1983

A statistical model to predict the incidence of pathogenic protozoa (amoebida: acanthamoebidae) in oceanic sediments using surrogate variables

Carl Robert Berman Jr
College of William and Mary - Virginia Institute of Marine Science

Recommended Citation

Berman, Carl Robert Jr, "A statistical model to predict the incidence of pathogenic protozoa (amoebida: acanthamoebidae) in oceanic sediments using surrogate variables" (1983). *Dissertations, Theses, and Masters Projects.* Paper 1539616564.
https://dx.doi.org/doi:10.25773/v5-65mg-nr33

INFORMATION TO USERS

This reproduction was made from a copy of a document sent to us for microfilming. While the most advanced technology has been used to photograph and reproduce this document, the quality of the reproduction is heavily dependent upon the quality of the material submitted.

The following explanation of techniques is provided to help clarify markings or notations which may appear on this reproduction.

1. The sign or "target" for pages apparently lacking from the document photographed is "Missing Page(s)". If it was possible to obtain the missing page(s) or section, they are spliced into the film along with adjacent pages. This may have necessitated cutting through an image and duplicating adjacent pages to assure complete continuity.
2. When an image on the film is obliterated with a round black mark, it is an indication of either blurred copy because of movement during exposure, duplicate copy, or copyrighted materials that should not have been filmed. For blurred pages, a good image of the page can be found in the adjacent frame. If copyrighted materials were deleted, a target note will appear listing the pages in the adjacent frame.
3. When a map, drawing or chart, etc., is part of the material being photographed, a definite method of "sectioning" the material has been followed. It is customary to begin filming at the upper left hand corner of a large sheet and to continue from left to right in equal sections with small overlaps. If necessary, sectioning is continued again—beginning below the first row and continuing on until complete.
4. For illustrations that cannot be satisfactorily reproduced by xerographic means, photographic prints can be purchased at additional cost and inserted into your xerographic copy. These prints are available upon request from the Dissertations Customer Services Department.
5. Some pages in any document may have indistinct print. In all cases the best available copy has been filmed.

University
Microfilms
International

300 N. Zeeb Road
Ann Arbor, MI 48106

Berman, Carl Robert, Jr.

A STATISTICAL MODEL TO PREDICT THE INCIDENCE OF PATHOGENIC PROTOZOA (AMOEBIDA:ACANTHAMOEBIDAE) IN OCEANIC SEDIMENTS USING SURROGATE VARIABLES

The College of William and Mary in Virginia PH.D. 1983

University
Microfilms
International 300 N. Zeeb Road, Ann Arbor, MI 48106

A STATISTICAL MODEL TO PREDICT THE INCIDENCE OF PATHOGENIC PROTOZOA (AMOEBIDA:ACANTHAMOEBIDAE) IN OCEANIC SEDIMENTS USING SURROGATE VARIABLES

A Dissertation
Presented to

The Faculty of the School of Marine Science
The College of William and Mary in Virginia

In Partial Fulfillment
of the Requirements for the Degree of
Doctor of Philosophy

---

by

Carl Robert Berman, Jr.
Commander, NOAA
National Marine Fisheries Service
Sandy Hook Laboratory
Highlands, New Jersey

APPROVAL SHEET

This dissertation is submitted in partial fulfillment
of the requirements for the degree of

Doctor of Philosophy

Author

Approved, July 1983

Herbert M. Austin
Dr. H. M. Austin, Chairman

Robert P. Byrne
Dr. Robert Byrne

M Bender
Dr. M. Bender

Robert J Diaz
Dr. R. Diaz

Dr. M. Lynch

Thomas K. Sawyer
Dr. T. K. Sawyer
National Marine Fisheries Service
Oxford, Maryland

DEDICATION

This dissertation is dedicated to my daughter, Suzanne Ferris Berman, who was born on the 13th of January 1981, in the hope that this work will, in some small way, make her world a better place in which to live.

TABLE OF CONTENTS

Note: Microfiche transparencies of all computer printouts are contained in the envelope inside the back cover.

ACKNOWLEDGEMENTS

The pursuit of a terminal degree is never an easy task. Whether one is a full-time student or involved in outside employment, the hours available for dissertation activities never seem sufficient.

I am indebted to RADM Harley Nygren, NOAA (Ret.) and to Dr. Thomas K. Sawyer, NMFS, for giving me the opportunity to follow my academic career while my work with NOAA was an everyday reality. Dr. Sawyer not only served on my committee but also followed the progress of this project with enthusiasm; providing valuable insight and criticism as the work progressed.

I also wish to thank the other members of my Committee, Drs. Herb Austin, Chairman, Bob Byrne, Mike Bender, "Mo" Lynch, and Bob Diaz of the Virginia Institute of Marine Science, College of William and Mary. Their scientific review and editorial tasks were carried out, for the most part, through the mail, and I appreciate their rapid response to the various drafts I submitted.

Drs. Aaron Rosenfield, Director, Oxford Laboratory, and J. B. Pearce, Chief, Environmental Assessment Division, Sandy Hook Laboratory, were also instrumental in allowing the concurrent scheduling of academic and professional responsibilities.

My wife, Ginger, and my daughter, Suzanne, who was born while this work was in progress, followed my activities with interest and provided the love and encouragement so necessary to the success of any personal undertaking. My mother-in-law, Sarah Ferris, cared for Suzanne throughout all the stages of this research and gave me the time required for visits to the library and computer center.

I also wish to thank my parents, Carl and Blanche Berman, for giving me a love of nature and knowledge, and for providing me, at an early age, with an understanding of the importance of hard work and scholarship.

I am especially indebted to Dr. Larry Jenkins, Tidewater Community College, for his advice during the analysis phase of the investigation. His knowledge of statistics and his unique ability to explain this sometimes esoteric field in a meaningful and straightforward manner were invaluable assets which permitted me to produce an analysis from widely diverse and unrelated data sets.

Last, but certainly not least, I wish to thank Ms. Maureen Montone, Editorial Assistant, NMFS, NOAA, who took time from her busy schedule and demanding responsibilities to process the final manuscript.

The individuals listed below gave of their time and expertise during the course of this project. I am grateful to them all.

Dr. G. H. Kim, Sandy Hook Laboratory
Dr. Don Lear, EPA
Mauria O'Malley, EPA
Dr. Don Phelps, EPA
CDR N. Adams, USPHS
Ms. Pat Fournier, Sandy Hook Laboratory
V. Zdanowicz, Sandy Hook Laboratory

Bob Pease, EPA/STORET
Bob Paine, EPA
Bruce Reynolds, EPA/STORET
H. Shirer, NOAA, NODC
G. Mayer, NOAA/OOAS
J. Odett, NODC
Solon E. Paul

LIST OF TABLES

LIST OF TABLES (continued)

Table Page

LIST OF FIGURES

ABSTRACT

Surrogate contaminant variables (heavy metals, organics, physical oceanographic data) can be used to predict the incidence of positive cultures of Acanthamoeba sp. in oceanic sediments. Amoebae data are drawn from five years of study involving stations in Narragansett Bay, Rhode Island, the New York Bight, and the Philadelphia-Camden dumpsite, and associated pollution parameters are drawn from literature sources, computerized marine pollution data bases, and other archives.

The Statistics Analysis System (SAS) MAXR^2 improvement technique (stepwise regression) and general linear model procedures are used to generate correlations for surrogate variables and produce final predictive models and tables. Model procedures for the three study areas are most valid for Narragansett Bay and the New York Bight but less valid for the Philadelphia-Camden dumpsite due to the small quantity of relevant data. The Durbin-Watson statistic is used to test for autocorrelation of model residuals and, using this test, the Philadelphia-Camden model is again found to be the least valid, although applicable within limits.

The division of contaminant variables into "tactical" (short-term, simple analysis) and "strategic" (long-term, more complex analysis) categories enhances the predictive effort through the introduction of a cost-effective procedure evaluation. Generally, the simple variables predict the incidence of positive Acanthamoeba cultures as well as the more complex data sets.

There are sufficient data and applicable computer programs to produce useful results for an investigation involving potentially pathogenic protozoans and public health management decisions may be made using the tables and formulae generated using these procedures.

A STATISTICAL MODEL TO PREDICT THE INCIDENCE OF PATHOGENIC PROTOZOA (AMOEBIDA:ACANTHAMOEBIDAE) IN OCEANIC SEDIMENTS USING SURROGATE VARIABLES

INTRODUCTION

In 1980 a microbiological study of Narragansett Bay, Rhode Island was conducted aboard the NOAA Ship GEORGE B. KELEZ (R-441). The study included stations from the vicinity of the Fields Point Sewage Treatment Plant seaward to 25 miles south of the Rhode Island shore. Statistical analysis of the data collected during this cruise indicated that there was, in this location and for these stations, a high positive correlation between bacterial MPN (most probable number of bacteria per 100 grams of sediment) and positive *Acanthamoeba* stations cultured from the same benthic materials (Sawyer, 1980). A negative correlation between these two microbiological measurements and distance from the Fields Point outfall also emerged as significant. Later cruises confirmed that the same correlations could be demonstrated for the New York Bight apex and portions of the inactive Philadelphia-Camden dumpsite (Lear and O'Malley, 1982; Sawyer, 1980).

During subsequent investigations, however, positive *Acanthamoeba* stations were recovered from sites in which no fecal coliform or streptococcal bacteria were found (Sawyer, 1980) and, the question arose as to whether or not the incidence of the *Acanthamoeba* could be predicted using variables other than the bacterial MPN. Since the amoebae were known to feed on bacteria which were alive (recoverable) and dead (nonrecoverable), the correlation appeared to break down in areas in which the bacteria were no longer viable. In contrast to enteric bacteria which may lose their viability after several weeks or months, most species of *Acanthamoeba* form resistant cysts which may survive for as long as 33 months after refrigeration of sediment samples (Sawyer, personal communication).

Statistical methods to be presented below show that significant levels of pollutants in marine sediments may be as useful as bacterial MPN's for predicting the presence of *Acanthamoeba*. *Acanthamoeba* are also an important public health consideration. The infection that these protozoans can cause may result in serious illness for healthy individuals but is more devastating, even fatal, in those persons already possessing an impaired immune system (Martinez, 1980).

The amount of sewage-related materials dumped in the oceans will increase substantially by the year 2000. During this same period, populations will increase and pressure on shoreline recreational facilities will rise accordingly (Cabelli et al., 1975; Goudette et al., 1981). For this reason, and because the study and culturing of the *Acanthamoeba* themselves is a highly technical and labor intensive process, pertinent statistical correlations between *Acanthamoeba* and other environmental contaminants which may be used to predict the incidence of the pathogenic protozoa in sediments using surrogate variables, becomes an important area for investigation.

The potential value of meaningful statistical correlations include:

1. Delineating and characterizing the dumpsite (hydrographic and geological properties);
2. Determining the degree of infestation, over time, represented by various microorganisms indigenous to waste materials;
3. Estimating potential public health considerations represented by concentrations of *Acanthamoeba* in or near areas of recreational fishing, swimming, or other activities associated with the marine environment;

4. Tracking the subsequent dispersal of the material in order to determine further threats to marine benthos and human populations;
5. Estimating the rate of recovery of inactive dumpsites once dumping activity ceases (Pearce, 1981).

Numbers 1-3 above were the primary considerations of the study. Numbers 4 and 5 represented additional information which could result from the statistical applications used to analyze the data sets.

The study used five years of accumulated Acanthamoeba field data and expanded the parameters to include the following:

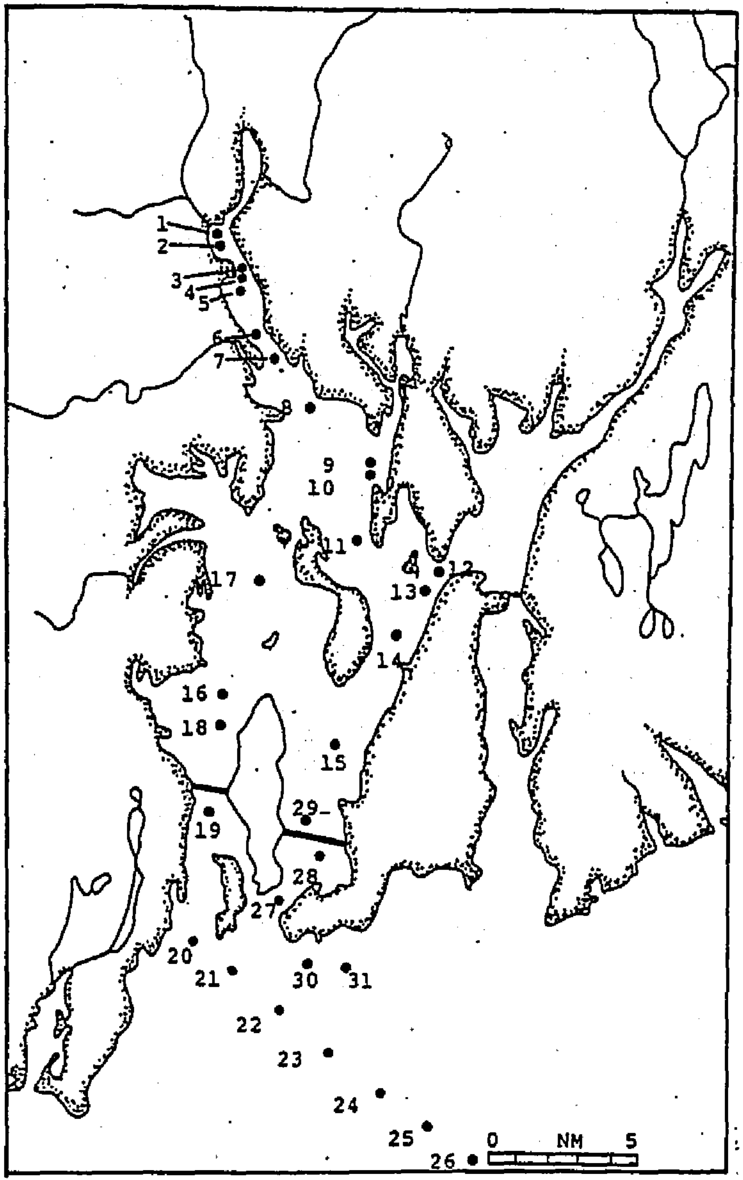
1. Bacterial (fecal coliform) MPN ;
2. Acanthamoeba cultures, positive and negative/station;
3. Sediment color, coded from five, black mud, to one, clean sand;
4. Sediment grain size (% silt and clay);
5. Polychlorinated biphenyls (PCBs);
6. Coprostanol (a fecal steroid);
7. Metals in sediments (copper, lead, zinc, etc.);
8. Ratio of total carbohydrates (TCH) to total organic carbon (TOC) or TCH:TOC;
9. Salinity at sample depth;
10. Temperature at sample depth;
11. Distance from point source (e.g., dumpsite depositional center or outfall pipe aperature);
12. Current patterns observed in the areas under study (direction and speed; current meter and remote sensing information).

Data sets which included but were not limited to the parameters listed above were known to exist for three different marine environments in which Acanthamoeba studies had been undertaken:

1. Narragansett Bay (estuary, inshore, surrounded on three sides by landforms; STORET, EPA, 1982; Wrens, 1953) Figure 1;
2. The New York Bight apex (shallow shelf, generally responding to meteorological conditions; Beardsley et al., 1976; NODC, EDIS, NOAA, 1982; STORET, EPA, 1982; Whitledge, personal communication) Figure 2;
3. The Philadelphia-Camden dumpsite (offshore, outer continental shelf; Boesch, 1977; O'Malley, personal communication) Figures 3 and 4.

