers.

• Fine sediments with their adsorbed chlorinated hydrocarbon pollutants move from the upper Bay into the lower reaches of the river with the bed load and in the water flowing upstream near the bottom.

• Trace metals occur at their highest concentrations near the mouth of the river and in the upper reaches of the tidal portion of the river. (Lack of positive correlations between trace metal distributions and chlorinated hydrocarbons indicate local river sources of trace metals outweigh Bay sources.)

¹ A glossary of terms is provided at the back of this report.

1.5 Shore Erosion is Serious and Protective Methods Largely Inadequate

- Shoreline erosion is extensive in the lower Chester River (82% of the shoreline) and is not caused just by erosion from the water side.
- Significant amounts of shore erosion are caused by water seepage and runoff from the landward side.
- Current shore protection measures are applied haphazardly and even some of the most expensive forms fail because they do not take into consideration all of the erosional processes.

1.6 Recommendations

- Initiate a program to pinpoint and identify the sources of chlorinated hydrocarbons in the upper Bay (particularly the contributions from the Susquehanna River and Baltimore Harbor).
- Initiate action (possibly through representation on the Susquehanna River Basin Commission) to evaluate controls on pollutants such as chlorinated hydrocarbons and monitor levels of these compounds in the Susquehanna watershed.
- Establish more stringent reporting and control methods for all materials containing chlorinated hydrocarbons that are sold or used in the State.
- Continue monitoring of commercially valuable species such as oysters, soft-shelled clams, blue crabs, and finfish to ensure that chlorinated hydrocarbons remain at safe levels.
- Investigate the low-level toxic effects of chlorinated hydrocarbons on oysters and soft-shelled clams to make sure that they are not having a deleterious effect on those resources.
- Further research on the relationship between environmental concentration levels of chlorinated hydrocarbon pollutants and the body accumulation levels in shellfish for the purposes of developing resource management guidelines.
- Test the applicability of the chlorinated hydrocarbon concentration factor for use as a possible direct method of water monitoring to ascertain the accumulation levels of these compounds in shellfish resources.
- Continue efforts with the U.S. Food and Drug Administration to adopt the proposed FDA 300 parts per billion chlordane "alert level" for shellfish.
- Determine more effective methods for reducing or eliminating shoreline erosion.

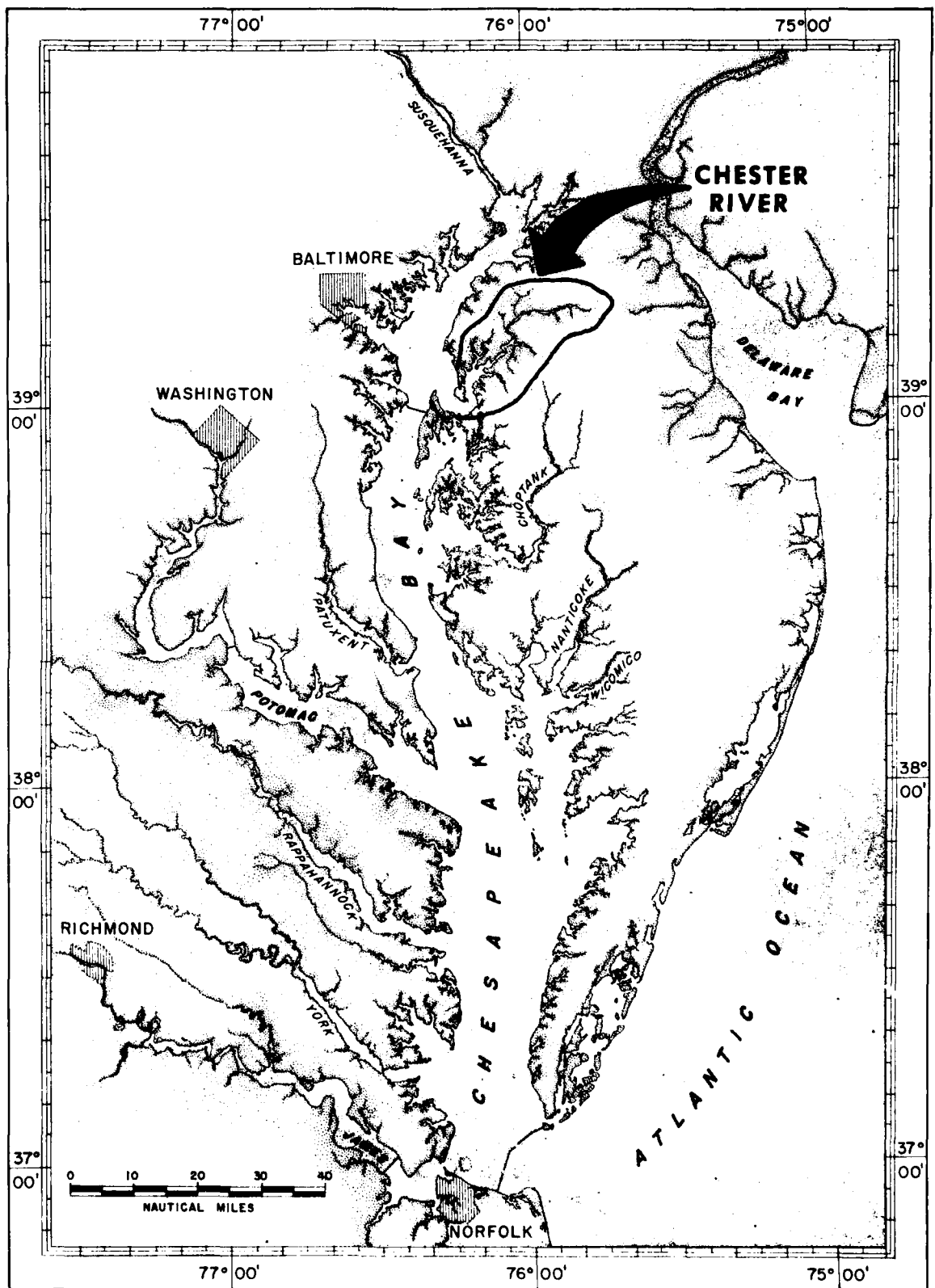


Figure 1 - Chart of Chesapeake Bay region showing the location of the Chester River.

2. INTRODUCTION

2.1 Reasons for Study

The Chester River Study was undertaken to provide the Maryland Department of Natural Resources with environmental and resource management information. As such, it was a joint effort between the Department of Natural Resources and the Westinghouse Electric Corporation with close cooperation of both staffs during the carrying out of the project. The present report covers a year's work (1 November 1971 to 31 October 1972) and presents the findings of the multi-discipline investigations carried out in the Chester River Drainage Basin (Figure 1).

Several environmental issues and resource management problems were the focus of the study. One environmental concern was a class of chemical compounds called chlorinated hydrocarbons. These compounds consist of the hard pesticides such as DDT and chlordane, and the polychlorinated biphenyls (PCB's) widely used in industrial applications. A recent example of the effects of these toxic materials on biological organisms has been the reproductive

failure of the California Brown Pelican. These compounds accumulate in greater amounts in the tissues of animals at the top of the food chain (i.e., animals which feed on other animals). In the case of the pelican, the accumulation of chlorinated hydrocarbons affects the mating behavior of the adults so that in many instances they fail to carry out fertilization successfully. The calcium metabolism of the birds is also upset so that eggs with thinner shells are produced and hence there is a higher incidence of egg breakage in the nest. Moreover, the yolk of the egg which forms the food supply for the embryo accumulates these materials and impairs the viability of the developing bird embryo. The adverse effects of chlorinated hydrocarbons on pelicans are summarized in Figure 2. Raptorial birds such as hawks and eagles have shown similar reproductive failures in many parts of North America, again related to the accumulation of chlorinated hydrocarbons.

Of more immediate concern to the present study, have been the massive mortalities of soft-shelled clams (*Mya arenaria*) in recent years in Chesapeake Bay (Figure 3). State biologists have been perplexed by these as yet unexplained die-offs since most of the environmental parameters measured at

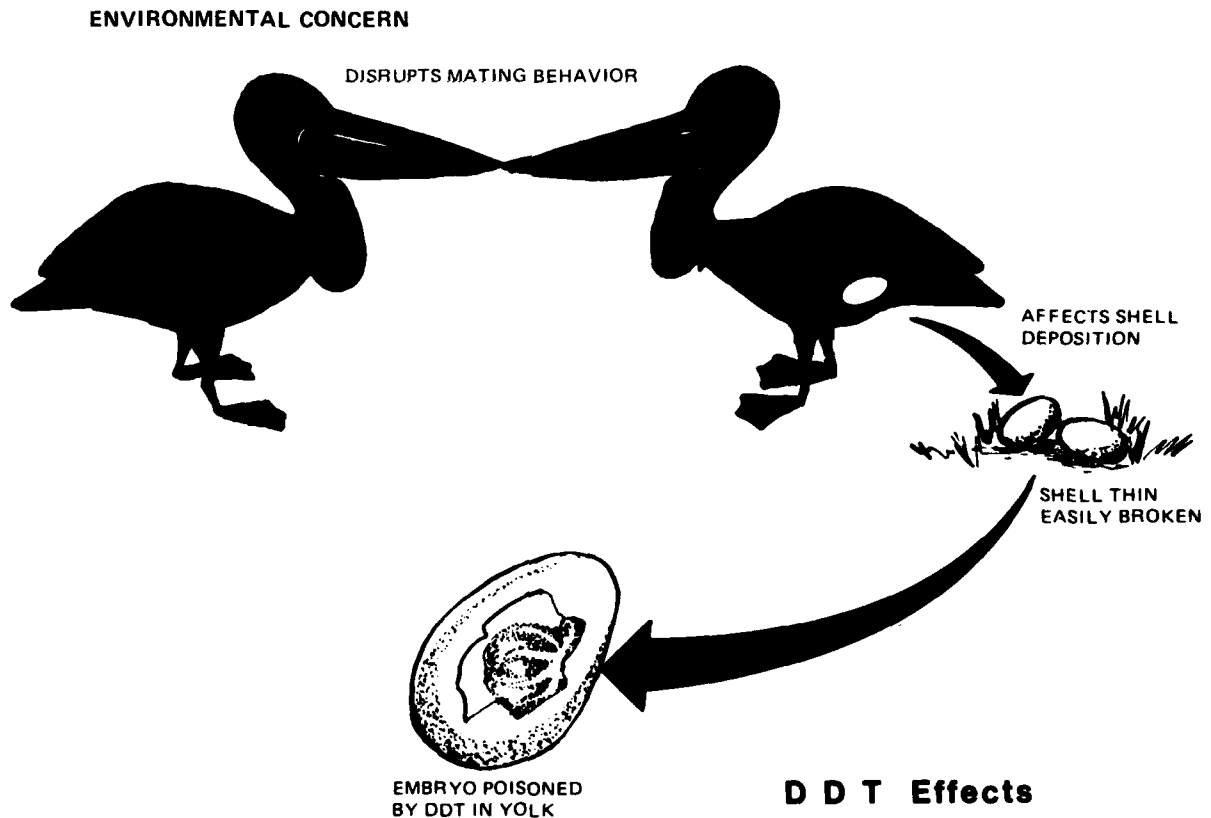


Figure 2 -- Effects of DDT accumulation on the California Brown Pelican.

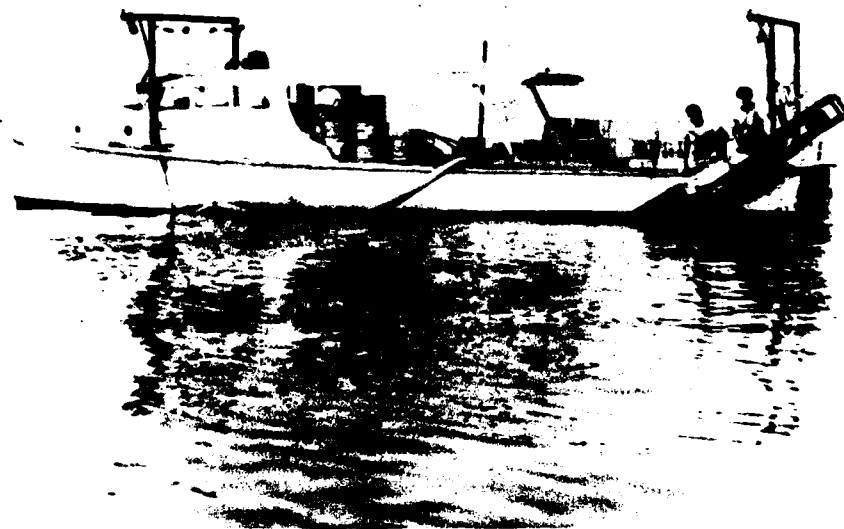


Figure 3 "Clammer boat" recovering soft-shelled clams with a hydraulic dredge. Soft-shelled clams, prior to their destruction by tropical storm "Agnes", were a major fishery in the Chester River.

the time of the mortalities seemed to be within the tolerance levels of the soft-shelled clam. Chlorinated hydrocarbons have been one of the environmentally present materials suspected to be possibly involved in these mortalities. Consequently, much of the research for the Chester River Study was oriented towards determining the levels of chlorinated hydrocarbons in the physical environment and biota as well as conducting controlled laboratory experiments on the uptake rates and effects of these compounds on soft-shelled clams and oysters. Another important aspect of the study of chlorinated hydrocarbons has been to identify the transport mechanisms of these pollutants in the aquatic environment, their paths through the environment, and their possible areas of origin. If the levels of these materials are to be controlled in the environment for resource management purposes or simply for conservation of the environment, the sources must ultimately be identified and regulated.

Trace metals were another area of concern since these materials in sufficient quantity can be deleterious to the environment and its living resources. Some of these metals in recent years have reached levels high enough to make food stocks unfit for

human consumption or have adversely affected the contaminated stocks themselves. Fortunately, findings for the Chester River have shown that most of these materials are at safe levels at the present time. The interaction of two classes of pollutants such as the trace metals and chlorinated hydrocarbons is important in the management of living resources since there may be synergistic effects and the two acting together may be more harmful even at lower concentrations. Considerable research needs to be done in this area, particularly in the form of carefully controlled laboratory experiments.

The findings from the Chester River Study indicate that trace metals move through the river environment by a different path than the chlorinated hydrocarbons even though the basic transport mechanism (carried on fine sediments) is the same. This difference in paths indicates that some sources of trace metals lie within the river drainage itself rather than primarily external to it as is the case with chlorinated hydrocarbons. The different riverine distributions of the two classes of pollutants points up the importance of identifying source areas of pollutant introduction when attempting to manage an environment containing valuable living resources.



Figure 4 Side-looking radar imagery of the Chester River drainage. This technique permits much sharper delineation of waterways and tributaries than conventional aerial photography.

Shoreline erosion was another important environmental concern of the study both from the point of view of protecting valuable agricultural and residential land from losses, and in understanding changes in conditions on the submerged river terraces extending out from the shoreline. These submerged terraces are the major harvesting areas for commercially valuable shellfish. The shoreline erosional processes vary from one point in the river to another and unfortunately, most shore protection has been applied in a haphazard way without due consideration to the processes at work at a given site or local. Too often, only the waterside erosional processes are considered. Landside water seepage and runoff along banks are critical erosional aspects to be considered in most shoreline protection situations, but they are rarely if ever taken into account even in the most expensive shore protection structures.

2.2 Selection of Study Area

The Chester River (Figure 4) was chosen because it was typical of Eastern Shore river drainages. The geological and physiographic unity of the Eastern Shore makes selection of one river unit valid for studying major environmental processes that are going on in the region as a whole. This regional unity is also reflected in the like composition of the flora and fauna of the Eastern Shore rivers. The selection of a single river drainage also permitted a more detailed study with the available personnel and research facilities than would otherwise have been possible for a larger area. The Chester River, therefore, represented the smallest meaningful element of the larger Chesapeake Bay environmental system that could be investigated and still produce results applicable to the Eastern Shore as a whole. Thus, sampling and measurement methods evolved during the study as well as transport mechanisms and environmental processes identified would be meaningful in application or investigations of other tributary river units such as the Wye and Miles Rivers feeding Eastern Bay, the Choptank and the Nanticoke.

The Chester River was also chosen on the basis of other criteria. Most of the river drainage lies within the State of Maryland. It has extensive, commercially valuable fisheries; oysters, soft-shelled clams, blue crabs, and finfish. The watershed of the river is used primarily for agricultural purposes although extensive tracts have reverted to second growth woodlands (Figure 5). There has been little in the way of urbanization or industrialization and because of the basically agrarian economy of the area, it was considered to be representative of a minimally perturbed environment as far as land modification and the presence of non-agricultural type pollutants.

Initially, it was assumed that environmental conditions in the river would reflect the situation for materials applied or discharged in the river drainage basin and thus give a measure of the effects of agri-



Figure 5 High-altitude aerial photograph of the lower Chester River showing the extensive use of land for agriculture.

cultural activities on the aquatic system. This initial assumption, however, proved not to be the case and it was found that much of the lower Chester River system was strongly affected by conditions in the upper Bay. The multi-discipline approach used in the study was primarily responsible for deducing the complex relationships of the river to its drainage basin on the one hand, and to the upper Bay on the other hand.

2.3 Description of Study Area

The Chester River discharges into Chesapeake Bay between Eastern Neck and the north end of Kent Island (Love Point) just above the bay bridges. The river has a meandering course and is quite broad in its lower reaches. It drains an area of approximately 440 square miles (1,140 square kilometers) in the northern portion of the Delmarva Peninsula. The river basin includes the major parts of Kent and Queen Anne's Counties in Maryland as well as a small portion of Kent County in Delaware. The river, moreover, forms the political boundary between Kent and Queen Anne's Counties in Maryland, the former lying north of the river, the latter lying south of the river.

The main river channel averages well over 20 feet (6 meters) in depth in its lower reaches. The bottom, however, is not uniform in depth and consists of a series of basin-like depressions which lie along the river channel and are separated by shallower areas 20 to 40 feet (6 to 12 meters) deep. Several of these depressions are in excess of 50 feet (15 meters) deep and three exceed 60 feet (18 meters) in depth. The major underwater topographic features of the lower Chester River are shown in the bathometric chart appearing on the inside front cover. The main channel is quite narrow compared to the total width of the river in these regions, being bordered by broad submerged terraces which support the principal shellfisheries of the area.

The Chester River is navigable by small, shallow-draft vessels to Millington approximately 42 miles (64 kilometers) upstream from the river mouth, but the 13-foot (4 meters) shipping channel extends only to Chestertown, a distance of 33 miles (53 kilometers). River flow averages about 300 cubic feet per second. In the river's lower reaches, current flow is strongly influenced by tidal action from the Bay. Although the length of the main river course is 51 miles (81 kilometers), tidal influence extends 42 miles (64 kilometers) upstream from the mouth.

The drainage basin of the Chester River is typical of the Mid-Atlantic Coastal Plain. The terrain is flat to gently rolling. In its upper reaches, the river crosses Wicomico Plain, an area of rolling hills which reach maximum elevations of 90 to 100 feet (27 to 30 meters). The lower reaches of the river cut through Talbot Plain which is flatter country compared with the former. Elevations range from sea level to about 60 feet (18 meters) and in a few places, exceed 80

feet (24 meters). The soils of the basin area are suitable for cultivating a wide variety of agricultural crops and much of the land is under active cultivation. Bluffs are common along the lower river course and shore erosion is extensive. There are also broad stretches of wetlands, totaling about 8,300 acres for the river drainage.

The populations of Kent and Queen Anne's Counties are 16,146 and 18,422 (1970 census) and are projected to be 28,000 and 24,000 respectively by the year 2000. The two largest towns had 1970 populations of 3,476 for Chestertown in Kent County and 1,853 for Centreville in Queen Anne's County. Urbanization will probably be one of the major changes in land use as the area develops.

At present, the Eastern Shore area is not easily accessible due to the limited rail, highway, water, and air transportation routes serving the area. As a consequence, the major economic activities of the area center on agriculture, forestry, and fisheries. In both counties, food processing is the predominant industry, although the manufacture of construction materials, wood products, chemicals and textiles is also significant. Fishery products from the area are chiefly oysters, soft-shelled clams, blue crabs, striped bass, perch, and other finfish. Agricultural products include corn, wheat, other grains, soybeans, hay, vegetables, and potatoes.

Although none of the environmental problems in the Chester River appear to be overly serious at present, the projected trends in the future development of the area give reason for concern. If the river's water quality is to be maintained, the impact of changing land uses and urban development must be carefully evaluated. The opening of the second span of the Bay Bridge and its anticipated effect on population growth will in turn modify the physical and biological characteristics of the river system. Changes in the aquatic environment will result from the construction of additional housing, roadways, marinas, shore protection structures, recreational facilities, fossil-fuel or nuclear power generation plants, and the attendant facilities to support population growth such as sewage disposal plants, light industry and transportation. Even though the Chester River Study was undertaken to assess the seriousness of present day environmental problems, its findings will also provide the base-line data against which to measure future changes in the river system. Moreover, the fundamental knowledge acquired of the Chester River should provide the basis for testing the effectiveness of living resource management techniques within its confines.

2.4 Study Approach and Methods

A multi-discipline approach was taken in the present study since environmental problems are not limited to one discipline. Studying the biological effects of pollutants on the fauna of a river system

will not give answers concerning the distributive mechanisms of the pollutants or their paths through the aquatic environment. During the course of the study, it was found that meteorological conditions can strongly affect the hydrological regime, drastically changing or modifying current patterns and tidal excursions in the river. The prevailing currents at a given locale determine the sediment regime and in turn the bottom conditions found in a given portion of the river. Moreover, the characteristics of the bottom sediments will to a greater or lesser degree dictate the organisms or communities that can exist there. Thus, the strong interdependence of environmental processes and the biological entities present, points up the necessity for carrying on investigations in several disciplines in order to gain a meaningful understanding of environmental problems.

Five major discipline areas were addressed during the study, but these discipline-oriented activities were integrated with respect to field measurements and collections as well as interpretive results from field and laboratory investigations. The five disciplines were chemistry (including biochemistry), biology, geology, meteorology, and hydrology. The field investigations were coordinated to gain an understanding of the environmental problems and resource management issues relating to chlorinated hydrocarbons, trace metals, and shoreline erosion. The matrix created by this multi-discipline approach is presented in Table I.

2.5 Report Organization

Table I also shows the organization of the Chester River Report. There are three volumes reporting various aspects of the study. Volume I is intended as an overview of the entire study, presenting in a condensed form the scope and major findings of the study. There is a minimum of analyzed data given and detailed discussions of methods are postponed to a

subsequent volume. Volume II contains the discipline-oriented reports upon which the contents of Volume I were based. Each report goes into far greater detail for the particular discipline investigated than the text in Volume I and it also supplies the necessary substantiating data for the conclusions reached during the study.

Volume II is organized into eight sections. Section 1 gives a description of the Chester River region for the reader's orientation so that he will have some perspective as to the relationship of the river drainage to Chesapeake Bay proper and other river drainages. Such matters as the local geography, climate, demography and economics are discussed in this section.

Section 2 covers the investigations of pesticides and PCB's carried out during the study, including both the field investigations and laboratory toxicity studies as well as discussions of the analytical techniques used for quantification of these pollutants. Section 3 takes up the trace metals investigated during the Chester River Study while Section 4 discusses the biological investigations. Section 5 covers the geological investigations, describing the regional geology and field findings as well as the sample collection and laboratory techniques used to obtain geological data. Section 6 presents the findings of the meteorological and hydrological investigations carried out during the study. Section 7 covers the data management techniques while Section 8 discusses instrumentation and equipment.

Volume III contains the serial and analyzed data for the discipline-oriented reports. Much of this material is too voluminous to be contained in the text of Volume II and so it is arranged by discipline in Volume III to serve as reference material for the reader requiring more detailed information on a particular aspect of the Chester River Study.

TABLE I - ORGANIZATIONAL MATRIX OF THE CHESTER RIVER STUDY

		Disciplines Volumes II & III				
		Chemistry	Biology	Geology	Meteorology	Hydrology
Environmental problems and resource management issues Volume I	Chlorinated Hydrocarbons	X	X	X		X
	Trace Metals	X	X	X		X
	Shoreline Erosion			X	X	X

3. CHLORINATED HYDROCARBONS

Chlorinated hydrocarbons are a class of chemical compounds used in many insecticides. Polychlorinated biphenyls (PCB's) are a special subclass of these chlorinated hydrocarbon compounds, used in large quantities in a variety of industrial products, such as plastics, as an insulating component in electrical transformer oils, as a flow improving agent in paints, and in dry reproducing papers such as computer printout paper. A recent voluntary action taken by the major U.S. manufacturer of PCB's may limit the uses of PCB's in the future to sealed systems.

Chlorinated hydrocarbons, when discharged to the environment, are known to be quite persistent, some lasting more than ten years before substantial chemical disintegration occurs. Moreover, because of their very low water solubility, these compounds adsorb readily on fine particulate matter suspended in the water, such as silts and clays; and they tend to concentrate in the fatty tissues of organisms at higher trophic levels in the food web, such as fish, predatory birds, and man. In some birds, behavioral abnormalities and deleterious effects including reproductive failure have been observed, which have been attributed to high concentrations of chlorinated hydrocarbons taken up from the environment through the food chain.

The waters of the Chesapeake Bay and its tributaries receive chlorinated hydrocarbons as a result of industrial, agricultural, and waste disposal activities occurring along the shorelines of these waterways and within the total watershed. The accumulation and passage of these materials through the aquatic environment are of great concern, since the Bay also supports a shellfish fishery valued at approximately \$60 million per year. If the shellfish stocks were to acquire a buildup of these harmful chemicals, it could pose a potential danger to both human health and the resource itself. Moreover, closure of the fishery because of unfitness for human consumption would have major economic effects. For these resource management reasons, the levels, accumulation and movements of chlorinated hydrocarbons through the aquatic environment are extremely important.

During the study, samples of the sediments and organisms from the Chester River were collected on a quarterly basis and analyzed for chlorinated hydrocarbon residues using electron-capture gas-liquid chromatography (Figure 6). However, because of the limitations inherent in the gas chromatographic technique, identifications in some cases had to be confirmed using thin-layer chromatography or mass spectrometry. The sample preparation and analytical methods used will detect the following chlorinated pesticides: chlordane, aldrin, dieldrin, endrin, DDT, DDE, DDD, and toxaphene, as well as polychlorinated biphenyls (PCB's) at the parts per billion level. These com-

pounds are generally considered the most significant of currently used pesticides and industrially used chlorinated hydrocarbons from the point of view of human health considerations and living resource management.

Three kinds of chlorinated hydrocarbons were found regularly in the sediments and biota of the Chester River; PCB's (almost exclusively Aroclor 1242), the pesticide DDT (and its breakdown derivatives DDE and DDD), and the pesticide chlordane. Table II shows the average values found for these compounds and their ranges of variability. These composite values are derived from all the data collected during the study and as such include the variability

TABLE II - LEVELS (PARTS PER BILLION) OF PCB's AND CHLORINATED PESTICIDES FOUND IN THE BIOTA AND SEDIMENTS OF THE CHESTER RIVER

SAMPLE	PCB's		DDT (Total)		Chlordane	
	Average	Range	Average	Range	Average	Range
Oysters	55	16-250	43	0-150	36	9-160
Soft-Shell Clams	58	13-180	21	4.1-130	14	0-38
Fish	185	2-570	134	50-260	74	34-180
Crabs	20	.4-51	33	18-28	14	3-24
Sediments	87	0-310	16	0-63	5.2	.2-14

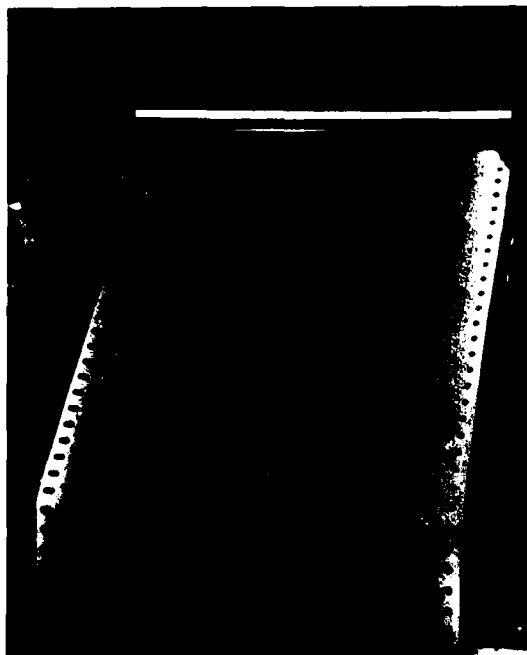


Figure 6 - Gas chromatograph record showing peaks for several chlorinated hydrocarbon compounds in the sample being analyzed.

due to seasonal fluctuations, distributional differences resulting from sample location, and species as well as individual uptake differences. Nevertheless, the table is useful in giving an overall view of chlorinated hydrocarbon levels in the biota and sediments of the river system.

Edible meats and other consumable body tissues are considered unfit for human consumption on a regular basis if the DDT or PCB concentrations exceed 5000 ppb (parts per billion) by wet weight. The DDT and PCB levels found in Chester River organisms clearly fall well below that level. The highest PCB value (570 ppb in fish) was about one tenth of the established 5000 ppb level while the highest DDT value (260 ppb in fish) was about one twentieth of that amount.

A similar standard or limit for the pesticide chlordane has not been established with respect to edible meats because chlordane contamination has not been found to be a widespread problem. However, an "alert level" for chlordane was provided by the U.S. Food and Drug Administration, so that should contamination become prevalent, safeguard action could be taken.

In the period immediately prior to the start of the Chester River Study, there was some concern that the Bay shellfish were in fact becoming contaminated with chlordane or some chemically similar compound. High levels of a material that appeared to be chlordane began to show up with some regularity in soft-shelled clams and oysters taken during State shellfish monitoring programs. These levels, moreover, were in excess of the U.S. Food and Drug Administration's established "alert level" of 30 parts per billion, but it was not entirely certain whether the material detected was in fact chlordane or some unknown substance.

In addition to the ambiguity of identification, there was a definite uncertainty as to whether this "alert level" had any real basis as far as representing a level of contamination dangerous to human health. If the material was indeed chlordane, and exceeded the "alert level" established to safeguard human health, it might be necessary to terminate all harvesting of soft-shelled clams and oysters in Maryland, therefore, curtailing a shellfish industry valued at \$60 million a year.

To clarify these matters, it is necessary to review the events leading up to this situation. In 1968, as part of the National Shellfish Sanitation Program, a workshop (hosted by the U.S. Food and Drug Administration) was held with representatives of the State Public Health Departments of all states shipping and receiving shellfish. The purpose of the meeting was to establish uniform quality standards for marketable shellfish products. In the report for this meeting, ("Proceedings of the 6th National Shellfish Sanitation Workshop, February 7-9, 1968") under the section, Interim Guidelines for Pesticides in Shellfish, the

statement was made that State Shellfish Control Agencies should "take suitable administrative action to close shellfish areas to harvesting if pesticide levels consistently exceed those in the following table." The "alert level" guideline for chlordane was 30 ppb. At the time the level was established, there was no evidence of a chlordane problem in Chesapeake Bay.

When field evidence began to indicate chlordane contamination exceeding 30 ppb in the Bay, inquiries by personnel of the Maryland Department of Natural Resources to the U.S. Food and Drug Administration revealed that no one could determine why the level had been set so low (the "alert level" for fresh vegetables is 300 ppb of chlordane) or whether the intention had been to make 30 ppb an enforceable closure level for the shellfisheries in Chesapeake Bay.

The early findings of the Chester River Study provided several pieces of information which proved instrumental in clarifying the chlordane "alert level" problem. Extensive analytical work in the Westinghouse Ocean Research Laboratory showed that chlordane residues were indeed present in shellfish populations and in some instances exceeded the established "alert level". Moreover, the carefully obtained laboratory findings indicated that the method of analysis recommended by the Food and Drug Administration Pesticide Analytical Manual did not yield reliable results for levels of chlordane as low as 30 ppb.

This information caused the Maryland Department of Natural Resources to press the U.S. Food and Drug Administration for clarification of the situation, and on October 19, 1972, a meeting was held with personnel in attendance from the Seafood Section of the U.S. Food and Drug Administration and Maryland's Department of Natural Resources. Also attending this meeting were representatives of the Pesticide Analytical Section and the Toxicology Section of the Food and Drug Administration, the Maryland Department of Mental Health and Hygiene and the Westinghouse Ocean Research Laboratory. The unequivocal consensus was that no rationale existed for having the chlordane "alert level" set at 30 ppb for shellfish when a 300 ppb "alert level" had been established for fresh vegetables. Moreover, it was agreed that the effective sensitivity limit for the recommended screening procedures for chlordane was on the order of 100 ppb and that levels as low as 30 ppb could not be screened for reliably.