These data were used to test the hypothesis that the development of a statistically valid method for predicting the incidence of pathogenic microorganisms in and around sewage disposal sites was possible, and that the correlation between the variables outlined above and the probability of obtaining positive/negative cultures of Acanthamoeba sp. may be determined using this method. Furthermore, the use of stepwise regression techniques may permit the computation of statistically valid probabilities for the presence or absence of one group of factors which have not been sampled based upon correlations between these surrogate variables and other groups of environmental indicators for which values are known.

Figure 1. Narragansett Bay showing stations sampled for *Acanthamoeba*. The Fields Point facility mentioned in the text is west of stations 3, 4, and 5 (Sawyer et al., 1980a, in press).



1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
0
NM
5

Figure 1

Figure 2. New York Bight apex showing stations sampled for *Acanthamoeba*. The dashed boundary represents the eastern and southeastern limits of the area closed to shellfishing (Sawyer, 1980b).

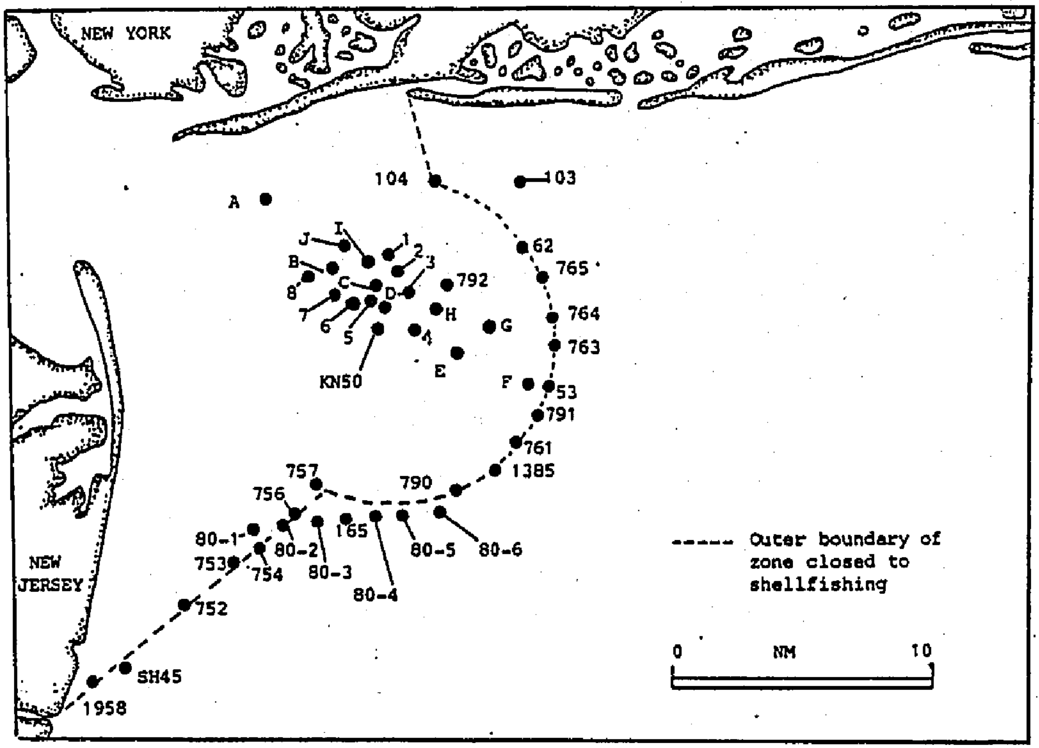

NEW YORK
NEW JERSEY
104
103
A
62
765
764
763
J
I
1
2
3
B
8
C
D
792
7
6
5
H
4
G
KN50
E
F
53
791
761
1385
757
790
756
80-1
80-2
165
80-3
80-4
80-5
80-6
753
754
752
SH45
1958
Outer boundary of zone closed to shellfishing
0
NM
10

Figure 2

Figure 3. Site location map for the Philadelphia-Camden dumpsite showing the dumpsite as a rectangle between the 40 and 70 m isobaths. Large area enclosed by dashed lines has been sampled extensively (400 stations). Also shown are the transects shoreward from the 40 m isobath to the Delaware Bay and Ocean City, Maryland outfall, and the transect northward to the New York Bight apex (from O'Malley et al., 1982).

Figure 4. Detail of the Philadelphia-Camden wastewater sludge disposal site in the northeast Atlantic Ocean. Upper box outlines an inactive acid dumpsite. Lower box delineates inactive sludge dumpsite. Positions are shown for stations in this area sampled for *Acanthamoeba* (from Sawyer et al., 1982).

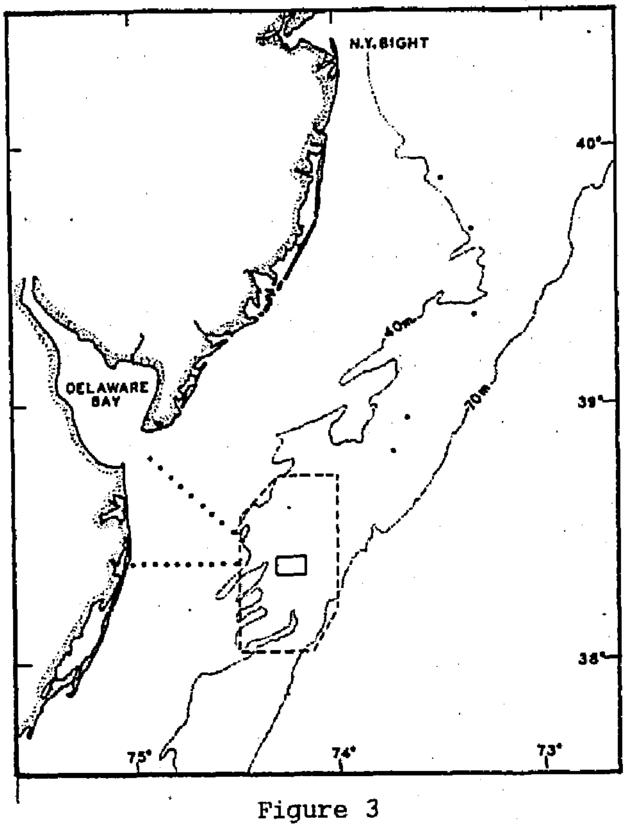


Figure 3

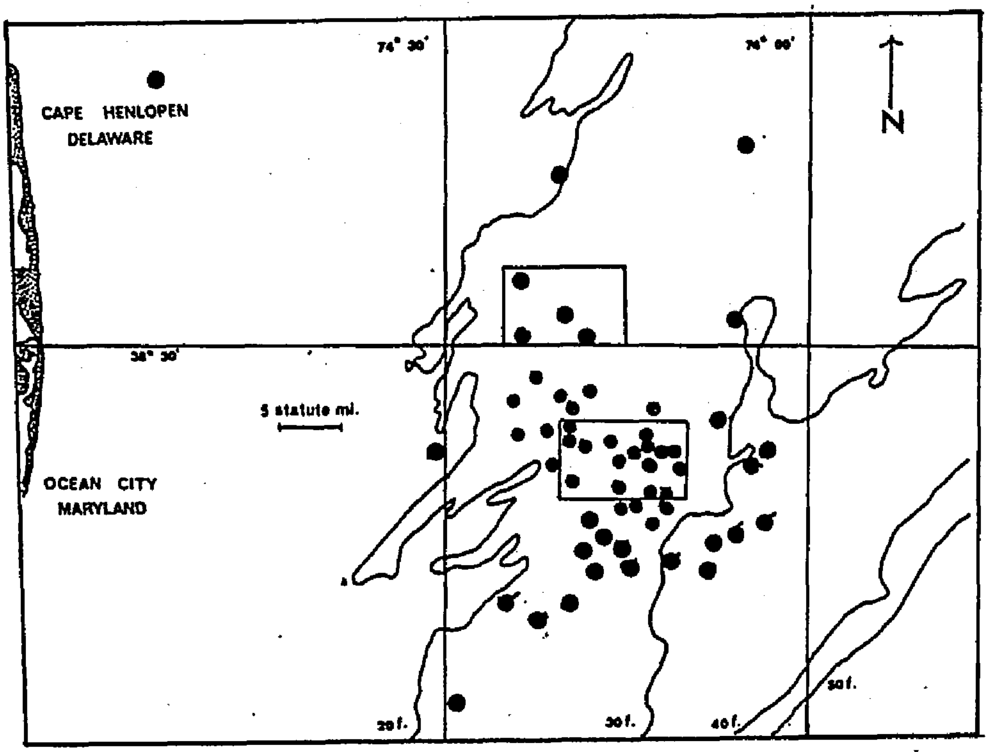


Figure 4

REVIEW OF THE LITERATURE

The purpose of the following literature review is to demonstrate that the selection of surrogate variables noted in the INTRODUCTION represents a valid approach to the problem of predicting the incidence of pathogenic protozoa (*Acanthamoeba*) in sediments using statistical methods. Such justification is a necessary first step in the formulation of any correlative model (Basta and Bower, 1979).

Amoebae and Bacteria

The association of species of *Acanthamoeba* and bacteria with sewage sludge has been noted by several investigators. Studies have included areas off the DelMarVa Coast (Lear et al., 1981; Lewis and Sawyer, 1979; Sawyer, 1979), Narragansett Bay (Sawyer et al., 1982), and the New York Bight apex (Sawyer, 1979). *Acanthamoeba* were abundant wherever sewage sludge was deposited. Species of *Acanthamoeba* included several that are known to cause death in man and animals. Page (1974) refers to these protozoans as "amphizoic", i.e., they are typically free living but may be opportunistically parasitic. The first known pathogenic species, *A. culbertsoni*, to be isolated from marine sediments was discovered in 1959 (Culbertson et al., 1959). Singh and Das (1972) found the same organisms in municipal sewage sludge from the city of Lucknow, India. The first recovery of this species from oceanic sediments was carried out at the National Marine Fisheries Service's Oxford Laboratory by Sawyer (1979).

Correlation analysis of *Acanthamoeba* culture and bacterial MPN data from field studies support the existence of a relationship between the distribution of *Acanthamoeba* and associated fecal indicator bacteria (coliforms and streptocci) and between these organisms and the degree of sewage sludge contamination (Mayer, 1982). These same investigations were also valuable in pointing out those areas in which the correlation between these biotic indicators and anthropogenic wastes appeared to break down (Lear et al., 1981; O'Malley et al., 1982; Sawyer, 1980).

These reports stress the importance of laboratory procedures required to determine the coliform counts (MPNs). Generally, appropriate facilities and a trained technician are required in order to obtain valid data. Of particular importance are the innoculation procedures, preparation of proper growth media, temperature control, and accurate species identification. The culturing of the Acanthamoeba requires painstaking accuracy and inordinate patience (Sawyer, 1980).

Even if a public health laboratory has the facilities and personnel to culture and identify these organisms and then carry out temperature specific tests to isolate pathogenic species which can grow at 37°C, human body temperature (Sawyer et al., 1982), the time element may be too long if an immediate management decision is necessary.

Distance from Point Sources

These same published reports contain evidence that there is a valid negative correlation between the incidence of the Acanthamoeba and the distance at which samples are taken from the dumpsite depositional center or outfall aperture. The further away from a point source the samples are taken, the less is the probability of obtaining positive cultures of the amoebae and high bacterial MPNs (O'Malley et al., 1982; Sawyer et al., 1982).

Metals in Sediments

The contamination of marine sediments by metals has been the subject of much attention in recent years (Donozzolo et al., 1981;

Selli et al., 1977). A large body of relatively recent data also exist for the New York Bight area (Calabrese et al., 1982; Gross, 1975; Young, 1982). Mueller and Anderson (1978) compiled an extensive monograph on the results of the Marine Ecosystems Analysis (MESA) studies carried out in the Bight including sources for environmental copper, zinc, cadmium, lead, and chromium. These studies indicate that concentrations of metals in sediments are highest near the depositional centers of sewage dumpsites and that the amount of metal present decreases as distance from this center increases (Hershelman et al., 1981). In fact, concentrations of some metals may be 100 times higher than ambient environmental levels in and around sewage disposal locations (Boehm, personal communication).

Fecal Steroids (Coprostanol)

The use of fecal steroids (coprostanol) as indicators of sewage contamination has been shown to have a practical application (O'Conner et al., 1982). When the coprostanol represents a high percentage of the total environmental steroids measured (10-15%), a quantitative relationship can be computed between the percentage of steroids and the amount of sewage related organic matter (Hatcher and McGillivary, 1979). In fact, once deposited, coprostanol persists in anaerobic low-lying areas in which these materials concentrate and can be used as an indicator of previous waste disposal activities (Hatcher and McGillivary, 1979). In these studies, coprostanol from actual sewage treatment facilities was analyzed in order to demonstrate that environmental steroids were derived from both ocean-dumped and sewage outfall materials. The results showed that coprostanol could be used to delineate vertical and horizontal sediment profiles for sewage contamination and that percentages of coprostanol decreased directly with distance from the pollution point source (Hatcher et al., 1977).

The Ratio of Total Organic Carbon (TOC) to Total Carbohydrate (TCH)

Hatcher and Keister (1976) reported that the ratio of TOC to TCH could also serve as an indicator of sewage sludge contamination. When the ratio TCH:TOC was greater than or equal to 30, the value may be attributed to materials derived from sewage. The extremely high values in the Christiaensen Basin, New York Bight, reported by Hatcher and Keister (1976), ratio values of 40 to 60, and the evident decrease in values toward the shelf edge, indicate a correlation which represents a valuable surrogate variable for the proposed correlative model.

Polychlorinated Biphenyls (PCBs)

PCBs also represent an appropriate surrogate variable for use as a sewage pollution indicator. West and Hatcher (1980) showed that:

1. "Despite the limited recent use of PCB's, sewage sludges continue to exhibit a high concentration of PCB's.
2. Upon dumping of sludge into the ocean, PCB's are rapidly removed from the water column via scavenging particulate matter. This settling of particulate matter occurs over a very short period of time and is probably an important mechanism for rapid transport of PCB's to surficial sediments.
3. The highest PCB concentrations in surficial sediments were found in a small area of the Christiaensen Basin near the sewage sludge dumpsite. These high values are probably associated with the recently deposited sludge which remains as a soupy layer above older, more consolidated muds.
4. PCB distribution in a box core suggest that high PCB concentrations have existed since the introduction of these chemicals in 1955, and their subsequent widespread use and that levels are also correlated to dramatically increased volumes of sludge deposited in the Bight Apex since 1952."

Sediment Parameters

Numerous studies have been made on the sediment regime in areas under consideration. Freeland and Swift (1978) treat the New York Bight in considerable detail. The majority of papers mentioned almost always include a description of sediment color and/or grain size for each sample taken regardless of the purpose for which the station was occupied (Douglas, 1981; Eisma, 1981). These descriptions range from "black mayonnaise" (Harris, 1974), to "clean white sand" (Hatcher and McGillivary, 1979). Sediment color, nominal data, can be coded into ordinal form (e.g. "5" for black sediments to "1" for clean sand) and used in statistical computations (Zar, 1974). There are also historical data of sufficient quality to permit comparison between archival data (literature, computer data base) and dominant sediment types/colors in the New York Bight (Gross, 1975) the outer continental shelf (Boesch, 1975), Narragansett Bay (Wrens, 1953), and for all three areas combined (National Geological Survey Marine Geology Data Inventory, 1982; ORCA, 1981; STORET, EPA, 1982).

Circulation Patterns

The circulation patterns which determine the distribution of sediments and other suspended solids are also well documented (Kavanaugh, 1980; Fisher et al., 1979). The New York Bight circulation has been described by Gross (1975), Hansen (1977), and, more recently, using satellite imagery, by Munday (1982). Data for the outer continental shelf are available in Goldsmith (1974, 1977) and Butman (1977). Narragansett Bay tidal currents are the subject of a paper by Swanson and Spauling (1979). Recent emphasis in current regime investigations has shifted somewhat from field to modelling studies. At present, many models exist for pollution dispersal and these may be applied to all of the geographic areas involved in the present study (Hinson, 1979; Ingham, 1982; Whitledge and O'Conner, personal communications).