Shortly thereafter, at a meeting of the Chemistry Task Force of the National Shellfish Sanitation Program, a Food and Drug Administration representative stated that the 30 ppb level would not be enforced and recommended that an interim 300 ppb "alert level" be adopted until further studies on the matter could be made. In light of this proposed 300 ppb guideline, the level of chlordane in oysters and soft-shelled clams taken from the Chester River is fairly low although levels in some finfish analyzed did slightly exceed one-half the newly proposed "alert level" (see Table II).

3.1 Distribution of Chlorinated Hydrocarbons

The solubility of chlorinated hydrocarbons is very low in water (on the order of 1 ppb). On the other hand, the affinity of chlorinated hydrocarbons to adsorb to fine suspended particulate matter (i.e., clay and silt-sized sediments) in water is very high. These compounds adhere to the surfaces of sediments due to ionic attraction and a high solubility in lipids) and other organic materials which coat particles in the aquatic environment. Suspended sediments and particularly the finer-sized particles act as very efficient "scrubbers" in removing chlorinated hydrocarbons and trace metals from the water. The major transport mechanism of chlorinated hydrocarbons, therefore, is suspended sediments and their distribution in the aquatic environment is linked to the movement of suspended materials.

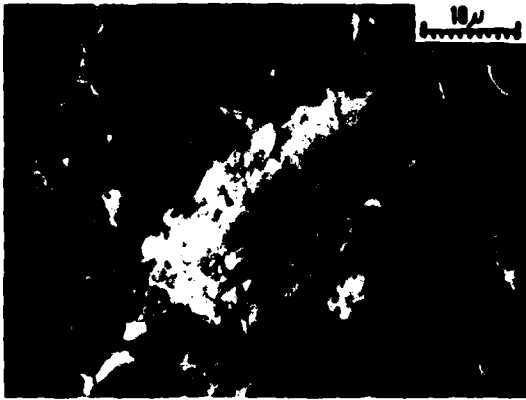


Figure 7 Scanning electron microscope image of individual clay particles and an agglomerated mass of particles (center) show at a magnification of 2000X. The scale at the top of the figure is 10 microns long.

Collections of suspended particulate matter from the waters of the Chester River consisted primarily of silts and clays (Figure 7). This suspensate was collected from a large water volume sampled at several levels in the water column at different station locations in the river using a continuous flow centrifuge. Sediment analyses results were similar to those obtained by other workers in the area, indicating that only a small percentage (4% to 6%) of the total suspended matter consisted of skeletal debris or living organisms. Analyses of these sediments for chlorinated hydrocarbons proved ineffective since several components of the continuous centrifuge were hopelessly contaminated with chlorinated hydrocarbon materials which masked the analytical values obtained by the gas chromatograph.

Sediment samples from the bottom of the Chester River were analyzed for geological parameters

and chlorinated hydrocarbon levels. The mean grain-size diameter of the sediments in these samples varied due to the natural sorting processes in the various river environments and inherent differences in the depositional regime at different points in the river.

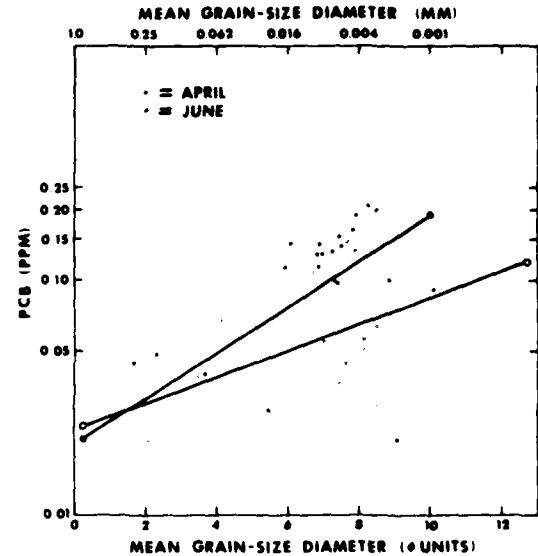


Figure 8 Relationship between mean-grain size of sediments and PCB concentrations for samples collected from the Chester River. Concentration increases as mean grain size decreases (see text for further explanation).

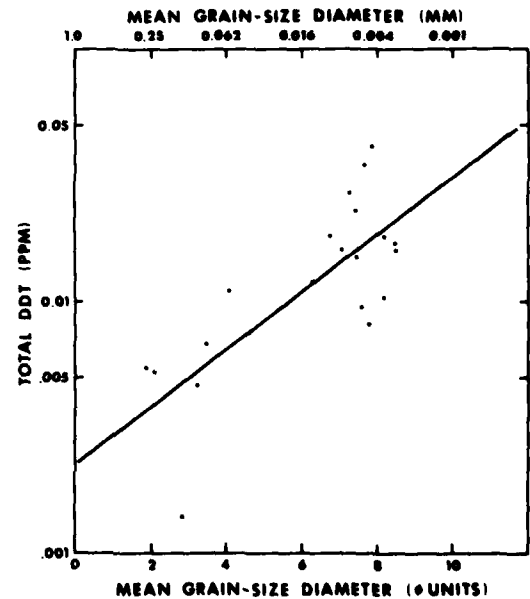


Figure 9 Relationship between mean-grain size of sediments and DDT concentrations for samples collected from the Chester River (see text for further explanation).

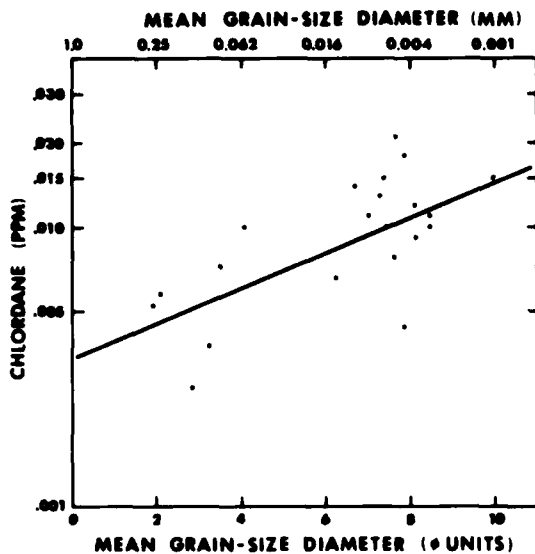


Figure 10 Relationship between mean-grain size of sediments and chlordanes concentrations for samples collected from the Chester River (see text for further explanation).

TABLE III - RATES OF DECREASE OF CHLORINATED HYDROCARBONS IN THE UPSTREAM DIRECTION BASED ON DATA COLLECTED 6 JUNE 1972 FROM THE NINE STATIONS ALONG THE MAIN RIVER COURSE

Chlorinated Hydrocarbon	RATE OF DECREASE UPSTREAM
PCB	4.20 ppb/Nautical Mile (2.27 ppb/kilometer)
DDE	0.17 ppb/Nautical Mile (0.09 ppb/kilometer)
DDD	0.49 ppb/Nautical Mile (0.26 ppb/kilometer)
DDT	0.26 ppb/Nautical Mile (0.14 ppb/kilometer)
Chlordane	0.42 ppb/Nautical Mile (0.23 ppb/kilometer)

TABLE IV - CORRELATION VALUES OF CHLORINATED HYDROCARBONS WITH RESPECT TO DISTRIBUTION ALONG THE MAIN RIVER COURSE

	PCB	CHLORDANE	DDE	DDD	DDT
PCB	1.00	0.92	0.89	0.88	0.59
CHLORDANE	0.92	1.00	0.94	0.94	0.65
DDE	0.89	0.94	1.00	0.97	0.69
DDD	0.88	0.94	0.97	1.00	0.77
DDT	0.59	0.65	0.69	0.77	1.00

Graph plots were made of the PCB and pesticide content of these sediment samples as a function of mean grain-size diameter. These data are presented in Figures 8 through 10 and confirm earlier findings by other investigators that the smaller the mean grain-size diameter of the sediment (hence, the larger surface area per unit weight), the higher the concentration of chlorinated hydrocarbons present. This relationship is to be expected when it is realized that adsorption is the principal mode by which these pollutant materials attach to particulate matter. It was concluded, therefore, that suspended clays and silts were the major transport mechanism by which chlorinated hydrocarbons moved through Chesapeake Bay and its tributaries. Furthermore it was deduced that the principal transport of these fine sediments and their adsorbed chlorinated hydrocarbons in the Chester River was from the Bay into the river. Each of the study disciplines contributed some evidence to support this conclusion.

- Analyses of the concentrations of PCB's, total DDT and chlordane as a function of distance up-river from its mouth at Love Point showed that the concentration levels of these materials diminished in the upstream direction (Table III). Moreover, there was a positive correlation between these pollutants as far as their distributions (Table IV). These findings strongly suggest that the chlorinated hydrocarbons are coming into the river from the Bay rather than from the river's watershed.

- In several sets of shellfish samples, the chlordane levels in soft-shelled clams taken from the lower portion of the river were significantly higher than in clams taken from the upper portion of the river. This finding also suggests that the concentration of chlordane in the near-bottom waters where the clams feed is greater near the mouth of the river than upstream.

- Yellow perch and white perch (fish which do not range far from their established living territories) from the vicinity of Hail Point in the lower portion of the river had considerably higher body burden levels of PCB, total DDT and chlordane than specimens of the same species taken about five miles upstream at the junction of the Corsica River with the Chester River.

- Mineralogical analyses of the clay portion of the Chester River sediments disclosed the abundant presence of a clay species (chlorite) which is common to the Bay but is known to be rare in formations lying within the Chester River watershed. The percentage of chlorite in the clay minerals of the river sediments is essentially the same as found in sediments of upper Chesapeake Bay.

- Integration of current velocity measurements (Figure 11) from surface to bottom shows that the prevailing flow patterns in the Chester River are typical of a two-layered estuarine system. This type of circulation has a net flow of water



Figure 11 - Personnel of the National Oceanic and Atmospheric Administration install current meters and other environmental monitoring instrumentation at the mouth of the Chester River. Instrumentation for much of the hydrographic work was provided by NOAA.

upstream near the bottom and a net flow of water downstream near and at the surface. Typical flow distribution patterns are shown in Figure 12. The upstream flow along the bottom provides a mechanism for the transport of fine sediments and their adsorbed chlorinated hydrocarbons from the Bay into the lower reaches of the river either as part of the bed load transport or in suspension.

Sediments are distributed in the bed of the Chester River in accordance with their grain size and the local water-current regimes. The shallow shoreline areas contain materials ranging from coarse to fine sands which have relatively large mean grain-size diameters. The silt and clay components of shoreline sediments are washed out and resuspended by wave-induced turbulence and in turn tidal or wind-driven currents remove these fine sediments from the submerged terrace deposits. The remaining coarser sediments, therefore, reflect the high-energy level of water movements in the shoreline and terrace environments.

The deeper channels of the river, on the other hand, receive some of the deposits of finer sediments and, therefore, are a depositional sink for these chlorinated hydrocarbon bearing materials. Figure 13 shows the distribution of sediments in these different hydrographic regimes. The finer sediments being deposited in the deeper portions of the river channel are quite thick based on seismic profiling data and overlie an older erosional surface of glacial age.

On the basis of the present study and work done by other individuals, several likely sources can be identified which may be contributing these sediments and chlorinated hydrocarbons to the Chester River. The quantity of pesticide products sold in Kent and Queen Anne's Counties containing chlorinated hydrocarbons of interest to the study is small compared to the quantities sold in Baltimore City and County immediately across the Bay or used in the Susquehanna watershed. Moreover, in upper Chesapeake Bay near the mouth of the Chester River, other studies have shown that at least 80% of the water in

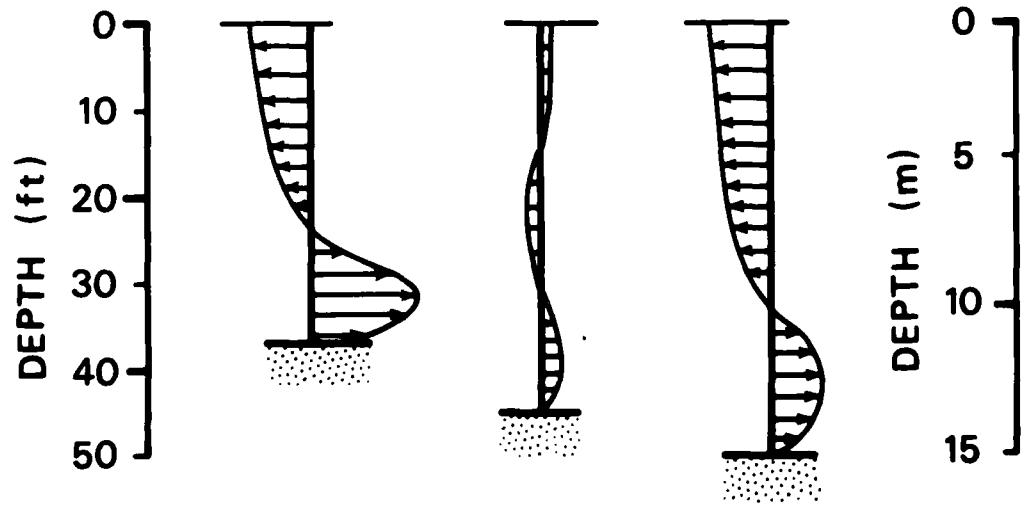
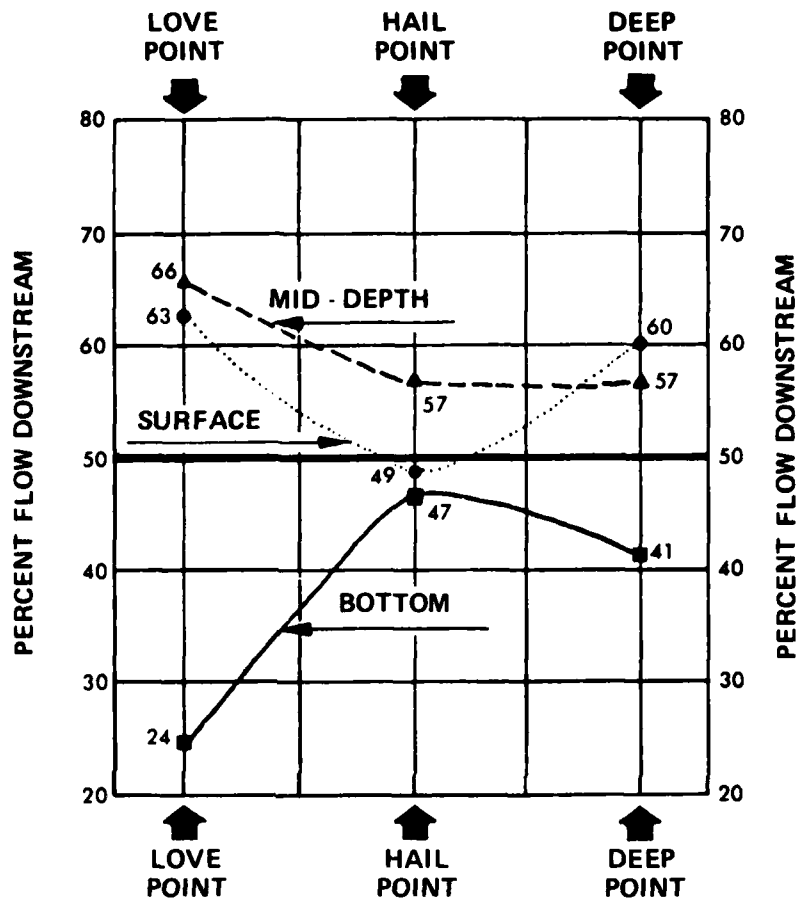


Figure 12 Diagrams of net flow from surface to bottom during the summer months at Love Point, Hail Point, and Deep Point in the Chester River. The net flow upstream along the bottom is indicated by the lowest line in the top diagram and the lower portions of the three current profiles in the bottom diagram. The length of the arrows in the bottom diagram is proportional to the velocity.

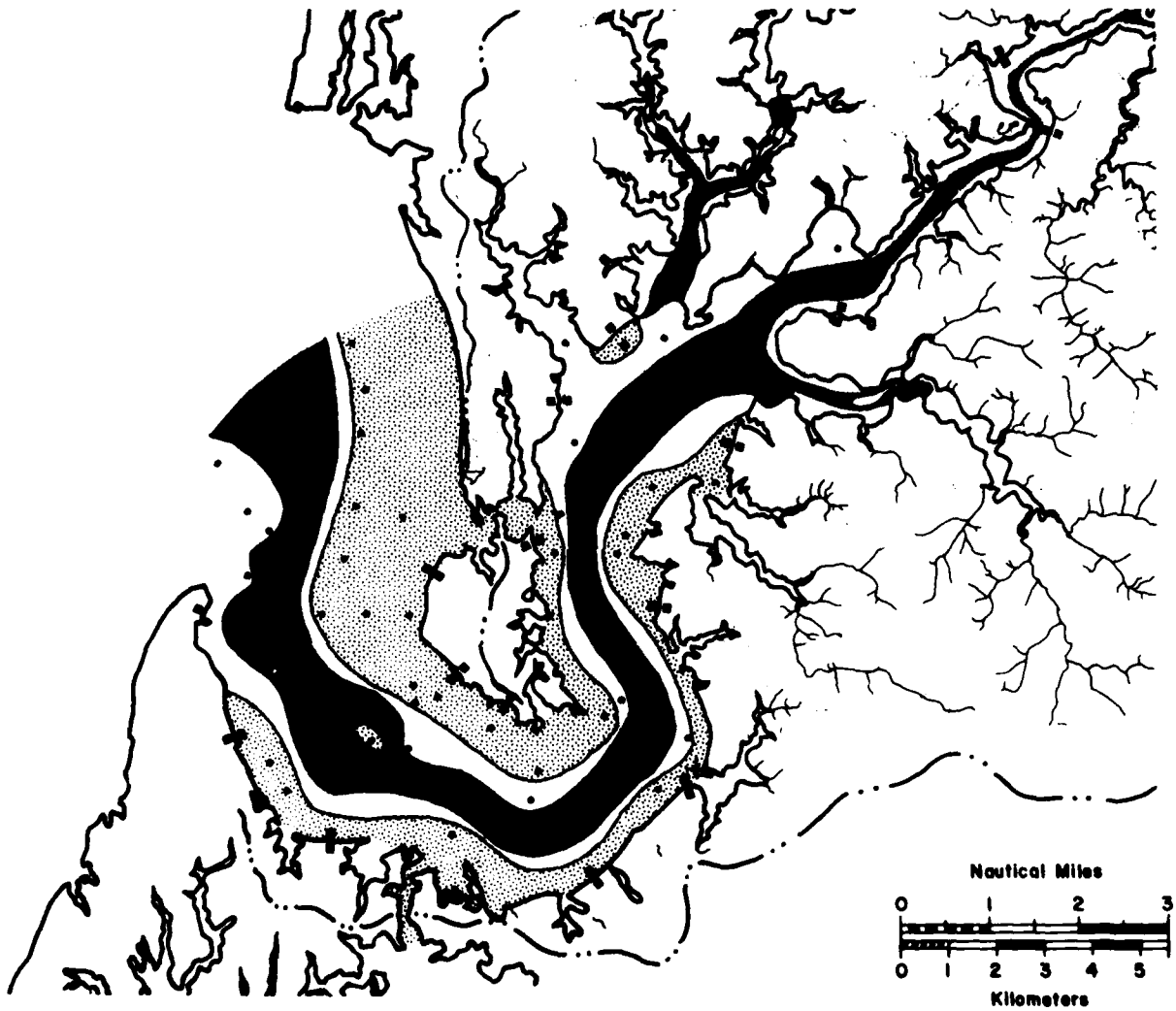


Figure 13 Distribution of bottom sediment types in the Chester River. Coarse stippling near shore indicates a preponderance of sandy materials. Lighter shading gives the distribution of mixed sands and silts on the terraces lying between the shoreline and the main river channel. Darker shading shows the channel muds which are primarily silts and clays. Distributions were determined from samples taken aboard ship (dots) and along shore (squares).

that portion of the Bay comes from the Susquehanna River and similarly, of the total annual supply of suspended sediments in these waters, 83% have originated in the Susquehanna watershed. The evidence cited in the present study for net transport of fine-grained sediments into the Chester River from the Bay and the inverse relationship between grain size and chlorinated hydrocarbon concentration leads to the conclusion that large portions of the PCB's, DDT, and chlordane present in sediments of the Chester River have very likely originated in the Susquehanna drainage.

Although the net circulation pattern for upper Chesapeake Bay reveals a northerly flow along the eastern shore of the Bay and a southerly return flow along the western shore, daily tidal currents and local winds cause widespread mixing and displacements of the surface waters of the Bay. Analysis of current and wind data reveal significant horizontal transport of water (meteorological tides) from West to East during sustained westerly winds together with extensive vertical mixing brought about by wave action. Thus, in addition to near-bottom flow into the Chester River with its associated sediment load, there are other mechanisms for moving sediments from the Bay into the River that are effective and significant in scale.

Analyses of bottom sediments from the Chester River revealed that the proportions of clay minerals (clay mineral ratios) present in the River sediments are very nearly identical to those in sediments of upper Chesapeake Bay. Previous work by other investigators has shown that most of the Bay sediments have been derived from the Susquehanna River watershed. Thus, even relatively high concentrations of clays introduced by local tributaries such as the Chester River would be rapidly diluted in the much larger volume of Bay sediments, and it would be difficult to identify local sources of clay minerals without sampling in the upper reaches of the tributaries themselves. Similarly, it would be difficult to pinpoint local sources of pollutants (pesticides, trace metals, etc.) which are associated with these fine-grained sediments. Apparently, the largely Bay-derived sediments carpeting the bottom of the Chester River are the major carriers of chlorinated hydrocarbons into the area of study based on the above evidence. Moreover, the greater part of these sediments are derived from the Susquehanna River watershed.

Studies of the distribution of aerosols have generally revealed high concentrations of pesticides in the atmosphere many miles downwind from the industrial and urban areas in which they were used. Such studies suggest that perhaps 50% of the pesticides present in the downwind environment are derived from atmospheric "fallout" on fine particulate matter or in precipitation (rain and snow). These materials are introduced into the atmosphere by vaporization (evaporation and incineration) and through



Figure 14 — Meteorological station located on Love Point at the mouth of the Chester River was used to gather data on prevailing winds.

co-distillation with water. Once in the air, their distribution is subject to the prevailing local meteorological regime (Figure 14). More than 95% of the winds reaching the Chester River watershed come from the western quadrant (Figure 15) and thus have crossed major industrial and urban centers lying west of Chesapeake Bay. This distributive mechanism may account for a portion of the pesticides found in the Chester River, but it was not within the scope of this study to evaluate the meteorological contribution to the area of these pollutants. By and large, the major contribution is probably on the suspended sediments brought into the area by water transport.

3.2 Laboratory Toxicity Studies

A major effort of the Chester River Study was devoted to laboratory investigations of the toxic effects of chlorinated hydrocarbons on the oyster (*Crassostrea virginica*) and the soft-shelled clam (*Mya arenaria*) with the ultimate long-term objective of developing data that would be useful for resource management purposes. Although these investigations were begun with the definite understanding that attainment of the long-term objective was not within the initial scope of the Chester River Study, some useful information could be gained during the first year's work.

A shellfish laboratory was constructed during the early phases of the study which used a continuously flowing supply of water from Chesapeake Bay

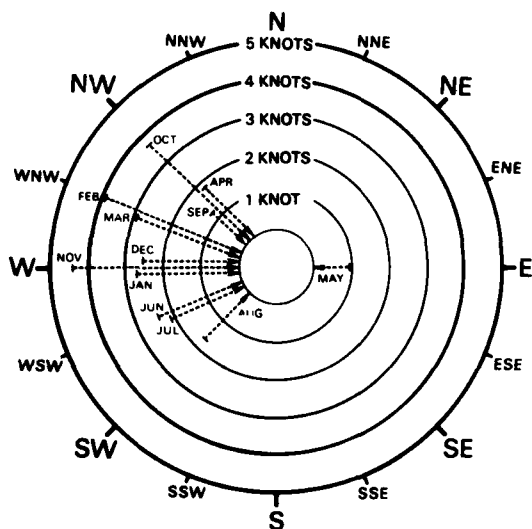


Figure 15 -- Monthly resultant wind speed and direction data gathered at Friendship Airport near Baltimore. Although this weather station is located on the opposite side of the Bay, the wind patterns reflect those of the Chester River region.

near Sandy Point to maintain stocks of oysters and soft-shelled clams for experimental purposes under essentially natural conditions. Stocks of both species were held successfully with very low mortalities. Temperature, dissolved oxygen, and salinity were measured during these experiments so that effects from changes in these parameters could be evaluated.

Of the various chlorinated hydrocarbons found to be present in the Chester River, chlordane was initially selected for investigation since it had been detected in shellfish at levels which approached or exceeded the then established Food and Drug Administration "alert level" of 30 ppb. Four experiments, run consecutively, were completed during the study period; an eight-day and a 31-day experiment with oysters, and an eight-day and a 69 day experiment with soft-shelled clams. Drastic environmental changes in water conditions during the immediate aftermath of tropical storm "Agnes" prevented laboratory investigations from being carried out for a significant period of time during the course of the study.

Several different exposure concentrations of chlordane were maintained in the experimental tanks of the shellfish laboratory by pumping solutions of this compound from reservoir bottles at predetermined rates into the supply streams of Bay water reaching each tank. Moreover, each tank was equipped with a circulating pump to insure that complete mixing occurred throughout the tank volume. It was

necessary to dissolve the chlordane in a 2:1 acetone-water solution to keep this water-insoluble compound in solution in the reservoir bottles. To distinguish between chlordane effects and acetone effects (the acetone exposure level for the shellfish was approximately 70 parts per million), each experiment included a control tank that received just the acetone-water solution and no chlordane. Prior to discharge, all water from the experimental tanks was filtered with activated charcoal to remove the introduced contaminants.

During the eight-day experiments, different lots of shellfish were exposed to 1, 10, and 100 parts per billion (ppb) levels of chlordane. These levels were expected to be high enough to produce some visible toxic effects on the organisms and at the same time give information on the uptake rates of chlordane. The body tissue accumulation levels generally reached a steady-state in less than five days of exposure to the chlordane solutions. Soft-shelled clams concentrated chlordane in their body tissues at levels varying anywhere from 400 to 1000 times the concentrations they were exposed to during the experiment. Oysters accumulated even greater amounts of chlordane, reaching body tissue levels five to twelve times higher than the clams or up to 10,000 times the exposure concentration.

In spite of these high body tissue concentrations, no mortalities occurred during the eight-day oyster experiment and the few mortalities that occurred during the soft-shelled clam experiment showed no strong correlation with the amount of chlordane they were exposed to during the experiment. In both cases, however, the higher exposure concentrations of chlordane produced morphological abnormalities which were interesting because of the similarity they bore to abnormalities observed in stressed soft-shelled clams and oysters in the field. At the higher chlordane concentrations, the soft-shelled clams developed greatly elongated, swollen siphons the surface tissues or integument of which was strongly blistered. The oysters, on the other hand, in the highest chlordane exposure concentration had smaller meats and poorly developed gonads compared to the oysters held in lower concentrations. Quite possibly the morphological changes observed in both of these cases are of a general nature and could be elicited by a wide variety of toxic materials, reflecting responses to stressful conditions. If these abnormalities are in fact specifically related to chlordane toxicity, they might become evident at much lower chlordane concentrations if the organisms were subjected to multiple stresses (such as extremes of temperature or salinity) as they often are in the field.

None of these morphological abnormalities were observed in the long-term experiments where much lower concentrations of 1, 10, and 100 parts per trillion (ppt) were used. The lowest experimental exposure concentration (1 ppt) produced approxi-

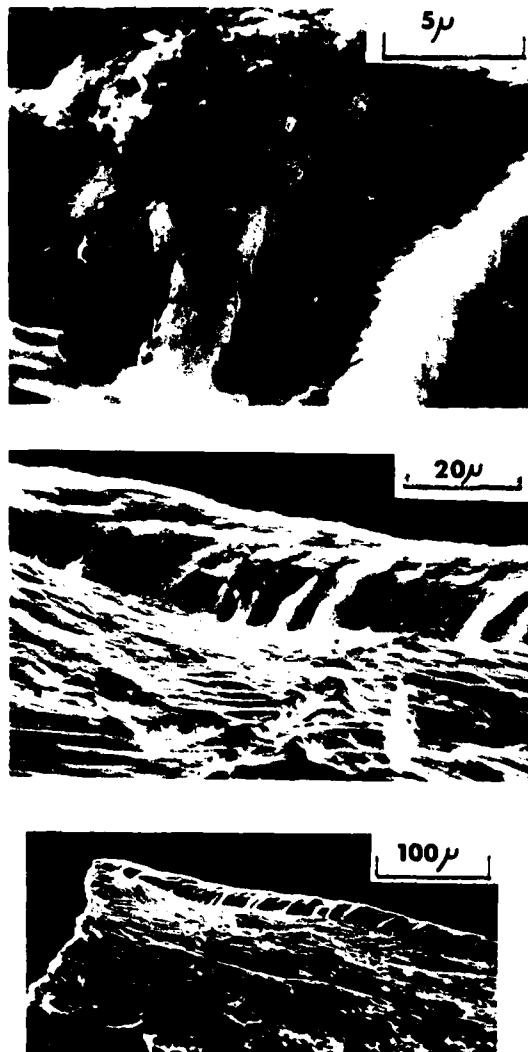


Figure 16 Scanning electron microscope photomicrographs of new shell growth structure in an oyster. The oyster was exposed to low levels of chlordane and the crystals of the prismatic layer (seen on a freshly broken edge) are slanted from the perpendicular and slightly curved along their axes. Compare with Figure 17. The scales at the tops of the pictures are in microns.

mately one-tenth higher body tissue accumulation levels than the levels observed in oysters collected from the Chester River.

During the long-term experiment on oysters, changes in total weight and shell growth rate were measured to determine if possible effects related to chlordane exposure could be detected, but several uncontrollable events which occurred during the course of the experiment, an oil spill in the vicinity of the

shellfish laboratory's water supply intake and several electrical power failures which stopped the water supply, made the resulting data difficult to interpret with any certainty. However, examination at higher magnifications with a scanning electron microscope of the crystal structure laid down in new shell growth showed that the oysters receiving even the lowest chlordane exposures were affected (Figure 16). Shell crystal structure was significantly different in these experimental organisms when compared with control organisms not exposed to chlordane (Figure 17). Thus, even extremely low levels of chlordane can produce measurable morphological changes in the case of oysters. Whether these manifestations are harmful or not to the organism cannot be determined at this point. It is, however, a matter of concern in respect to making living resource management decisions, for even if body tissue accumulation levels of pollutants in shellfish stocks are considered safe as far as human standards, it has not been established in most instances that these levels are completely harmless to the stocks themselves. The shell crystal structure modification in oysters recalls to mind the eggshell thinning in birds mentioned earlier, suggesting that calcium metabolism is one of the physiological processes often affected by chlorinated hydrocarbon accumulation.

During the 31-day low-level chlordane exposure experiments with oysters, the maximum uptake rate occurred during the first five days of exposure. The body tissue levels subsequently fell or rose from time to time during the balance of the experiment, however, the end results were similar to the eight-day experiments. Although the ultimate body tissue concentrations were much lower than in the eight-day experiment, as would be expected from the much lower exposure concentrations of chlordane used, the relative amount of chlordane accumulated was considerably greater at these lower exposure concentrations. Thus, tissue levels of chlordane in the 31-day experiment were 9,000 to 160,000 times higher than the exposure concentrations compared to 2,000 to 10,000 times higher in the eight-day experiments. This changing relative concentration factor will be discussed in greater detail later.