Salinity and Temperature

Salinity and temperature represent the most complete marine data files available (NODC/EDIS/NOAA, 1982). These measurements, which are routinely taken in almost all oceanographic investigations, describe the basic environmental limits within which all marine biological activities take place and, for this reason alone, represent important parameters in any correlative model. There are indications that many of the Acanthamoeba cultured from marine sediments are in cyst form and become active when exposed to appropriate temperature and nutrient regimes in the laboratory (Sawyer, 1980). There may be a connection between the ability of the amoebae to form cysts and ambient temperature and salinity. There may be some temperatures at which the amoebae forming cysts die and another at which the viable organisms may emerge under the proper conditions. Statistical correlations may provide evidence for such a relationship if one exists.

The preceeding review has cited numerous examples of surrogate variables which may follow the same general distributional trend as the Acanthamoeba in and around ocean disposal sites for municipal sewage sludge. Salinity and temperature, which tend to be positively correlated with distance from a point source in estuaries, and current patterns, which are a mechanism through which pollutant distribution may be explained, are the only two variable sets which do not follow this general pattern. The rationale for including these two measurements, however, has been noted.

METHODOLOGY

Rationale for Separation of Surrogate Variables into "Strategic" (Long-Term) and "Tactical" (Short-Term)

The primary objective of the present investigation was the identification and quantification of valid surrogate variables which could be used to predict the incidence of *Acanthamoeba* in sediments. A secondary, but no less important aspect of the project was the development of a procedure which could be used by public health and environmental managers to rapidly assess a given situation. These situations would be those in which the presence of *Acanthamoeba* would represent a threat to human health (e.g., contamination of a beach area; Martinez, 1980).

If an immediate decision in such cases was required, the parameters used must be selected so that they represent the best combination of accurate prediction (determined by statistical methods), and uncomplicated analysis. The separation of surrogate variables into "strategic" and "tactical" categories appears in Table 1.

The most complex of the "tactical" or short-term analyses is bacterial MPN which can be ascertained in a minimum of 48 hours. Although 48 hours is required for a fecal coliform analysis, public health laboratories, including those at the municipal level, maintain facilities for this purpose. The degree of contamination by other substances (metals, steroids, etc.) is generally sent to organizations with more expensive and sophisticated equipment. The reason, then, for including the MPN analysis in the short-term column is that this procedure is the most complex procedure which public health laboratories can perform on a routine basis (Adams, personal communication; American Public Health Association, 1970).

Once this division of variables had been made, the modeling procedure was repeated using each variable set (complex and rapid response) to decide if an analysis of a given environmental problem involving *Acanthamoeba* could be realistically accomplished using only the "tactical" set of variables. If these variables, in themselves, were not sufficient, then the variables from the "complex" set would have to be included in order to make the prediction procedure valid. The program was adjusted to reveal which variables, if any, were the most applicable in the short-term mode.

Assessment of Data Availability

The literature review indicated that several surrogate variables existed which might be incorporated into a correlative statistical model. The next step involved an evaluation of existing literature, automated archives, and data base listings to determine the availability and suitability of actual, *in situ* values for these parameters (see Appendix A for description of archives used during this phase).

Bibliographic files were accessed (DIALOG, SDI, etc.) using appropriate keyword entries to insure that the most recent citations were being used as source references. Other data bases (NODC, NGSDC, etc.) were queried using geographic coordinates which described the boundaries of the three areas under study (Narragansett Bay, New York Bight, and Philadelphia-Camden dumpsite).

Once the general information from each source had been received in computer printout form, data were sorted so that the archival information matched, as closely as possible, the time of sampling and location of the 134 *Acanthamoeba* study stations. To accomplish this sorting task, a radius of 0.05 nautical miles (nm) was drawn from the

Table 1. Tactical (short-term, simple) and strategic (long-term, complex) variables.[++]

Tactical*	Strategic**
Coliform MPNs	Heavy metal analysis
Temperature	PCB Analysis
Salinity	Organic analyses (coprostanol, organic carbon)
Distance	Geological analyses (grain size, percent silt and clay)
True bearing	
Sediment color	

[++] Since Acanthamoeba cultures are the dependent variable. This procedure is not included in the table.

*The term "tactical" refers to analyses which are relatively easy to perform or to values which can be determined by inspection *in situ*. The most "complex" of these is bacterial MPN. These variables, with exception of MPNs and sediment color are generally collected during any oceanographic investigation.

**The term "strategic" refers to analyses which require more time and sophisticated equipment than those listed as tactical.

center of each station location establishing a 0.10 nm circle around each of the 134 stations (the optimum repeatability of Loran "C", the most widely used navigation aid for positioning the vessels involved). The date and time of each station sampled (31 for Narragansett Bay, 44 for the New York Bight, and 59 for the Philadelphia-Camden dumpsite) were entered and sorted so that the information taken from the archival data had been sampled as closely as possible to the actual date and time of *Acanthamoeba* station occupation.

The data were then resorted using these time and location limits. The final product was a listing of values for surrogate variables (12 for Narragansett Bay, 20 for the New York Bight, and 12 for the Philadelphia-Camden dumpsite) matched in time and space to the *Acanthamoeba* stations (see Table 2).

Evaluation of Modeling Strategies

There were numerous excellent resources available which described various modeling strategies (Basta and Bower, 1979; Gold, 1977; Green, 1979; Nihoul, 1975). Because the primary objective of the present effort was the prediction of the incidence of pathogenic protozoa in marine sediments using surrogate variables, the statistical or correlative approach using stepwise regression was considered to be the most productive. This method emphasized the statistical relationship (correlation) between variables as opposed to the mass-energy modeling scheme which attempts to explain, identify, and create equations which describe the physical mechanisms which drive a particular system (Amick and Walberg, 1975; Hinson, 1979; Leedertse and Gritton, 1972, 1977; Leedertse and Liu, 1974; Tracor, 1971).

Table 2. Variable sets for the three geographic areas under study based on time/space sorting restraints of archived data.

Variable	ADP Code	Narragansett Bay	New York Bight apex	Philadelphia-Camden Dumpsite
Distance from point source or site center	DIST	X	X	X
True bearing, in degrees, from point source or site center	BNT		X	
Percent positive *Acanthamoeaba* cultures at station	PCUL (dependent variable)	X	X	X
Total organic carbon (using modified Schollenberger chromic acid oxidation technique)	TOC	X	X	X
Lead (PPM)	PB	X	X	X
Mercury (PPB)	HGB	X	X	X
Copper (PPM)	CU	X	X	X
Chromium (PPM)	CR	X	X	X
Cadmium (PPM)	CDM	X	X	
Zinc (PPM)	ZNM	X	X	X
Silver (PPM)	AGM		X	
Nickel (PPM)	NIPM		X	X
Coliform count (log)	LFCC	X	X	X
Temperature (°C)	TC	X	X	X
Salinity (PPT)	SPT	X	X	X

Table 2. (continued)

Variable	ADP code	Narragansett Bay	New York Bight apex	Philadelphia-Camden dumpsite
Sediment color (coded)	SCLR	X	X	X
Percent silt	PSILT		X	X
Percent clay	PCLAY		X	
PCBs (PPB)	PCB		X	
Percent coprostanol of total steroids	PCOP		X	
The ratio of total carbohydrate to total organic carbon (TCH:TOC)	TCHTOC		X	

Note: Some variables listed under a particular site may not have met the criteria for entry into the modeling process. See text for explanation.

At this point, the three initial steps for developing a correlative model had been completed (Basta and Bower, 1979);

1. Relevant causal surrogate variables had been selected based on a study of the system;
2. The structural form of the relationship between the surrogate variables and the dependent variable (e.g., correlation) had been hypothesized;
3. Data sets for each of the surrogate variables had been obtained from archives and the literature for use in the model.

Selection of a Suitable Computer Program

The small array of 134 stations and the availability of values for only 20 surrogate variables made maximum utilization of all information vital to the success of the project. Since the proposed correlative model was based on the validity of correlations between independent variables and positive *Acanthamoeba* cultures/station, a program which evaluated all variables, regardless of their individual contribution to the system, and produced a result based on an optimum selection for each factor was essential (Chatterjee and Price, 1975).

After a review of several program options (Martin, 1975; Ralston, 1983), the Maximum R^2 Improvement (MAXR; stepwise regression) contained within the Statistical Analysis System (SAS) package was selected as the best option (Goodnight, 1979).

Preparation of Data for Analysis

Raw data were extracted from the computer files which had been sorted using time/location restraints and transformed for use with the IBM 4341-2 system (8 megabytes, MVS 3.8H) at the Virginia Community College Host Computer Center.

Reported Distribution of *Acanthamoeba* on the East Coast

A number of other stations were considered in this study which represented a series of samples from Ocean City, Maryland to Georges Bank. These stations, which were initially clear of both *Acanthamoeba* and bacteria, were located from two to 100 miles offshore (Sawyer, et al., 1982). All of these stations were located in areas in which there were no known anthropogenic inputs (e.g., dumpsites or outfalls). However, repeated sampling of stations located near the mouths of major east and gulf coast rivers and estuaries, revealed pockets of *Acanthamoeba* not previously reported in these areas. Analysis of samples from these stations indicated that increased waste loading at these sites had caused a buildup of organic materials and subsequent decay, which encouraged the growth of the protozoans. Other offshore areas not subject to organic loading continued to remain clear of any infestation (Sawyer, personal communication).

RESULTS

The stepwise regression technique was applied to three sets of data, one from each geographic area. When this procedure yielded a sufficient mix of "tactical" and "strategic" parameters, the stepwise regression was rerun using the two different variable sets. In this way, an evaluation could be made between the complex and short-term analytical results to see if the addition of one or more of the surrogate variables requiring more complicated laboratory analysis significantly increased the R^2 values obtained.

Correlation matrices were generated for all variables from all regions. These results made possible a tabulation of all variables correlated with the positive *Acanthamoeba* stations for each study area. In addition, preliminary relationships between all variables in the set could be determined, by inspection, from these tables.

The general linear model package was used, in the last stage of analysis, to produce the "best" model or models from a given area based upon those variables which were selected as most highly correlated with the positive *Acanthamoeba* stations and which were found to significantly increase the R^2 values. For each model so produced, a prediction table was generated which could be used by an environmental manager in decision-making. This table was designed to discriminate between a preselected level of "ambient infestation" by *Acanthamoeba* and possible population levels elevated above this preselected baseline. The table also made possible a determination of error rate (percentage of correct or incorrect predictions) determined by the baseline selected.

Once these analyses were completed, summaries were produced for each area and comparisons made between the different environmental and hydrographic regimes. The significance of these findings is discussed below.

Data Summaries

These data summaries are arranged by geographic area from north to south. For complete listings of all raw data, see microfiche appendices.

Narragansett Bay

Table 3 contains the summary for all variables used in the Narragansett Bay study correlated with the variable PCUL (percent positive *Acanthamoeba* cultures/station). Figure 5a is a graphic presentation of these correlations. Appendix B (four pages) contains the complete correlation matrix for all Narragansett Bay variables.

In Table 4, the stepwise regression improvement technique is summarized. Variables are presented in the order in which the procedure added them to the model. Tables 5 and 6 contain data for the two "best" models for the Narragansett Bay stations sampled. Figure 6a presents a graph of the actual *in situ* values for positive *Acanthamoeba* cultures/station plotted against the predicted positive cultures for these same stations based on the surrogate variable model.

New York Bight

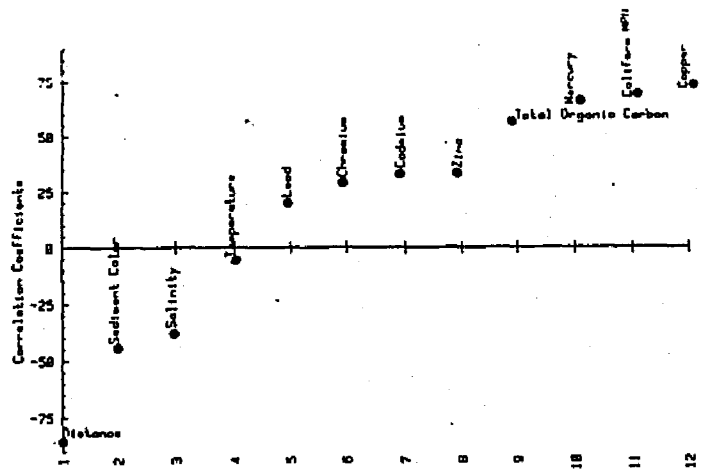
Table 7 is a summary of correlations between 20 surrogate variables and the variable PCUL. Figure 5b is a graphic representation of these same data designed to show the range of correlation coefficients. Appendix C (six pages) contains the complete correlation matrix for all 21 variables used in the New York Bight phase of the investigation.

Table 3. Summary table for the Narragansett Bay area. All variables correlated with variable "PCUL" (percent positive Acanthamoeba cultures/station).

Environmental variable	"N" for variable	Correlation with PCUL	Significance of correlation
Distance in nautical miles from point source	31	-.83	.0001
Sediment color (coded)	31	-.42	.0016
Salinity	29	-.35	.0614
Temperature (°C)	29	-.04	.8462
Lead	16	.23	.3936
Chromium	12	.32	.3053
Cadmium	14	.36	.2056
Zinc	12	.36	.2565
Total organic carbon	31	.58	.0006
Mercury	15	.59	.0199
Coliform MPN	31	.68	.0001
Copper	9	.72	.0292

Note: For complete listing of all raw data see microfiche appendices.

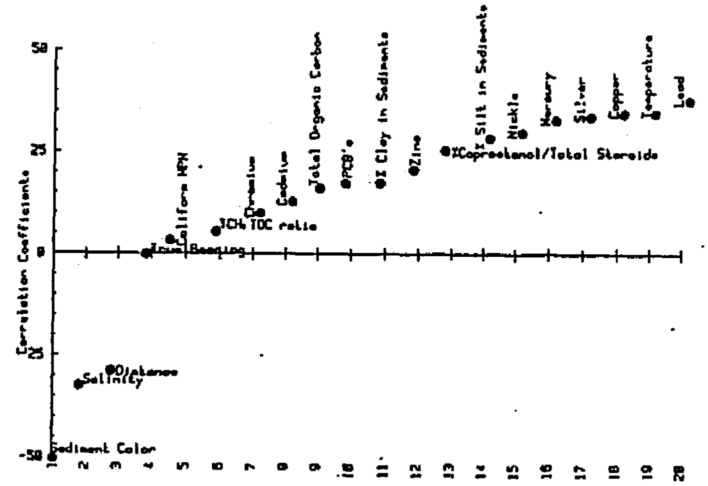
Figure 5. A comparison of correlation coefficients for all variables with the variable "PCUL" (positive Acanthamoeba cultures/station) for all three geographic areas under study.



correlations for NARRAGANSETT BAY between 12 variables and positive ACANTHAMOEBA cultures.

5a.

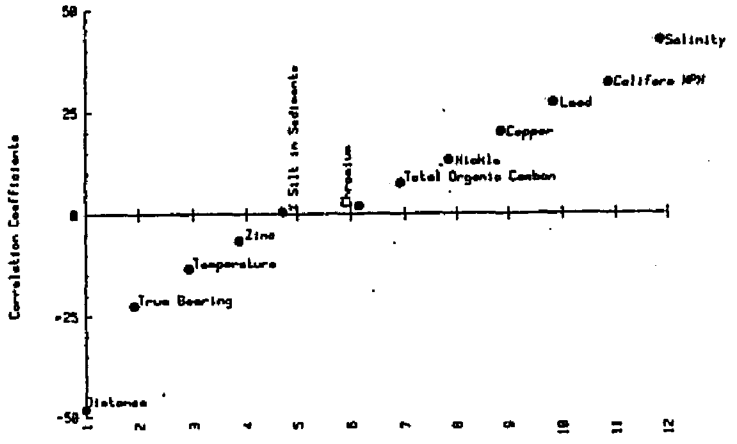
Correlation Coeff.
Narragansett Bay



correlations for the NEW YORK BIGHT APEX between 20 variables and positive cultures of ACANTHAMOEBA, N=44 for all variables.

5b.

Correlation Coeff.
New York Bight



correlations for the PHILADELPHIA-CAMDEN DUMPSITE between 12 variables and positive cultures of ACANTHAMOEBA.

5c.

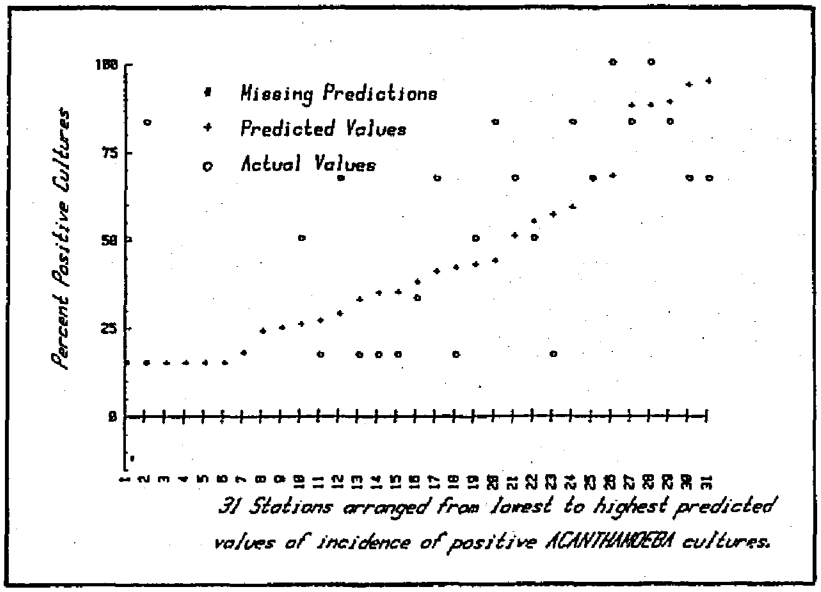
Correlation Coeff.
Philadelphia Dump
Site

Table 4. Stepwise regression procedure for all variables and the variable "PCUL" (percent positive _Acanthamoeba_ cultures/station) for Narragansett Bay.

Variables added to model in order added	Multiple R^2	Multiple R value	F value	Probability of larger F
Distance	.73	.85	71.44	.0001
Salinity	.74	.86	37.07	.0001
Total organic carbon	.76	.87	26.60	.0001
Temperature (°C)	.77	.88	20.22	.0001
*				
Sediment color (coded)	.77	.88	15.71	.0001
Coliform MPN	.77	.88	12.53	.0001

*This line represents an arbitrary cutoff point above which R^2 did not appear to increase.

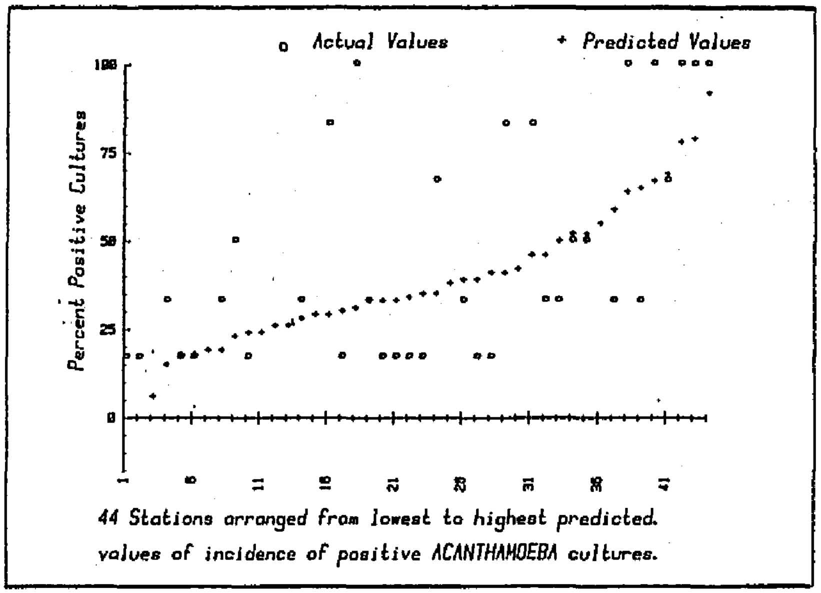
Figure 6. A comparison of predicted values for the variable "PCUL" (positive _Acanthamoeba_ cultures/station) and the actual _in situ_ values obtained from field studies for all geographic areas under study. Stations arranged from lowest to highest _predicted_ culture values.



6a.

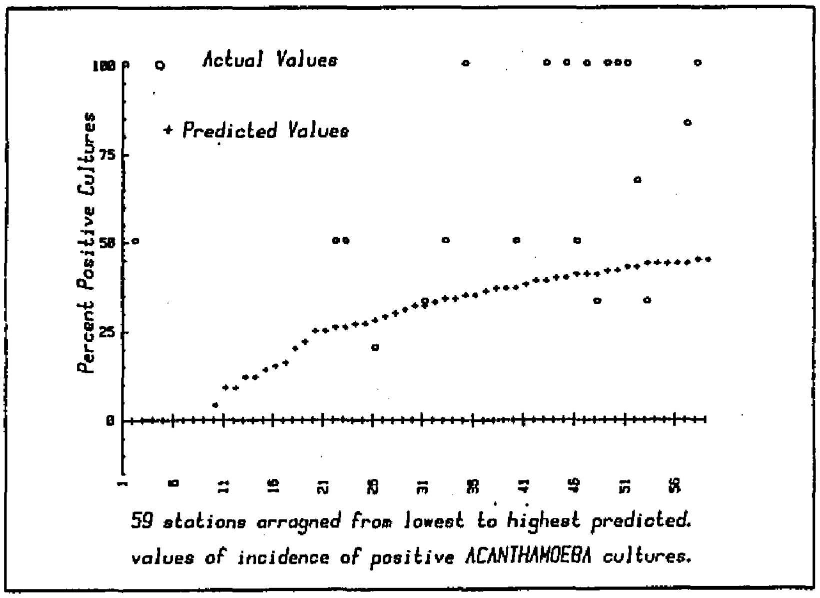
Model vs. In-situ
Data
Narragansett Bay

(Stations for all plots arranged from lowest to highest predicted value for Acanthamoeba cultures.)



6b.

Model vs. In-situ
Data
New York Bight



6c.

Model vs. In-situ
Data
Philadelphia Dump
Site

Table 5. General linear models procedure for "tactical" (short-term, or rapid analysis) variables for Narragansett Bay.

Variables used in model	Multiple R^2 for model	Multiple R value for model	F value for model	Probability of larger F for model
Distance Coliform MPN Temperature	.53	.73	14.81	.0001

Table 6. The addition of total organic carbon (TA) to the variables in Table 5: distance, coliform MPN, and temperature, provided the only significant increase in the multiple R^2 value (from .53 to .56, which resulted in an increase in R from .73 to .75).

Variables used in model	Multiple R^2 for model	Multiple R value for model	F value for model	Probability of larger F for model
Distance Coliform MPN Temperature *Total organic carbon	.56	.75	10.67	.0001

*Note: The addition of total organic carbon to the variables distance, coliform MPN, and temperature, provided the only apparent increase in the R^2 value.

Table 8 provides an overview of the stepwise regression procedure. Variables are listed in the order chosen by the program together with pertinent statistical parameters. Tables 9 and 10 compare the stepwise regression procedures for "tactical" and "strategic" surrogate variables. In Tables 11 and 12, the models for "tactical" and "strategic" surrogate variables are compared and appropriate statistical descriptors are provided. Figure 6b is a plot of actual *in situ* values of the variable PCUL compared with predicted values for the same stations based on the models summarized in Tables 11 and 12.

Philadelphia-Camden Dumpsite

Table 13 is a correlation summary for all variables with the variable PCUL for the Philadelphia-Camden dumpsite. Figure 5c is a presentation of these correlation data which graphically represents the range of correlations. Appendix D (four pages) is the complete correlation matrix for all variables used in the Philadelphia-Camden dumpsite study. Table 14 provides a listing of the results of the stepwise regression technique for the Philadelphia-Camden dumpsite variables. Table 15 is a summary of the general linear models procedure for these same variables. Figure 6c represents predicted values of PCUL from the "best model" for each station compared to actual values for positive *Acanthamoeba* cultures. Figure 7 contains "contours" delineating areas of microbial/protozoan contamination in the Philadelphia-Camden area indicating a dispersal of materials from the depositional center of the site.

General Result Summaries

Table 16 contains the results of correlations between the variable PCUL and the variables DIST (distance) and LFCC (coliform MPN) for

Table 7. Summary table of correlations for the New York Bight area. All variables correlated with variable "PCUL" (percent positive *Acanthamoeba* cultures/station). N for all variables equals 44.

Environmental variable	Correlation with "PCUL"	Significance of correlation
Sediment color (coded)	-.49	.0008
Salinity	-.32	.0343
Distance in nautical miles from point source	-.30	.0449
True bearing from point source in degrees	.00	.9959
Coliform MPN	.02	.9131
Ratio of total carbohydrate to total organic carbon	.06	.7009
Chromium	.07	.6447
Cadmium	.12	.4236
Total organic carbon	.17	.2626
PCBs	.19	.2046
% clay in sediment	.19	.2171
Zinc	.22	.1454
% coprostanol in total steroids	.24	.1205
% silt in sediment	.26	.0853
Nickel	.29	.0562
Mercury	.32	.0334
Silver	.33	.0298
Copper	.34	.0259
Temperature (°C)	.34	.0225
Lead	.37	.0123

Note: For complete listing of all raw data see microfiche appendices.

Table 8. Stepwise regression procedure for all variables and the variable "PCUL" (percent positive <u>Acanthamoeba</u> cultures/station) for the New York Bight.

Variables added to model in order added	Multiple R^2	Multiple R value	F value	Probability of larger F
Sediment color (coded)	.24	.49	13.19	.0008
Temperature (°C)	.32	.57	9.44	.0004
Ratio of total carbohydrate to total organic carbon	.40	.63	8.88	.0001
Silver	.45	.67	7.88	.0001
Chromium	.52	.72	8.12	.0001
Cadmium	.58	.76	8.09	.0001
PCBs	.59	.77	7.51	.0001
*- - - - - - - - - -	- - - - - - - -	- - - - - - - -	- - - - - - - -	- - - - - - - -

*This line represents an arbitrary cutoff point above which R^2 did not appear to increase.

Table 9. Stepwise regression procedure for "tactical" (short-term, or rapid response) variables for the variable "PCUL" (percent positive *Acanthamoeba* cultures/station) for the New York Bight.

Variables added to model in order added	Multiple R^2	Multiple R value	F value	Probability of larger F
Sediment color (coded)	.24	.49	13.19	.0008
Temperature (°C)	.32	.57	9.44	.0004
Salinity	.35	.59	7.23	.0005
Coliform MPN	.37	.61	5.67	.0011
*- -				
True bearing	.37	.61	4.41	.0029
Distance	.37	.61	3.58	.0068

*This line represents an arbitrary cutoff point above which R^2 did not appear to increase.

Table 10. Stepwise regression procedure for "strategic" (long-term, or complex analysis) variables for the variable "PCUL" (percent positive *Acanthamoeba* cultures/station) for the New York Bight.

Variables added to model in order added	Multiple R^2	Multiple R value	F value	Probability of larger F
Lead	.14	.37	6.84	.0123
Cadmium	.19	.44	4.69	.0146
Chromium	.24	.49	4.12	.0123
Silver	.27	.52	3.60	.0136
Total organic carbon	.29	.54	3.18	.0171
PCBs	.33	.57	3.06	.0155
Ratio of total carbohydrate to total organic carbon	.36	.60	2.84	.0183
Mercury	.37	.61	2.58	.0248
% clay	.38	.62	2.29	.0396
*- - - - - - - - - -	- - - - - - - -	- - - - - - - -	- - - - - - - -	- - - - - - - -
% silt	.38	.62	2.03	.0622
Nickel	.39	.62	1.82	.0913
% coprostanol of total steroids	.39	.62	1.62	.1367
Zinc	.39	.62	1.45	.1953
Copper	.39	.62	1.30	.2659

*This line represents an arbitrary cutoff point above which R^2 did not appear to increase.

Table 11. General linear models procedure for "tactical" (short-term, or rapid response) variables and the "PCUL" (percent positive *Acanthamoeba* cultures/station) for the New York Bight.

Variables used	Multiple R^2 for model	Multiple R for model	F value for model	Probability of larger F for model
Sediment color (coded)	.36	.60	5.65	.0011
Temperature (°C)				
Salinity				
Coliform MPN				

Table 12. General linear models procedure for "strategic" (long-term, or complex analysis) variables and the variable "PCUL" (percent positive *Acanthamoeba* cultures/station) for the New York Bight.

Variables used in model	Multiple R^2 for model	Multiple R for model	F value for model	Probability of larger F for model
Lead	.37	.61	2.58	.0248
Cadmium				
Silver				
Total organic carbon				
PCBs				
Ratio of total carbohydrate to total organic carbon				
Mercury				
% clay				

Table 13. Summary table of correlations for the Philadelphia-Camden dumpsite. All variables correlated with variable "PCUL" (percent positive <u>Acanthamoeba</u> cultures/station).

Environmental variable	"N" for variable	Correlation with PCUL	Significance of correlation
Distance in nautical miles from point source	59	-.47	.0002
True bearing from point source in degrees	59	-.22	.0962
Temperature (°C)	8	-.13	.7576
Zinc	22	-.06	.7901
% silt in sediments	17	.01	.9825
Chromium	20	.02	.9205
Total organic carbon	20	.08	.7429
Nickel	8	.12	.7687
Copper	22	.19	.3882
Lead	22	.26	.2350
Coliform MPN	58	.31	.0165
Salinity	8	.41	.3175

Note: For complete listing of all raw data see microfiche appendices.

quadrants taken through the center of the New York dumpsite. Below is a plot of two transects described in the table which were used to separate the area into four equal portions.

Table 17 contains correlations between the same variables used to develop the information found in Table 16 (DIST, LFCC, and PCUL) for a northeast-southwest transect drawn through the center of the Philadelphia-Camden dumpsite, roughly parallel to the 40 m isobath.

Table 18 is the result of residual analysis and test for autocorrelation for the three "best" models, one from each geographic area, using the Durbin-Watson statistic (Chatterjee and Price, 1975).

Figure 8 is a "predication" table. This example was generated by the "best" model for the Narragansett Bay area. The use of this table in an environmental situation is discussed, in detail, below. Figures 5 and 6 compare overall results from the three geographic regions. Figure 5 compares the range and clustering of variables used in the stepwise regression technique and the general linear models procedures. Figure 6 compares the predicted values for PCUL, generated by the particular model involved, with the actual values obtained for each station in each location involved in the study.

Table 14. Stepwise regression procedure for all variables and the variable "PCUL" (percent positive *Acanthamoeba* cultures/station) for the Philadelphia-Camden dumpsite.

Variables added to model in order added	Multiple R^2	Multiple R value	F value	Probability of larger F
Distance	.20	.45	14.39	.0004
Coliform MPN	.21	.46	7.21	.0017

Note: No other variables were found to significantly increase R^2 values.

Table 15. General linear models procedure for two valid variables determined through the stepwise regression procedure and the variable "PCUL" (percent positive *Acanthamoeba* cultures/station) for the Philadelphia-Camden dumpsite.