The 69-day soft-shelled clam experiments were conducted during a period of low water temperatures and hence were not fully comparable with the other experiments. The feeding and pumping rates of the clams were considerably lower and this was reflected to some degree in the uptake rates of chlordane. At the 1 ppt and 10 ppt exposure levels, there was no significant change in the body tissue accumulations of the clams throughout the course of the experiment. At the 100 ppt level, however, body tissue concentrations rose to 5000 times the exposure concentration of chlordane. Moreover, the initial relatively rapid rise in concentration took about 20 days before leveling off, again probably reflecting the

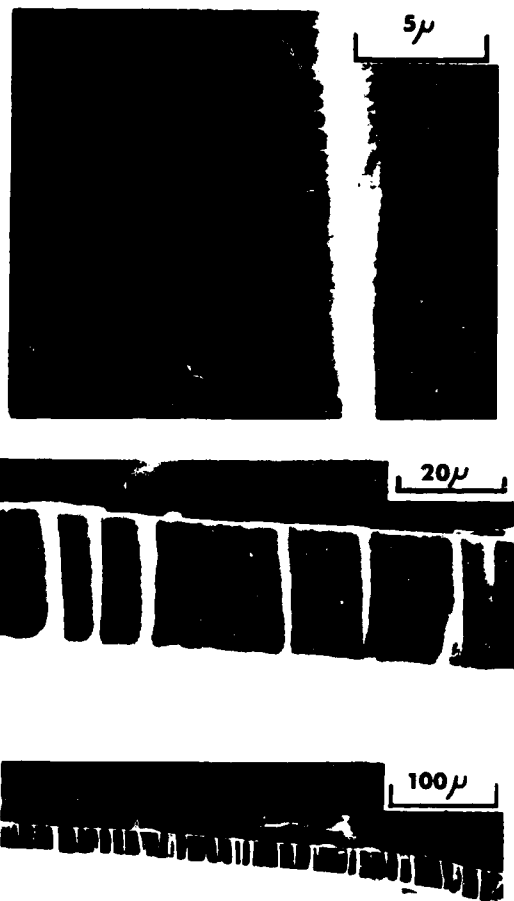


Figure 17. Scanning electron microscope photomicrographs of new shell growth in an oyster. The oyster was not exposed to chlordane and the crystals of the prismatic layer (seen on a freshly broken edge) are perpendicular and not curved along their axes. Compare with Figure 16. The scales at the tops of the pictures are in microns.

slowed metabolism due to low water temperatures. In this experiment, the trend to accumulate higher relative body tissue concentrations at lower exposure concentrations observed in oysters, is repeated in the soft-shelled clam's uptake of chlordane.

Perhaps the most practical finding from the laboratory toxicity studies is the change in relative body tissue concentrations of chlordane by oysters at lower exposure concentrations. If one defines the concentration factor, K_C , for chlordane uptake by oysters as the chlordane level accumulated in tissues divided by the chlordane exposure concentration in the water, the experimental data show that K_C is not a constant, but is inversely proportional to the exposure concentration in the water. In other words, the lower the concentration of chlordane in the water, the higher will be the ratio of the oyster tissue chlordane content to that of the chlordane content of

the water once a steady-state is reached. This relationship can more easily be seen in the hypothetical situation shown in Figure 18. If oysters are continually exposed to a specific concentration of chlordane (shown in the first container), once a steady-state is reached, we will find the body tissue concentration to be a certain value shown in the oyster beside the container. If the initial solution is diluted in half we will have a solution half the concentration of chlordane we had in the first instance, (shown in the second container). Assuming the concentration factor, K_C , were a constant, we would expect the body tissue concentration in oysters exposed to this second solution to be one-half the original value, shown by the lighter stippled area in the oyster next to the second container. Actually, this is not the case since K_C is not a constant and the steady-state concentration is somewhat higher, shown by the darker stippled area above the lighter stippled area in the oyster. Again, repeating the same operation and diluting the second solution to half its original concentration (shown in the third container) we find that the oysters exposed to this third solution concentrate chlordane at even slightly higher levels than expected. The darker stippled area in the oyster next to the third container shows this additional amount of concentration.

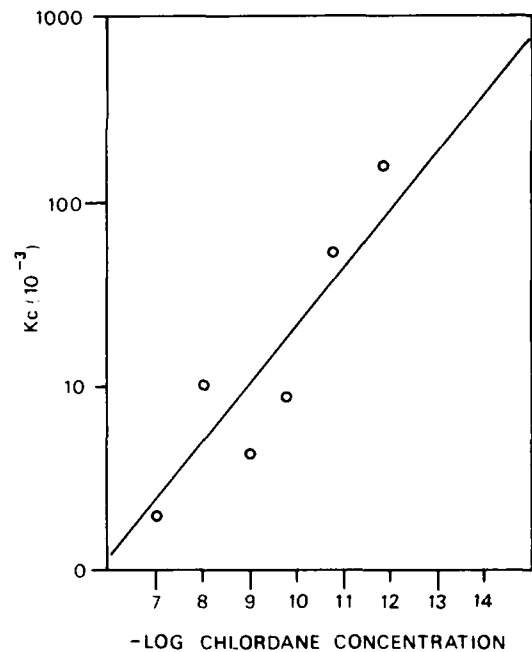


Figure 19. Log-log plot of the chlordane concentration factor versus the chlordane concentration dosing level demonstrating that the ratio of oyster tissue chlordane concentration to a given water chlordane concentration exposure is not constant. The ordinate scale is the tissue chlordane concentration divided by the chlordane dosing concentration and the abscissa scale is the negative log of the chlordane dosing concentration.

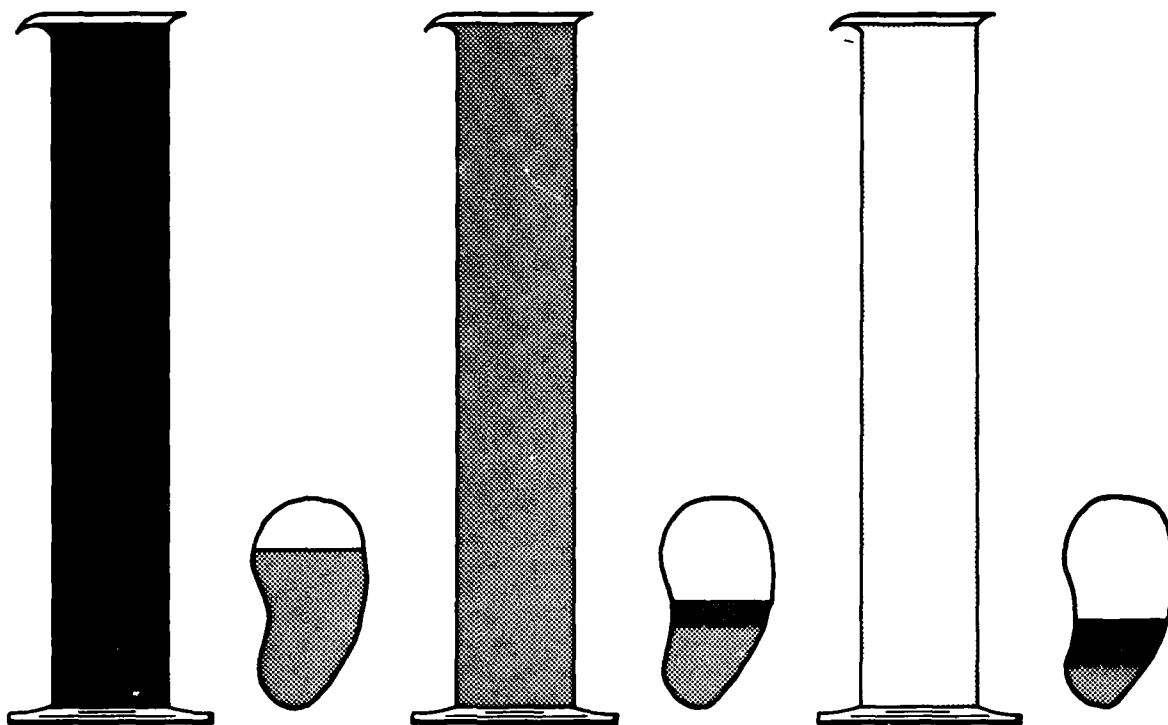


Figure 18 The relationship of different chlordane concentrations in the water environment with chlordane concentrations in oysters. Each container has a different concentration of chlordane. The two containers to the right of the first container have chlordane solutions one-half and one-quarter that of the first container. Oysters exposed continuously to solutions of these concentrations would be expected to reach steady-state concentrations in their body tissues indicated by the lighter stippling if the concentration factor (K_C) were a constant. Since the concentration factor is not a constant, the relative amounts of chlordane concentrated in the tissues at lower exposure concentrations is greater shown by the darker stippling.

Using values derived from the laboratory experiments themselves, the changes in relative concentration of chlordane can be expressed numerically. Table V presents these numbers.

TABLE V - CONCENTRATION FACTORS OF CHLORDANE IN OYSTERS AT DIFFERENT EXPOSURE CONCENTRATIONS

Exposure Concentrations in Parts Per Trillion	Relative Concentration Factors in Body Tissues (K_C)
100	9,000 x
10	54,000 x
1	160,000 x

Figure 19 shows that a log-log plot of K_C versus the chlordane exposure concentration yields a fairly straight line. If the relationship between K_C and the chlordane exposure concentration proves upon further investigation to hold true for oysters under field conditions, a useful resource management tool would be available to establish a water quality stan-

dard for chlordane. Based on the inverse relationship established in Figure 19 for K_C , chlordane concentrations, in order to stay below the previously set "alert level" of 30 ppb in oyster tissues, would have to be less than 0.2 ppt in the water environment inhabited by the oysters. On the other hand, the chlordane level in the water environment would have to exceed 6.5 ppt in order to raise chlordane levels in oyster tissue above the newly proposed interim "alert level" of 300 ppb.

If one were not aware that K_C was not a constant and calculated a water quality standard for chlordane using K_C determined from an exposure experiment at the 100 ppb level of chlordane (a procedure which is frequently followed in establishing such standards), one would erroneously set the maximum allowable water environment chlordane concentration at 150 ppt instead of the true 6.5 ppt level. Using Figure 19, one finds that if the chlordane concentration in the water environment ever reached 150 ppt, the chlordane level in oyster tissues would be expected to reach 2,700 ppb or nine times the maximum allowable level of 300 ppb.

Upon further testing with other materials of environmental concern (such as PCB's, additional

chlorinated hydrocarbon pesticides, and trace metals) should this K_C relationship appear valid for determining levels for water standards, it would allow the State of Maryland to establish a meaningful water quality monitoring program to protect its valuable shellfish stocks. The K_C relationships, would not only enable resource management personnel to establish water quality standards, but at the same time would permit them to predict the concentration levels these materials would reach in shellfish stocks directly from water quality data without the need for extensive shellfish monitoring programs. Moreover, some of the instrumentation for carrying out such a program already exists.

A past national pesticide program estimated average pesticide loadings in watersheds by setting up

stations along rivers where water was automatically pumped at known rates through activated charcoal columns to remove the contained pesticides. These columns were collected at regular intervals and the adsorbed pesticides analyzed, yielding a value for the average pesticide concentrations in the water during the sampling period. If the K_C relationships for various other compounds of environmental concern were known, water quality data provided by just a few judiciously placed sampling stations would permit resource management personnel to evaluate the levels of toxic substances in the shellfish stocks without maintaining extensive monitoring programs of the stocks themselves.

4 TRACE METALS

Trace metals (such as iron and copper) in small quantities are essential to the well being of organisms and the efficient functioning of their metabolism. However, an excess of many of these metals in the environment can lead to adverse effects which weaken weaker organisms. The toxic effects of high metal concentrations in lower organisms in the aquatic food chain can also be passed on to higher food-chain organisms which use the lower form for food. When man feeds on these organisms, he in turn is subject to the toxic effects of the concentrated metal. A recent example of such an occurrence in humans was the widespread mercury poisonings in the Minamata region of Japan. Mercury released from a factory into a nearby bay was taken up by edible aquatic organisms. The neighboring human population fed upon these organisms extensively and thus were poisoned by the mercury the organisms had concentrated.

In Chesapeake Bay, there has been concern over the possibility of accumulations of excess amounts of trace metals in economically important species such as the oyster and soft-shelled clam. Potentially significant sources of such metals are the sediments of the Bay and river themselves. Routine analyses of shellfish meats are done by the Public Health Service, but sediments are infrequently analyzed.

To obtain a better understanding of the possible environmental sources of trace metals, it was felt important to determine the existing levels of these metals in Chester River sediments that might be available for uptake and concentration by species living upon or within the materials forming the floor of the river. Six metals (chromium, zinc, iron, copper, cadmium, and lead) generally considered hazardous to human health, were investigated.

Samples of Chester River sediments were analyzed for trace metals using atomic absorption methods to

determine the concentrations of the various metal elements. Selection of this widely used analytical procedure permitted comparisons of the concentrations of the six metals in Chester River sediments with the concentrations determined for other areas by different laboratories in the Chesapeake Bay region. To ascertain the relative degree of sediment contamination in the Chester River, values obtained for the six metals from Chester River sediments were compared with values obtained for other areas in the Chesapeake Bay system. These areas were selected because of known high or low levels of trace metal contamination. Baltimore Harbor was chosen because of its highly contaminated condition. The Potomac Estuary was also chosen because of the substantial urban and industrial inputs of pollutants from the Washington D.C. area. The Bay Bridge site in upper Chesapeake Bay was selected primarily for its intermediate position between upper and lower Bay sources. Finally, the Rhode River on the western side of Chesapeake Bay south of Annapolis was chosen because of its light to moderate urban and industrial inputs. The Chester River by comparison with these other areas has small urban and industrial inputs, but heavy contributions from agricultural activities.

Table VI summarizes the trace metal findings for these five areas. As would be expected, Baltimore Harbor shows very high levels for all six metals. The Potomac Estuary, on the other hand, shows somewhat intermediate conditions in most instances between Baltimore Harbor and the Chester River. It is apparent that of the six metals analyzed from the Chester River sediments only three, chromium, zinc, and iron, occurred in concentrations exceeding maxima found in the similar environment of the Rhode River on the western side of Chesapeake Bay. Of these three metals, zinc alone had a significantly higher value than the maximum found in the sediments of the Rhode River estuary. Only at one station out of a total of twenty-five in the Chester River did chro-

mium and iron concentrations exceed the maxima found in the Rhode River. It would appear that the concentrations of the six metals studied in the Chester River are, with the possible exception of zinc, comparable with the similar but much smaller Rhode River, both having relatively low levels of contamination.

In the case of the Chester River sediment samples, each sample was divided into two sub-samples, one portion being used to determine sediment parameters such as grain-size distribution and clay mineralogy and the other portion being used to determine trace metal content. As a result of this dual analysis procedure, it was possible to compare trace metal concentrations with grain-size characteristics of the sediments for possible correlations. These comparisons indicated a relationship similar to the one found for pesticides, i.e., the finer the average grain size of the sediments the higher the trace metal concentration. This correlation is interpreted as having a direct relationship with several phenomena common to fine grained sedimentary materials rich in clay minerals. For example, clay minerals in suspension in water are very efficient chemical "scavengers", and they tend to attract and adsorb several classes of materials to their surfaces. Part of this scavenging action is due to their crystallographic structure, which provides them with an enormous surface to volume ratio, as well as a slightly negative surface charge. The surface charge attracts positive ions and compounds, especially free metals and organics such as chlorinated hydrocarbons, to the surfaces and inter-layer regions where broken chemical bonds and reactive surfaces seek to regain equilibrium. Upon exposure to such materials, clays will very quickly "scrub" from the water all available ions and compounds susceptible to adsorption and other forms of chemical attachment. Once the fine-grained clays have become saturated with such materials, it requires unusual environmental conditions to

free these ions and compounds again. Normally, the deposition of these clay materials effectively removes the bound trace metals on their surfaces from the water environment and it is only when there are massive resuspensions of these sedimentary materials, such as during major dredging operations, that there is environmental concern.

Although the levels of trace metals in sediments of the Chester River were in a few cases relatively high, no conclusion at present can be drawn as to how much of these metals are entering into the food web and thus ultimately affecting human consumers. The uptake and concentration of such metals by organisms vary with the condition of the organism and its place in the food chain. Moreover, the rate and magnitude of uptake are dependent on such matters as seasonal fluctuations in temperature, salinity, and other environmental parameters.

It is apparent from the strength of the bonding of metals to sedimentary particulate matter, evidenced by the chemical procedures required to remove them during sample preparation for analyses, that although substrate concentrations of these metals may be high this does not necessarily mean that high levels of the metals are available for uptake by benthonic organisms under the conditions normally present in an estuarine environment. Once deposited in the substrate, metals may be fairly well isolated from uptake by bottom feeders unless resuspension of the sediment occurs. However, until additional laboratory studies are conducted to determine the degree of correlation between sediment levels and the amount of metal uptake and concentration in tissues of organisms, further discussion of these relationships remains speculative. It is recommended that studies of these relationships be undertaken and that the uptake mechanisms of metals by organisms be more thoroughly investigated.