Variables used in model	Multiple R^2 for model	Multiple R for model	F value for model	Probability of larger F for model
Distance Coliform MPN	.21	.46	7.21	.0017

Figure 7. The spread of contaminated materials from a depositional center. Analysis of stations taken near the apex of the now inactive Philadelphia-Camden dumpsite indicate that sediments containing bacteria and <u>Acanthamoeba</u> have been dispersed by current regimes prevalent in the area. The general dispersion pattern is to the east (down slope) and in a northeast-southeast direction. This general trend is in keeping with findings in the New York Bight apex and in Narragansett Bay (see Table 19).

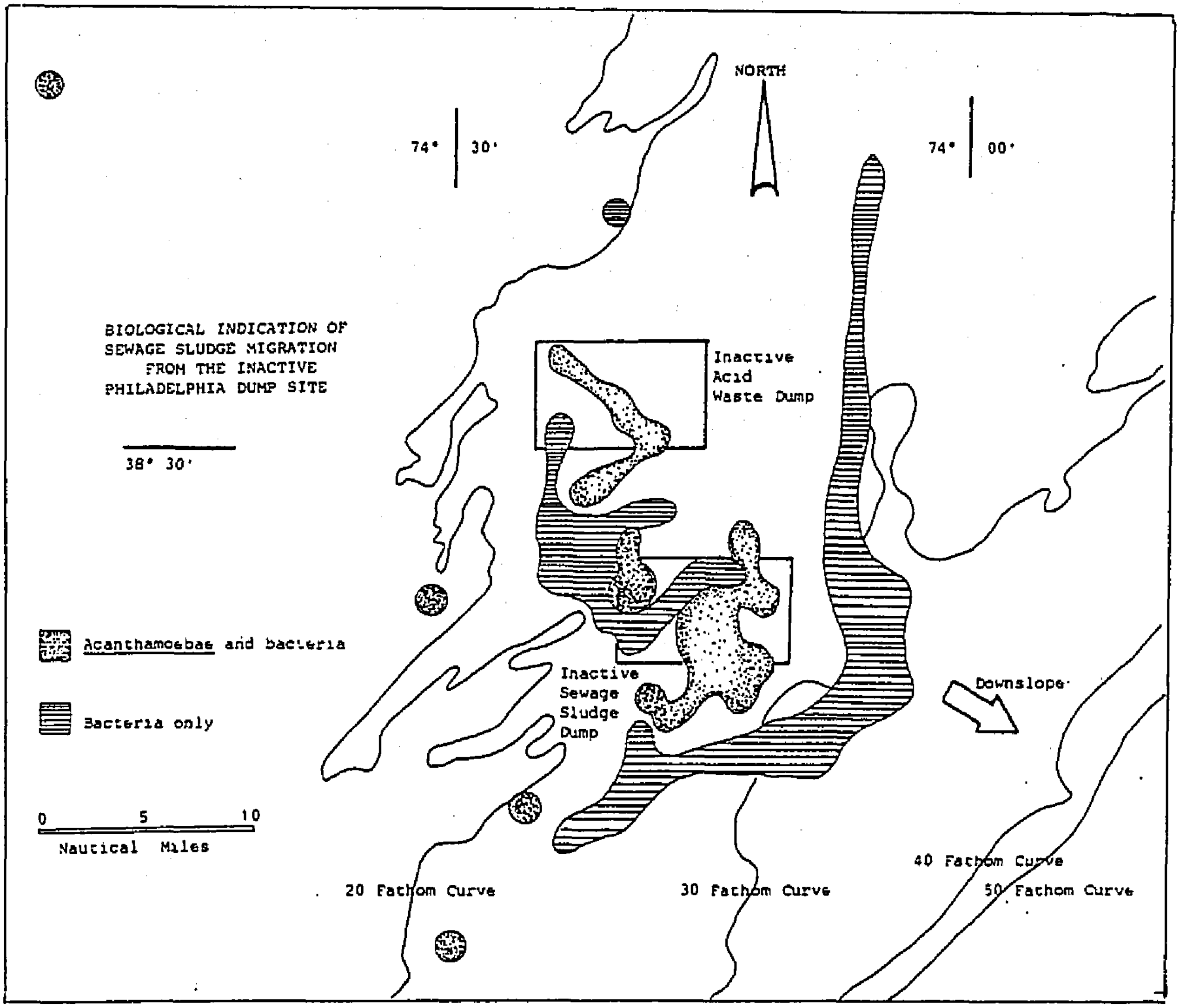
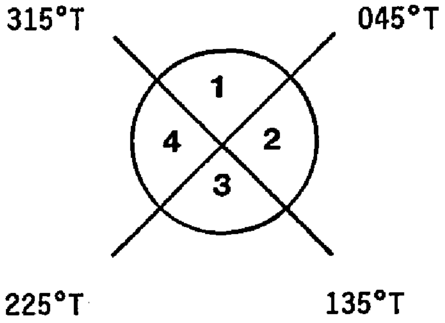

NORTH
74° 30'
74° 00'
38° 30'
BIOLOGICAL INDICATION OF SEWAGE SLUDGE MIGRATION FROM THE INACTIVE PHILADELPHIA DUMP SITE
Inactive Acid Waste Dump
Inactive Sewage Sludge Dump
Acanthamoebae and bacteria
Bacteria only
0 5 10
Nautical Miles
Downslope
20 Fathom Curve
30 Fathom Curve
40 Fathom Curve
50 Fathom Curve

Figure 7

Table 16. Correlations between PCUL and the variables DIST and LFCC for quandrants drawn through the center of the New York dumpsite (see below).

NEW YORK DUMPSITE QUADRANTS
CORRELATION SUMMARY

Quadrant	N	PCUL with variable	R	Level of significance
1	8	DIST	.08	.8538
2	12	DIST	.28	.3792
3	14	DIST	-.54	.0452
4	10	DIST	-.69	.0257
1	8	LFCC	-.14	.7382
2	12	LFCC	.12	.7142
3	14	LFCC	-.03	.9160
4	10	LFCC	.73	.0176



Quadrants through the center of the New York dumpsite (or 12-mile site). Circle represents 6 nautical miles. See figure for quadrant contours.

Table 17. Statistics for the variable PCUL correlated with the environmental variables DIST and LFCC for all stations in the Philadelphia site located east and seaward of a transect drawn through the center of the site bearing 045-225°T.

	*Dependent variable PCUL correlation with:		
	R	"N"	Significance
DIST	-0.71823	22	0.0001
LFCC	-0.10832	22	0.6314

*See text for explanation.

Table 18. Values for the Durbin-Watson statistic, "d", for determining the autocorrelation residuals for a given procedure (Chaterjee and Price, 1975).

Value for "d" for model	"N" for model	Autocorrelation	Significance level
Narragansett Bay model = 1.3011	31	No	.01
New York Bight model = 1.4453	45**	No	.01
Philadelphia site model = 1.4162	60**	Inconclusive	*

*The value for the Philadelphia site falls between d_L and d_U in the table (A.4b) in the reference cited. In this case, the test does not present conclusive evidence that autocorrelation is not present. The other two values are both greater than the d_U for their given "N" values (1.27 and 1.38 respectively) indicating that autocorrelation is not present at the confidence level noted. As discussed below, the Philadelphia model was constructed with data some of which could not meet minimum significance level conditions imposed on the procedure.

**Tables values closest to actual "N".

Figure 8. A "prediction table" generated by the model for the Narragansett Bay area. The box below the table is used to determine error probability in an environmental-management situation. See DISCUSSION for details.

Figure 8

*PREDICTION MODEL GENERATED BY THE "BEST" MODEL FOR THE NARRAGANSETT BAY SITE

Obs. #	Predicted%	Actual%
1	.	
2	.	
3	13.5995	0
4	14.0727	0
5	14.0727	0
6	14.0727	0
7	16.9115	0
8	22.9153	0
9	24.3347	50
10	25.3665	17
11	26.3128	67
12	27.7322	17
13	31.7740	17
14	33.6666	17
15	33.7360	33
16	36.8768	67
17	40.2129	17
18	40.6942	50
19	41.9827	83
20	42.8435	83
21	50.0794	67
22	53.8514	50
23	55.7440	17
24	57.6365	83
25	65.5490	67
26	67.4415	100
27	87.2227	83
28	87.2227	100
29	88.2916	83
30	93.4642	67
31	94.3197	67

		Actual Values	
		- cultures	+ cultures
Predicted values	- cultures	Correct prediction	Incorrect prediction predicting - when +
	- cultures	Incorrect prediction predicting + when -	Correct Prediction

*Values are arranged from the lowest to the highest predicted value for positive Acanthamoeba cultures per station.

DISCUSSION

This study was concerned with predicting the incidence of positive Acanthamoeba cultures in oceanic sediments using surrogate variables. These variables were selected based on literature descriptions of their environmental distribution and relevance to the investigation. Values used as inputs to the modeling program were based upon the applicability and quality of data from all sources researched.

Correlations

A comparison between the correlation distributions for surrogate variables used in all three areas studied (Narragansett Bay, New York Bight, Philadelphia-Camden dumpsite) demonstrated that the general pattern of relationships was similar in each location (Figure 5a,b,c).

Narragansett Bay had the widest range of correlation coefficients (-.83 to .72) because this estuary represented the most "linear" situation studied. In the bay, the material from the Fields Point facility flowed downstream from a single point source, the outfall pipe. The flow of these contaminants resulted in a gradual downstream dilution of materials. In this instance, distance had the highest negative correlation (-.83) while coliform MPN had the highest positive correlation (.72).

In the New York Bight, the correlations ranged from -.49 to .37 (for sediment color (coded), and lead, respectively). This area did not represent a linear flow. The complex circulation patterns which have been revealed by remotely sensed imagery (Munday, 1983), can be represented as a combination of plumes from the Hudson-Raritan estuary and a meteorologically-forced current regime. In spite of this complexity, there is an area in the New York Bight which resembles, in some respects, the Narragansett region. The New York Bight site is east of the Hudson Canyon and northeast of the Christiaensen Basin. Both these low lying areas have become depositional centers for sludge related materials deposited at the dumpsite which flow "down hill" into the depressions (Hatcher and McGillivary, 1979). When the New York Bight dumpsite area is divided into four sections (Table 16) the correlation between distance and positive Acanthamoeba cultures in quadrant number four (the westernmost division) becomes -.69 as compared to an overall correlation for distance of -.30. The correlation between coliform MPN and positive Acanthamoeba cultures for this same quadrant is .73 as compared to an overall value of .02. These figures compare favorably with those for Narragansett Bay (-.83 and .72) indicating that, at least in this portion of the New York Bight site, a situation exists which is similar to that found in the more northern study area.

As noted above, the distribution of contaminants was found to follow a general pattern of decreasing concentration from a point source or depositional center. Because salinity and temperature were not subject to the same distributional forces as pollutants, further mention of these environmental variables is necessary. In all cases and for all geographic areas, temperatures and salinities at sample depth were the values used to develop the model.

In Narragansett Bay, the correlation coefficients for temperature and salinity were -.04 and -.35, respectively. In the bay study, the temperature varied from a high of 9°C to a low of 6°C. This range was spread over a 35 mile track line represented by the distance from the Fields Point facility to offshore, open ocean stations and accounted for the very low correlation value. Salinity, in contrast, ranged from a low of 26 ppt to a high of 34 ppt. Because of the configuration of the estuarine system, all the lowest salinities were found at the northernmost stations and the salinity values increased downstream toward the ocean. Although the range for salinity was small (8 ppt), the lower salinity values coincided with the highest percentages of positive *Acanthamoeba* cultures (near the Fields Point facility) and, conversely, the higher salnity values were found in the open ocean at stations for which *Acanthamoeba* percentages were smallest. Therefore, the distribution of salinity and positive cultures should not be considered a causal relationship but should be seen as the result of a natural, estuarine distribution of the salinity.

In the New York Bight area, the correlation coefficient for salinity was -.32 and that for temperature was .34. In this location, as noted, much of the sewage-related material had moved away from the shallow depositional center (the 12 mile dumpsite) into deeper waters of the Christiaensen Basin and Hudson Canyon. For this reason, many of the higher *Acanthamoeba* values were found in relatively deeper, cooler, and less saline waters. Again, there was only a coincidental relationship between the distribution of these environmental factors and the protozoa.

In the Philadelphia-Camden dumpsite, the *Acanthamoeba* data were found to be positively correlated with salinity (.41) and negatively correlated with temperature (-.13). Although these values appeared to be valid, the "N" for these variables represented only a small fraction of the samples taken and their significance levels were marginal (see Table 13). For this reason, the numbers were reported but were not used in the stepwise regression procedure which produced the final model for this site.

Although the Philadelphia-Camden dumpsite model did not have the strength of the other two, the correlation range (-.47 to .41) compared favorably with the New York Bight simulation. The Philadelphia-Camden site was divided into an upslope and downslope component. The correlation coefficient for distance increased from -.47 for the entire study area to -.72 for the areas in which materials appeared to be slowly flowing over the shelf break (Table 17). These figures seemed to suggest a similar distributional mechanism for sewage-related materials existed in situations in which there was a downslope or downstream flow from an upslope or upstream depositional center.

Because the Philadelphia-Camden site was an inactive disposal area, there was an opportunity to observe the change in the benthic distribution of the sludge materials. As noted above, there was a high correlation between distance and positive culture of Acanthamoeba southwest of the dumpsite center (-.72). Figure 7 represents the pattern of microbial contamination in and around the depositional center of the area. These patterns were contoured using bacteriological data from the study stations and present strong evidence that dumped materials were migrating away from the central disposal area in a northeast-southwest direction and to a small extent down the continental slope. Thus, the spread of organic contaminants and their associated protozoan components could be tracked using the bacteria and amoebae or surrogate correlative variables as indicators of the presence of sewage-related sediment fractions.

Generally, heavy metals and organics were positively correlated with the percent of positive cultures of Acanthamoeba/station. The other variables showed a less fixed pattern but, in two out of three cases, were negatively correlated with the percentage of positive cultures.

Models

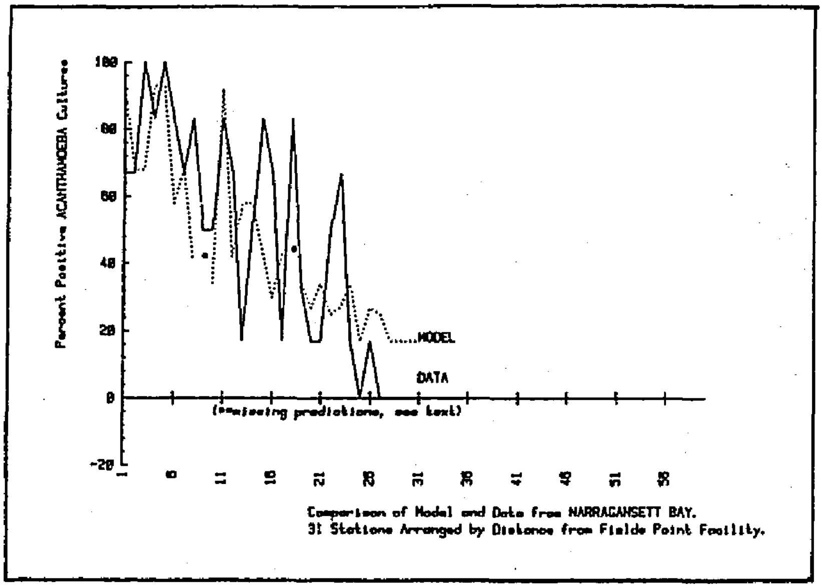
When stations for all areas were arranged from the lowest to the highest predicted values, a linear pattern resulted (Figure 6a,b,c). However, such a presentation may be considered somewhat artificial since the resulting graph is based on the model and not on the actual *in situ* data. If, however, stations are arranged according to distance from the particular depositional center (Figure 9a,b,c) and the actual data are compared to modeling results, a more valid picture of the comparison between the two curves is produced.

An analysis of the three models using the Durbin-Watson statistic (Table 18) revealed that residuals for the Narragansett Bay and New York Bight models were not autocorrelated. Results for the Philadelphia-Camden model (Figures 5c, 6c, 9c) produced the poorest environmental simulation.

The stepwise regression technique, as has been described, tested all variables to determine those which most significantly increased the R^2 values. In the case of the Philadelphia-Camden dumpsite, there were 59 stations. The "N" for most of the variables used, excluding distance and coliform MPN, ranged from a low of eight to a high of 22. In this instance, the procedure determined that only coliform MPN and distance were valid parameters. The Philadelphia-Camden model, then, was based on these two variables.

If a highly significant contributing variable was absent from a particular station, the procedure would not make a prediction for that set of data because one or more of the maximizing contributors was

Figure 9. A comparison of models generated for the three geographic areas under study with the actual _in situ_ data. Stations are arranged by _distance from the depositional center_ of the particular disposal/area outfall.

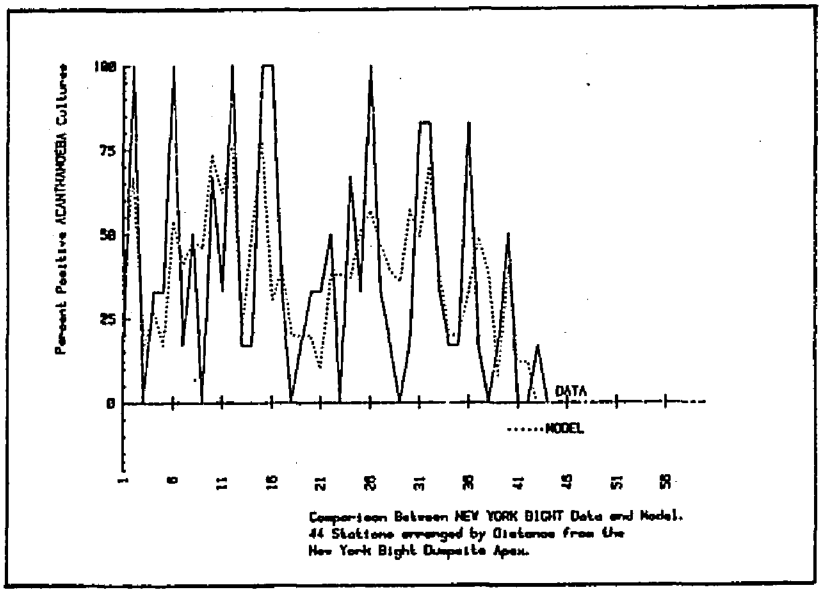


Comparison of Model and Data from NARRAGANSETT BAY.
31 Stations Arranged by Distance from Fields Point Facility.

9a.

Model vs. In-Situ
Data
Narragansett Bay

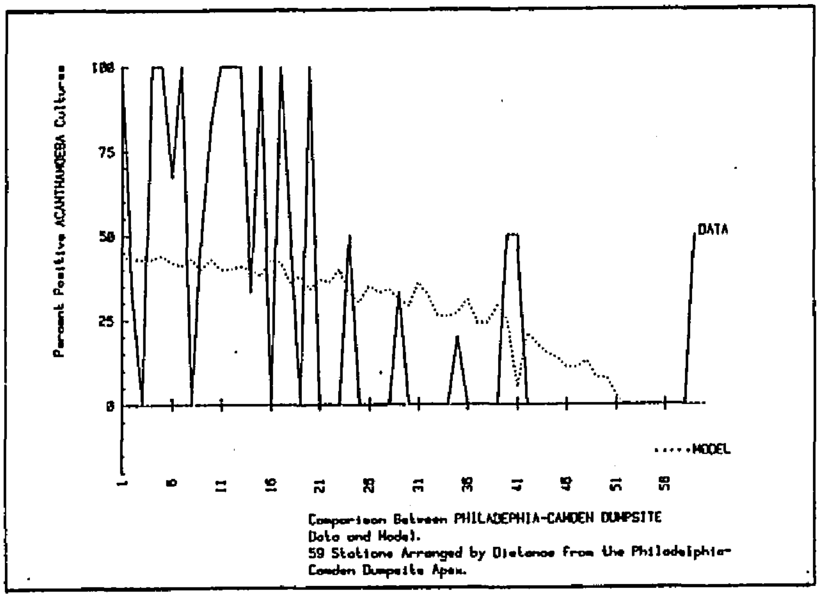
(Stations for all
plots arranged
by <u>increasing</u>
<u>distance</u> from
dumpsite or out-
fall.)



Comparison Between NEW YORK BIGHT Data and Model.
44 Stations arranged by Distance from the
New York Bight Dumpsite Apex.

9b.

Model vs. In-situ
Data
New York Bight



Comparison Between PHILADEPHIA-CAMDEN DUMPSITE
Data and Model.
59 Stations Arranged by Distance from the Philadelphia-
Camden Dumpsite Apex.

9c.

Model vs. In-situ
Data
Philadelphia Dump
Site

missing. The two missing predictions for the Narragansett Bay data (Figures 5a, 6a, 9a) were an example of this situation. There were no temperature, salinity, or total organic carbon values for these stations.

The models generated for the three areas were valid for the prediction of the incidence of positive cultures of Acanthamoeba within the limitations of the stepwise regression and linear model procedures (Tables 6, 11, 12, 15). The validity of any model, however, is dependent upon the number of data points used in the initial construction. The more data points available, the better the simulation will be (Gold, 1977). The present study took advantage of all applicable data sources and computer procedures to produce the best possible models from the widest assemblage of information.

Use of Models

In the simplest situation, models may be used in a straightforward manner using intercept and constant values. These values are generated by the linear model procedures. A constant figure is available for each variable used to obtain the particular model. This number is multiplied by the *in situ* value for that variable. The intercept value is added or subtracted from the results depending upon the sign of the number (see Microfiche Appendices).

For example, the "tactical" or short-term model for the New York Bight area generated the following constants and intercept value for the variables involved (see Table 11 and microfiche appendix):

Intercept value....594

Sediment color constant...-10	Sediment color *in situ* value...5
Temperature constant......9	Temperature *in situ* value......10°C
Salinity constant.........-20	Salinity *in situ* value.........28 ppt
Coliform MPN constant.....5	MPN *in situ* value.............3.4

The constants would be multiplied by the *in situ* values found at a particular station, these values would be added together, and the intercept would be added to the result, since the sign of this number if positive, as follows:

$$(-10)(5)+(9)(10)+(-20)(28)+(5)(3.4)+594 = 71$$

In this case, the formula predicts, based upon the model used, that there would be 71% positive culture incidence in replicates taken at the station represented by *in situ* values. The same procedure applied to any of the models generated for any geographic area under study.

The application described above is a simple procedure which could be accomplished using a simple four-function calculator. In this case, the investigator would examine the "tactical" and "strategic" models and determine whether or not the addition of variables requiring more extensive laboratory analysis would be required to significantly increase the multiple R values and select a model accordingly.

The formula approach would work best in areas in which sewage sludge was a known contaminant but for which the ambient population for the *Acanthamoeba* was unknown. In regions similar to the New York Bight in which *Acanthamoeba* are known to exist, another approach may be required. In this case, the use of a prediction table (Figures 10, 11) is required.

The most important consideration to keep in mind when examining these prediction tables is that values are arranged in order from the lowest to highest predicted values for positive Acanthamoeba cultures generated by the model. The actual station values are arranged according to the manner in which they correspond to the model's prediction. The table permits an investigator to ascertain the error rate which can be expected when the prediction table is used and a given background concentration, or population, of Acanthamoeba, represented by the percent of positive cultures/station, is assumed.

An example will serve to illustrate this point. In the Narragansett Bay study, the experimental design called for six culture replicates from each sediment sample. The table (Figure 10) is based on this sampling scheme. If another study were to be undertaken in the Narragansett Bay area using the six sample method and the ambient population was considered to be one out of six cultures/station or 17%, the table would be used in the following manner.

Section AA (Figure 10) would be drawn midway between 17% (one culture) and 33% (two cultures) or 25.3665 on the table. Stations above this line, in the "Actual %" column which represented 17% or less would now be considered the ambient population level and be the new "zero" point. In this case, there are seven values above the line representing zero or 17%. Based on the ordering used to set up the table, these values represent a correct prediction of negative incidence. The one value of 50% above the line represents a prediction of negative incidence when the actual situation is positive. The first two values

Figure 10. A prediction table for Narragansett Bay. Section 'AA' is drawn to delineate an "ambient" population level of one positive culture/station of 17% (one culture out of six). Matrix below the table indicates a possible error rate of one in 29.

Figure 10

*PREDICTION MODEL GENERATED BY THE "BEST" MODEL FOR THE NARRAGANSETT BAY SITE

Obs. #	Predicted%	Actual%
1	.	
2	.	
3	13.5995	0
4	14.0727	0
5	14.0727	0
6	14.0727	0
7	16.9115	0
8	22.9153	0
9	24.3347	50
10	25.3665	17
A		A
11	26.3128	67
12	27.7322	17
13	31.7740	17
14	33.6666	17
15	33.7360	33
16	36.8768	67
17	40.2129	17
18	40.6942	50
19	41.9827	83
20	42.8435	83
21	50.0794	67
22	53.8514	50
23	55.7440	17
24	57.6365	83
25	65.5490	67
26	67.4415	100
27	87.2227	83
28	87.2227	100
29	88.2916	83
30	93.4642	67
31	94.3197	67

		Actual Values	
		- cultures	+ cultures
Predicted values	- cultures	Correct prediction 7	Incorrect prediction predicting - when + 1
	- cultures	Incorrect prediction predicting - when - 5	Correct Prediction 16

*Values are arranged from the lowest to the highest predicted value for positive *Acanthamoeba* cultures per station.

of 50% and 83% in the "Actual %" column are ignored since no prediction is available. Below the line AA are 16 values of 33% or more. These values represent correct positive predictions. The five values of 17% below the line represent incorrect positive predictions. All these figures appear in the appropriate box in the matrix below the table.

The most serious error which can be made, from a public health standpoint, is a negative prediction when the actual situation is positive. The matrix indicates that there is a 1 in 29, or 3% chance of making such an error if the ambient population level is considered to be one positive culture/station.

If an ambient level of two positive cultures/station, or 33%, was chosen, section BB would be drawn at the midpoint between 33% (two cultures) and 50% (three cultures) (Figure 11) or about 41%. Using the same rationale as in the previous case, the matrix now indicates that there is a 5/29 or 17% chance of making the error or predicting a negative incidence in a positive incidence situation.

Based on these criteria, the appropriate procedure may be applied to a given environmental situation. For a preliminary investigation in which a sewage sludge impact is known but for which no previous Acanthamoeba data exist, the formula represents the most rapid and economical method. In other areas which have a history of sewage contamination, the table produces the best information.

The preceding examples do not rule out the possibility that a "background level" of one or two cultures may represent a definite public health consideration. Such a decision would be made by the official using the tables based upon his familiarity with area under study and the seriousness of the preceived threat.

In such a case, the tables would be used as presented with the caveat that their success rate is based upon the significance of the model used to generate the values for the table (in the case of Narragansett Bay, the R value for the model is .73 and the probability of a larger "F" is .0001).

Applicability of Procedures

These same procedures may be applied to any variable within the correlation matrices presented (Appendices B, C, D). The programs used to obtain the Acanthamoeba models, tables, and formulae, may be used to produce similar products pertaining to other pollutants. Some modification would be required (e.g., substituting PPM or PPB for percent positive cultures/station), but the results would be equally valid. The stepwise regression procedure or similar package should be used since all variables are evaluated reducing the possibility of invalid predictions based on too few comparisons. The investigator must obtain maximum utility from the available information and insure that the proceudres used are designed to produce the most in-depth analysis possible.

Figure 11. A prediction table for Narragansett Bay. Section 'BB' is drawn to delineate an "ambient" population level of two positive cultures/station or 33% (two cultures out of six). Matrix below the table indicates a possible error rate of five in 29.

Figure 11

*PREDICTION MODEL GENERATED BY THE "BEST" MODEL FOR THE NARRAGANSETT BAY SITE

Obs. #	Predicted%	Actual%
1	.	
2	.	
3	13.5995	0
4	14.0727	0
5	14.0727	0
6	14.0727	0
7	16.9115	0
8	22.9153	0
9	24.3347	50
10	25.3665	17
11	26.3128	67
12	27.7322	17
13	31.7740	17
14	33.6666	17
15	33.7360	33
16	36.8768	67
17	40.2129	17
18	40.6942	50
19	41.9827	83
B		B
20	42.8435	83
21	50.0794	67
22	53.8514	50
23	55.7440	17
24	57.6365	83
25	65.5490	67
26	67.4415	100
27	87.2227	83
28	87.2227	100
29	88.2916	83
30	93.4642	67
31	94.3197	67

		Actual Values - cultures	Actual Values + cultures
Predicted values	- cultures	Correct prediction 12	Incorrect prediction predicting - when + 5
	+ cultures	Incorrect prediction predicting + when - 1	Correct Prediction 11

*Values are arranged from the lowest to the highest predicted value for positive <u>Acanthamoeba</u> cultures per station.

CONCLUSIONS

1. Sufficient data exist in the literature, computerized data bases, and other archives to permit the development of a statistically valid method for predicting the incidence of pathogenic protozoans in oceanic sediments. The correlation between surrogate variables and the probability of obtaining positive/negative cultures of *Acanthamoeba* sp. may be determined using statistical procedures.
2. Use of the stepwise regression technique permits the determination of statistically valid probabilities for the presence/absence of one group of factors (not sampled) based upon correlations between these surrogate variables and other groups of environmental factors (sampled).
3. Tables and formulae may be produced by computer programs which may be used, in a cost effective manner, to evaluate public health situations in which the presence or absence of *Acanthamoeba* is a contributing factor. Data resulting from such studies may be used to document the spread of sewage-related organic materials from the original depositional centers even after the particular dumpsite is no longer active.
4. These same procedures may be applied to other variables in the data set to produce models similar to those generated for the *Acanthamoeba*.

Appendix A. Major computerized marine data archives used in this study.

Numerical Data Bases

*ADP	In-house computerized data base used by the Northeast Fisheries Center (NMFS/NOAA).
*NERFIS	Northeast Regional Fisheries Information Service, NOAA/NEFC, Woods Hole, MA.
*NODC	National Oceanographic Data Center, Environmental Data and Information Service, National Oceanic and Atmospheric Administration, Washington, DC. The national repository for all oceanographic data for all disciplines.
*PIDS	Parameter Inventory Display System (NODC). This data base provides listings of cruises, stations, and data available within a particular geographic area for a particular discipline.
*MCCDB	Marine Core Curators Data Base, National Geological Survey Data Base providing lists of authors and principal investigators as well as raw data printouts.
*NGSDC	National Geological Survey Data Center, Boulder, CO. Marine geology/sedimentology information.
*STORET	U. S. Environmental Protection Agency Storage and Retrieval system. Contains raw data from pollution studies conducted under the auspices of EPA.

Appendix A. (continued)

Bibliographic Data Bases

DIALOG/ENVIROLINE......	Computerized information service, accessed through NODC. Provides listings and abstracts of pertinent bibliographic materials using keyword searches.
SDI/NLISD.............	Selective Dissemination of Information, NOAA Library and Information Services, WSC-4, Washington Science Center, Rockville, MD. This data base is available to NOAA employees on a subscription basis. Monthly updates on pertinent literature sorted by keyword search for a desired area or discipline are available.

*NOTE: Within these data bases, numerous subfiles were selected in order to access the widest number of sources possible to obtain values and/or references for surrogate variables.