TABLE VI - TRACE METAL CONCENTRATIONS IN SEDIMENTS PARTS PER MILLION (ppm) DRY WEIGHT

	BALTIMORE HARBOR	POTOMAC ESTUARY	BAY BRIDGE	RHODE RIVER	CHESTER RIVER
Zn (Zinc)	2599.9	75-1050		0-80	7-322
Pb (Lead)	1502.5	5-170	11-60	8-130	2.3-60
Cd (Cadmium)	192.3	0-0.6		.2-4.3	0.12-2.0
Cu (Copper)	320.1	8-73	18-54	3-120	1.6-35
Cr (Chromium)	3034.9	7-87		9-54	2.2-110
Fe (Iron)		8,000-87,000		7,300-38,000	1,600-41,200



Figure 20 – Severe shoreline erosion along the unprotected western shore of Eastern Neck Island. Scale divisions on white card are in inches.

5. SHORE EROSION

A detailed survey of 113 miles (182 kilometers) of the tidal portions of the Chester River shoreline in both Kent and Queen Anne's Counties resulted in the following classification of river bank conditions from Chestertown to the mouth of the River at Love Point (Table VII).

TABLE VII – SHORELINE CLASSIFICATION IN THE LOWER CHESTER RIVER

PROVINCE	DESCRIPTION	MILES (kilometers)	PERCENT
1	Severe erosion present, active destruction of shoreline.	30 (48)	27
2	Moderate erosion along mud-marsh shoreline.	62 (100)	55
3	Beach or spit providing natural protection to shoreline.	10.5 (17)	9
4	Man-made protective measures.	10.5 (17)	9

This appraisal of erosional shore vs. protected shore, although not carried into the upper reaches of many of the small tributaries flowing into the Chester River, is by and large in agreement with figures provided by the U.S. Soil Conservation Service as of 1967 (last year of record) for both Kent and Queen Anne's Counties. These latter data, and those of the Maryland Department of Natural Resources, show that within the confines of the two counties, more than 90% of the shoreline is eroding at rates ranging from 1 to 10 feet (0.3 to 3 meters) per year (see Volume II of this report for additional information). If one excludes the relatively minor percentage of river front where attempts have been made to control erosion, it is obvious that valuable property adjacent to the river is being lost at an alarming rate. In most cases, no effort has been made to retard shoreline loss (Figure 20), and even where expensive protective measures have been taken (Figure 21) erosion continues. In view of the extensive loss of shoreline property and the ineffectiveness of most protective measures, a closer look at the individual causes of erosion is appropriate.



Figure 21 – Collapse of an expensive, cement shore protection structure due to water sapping from the landward side.

The shorelines of the Eastern Shore of Chesapeake Bay and the river tributaries draining the Delmarva Peninsula are, for the most part, composed of weakly compacted Quaternary sands and clays deposited during glacial periods when sea level was lower. They lack the interparticle cement of sandstones and siltstones, and thus are more easily eroded than the older Tertiary sedimentary formations which, over the span of geologic time, have become more consolidated and resistant to erosion. The weak lowland Quaternary deposits carpeting much of the drainage area and bordering the Chester River have been eroded away both by the streams flowing across them and the combination of waves, currents and tides which attack the shores of the river in its tidal portions.

Unlike the open sea, the shallow Chesapeake Bay is subject to relatively rapid changes in water level in response to strong winds which sweep across its surface and pile up water on the downwind shore. When these meteorological "tides" occur during the period of the highest ocean tides (spring tides), the water level on a downwind shoreline may rise several feet above the normal level and thus subject the bases of the weak cliffs and bluffs bordering the river to wave attack which would not occur under normal tidal conditions. In such situations, these high tides, augmented by wind set-up of the water level and the waves the wind produces, may in several hours erode away great amounts of land which under average conditions would require many weeks or months.

Erosion of the shoreline represents more than just a loss of land area, since property owners continue to be taxed for acreage which has vanished, and the material which has eroded must ultimately be deposited in some portion of the estuarine system, where it may become a problem to navigation (Figure 22). Heavy sedimentation from erosion produces shoal areas and bars in harbor approaches and shipping channels which necessitate costly dredging. Sedimentation also leads to the burying of oyster bars and destruction of oyster bottoms, resulting in the loss of economically valuable resources. It is, therefore, in the broadest public interests to reduce, and where possible, eliminate shore erosion as well as control sediment run-off from the land.

The shorelines of the Chester River exposed to open reaches of Chesapeake Bay are clearly receiving the brunt of the wind-generated waves and currents produced by winter storms. In this particular respect, the western shores of Eastern Neck and Eastern Neck Island are especially vulnerable to wave erosion. The same sort of situation is found, to a lesser degree, along the west-facing river banks in Queen Anne's County, from the Corsica River south to Queenstown. There is sufficient fetch, that is, an open stretch of water over which the wind can blow, to raise water levels above normal along the shore and generate destructive waves. These last mentioned river shore areas are again most vulnerable to waves generated by

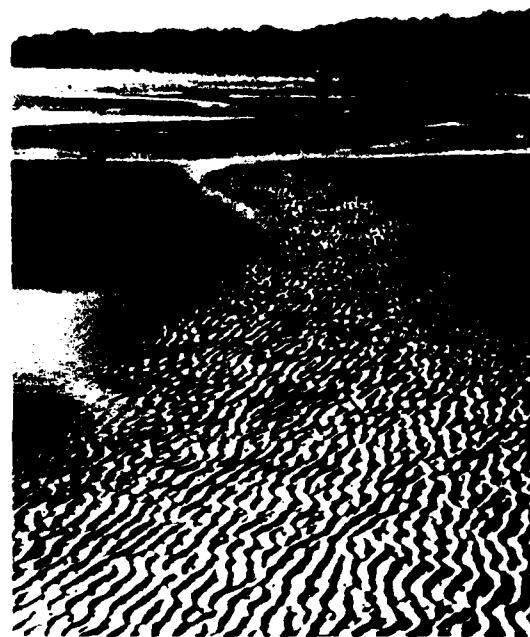


Figure 22 - Redistribution of sands and silts from eroded shorelines have created shoal areas which are a hindrance to navigation. This large tidal flat extends hundreds of feet off the eastern side of Kent Island.

strong winter winds blowing out of the northwest. Moreover, both directly approaching waves and refracted waves are equally effective in cutting away the soft shoreline formations. The results of such wave-caused attrition are dramatically shown in Figure 23. The black areas denote land that has been lost from around Love Point over the period from 1846 to 1942.

Property owners in some cases have dumped old automobile bodies along the bases of the bluffs to slow additional loss of farmland (Figure 24). Although this method of shoreline protection is esthetically offensive, it does provide a reasonably effective means for slowing wave-caused erosion of shoreline property. However, at the site pictured in Figure 24 and at many others along the river, wave-related erosion cannot account satisfactorily for the amount of erosion observed. Along protected portions of the river which are sheltered from the impact of high waves and strong currents, there is often severe shoreline erosion. Figure 25 shows a heavily eroded bluff which is at a protected site along the river. In spite of this natural protection, it has been severely cut away by some erosive mechanism.

Close inspection of Figures 20 and 25 reveals arcuate indentations at or near the bases of the bluffs. The shoreward surface of the beach at these two sites is buried under materials which have slumped out of the indentations in the lower cliff face. This "apron" of sediments, consisting of sand, clay and



Figure 23 Shoreline erosion (black area) around Love Point at the north end of Kent Island during the period 1846 to 1942 based on measurements from old charts and aerial photographs compiled by the Maryland State Geological Survey.



Figure 24 - Randomly dumped automobiles used for shore protection against wave erosion.

occasionally gravel, now provides some temporary protection to the base of the cliffs from waves and currents.

The cause of this erosion can be attributed to the seepage of ground water through the porous sedimentary materials forming much of the exposed banks along the Chester River. These deposits extend inland from the river banks and form the fertile fields used primarily for agriculture in the area. Examination of aerial photographs of the region and direct inspection of many of the eroding banks shows that farmers frequently plow their fields to the very edge of the bluffs, a practice which insures the trapping of rainwater and its ultimate seepage into the soil. The downward percolation of water once it enters the soil tends to follow the path of least resistance, in this case toward the exposed cliff face, where it finally emerges as numerous small rivulets. In the case of the cliff shown in Figure 20, these small rivulets can be seen flowing across the apron of sediments at its base. At the time the photograph was taken, it had not rained for three days. In some cases, water seepage is confined to the upper surfaces of impervious beds exposed in the faces of the bluffs along the river. The clay stratum appearing in Figure 25 near the base of the vertical meter stick is such an impervious layer. The overall process by which water seepage erodes away the cliff's exposed surface is shown diagrammatically in Figure 26.

Shoreline erosion caused by the percolation and seepage of ground water through the exposed surfaces of banks is a significant factor in the loss of shoreline property along the Chester River. Contrary to the widespread belief that waves and currents alone are responsible for the extensive shoreline erosion observed in the river, one finds that rainfall and farming practices play an important role in the loss of many of these shorelines. Identification of this erosion mechanism resolves why severe shoreline attrition can occur in relatively protected areas where the fetch is not sufficient to generate even moderate-sized waves and the only currents of note are those associated with the tides.

Shoreline erosion resulting from groundwater seepage, though widespread in the Chester River, cannot be considered as the only process destroying the shoreline at any given site. Other processes are often at work such as surface water run-off after heavy rain storms. The rapid destruction of shoreline areas during major storms attests to the erosive efficiency of waves and currents in cutting back shorelines. As is generally the case when dealing with environmental phenomena, there is no simple direct relationship between the observed situation and a single process. Thus, one can attribute shoreline erosion to several interacting processes.

Recognizing the different processes responsible for shoreline erosion (those acting from the waterside and those working from the landside), it is obvious

that designs for shore-protection structures which only eliminate the erosive action of waves and currents may not prove effective in cases where ground water percolation is also responsible for the erosion (see Figure 21). In areas where ground water seepage is the major erosive force, shoreline protection schemes may be completely ineffectual unless some sort of drainage system is provided to divert this water away from the exposed surfaces of the bank which are susceptible to erosion. A study to determine water seepage processes should be undertaken, since it may be possible to modify agricultural methods to reduce ground percolation or construct drainage systems near affected areas which would lessen or eliminate water seepage to the free face of the banks. Placing retaining structures at the bases of eroding cliffs has proved by and large to be ineffective in many areas (additional discussion is provided in Section 6 of Volume II). There is a major need to develop better shore protection structures which take into account the multiple erosive forces at work on the shoreline. The valuable acreage lost each year by property owners and the State cannot be allowed to go on unabated.



Figure 25 — Severe erosion along a protected shoreline area due to the slumping away of soil caused by groundwater percolating down through the porous soils and emerging from the face of the bluff (arrow). The water flowing out of the bluff is confined to the zone above the dashed line because of the presence of an impervious clay layer at the base of the bluff. The vertical white stick is a meter in length.

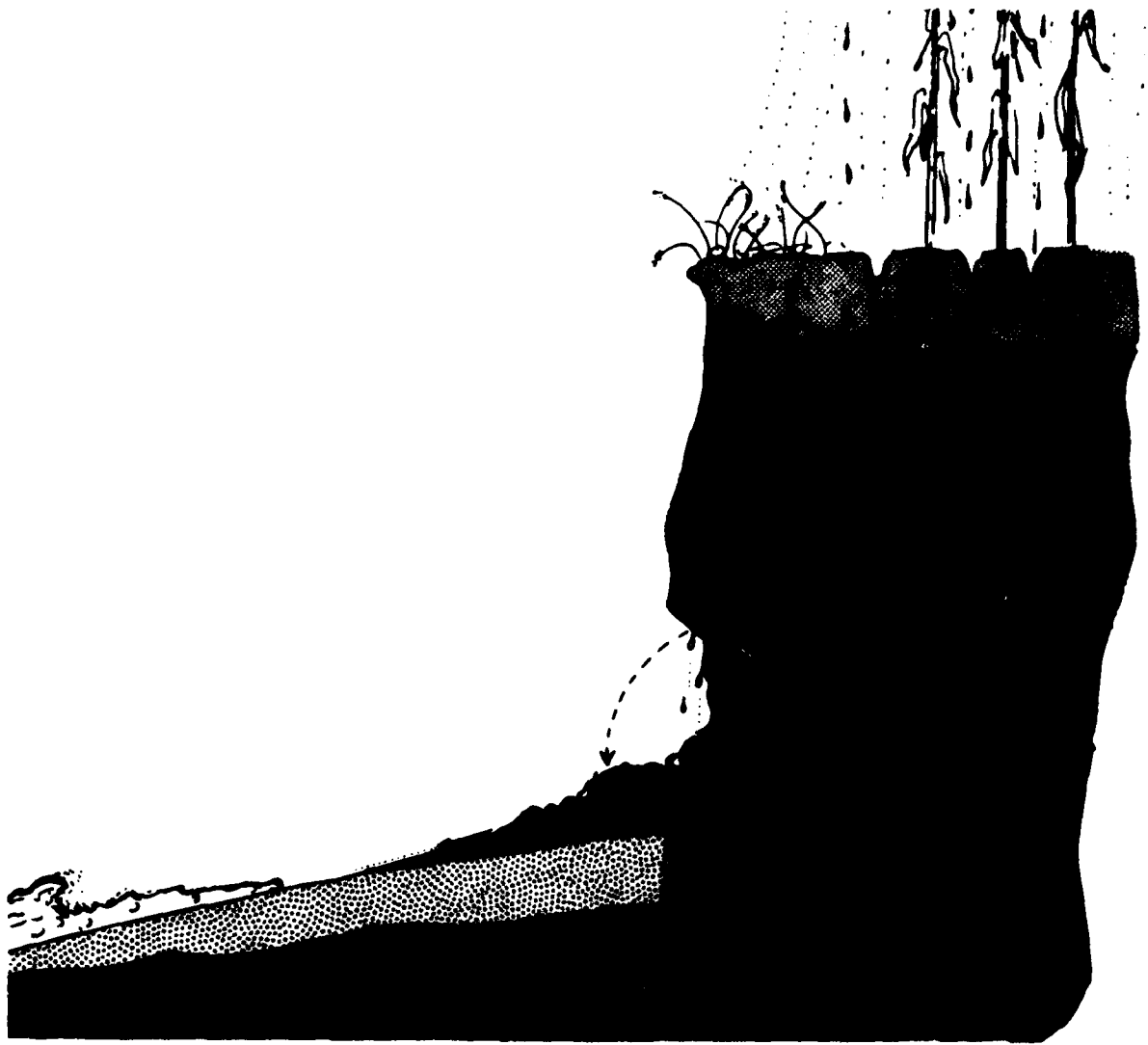


Figure 26 – Diagrammatic illustration of bank erosion caused by the seepage of groundwater. Water from rain or snow melt percolates downward through the porous soils, and then flows out through the exposed faces of banks. The process is accelerated where an impermeable layer, such as the clay (shown in grey), forces water to flow outward near the base of the porous soils. Cultivation of the top of the bank increases the soil permeability and hence the rate of erosion.

APPENDIX – TROPICAL STORM "AGNES"

During the Chester River Study, an extraordinary meteorological event took place in the area. Over the period of 21 to 23 June 1972, the Chesapeake Bay region was struck by tropical storm "Agnes". The severity of the storm has been rated as a "once in 200 years storm". The effects of the storm on the region lasted long after the storm itself had subsided. Fortunately, the Chester River Study was well underway by the time the storm struck so that a well established "baseline" for physical parameters existed to compare with changes brought about by the storm.

Tropical storm "Agnes" produced heavy and prolonged rainfall over a large geographical area of the eastern seaboard. The rainfall in the Chester River area was moderately heavy compared to other areas, amounting to approximately six inches. This rainfall substantially increased the flow from tributaries into the Chester River. The daily mean flow at Morgan Creek, for instance, reached 2810 cubic feet (80 cubic meters) per second compared to a normal flow of approximately nine cubic feet (0.25 cubic meter) per second. Consequently, there was a large influx of freshwater into the upper reaches of the river as a result of the storm.

Of even greater significance to hydrological conditions in the river and upper Bay was the torrential rainfall in the Susquehanna River drainage which is the major tributary to Chesapeake Bay. The rainfall in this area amounted to 12 to 14 inches (30.5 to 35.6 centimeters) and resulted in widespread flooding. In addition to tons of debris and sediment, the river discharged an enormous amount of fresh water into the upper Bay. A measure of this flow can be gained by comparing the long-term average flow of the Susquehanna River at Conowingo Dam, 34,780 cubic feet (985 cubic meters) per second, with the peak flood flow which exceeded 1,000,000 cubic feet (28,320 cubic meters) per second. Considerable amounts of this flood water pushed into the lower reaches of the Chester River and dropped salinities drastically as well as altering other physical parameters.