Appendix B. Complete correlation matrix for all 13 variables (12 surrogate variables and one dependent variable) used in the Narragansett Bay study.

```
                    NARRAGANSETT BAY  -  DESCRIPTIVE STATISTICS

 CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS

                 DIST      PCUL        TA        PB        CU        CR       HGB       CDM

DIST          1.00000  -0.82735  -0.77344  -0.54166  -0.92117  -0.72819  -0.74664  -0.61426
               0.0000    0.0001    0.0001    0.0302    0.0004    0.0072    0.0014    0.0194
                   31        31        31        16         9        12        15        14

PCUL         -0.82735   1.00000   0.58053   0.22901   0.71865   0.32330   0.59253   0.36040
               0.0001    0.0000    0.0006    0.3936    0.0292    0.3053    0.0199    0.2056
                   31        31        31        16         9        12        15        14

TA           -0.77344   0.58053   1.00000   0.74398   0.75921   0.64687   0.72842   0.40478
               0.0001    0.0006    0.0000    0.0010    0.0177    0.0230    0.0021    0.1511
                   31        31        31        16         9        12        15        14

PB           -0.54166   0.22901   0.74398   1.00000   0.36334   0.78653   0.40138   0.84355
               0.0302    0.3936    0.0010    0.0000    0.5478    0.0070    0.1959    0.0003
                   16        16        16        16         5        10        12        13

CU           -0.92117   0.71865   0.75921   0.36334   1.00000  -1.00000   0.96014   1.00000
               0.0004    0.0292    0.0177    0.5478    0.0000              0.0024    0.0001
                    9         9         9         5         9         2         6         4

CR           -0.72819   0.32330   0.64687   0.78653  -1.00000   1.00000   0.59138   0.58420
               0.0072    0.3053    0.0230    0.0070              0.0000    0.0553    0.1283
                   12        12        12        10         2        12        11         8

HGB          -0.74664   0.59253   0.72842   0.40138   0.96014   0.59138   1.00000  -0.07182
               0.0014    0.0199    0.0021    0.1959    0.0024    0.0553    0.0000    0.8543
                   15        15        15        12         6        11        15         9

CDM          -0.61426   0.36040   0.40478   0.84355   1.00000   0.58420  -0.07182   1.00000
               0.0194    0.2056    0.1511    0.0003    0.0001    0.1283    0.8543    0.0000
                   14        14        14        13         4         8         9        14
```

```
                    NARRAGANSETT BAY  -  DESCRIPTIVE STATISTICS

  CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS

                  ZNM       LFCC         TC        SPT       SCLR

PB            0.90267    0.52652   -0.33884    0.05654   -0.57134
               0.0009     0.0361     0.2167     0.8414     0.0208
                    9         16         15         15         16

CU            1.00000    0.66720   -0.54006    0.27517   -0.91405
                          0.0496     0.2108     0.5503     0.0006
                    2          9          7          7          9

CR            0.80498    0.70169   -0.49128    0.23754   -0.71735
               0.0159     0.0110     0.1249     0.4818     0.0086
                    8         12         11         11         12

HGB           0.30228    0.60964   -0.58262    0.35756   -0.79058
               0.4668     0.0158     0.0288     0.2094     0.0005
                    8         15         14         14         15

CDM           0.95416    0.62347   -0.39126   -0.23171   -0.61802
               0.0008     0.0172     0.1862     0.4462     0.0185
                    7         14         13         13         14

ZNM           1.00000    0.78151   -0.46572    0.06442   -0.72408
               0.0000     0.0027     0.1270     0.8423     0.0077
                   12         12         12         12         12

LFCC          0.78151    1.00000   -0.32811   -0.28491   -0.64240
               0.0027     0.0000     0.0823     0.1341     0.0001
                   12         31         29         29         31

TC           -0.46572   -0.32811    1.00000   -0.32818    0.39694
               0.1270     0.0823     0.0000     0.0822     0.0330
                   12         29         29         29         29
```

```
                 NARRAGANSETT BAY  -  DESCRIPTIVE STATISTICS

  CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS

              DIST      PCUL        TA        PB        CU        CR       HGB       CDM

ZNM       -0.69403   0.35567   0.52888   0.90267   1.00000   0.80498   0.30228   0.95416
            0.0123    0.2565    0.0771    0.0009              0.0159    0.4668    0.0008
                12        12        12         9         2         8         8         7

LFCC      -0.78000   0.68165   0.62800   0.52652   0.66720   0.70169   0.60964   0.62347
            0.0001    0.0001    0.0002    0.0361    0.0496    0.0110    0.0158    0.0172
                31        31        31        16         9        12        15        14

TC         0.09704  -0.03767  -0.21287  -0.33884  -0.54006  -0.49128  -0.58262  -0.39126
            0.6165    0.8462    0.2676    0.2167    0.2108    0.1249    0.0288    0.1862
                29        29        29        15         7        11        14        13

SPT        0.53287  -0.35165  -0.24244   0.05654   0.27517   0.23754   0.35756  -0.23171
            0.0029    0.0614    0.2051    0.8414    0.5503    0.4818    0.2094    0.4462
                29        29        29        15         7        11        14        13

SCLR       0.52015  -0.42342  -0.54396  -0.57134  -0.91405  -0.71735  -0.79058  -0.61802
            0.0027    0.0176    0.0016    0.0208    0.0006    0.0086    0.0005    0.0185
                31        31        31        16         9        12        15        14

               ZNM      LFCC        TC       SPT      SCLR


DIST      -0.69403  -0.78000   0.09704   0.53287   0.52015
            0.0123    0.0001    0.6165    0.0029    0.0027
                12        31        29        29        31

PCUL       0.35567   0.68165  -0.03767  -0.35165  -0.42342
            0.2565    0.0001    0.8462    0.0614    0.0176
                12        31        29        29        31

TA         0.52888   0.62800  -0.21287  -0.24244  -0.54396
            0.0771    0.0002    0.2676    0.2051    0.0016
                12        31        29        29        31
```

```
                    NARRAGANSETT BAY  -  DESCRIPTIVE STATISTICS

 CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS

                ZNM      LFCC        TC       SPT      SCLR

SPT         0.06442  -0.28491  -0.32818   1.00000  -0.13864
             0.8423    0.1341    0.0822    0.0000    0.4732
                 12        29        29        29        29

SCLR       -0.72408  -0.64240   0.39694  -0.13864   1.00000
             0.0077    0.0001    0.0330    0.4732    0.0000
                 12        31        29        29        31
```

Appendix C. Complete correlation matrix for all 21 variables (20 surrogate variables and one dependent variable) for the New York Bight apex study.

```
                       NEW YORK SITE  -  DESCRIPTIVE STATISTICS

              CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 /  N = 44

               DIST        BNT       PCUL         TA         PB        HGB         CU         CR

DIST        1.00000    0.23707   -0.30384   -0.21436   -0.45205   -0.29400   -0.49577   -0.33909
             0.0000     0.1213     0.0449     0.1623     0.0021     0.0527     0.0006     0.0243

BNT         0.23707    1.00000    0.00080    0.34881    0.22985    0.13973    0.15595    0.10195
             0.1213     0.0000     0.9959     0.0203     0.1334     0.3657     0.3121     0.5102

PCUL       -0.30384    0.00080    1.00000    0.17259    0.37432    0.32142    0.33564    0.07149
             0.0449     0.9959     0.0000     0.2626     0.0123     0.0334     0.0259     0.6447

TA         -0.21436    0.34881    0.17259    1.00000    0.76646    0.77689    0.63942    0.59823
             0.1623     0.0203     0.2626     0.0000     0.0001     0.0001     0.0001     0.0001

PB         -0.45205    0.22985    0.37432    0.76646    1.00000    0.85114    0.82588    0.60455
             0.0021     0.1334     0.0123     0.0001     0.0000     0.0001     0.0001     0.0001

HGB        -0.29400    0.13973    0.32142    0.77689    0.85114    1.00000    0.69310    0.54041
             0.0527     0.3657     0.0334     0.0001     0.0001     0.0000     0.0001     0.0002

CU         -0.49577    0.15595    0.33564    0.63942    0.82588    0.69310    1.00000    0.37433
             0.0006     0.3121     0.0259     0.0001     0.0001     0.0001     0.0000     0.0123

CR         -0.33909    0.10195    0.07149    0.59823    0.60455    0.54041    0.37433    1.00000
             0.0243     0.5102     0.6447     0.0001     0.0001     0.0002     0.0123     0.0000

CDM        -0.25990    0.21689    0.12373    0.60348    0.72541    0.59533    0.58200    0.36925
             0.0884     0.1573     0.4236     0.0001     0.0001     0.0001     0.0001     0.0136

ZNM        -0.46595    0.23499    0.22313    0.77228    0.76904    0.69873    0.73596    0.48681
             0.0014     0.1247     0.1454     0.0001     0.0001     0.0001     0.0001     0.0008

AGM        -0.36136    0.24915    0.32786    0.73009    0.77030    0.58903    0.70591    0.51698
             0.0159     0.1029     0.0298     0.0001     0.0001     0.0001     0.0001     0.0003
```

```
                  NEW YORK SITE  -  DESCRIPTIVE STATISTICS

        CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 /  N = 44

               DIST       BNT      PCUL        TA        PB       HGB        CU        CR

NIPM       -0.36637   0.25274   0.29000   0.71882   0.76801   0.63042   0.71197   0.43241
             0.0144    0.0979    0.0562    0.0001    0.0001    0.0001    0.0001    0.0034

LFCC       -0.46872   0.32955   0.24175   0.53566   0.76265   0.51547   0.69545   0.38623
             0.0013    0.0289    0.1139    0.0002    0.0001    0.0003    0.0001    0.0096

TC         -0.28403  -0.02585   0.34342  -0.10487  -0.00670   0.02033   0.08854  -0.14503
             0.0617    0.8677    0.0225    0.4981    0.9656    0.8958    0.5676    0.3476

SPT         0.08537   0.29551  -0.31983   0.07046  -0.04848  -0.13295  -0.03904   0.06253
             0.5816    0.0515    0.0343    0.6495    0.7546    0.3896    0.8014    0.6868

SCLR        0.40690  -0.03445  -0.48880  -0.35304  -0.54299  -0.56458  -0.36043  -0.52749
             0.0061    0.8243    0.0008    0.0187    0.0001    0.0001    0.0162    0.0002

PSILT      -0.35970   0.08287   0.26240   0.80843   0.87380   0.87677   0.69560   0.64341
             0.0165    0.5928    0.0853    0.0001    0.0001    0.0001    0.0001    0.0001

PCLAY      -0.06096   0.41952   0.18986   0.60000   0.51582   0.53377   0.39658   0.41432
             0.6942    0.0046    0.2171    0.0001    0.0003    0.0002    0.0077    0.0052

PCB        -0.38961   0.21054   0.19424   0.47017   0.60333   0.39531   0.69716   0.25509
             0.0089    0.1701    0.2064    0.0013    0.0001    0.0079    0.0001    0.0947

PCOP       -0.37989   0.16749   0.23756   0.44038   0.58006   0.55983   0.54198   0.41612
             0.0110    0.2772    0.1205    0.0028    0.0001    0.0001    0.0001    0.0050

TCHTOC     -0.42216  -0.15452   0.05957   0.14425   0.04309   0.07871  -0.05912   0.25341
             0.0043    0.3166    0.7009    0.3502    0.7812    0.6115    0.7030    0.0970

                CDM       ZNM       AGM      NIPM      LFCC        TC       SPT      SCLR
```

```
                    NEW YORK SITE  -  DESCRIPTIVE STATISTICS

        CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 /  N = 44

               CDM       ZNM       AGM      NIPM      LFCC        TC       SPT      SCLR

DIST      -0.25990  -0.46595  -0.36136  -0.36637  -0.46872  -0.28403   0.08537   0.40690
            0.0884    0.0014    0.0159    0.0144    0.0013    0.0617    0.5816    0.0061

BNT        0.21689   0.23499   0.24915   0.25274   0.32955  -0.02585   0.29551  -0.03445
            0.1573    0.1247    0.1029    0.0979    0.0289    0.8677    0.0515    0.8243

PCUL       0.12373   0.22313   0.32786   0.29000   0.24175   0.34342  -0.31983  -0.48880
            0.4236    0.1454    0.0298    0.0562    0.1139    0.0225    0.0343    0.0008

TA         0.60348   0.77228   0.73009   0.71882   0.53566  -0.10487   0.07046  -0.35304
            0.0001    0.0001    0.0001    0.0001    0.0002    0.4981    0.6495    0.0187

PB         0.72541   0.76904   0.77030   0.76801   0.76265  -0.00670  -0.04848  -0.54299
            0.0001    0.0001    0.0001    0.0001    0.0001    0.9656    0.7546    0.0001

HGB        0.59533   0.69873   0.58903   0.63042   0.51547   0.02033  -0.13295  -0.56458
            0.0001    0.0001    0.0001    0.0001    0.0003    0.8958    0.3896    0.0001

CU         0.58200   0.73596   0.70591   0.71197   0.69545   0.08854  -0.03904  -0.36043
            0.0001    0.0001    0.0001    0.0001    0.0001    0.5676    0.8014    0.0162

CR         0.36925   0.48681   0.51698   0.43241   0.38623  -0.14503   0.06253  -0.52749
            0.0136    0.0008    0.0003    0.0034    0.0096    0.3476    0.6868    0.0002

CDM        1.00000   0.71197   0.71214   0.56106   0.48631  -0.20253  -0.06913  -0.33617
            0.0000    0.0001    0.0001    0.0001    0.0008    0.1874    0.6557    0.0257

ZNM        0.71197   1.00000   0.79329   0.66241   0.53712  -0.03795   0.02116  -0.39683
            0.0001    0.0000    0.0001    0.0001    0.0002    0.8068    0.8916    0.0077

AGM        0.71214   0.79329   1.00000   0.61825   0.53101  -0.18000   0.03159  -0.28973
            0.0001    0.0001    0.0000    0.0001    0.0002    0.2423    0.8387    0.0564
```

```
                    NEW YORK SITE  -  DESCRIPTIVE STATISTICS

        CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 /  N = 44

                CDM       ZNM       AGM      NIPM      LFCC        TC       SPT      SCLR

NIPM        0.56106   0.66241   0.61825   1.00000   0.68847  -0.09153   0.03756  -0.36751
             0.0001    0.0001    0.0001    0.0000    0.0001    0.5546    0.8087    0.0141

LFCC        0.48631   0.53712   0.53101   0.68847   1.00000   0.06949   0.06860  -0.29702
             0.0008    0.0002    0.0002    0.0001    0.0000    0.6540    0.6581    0.0502

TC         -0.20253  -0.03795  -0.18000  -0.09153   0.06949   1.00000  -0.12479  -0.14306
             0.1874    0.8068    0.2423    0.5546    0.6540    0.0000    0.4196    0.3542

SPT        -0.06913   0.02116   0.03159   0.03756   0.06860  -0.12479   1.00000   0.22268
             0.6557    0.8916    0.8387    0.8087    0.6581    0.4196    0.0000    0.1463

SCLR       -0.33617  -0.39683  -0.28973  -0.36751  -0.29702  -0.14306   0.22268   1.00000
             0.0257    0.0077    0.0564    0.0141    0.0502    0.3542    0.1463    0.0000

PSILT       0.64175   0.73253   0.60961   0.76901   0.56668  -0.06069  -0.09346  -0.58639
             0.0001    0.0001    0.0001    0.0001    0.0001    0.6955    0.5462    0.0001

PCLAY       0.54891   0.60762   0.52288   0.53759   0.26674  -0.01927   0.15329  -0.46372
             0.0001    0.0001    0.0003    0.0002    0.0801    0.9012    0.3205    0.0015

PCB         0.64759   0.77069   0.81156   0.46420   0.46444   0.01888   0.01091  -0.07291
             0.0001    0.0001    0.0001    0.0015    0.0015    0.9032    0.9440    0.6381

PCOP        0.41746   0.41934   0.29039   0.60153   0.49069   0.13675  -0.03099  -0.60732
             0.0048    0.0046    0.0558    0.0001    0.0007    0.3761    0.8417    0.0001

TCHTOC      0.05269   0.14474  -0.02519   0.07979  -0.01104   0.23497   0.03370  -0.52686
             0.7341    0.3486    0.8711    0.6066    0.9433    0.1247    0.8281    0.0002
```

```
                    NEW YORK SITE  -  DESCRIPTIVE STATISTICS

            CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 /  N = 44

             PSILT     PCLAY       PCB      PCUP    TCHTOC

DIST      -0.35970  -0.06096  -0.38961  -0.37989  -0.42216
            0.0165    0.6942    0.0089    0.0110    0.0043

BNT        0.08287   0.41952   0.21054   0.16749  -0.15452
            0.5928    0.0046    0.1701    0.2772    0.3166

PCUL       0.26240   0.18986   0.19424   0.23756   0.05957
            0.0853    0.2171    0.2064    0.1205    0.7009

TA         0.80843   0.60000   0.47017   0.44038   0.14425
            0.0001    0.0001    0.0013    0.0028    0.3502

PB         0.87380   0.51582   0.60333   0.58006   0.04309
            0.0001    0.0003    0.0001    0.0001    0.7812

HGB        0.87677   0.53377   0.39531   0.55983   0.07871
            0.0001    0.0002    0.0079    0.0001    0.6115

CU         0.69560   0.39658   0.69716   0.54198  -0.05912
            0.0001    0.0077    0.0001    0.0001    0.7030

CR         0.64341   0.41432   0.25509   0.41612   0.25341
            0.0001    0.0052    0.0947    0.0050    0.0970

CDM        0.64175   0.54891   0.64759   0.41746   0.05269
            0.0001    0.0001    0.0001    0.0048    0.7341

ZNM        0.73253   0.60762   0.77069   0.41934   0.14474
            0.0001    0.0001    0.0001    0.0046    0.3486

AGM        0.60961   0.52288   0.81156   0.29039  -0.02519
            0.0001    0.0003    0.0001    0.0558    0.8711
```

```
                    NEW YORK SITE  -  DESCRIPTIVE STATISTICS

          CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 /  N = 44

              PSILT     PCLAY       PCB      PCOP    TCHTOC

NIPM        0.76901   0.53759   0.46420   0.60153   0.07979
             0.0001    0.0002    0.0015    0.0001    0.6066

LFCC        0.56668   0.26674   0.46444   0.49069  -0.01104
             0.0001    0.0801    0.0015    0.0007    0.9433

TC         -0.06069  -0.01927   0.01888   0.13675   0.23497
             0.6955    0.9012    0.9032    0.3761    0.1247

SPT        -0.09346   0.15329   0.01091  -0.03099   0.03370
             0.5462    0.3205    0.9440    0.8417    0.8281

SCLR       -0.58639  -0.46372  -0.07291  -0.60732  -0.52686
             0.0001    0.0015    0.6381    0.0001    0.0002

PSILT       1.00000   0.63527   0.37242   0.64637   0.21127
             0.0000    0.0001    0.0128    0.0001    0.1686

PCLAY       0.63527   1.00000   0.34727   0.55874   0.26960
             0.0001    0.0000    0.0209    0.0001    0.0768

PCB         0.37242   0.34727   1.00000   0.11109  -0.15955
             0.0128    0.0209    0.0000    0.4728    0.3009

PCOP        0.64637   0.55874   0.11109   1.00000   0.34064
             0.0001    0.0001    0.4728    0.0000    0.0237

TCHTOC      0.21127   0.26960  -0.15955   0.34064   1.00000
             0.1686    0.0768    0.3009    0.0237    0.0000
```