Extremes in meteorological and hydrological conditions observed in the Chester River Basin during the

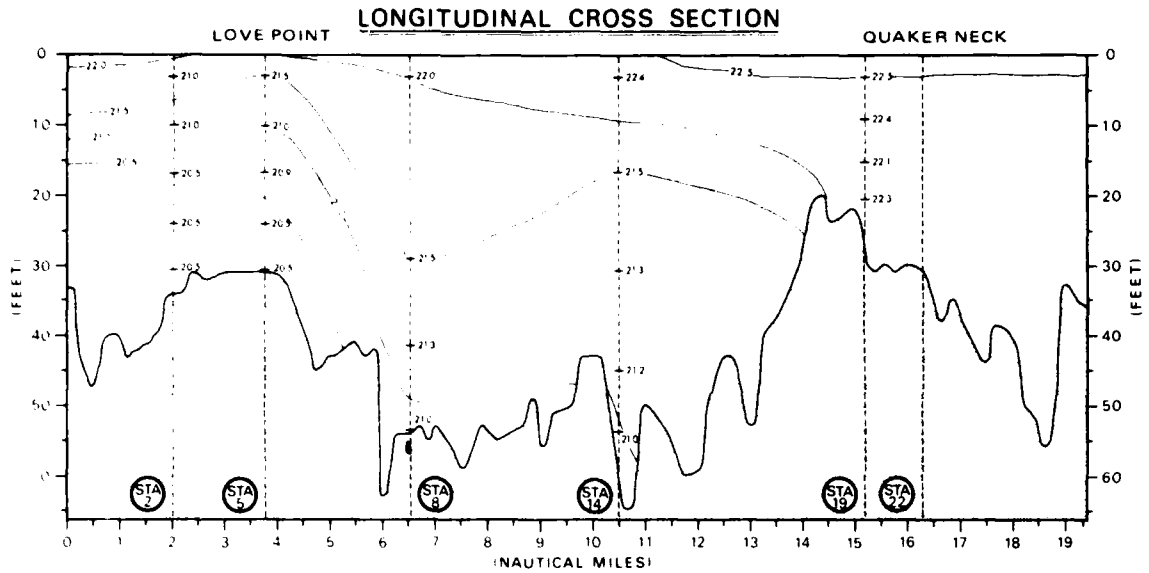
tropical storm "Agnes" period are summarized below:

- **Highest Wind Velocity**
 - 41 knots (76 kilometers/hour) from N.W. at Love Point
 - 44 knots (82 kilometers/hour) from N.W. at Kentmorr Marina
- **Greatest Daily Precipitation**
 - 4.22 inches (10.7 centimeters) at Centreville
 - 2.70 inches (6.9 centimeters) at Eastern Neck Island
 - 6.28 inches (15.9 centimeters) at Chestertown
 - 4.87 inches (12.4 centimeters) at Millington
- **Peak Stream Flow**
 - 7,500 cubic feet (212 cubic meters) per second at Morgan Creek
 - 1,010 cubic feet (29 cubic meters) per second at Unicorn Branch
- **Highest Tide**
 - 3.61 feet (1.10 meters) above mean low water at Love Point
 - 3.99 feet (1.22 meters) above mean low water at Cliffs Point
 - 4.54 feet (1.38 meters) above mean low water at Chestertown
- **Lowest Salinity**
 - 0.6 ‰ (parts per thousand) at the surface off Love Point
 - 2.0 ‰ (parts per thousand) near the bottom off Love Point

Comparisons of the vertical distributions of temperature, salinity, dissolved oxygen, and pH along the axis of the Chester River course before and after the storm are shown in Figures A-1 through A-4. The great quantity of fresh water introduced into the river from the Bay by the flood waters of the Susquehanna reduced salinity at the surface from 6.2 ‰ to 0.6 ‰, and near the bottom from 7.0 ‰ to 2.0 ‰ at Station 2 off Love Point. This same massive influx from the Bay altered the pH and increased the amount of dissolved oxygen near the bottom. Because of the cold, fresh waters from the

**CHESTER RIVER
CHESAPEAKE BAY, MARYLAND**

**TEMPERATURE (°C)
JUNE 19, 1972**



**CHESTER RIVER
CHESAPEAKE BAY, MARYLAND**

**TEMPERATURE (°C)
JUNE 30, 1972**

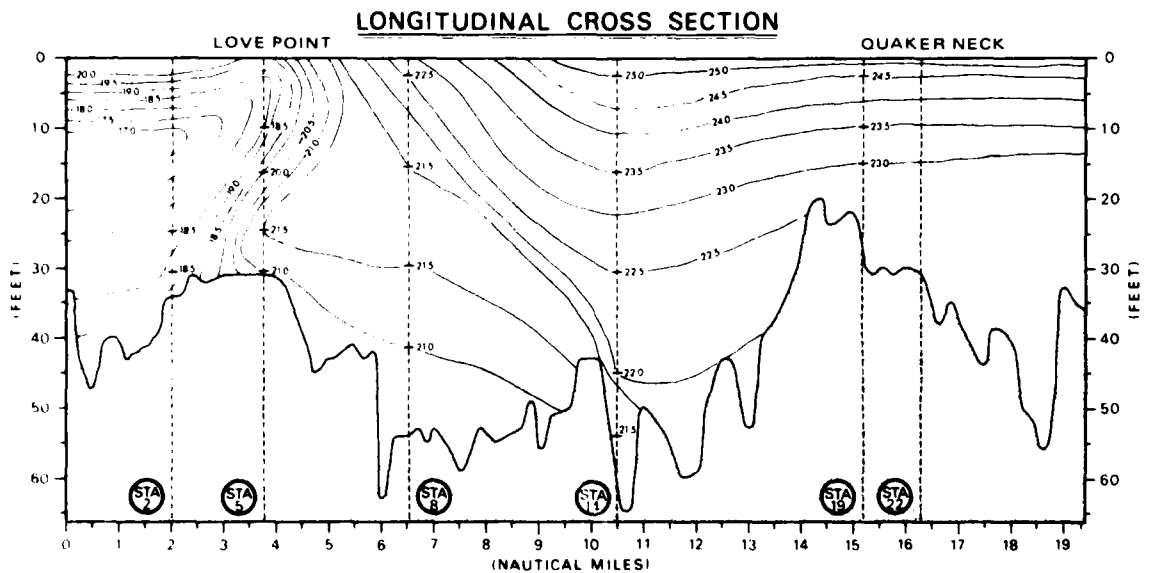
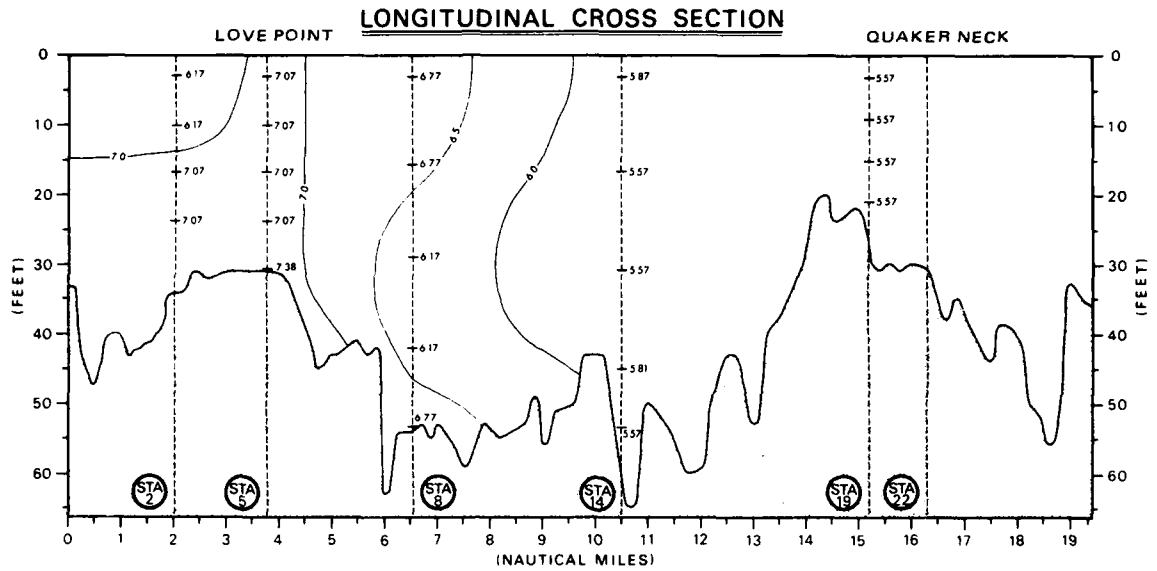


Figure A-1 Variations in water temperature along the main channel of the Chester River before and after tropical storm "Agnes"

**CHESTER RIVER
CHESAPEAKE BAY, MARYLAND**

SALINITY (ppt)
JUNE 19, 1972



**CHESTER RIVER
CHESAPEAKE BAY, MARYLAND**

SALINITY (ppt)
JUNE 30, 1972

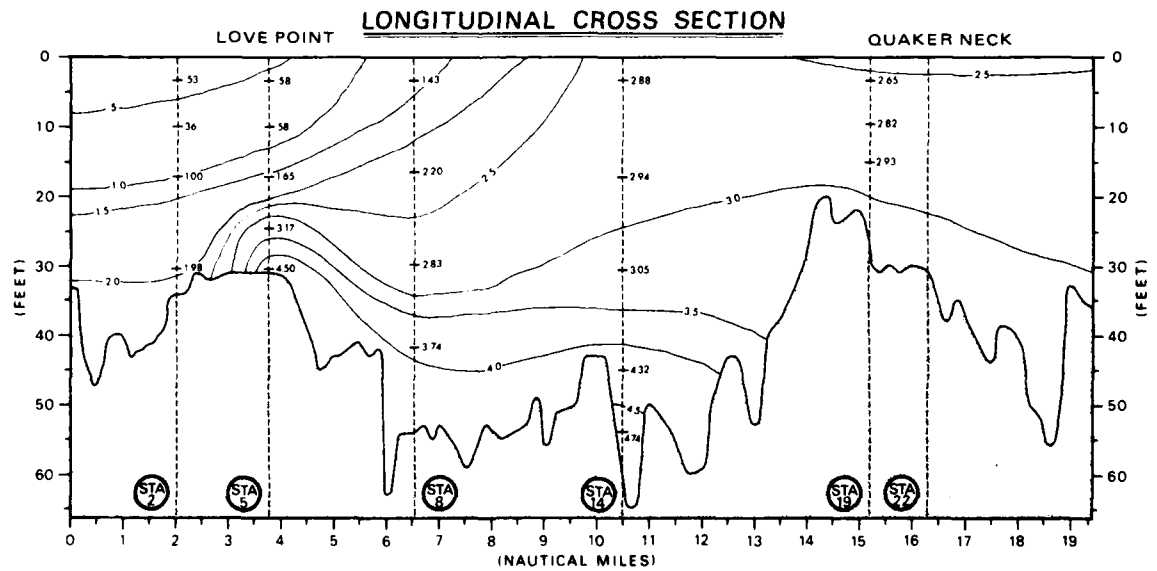
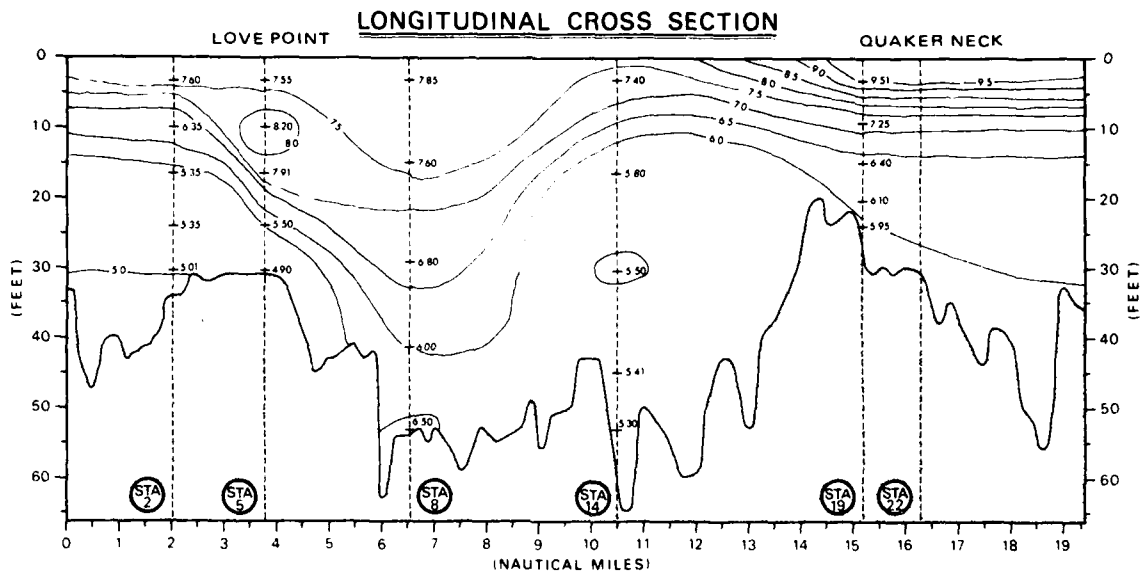


Figure A-2 - Variations in salinity along the main channel of the Chester River before and after tropical storm "Agnes"

**CHESTER RIVER
CHESAPEAKE BAY, MARYLAND**

DISSOLVED OXYGEN (mg/l)
JUNE 19, 1972



**CHESTER RIVER
CHESAPEAKE BAY, MARYLAND**

DISSOLVED OXYGEN (mg/l)
JUNE 30, 1972

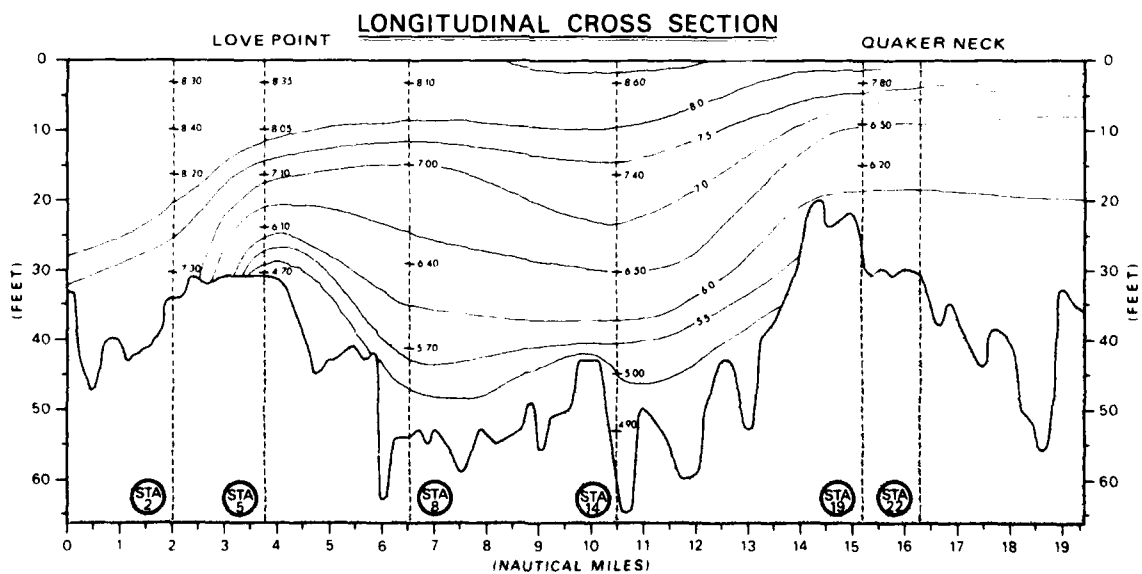
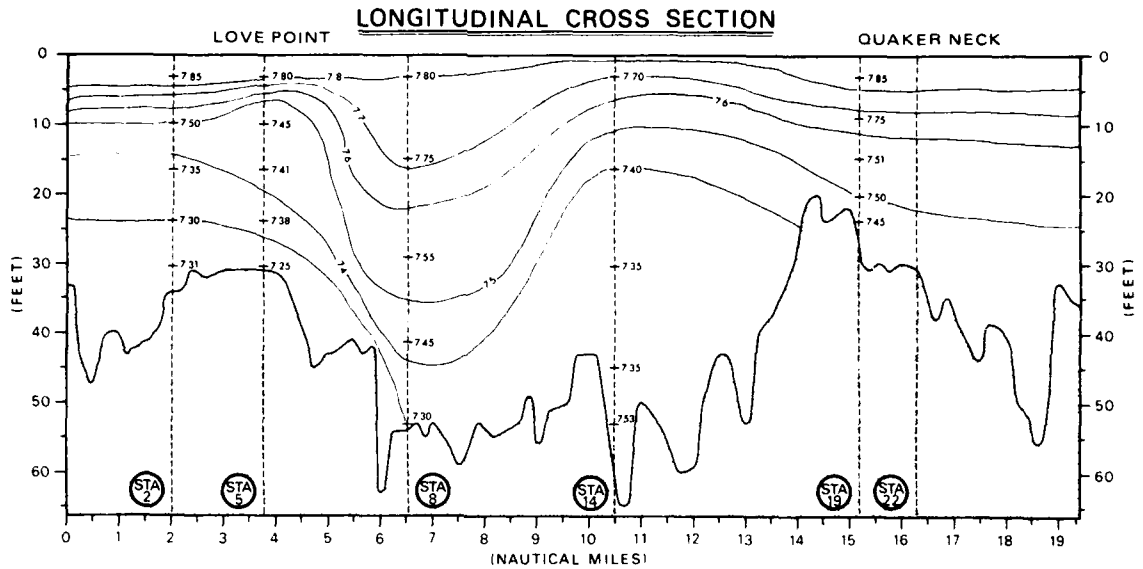


Figure A-3 — Variations in dissolved oxygen along the main channel of the Chester River before and after tropical storm "Agnes"

**CHESTER RIVER
CHESAPEAKE BAY, MARYLAND**

**pH
JUNE 19, 1972**



**CHESTER RIVER
CHESAPEAKE BAY, MARYLAND**

**pH
JUNE 30, 1972**

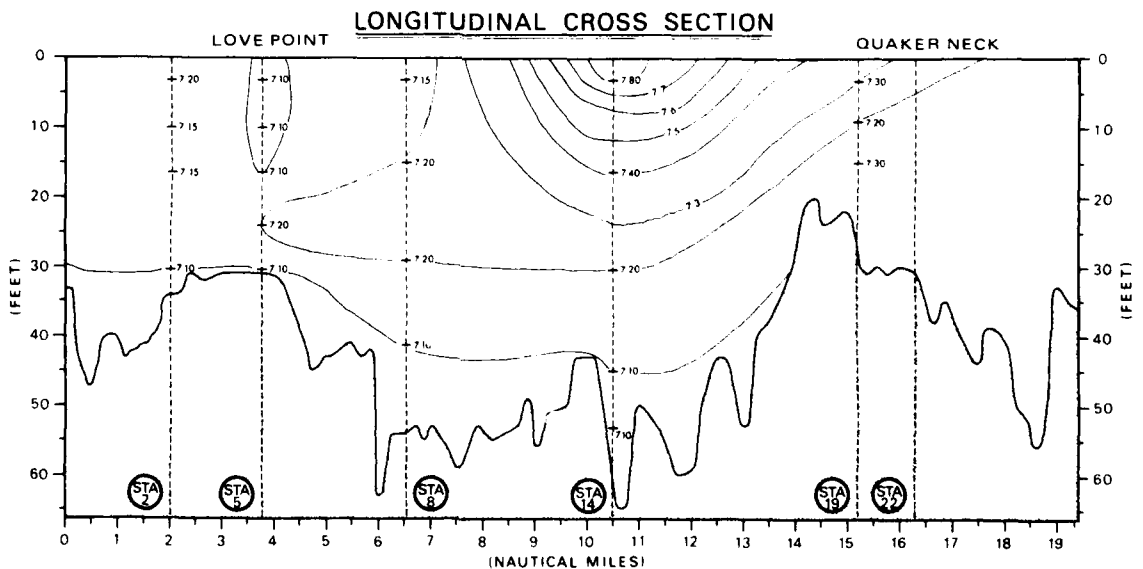


Figure A-4 -- Variations in pH along the main channel of the Chester River before and after tropical storm "Agnes"

TEMPERATURE (°C)

SALINITY (‰)

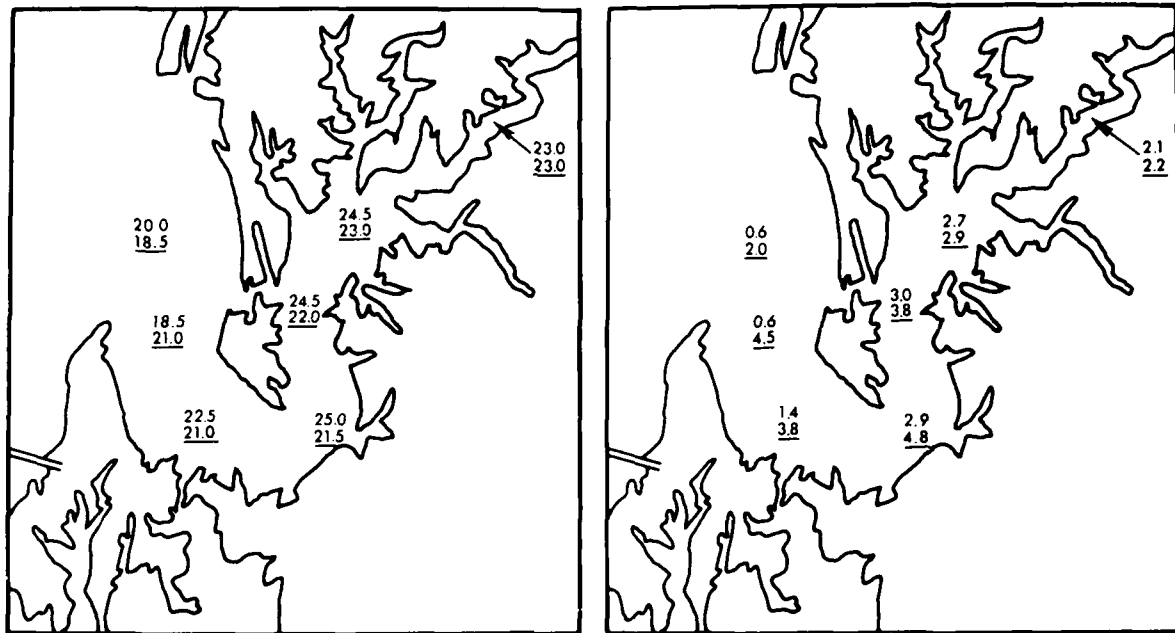


Figure A-5 — Temperature and salinity distributions in the Chester River one week after tropical storm "Agnes" (June 30, 1972). Underlined values are bottom measurements; others are surface measurements.

flooding Susquehanna River, the vertical temperature profile also became greatly changed at this same station, dropping two to three degrees over the entire water column. The blocking of the Chester River's flow by the influx of water from the Bay can be seen quite clearly in these figures and the next. Figure A-5 shows temperature and salinity distributions in the Chester River one week after the storm. Examination of surface temperatures and salinities show that they generally increase in the upstream direction; from 20.0°C and 0.6 ‰ at Love Point to around 25.0°C and 3.0 ‰ in the Queenstown to Tilghman Neck section of the river, indicating that a mass of water was effectively blocked off in that portion of the river. Moreover, the fresh waters coming down from the tributaries of the Chester River were not sufficient to displace this mass of warmer, more saline water.

Twelve samples of sediments taken at stations along the main river channel three weeks after tropical storm "Agnes" were compared with samples taken at the same stations three weeks before the storm struck. With the exception of two of these stations which showed very slight changes, no significant changes could be noted in the sediment properties.

Shoreline areas photographed before the storm were revisited and photographed again in late July. Comparisons of photographs taken at the same sites on the two different dates revealed no change in beach levels or bank erosion. However, along the eastern side of Kent Island there were reports of significant shoreline loss (up to seven feet) and the amounts of suspended sediments in the water were definitely higher.

Some unexpected difficulties with chlorinated hydrocarbon analyses of samples resulted from tropical storm "Agnes". Flood waters apparently contained a substance or substances which masked or interfered with the chlorinated hydrocarbon determinations from the gas chromatograph. This interference prevented the quantitation of chlordane and PCB in some of the analyzed shellfish and sediment samples collected from the Chester River immediately following "Agnes". The most dramatic biological change as a result of tropical storm "Agnes" was the almost immediate dying out of the stocks of soft-shelled clams in the Chester River as a result of lowered salinities.

GLOSSARY

Aldrin: A chlorinated organic compound used as an agricultural pesticide. Aldrin is long-lived because of its resistance to chemical and biological breakdown and, therefore, is of concern as an environmental pollutant.

Arcuate Indentations: Concave or arc-shaped depressions in the face of an eroding bluff which are caused by the slumping away of water saturated soil.

Atomic Absorption Analysis: A method widely used for trace metal analysis. Samples to be analyzed are digested in acid to convert all of the metallic elements to metal salts. These metal salt solutions are aspirated into a flame where the metals are dissociated into individual atoms. The metallic atoms are identified and quantified by measuring the absorption of specific light wave lengths.

Bed Load Transport: A means of sediment movement in which the materials are transported along the bottom of a river or stream course as a mobile bed rather than in suspension in the overlying water.

Biota: The total plant (flora) and animal (fauna) species living in a specific region or environment.

Chlordane: A chlorinated organic compound used as an agricultural and urban pesticide. Chlordane is long-lived because of its resistance to chemical and biological breakdown and, therefore, is of concern as an environmental pollutant.

Chlorinated Hydrocarbons: A class of chemical compounds containing primarily hydrogen, carbon, and chlorine some of which are used widely as pesticides and insecticides. They are chemically long-lived, lasting for years in the environment before they breakdown. Another sub-class of these compounds which are of environmental concern are the PCB's or polychlorinated biphenyls used widely in industrial applications.

Chromatogram: A paper chart record produced by a gas chromatograph when a sample is analyzed. Typically, the record consists of a series of peaks traced on the paper chart by the instrument. The compounds represented by these peaks can be identified and quantified by comparing them with records obtained from known compound standards run through the gas chromatograph.

Clay: Fine-grained sediments which range in size from 0.00025 mm (0.25 micron) to 0.004 mm (4 microns). See definition for silt.

Continuous-Flow Centrifuge: An instrument used to remove fine suspended sediments from liquids by spinning them at high speeds. The continuous-flow centrifuge works on much the same principle as a cream separator.

Correlation Analysis: A statistical analysis used to find the relationships between different variables, for example between rainfall and river flow. See positive correlation.

Crystalline Style: A rod-like structure in the digestive system of the oyster which provides enzymes for digesting its food.

Crystallographic Structure: The regular, physical form assumed by various minerals because of the systematic arrangement of atoms in their crystal lattice. Clays are typically tabular in structure consisting of layers of silica and alumina sheets.

DDD: A natural breakdown product of the pesticide DDT. See definition of DDT.

DDE: A natural breakdown product of the pesticide DDT. See definition of DDT.

DDT: A chlorinated organic compound used as an agricultural pesticide. DDT is long-lived because of its resistance to chemical and biological breakdown and, therefore, is of concern as an environmental pollutant.

Dieldrin: A chlorinated organic compound used as an agricultural pesticide. Dieldrin is long-lived because of its resistance to chemical and biological breakdown and, therefore, is of concern as an environmental pollutant.

Endrin: A chlorinated organic compound used as an agricultural pesticide. Endrin is long-lived because of its resistance to chemical and biological breakdown and, therefore, is of concern as an environmental pollutant.

Food Chain: The feeding relationships between organisms in a given environment. For example, man is the third link in the food chain when he feeds on oysters, since oysters in turn feed on one-celled algae which are at the base of that food chain.

Gas-Liquid Chromatography: An analytical technique for separating structurally similar chemical compounds based upon their differences in relative distribution coefficients between a gas phase and a liquid phase. In this instance the moving phase is the gas and the stationary phase is a liquid (oil) coated on an inert support material. Compounds are identified by the time they take to pass through the gas-liquid column (this property is as specific for a compound as is its vaporization point). Compounds are quantified by comparing the magnitude of the detector response for the sample with known standards.

Gonads: The sexual reproductive organs of animals.

Groundwater: Water from rain or snowmelt trapped within the sub-surface soil. The upper extent of this water saturated zone (the water table) fluctuates vertically depending on additions or removals of water from the system.

Integument: The tough outer tissue covering of the siphon or "neck" of a clam.

Lipids: Oily or greasy organic compounds such as fats, waxes and sterols which often form food-storage materials in animals.

Mass-Spectrometry: An analytical method of determining the molecular structure of compounds. The unknown compounds are vaporized and broken

- into ionic fragments by electron beam bombardment in a mass spectrometer. The charged ionic fragments are then separated and collected on the basis of their charge-to-mass ratio by passing through a magnetic field. The structures of the unknown compounds are obtained by comparing the pattern of ionic fragments from those compounds with the patterns from known compounds.
- Micron:** One thousandth of a millimeter (a millimeter equals approximately 1/25 of an inch).
- Morphological:** Referring or pertaining to body form and structure.
- Multi-Discipline Study:** A study which involves coordinated investigations in several disciplines (examples of disciplines are: chemistry, geology, biology, etc.).
- National Oceanic and Atmospheric Agency (NOAA):** A federal agency within the Department of Commerce charged with research and services in the marine and atmospheric sciences.
- Parameter:** A variable such as temperature, salinity or dissolved oxygen which sets the physical conditions in the environment.
- PCB's:** Properly called polychlorinated biphenyls. These compounds are a subclass of chlorinated hydrocarbons used in chemical preparations for industrial uses including electrical insulating fluids, hydraulic fluids, heat exchanger fluids, as additives to plastics, inks, embedding compounds, paints and sealants. Formulations of these compounds with differing degrees of chlorination are sold under the trade name Aroclor by the Monsanto Chemical Corporation.
- Pesticides:** Compounds used to control insects and other pests. In this report, the term refers primarily to the "hard" chlorinated pesticides or insecticides which are resistant to biological and chemical degradation.
- Physiographic:** Pertaining to the general topographic or land-relief features in an area.
- Positive Correlation:** The condition where there is a direct relationship between variables or phenomena in the environment: i.e. as the salinity or water increases, the density increases. A negative correlation indicates an inverse relationship between variables or phenomena in the environment; i.e. as the temperature of water increases the density decreases.
- Qualitation:** The analysis of materials to determine what kinds of materials are present, in the case of this study primarily the identification of chemical compounds.
- Quantitation:** The analysis of materials to determine how much of the different kinds of materials are present.
- Raptorial:** Pertaining to the large birds of prey which hunt and seize their food alive, such as the hawks, eagles and falcons.
- Refracted Waves:** Waves which have had their direction of advancement changed because of the shoalness of the bottom. When waves enter shallow areas they are slowed and turned towards shore because of the drag produced on the wave's motion by the bottom.
- Scanning Electron Microscope:** An instrument for greatly magnifying (up to several 100,000 times) small objects. The image of the magnified object is produced by scanning the material examined with a controlled beam of electrons and recording the image on photographic film.
- Sediment:** Solid particulate matter such as sands, silts and clays. Suspended sediments are any of the above materials carried by the water.
- Seismic Profiling:** A survey method using sound to map the structure of sediments underlying a river course or other body of water.
- Silt:** Small-grained sediments ranging in size from 0.004 mm (4 microns) to 0.062 mm (62 microns). See definition of clay.
- Siphons:** Tubular body structures of clams used to convey water with its associated food and oxygen to the mouth and gills and to conduct away waste and respiratory products from the mantle cavity surrounding the body of the clam.
- Synergistic:** Two factors acting together where the combined effect is greater than the sum of the two acting independently.
- Thin-Layer Chromatography:** An analytical technique using plates coated with a thin-layer of inorganic adsorbent materials (the stationary phase) upon which the chemical compounds to be analyzed are spotted at a known position. A solvent (the moving phase) is passed over the plate and the chemical compounds are separated by moving different distances because of their differing relative distribution coefficients in the two phases. The distance of separation from the spotting point for the unknown compounds are noted relative to distances for known compounds analyzed in the same manner thereby identifying the unknown compounds.
- Toxaphene:** A chlorinated organic compound used as an agricultural pesticide. Toxaphene is long-lived because of its resistance to chemical and biological breakdown and, therefore, is of concern as an environmental pollutant.
- Toxicity:** The determination of the degree of poisonous effect on an organism from a known amount of toxic material.
- Trace Metals:** Metal elements which are present in the environment usually in very small quantities, less than one part per thousand. This term is more or less synonymous with "heavy metals" or "toxic metals" as used by some other authors.
- Trophic Level:** Refers to the feeding level within the food chain occupied by an organism. For example, algae are the first trophic level in the food chain where they form the food of oysters which are the second trophic level while humans form a third trophic level when they eat oysters.
- °/oo:** Symbol designating parts per thousand.

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— 8