Appendix D. Complete correlation matrix for 13 variables (12 surrogate variables and one dependent variable) used in the Philadelphia-Camden dumpsite study.

```
                    PHILADELPHIA SITE  -  DESCRIPTIVE STATISTICS


  CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS

                 DIST       BNT      PCUL        TA        PB        CU        CR       ZNM

 DIST         1.00000   0.37522  -0.46800  -0.03341  -0.23769  -0.18418   0.03224  -0.02070
               0.0000    0.0034    0.0002    0.8888    0.2868    0.4119    0.8927    0.9271
                   59        59        59        20        22        22        20        22

 BNT          0.37522   1.00000  -0.21865   0.10865  -0.22328   0.17498   0.18158   0.10808
               0.0034    0.0000    0.0962    0.6484    0.3179    0.4361    0.4436    0.6321
                   59        59        59        20        22        22        20        22

 PCUL        -0.46800  -0.21865   1.00000  -0.07828   0.26409   0.19352   0.02385  -0.06022
               0.0002    0.0962    0.0000    0.7429    0.2350    0.3882    0.9205    0.7901
                   59        59        59        20        22        22        20        22

 TA          -0.03341   0.10865  -0.07828   1.00000   0.59470   0.70370   0.91859   0.90477
               0.8888    0.6484    0.7429    0.0000    0.0057    0.0005    0.0001    0.0001
                   20        20        20        20        20        20        19        20

 PB          -0.23769  -0.22328   0.26409   0.59470   1.00000   0.70148   0.71210   0.69166
               0.2868    0.3179    0.2350    0.0057    0.0000    0.0003    0.0004    0.0004
                   22        22        22        20        22        22        20        22

 CU          -0.18418   0.17498   0.19352   0.70370   0.70148   1.00000   0.77380   0.77007
               0.4119    0.4361    0.3882    0.0005    0.0003    0.0000    0.0001    0.0001
                   22        22        22        20        22        22        20        22

 CR           0.03224   0.18158   0.02385   0.91859   0.71210   0.77380   1.00000   0.90904
               0.8927    0.4436    0.9205    0.0001    0.0004    0.0001    0.0000    0.0001
                   20        20        20        19        20        20        20        20
```

```
                         PHILADELPHIA SITE  -  DESCRIPTIVE STATISTICS



 CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS

               DIST       BNT      PCUL        TA        PB        CU        CR       ZNM

 ZNM       -0.02070   0.10808  -0.06022   0.90477   0.69166   0.77007   0.90904   1.00000
             0.9271    0.6321    0.7901    0.0001    0.0004    0.0001    0.0001    0.0000
                 22        22        22        20        22        22        20        22

 NIPM      -0.12972  -0.16059   0.12467   0.92546   0.43586  -0.09306   0.52709   0.38279
             0.7595    0.7040    0.7687    0.0028    0.2804    0.8265    0.2241    0.3493
                  8         8         8         7         8         8         7         8

 LFCC      -0.59062  -0.38448   0.31362   0.07294   0.38526   0.37287   0.08180   0.00401
             0.0001    0.0029    0.0165    0.7599    0.0766    0.0874    0.7317    0.9859
                 58        58        58        20        22        22        20        22

 TC        -0.13103   0.19232  -0.13135   0.65782   0.95215   0.83947   0.93071   0.98628
             0.7571    0.6482    0.7565    0.5430    0.1977    0.3657    0.2384    0.1056
                  8         8         8         3         3         3         3         3

 SPT       -0.17541  -0.28258   0.40656   0.00000   0.00000   0.00000   0.00000   0.00000
             0.6778    0.4977    0.3175    1.0000    1.0000    1.0000    1.0000    1.0000
                  8         8         8         3         3         3         3         3

 PSILT      0.27804   0.30828   0.00575   0.23744   0.31989   0.38689   0.33562   0.26061
             0.2799    0.2286    0.9825    0.3941    0.2107    0.1250    0.2213    0.3124
                 17        17        17        15        17        17        15        17

               NIPM      LFCC        TC       SPT     PSILT


 DIST      -0.12972  -0.59062  -0.13103  -0.17541   0.27804
             0.7595    0.0001    0.7571    0.6778    0.2799
                  8        58         8         8        17
```

```
                    PHILADELPHIA SITE  -  DESCRIPTIVE STATISTICS


CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS

             NIPM      LFCC        TC       SPT     PSILT

BNT      -0.16059 -0.38448   0.19232 -0.28258   0.30828
           0.7040   0.0029    0.6482   0.4977    0.2286
                8       58         8        8        17

PCUL      0.12467  0.31362  -0.13135  0.40656   0.00575
           0.7687   0.0165    0.7565   0.3175    0.9825
                8       58         8        8        17

TA        0.92546  0.07294   0.65782  0.00000   0.23744
           0.0028   0.7599    0.5430   1.0000    0.3941
                7       20         3        3        15

PB        0.43586  0.38526   0.95215  0.00000   0.31989
           0.2804   0.0766    0.1977   1.0000    0.2107
                8       22         3        3        17

CU       -0.09306  0.37287   0.83947  0.00000   0.38689
           0.8265   0.0874    0.3657   1.0000    0.1250
                8       22         3        3        17

CR        0.52709  0.08180   0.93071  0.00000   0.33562
           0.2241   0.7317    0.2384   1.0000    0.2213
                7       20         3        3        15

ZNM       0.38279  0.00401   0.98628  0.00000   0.26061
           0.3493   0.9859    0.1056   1.0000    0.3124
                8       22         3        3        17
```

```
                      PHILADELPHIA SITE  -  DESCRIPTIVE STATISTICS



CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS

                NIPM      LFCC        TC       SPT     PSILT

NIPM         1.00000   0.11956                      -0.52165
              0.0000    0.7780                        0.3673
                   8         8         0         0         5

LFCC         0.11956   1.00000  -0.12623   0.35839  -0.10753
              0.7780    0.0000    0.7658    0.3833    0.6812
                   8        58         8         8        17

TC                    -0.12623   1.00000   0.16783   0.98286
                        0.7658    0.0000    0.6912    0.1180
                   0         8         8         8         3

SPT                    0.35839   0.16783   1.00000   0.00000
                        0.3833    0.6912    0.0000    1.0000
                   0         8         8         8         3

PSILT       -0.52165  -0.10753   0.98286   0.00000   1.00000
              0.3673    0.6812    0.1180    1.0000    0.0000
                   5        17         3         3        17
```

BIBLIOGRAPHY

American Public Health Association. 1970. Recommended procedures for the examination of sea water and shellfish. APHA, Inc., Washington, DC. 105 p.

Amick, D. and H. J. Walberg. 1975. Introductory Multivariate Analysis. McCutchan Publishing Corp., Berkley, CA. pp. 10-12, 43-51.

Babinchak, J. A. 1977. Distribution of fecal coliforms in bottom sediments from the New York Bight. Mar. Poll. Bull. 8(7): 150-153.

Basta, D. J. and B. T. Bower. 1979. Analyzing natural systems resources for the future, Washington, D.C. (unpublished), Ch. 1, 6 and 7.

Basta, D. J., B. P. Chambers, C. N. Ehler, and T. F. LaPointe. 1982. Identifying and evaluating alternative ocean dump sites; an operational framework for strategic assessment and estimates of sludge generated by publicly owned municipal wastewater treatment plants. Office of Ocean Resources Coordination and Assessment (ORCA), Office of Coastal Zone Management, National Oceanic and Atmospheric Administration, Washington, DC, 20235.

Beardsley, R. C. 1975. Physical oceanography of the Middle Atlantic Bight. In: Gross, M. G. (ed.). 1976. Middle Atlantic Continental Shelf and New York Bight. Proc. Symp. Amer. Mus. Nat. Hist., 3-5 Nov., 1975. pp. 20-34.

Bertine, K. K. and E. D. Goldberg. 1977. History of heavy metal pollution in southern California coastal zone - reprise, Env. Sci. Tech., 8: 425-432.

Boehmer-Christiansen, S. 1981. Marine pollution control. Env. Policy and Law 7(1): 71-74.

Boesch, D. F. 1977. Analysis and interpretation of sediments collected during the Middle Atlantic Outer Continental Shelf Environmental Studies, 1975-76. VIMS SRAMSOE No. 174, pp. 5/31-5/51.

Bopp, E. and R. B. Biggs. 1981. Metals in estuarine sediments, factor analysis and its environmental significance. Science 214(4519): 441-443.

Brooks, N. H. 1960. Diffusion of sewage effluent in an ocean current. Proc. Int. Conf. Waste Disposal Mar. Environ., 1st, New York, Pergamon Press, pp. 246-267.

Brooks, N. H. and J. E. Krier. 1981. Alternative strategies for ocean disposal of municipal wastewater and sludge, prepared for presentation at a public hearing before the Subcommittee on Fisheries and Wildlife Conservation and the Environment of the Committee on Merchant Marine and Fisheries, U. S. House of Representatives (also In: Marine Board Assembly of Enginerring, National Research Council, 1981).

Butman, B. M. 1977. Long term observations of bottom current and bottom sediment movement on the Middle Atlantic Continental Shelf. U. S. Geological Survey, Final report to the Bureau of Land Management.

Cabelli, V. J. 1981. The impact of pollution on marine bathing beaches, an epidemiological study. In: Gross, M. G. (ed.). Middle Atlantic Continental Shelf and the New York Bight. Proc. Symp. Amer. Mus. Nat. Hist., 3-5 Nov., 1975, pp. 424-432.

Calabrese, A., E. Gould, and F. P. Thurberg. 1982. Effects of toxic metals in marine animals of the New York Bight; some laboratory observations. In: Ecological stress and the New York Bight; science and management, G. F. Mayer (ed.), Estuarine Research Federation, pp. 281-288.

Camp, R., S. Dresser and T. R. McKee. 1975. Phase 1 report of technical alternatives to ocean disposal of sludge in the New York City-New Jersey metropolitan area, prepared for the Interstate Sanitation Commission.

Carmody, D. J. 1973. Trace metals in sediments of New York Bight. Mar. Poll. Bull. 4: 132-135.

Chaterjee, S. and B. Price. 1975. Regression analysis by example, Wiley-Interscience, New York, pp. 123-142, Table A.4b, p. 224.

Daniel, C. and F. S. Wood. 1971. Fitting equations to data. Wiley Interscience, N. Y., N. Y., pp. 282-287, 310.

Devanas, M. A. 1980. Coincidence of cadmium and antibiotic resistance in New York Bight apex benthic microorganisms. Mar. Poll. Bull., 11: 264-269.

Donazzolo, R. 1981. Heavy metal contamination in surface sediments from the Gulf of Venice, Italy. Mar. Poll. Bull., 12(12): 417-425.

Douglas, A. G. 1981. Analysis of hydrocarbons in sediments as indicators of pollution. Presented at SMBA, OBAN, 18-19 April 1979. Proc. Roy. Soc. Edinburgh. B-80; 113-134.

Eisma, D. 1981. Suspended matter as a carrier for pollutants in estuaries and the sea. In: R. A. Geyer (ed.). 1981. Marine Environmental Pollution, 2: Dumping and Mining. Elsevier Publ. Co., Amsterdam, pp. 281-295.

Feliciano, D. W. 1981. Bringing about an end to ocean dumping. WPCF Jo., 53(3): 276-287.

Finstein, M. L. and M. L. Morris. 1980. Fate of coliform bacteria in Upper New York Bay. NTIS, Springfield, VA, 44 pp.

Fisher, H. B., J. E. List, R. C. Y. Koh, J. Imberger, and N. H. Brooks. 1979. Mixing in inland and coastal waters, Academic Press, N.Y., 276 pp.

Freeland, G. L. and D. J. P. Swift. 1978. Surficial sediments. MESA New York Bight Atlas Monograph No. 10. New York Sea Grant Institute, 93 pp.

Garfinkel, C. R. 1970. Computer applications to biochemical kinetics. Ann. Rev. Biochem., 39: 473-498.

Gaudette, M. and C. T. Lamont. 1981. A mathematical model of sediments movement in estuaries. Presented at ASCE Conservation and Utilization of Water and Energy Resources Sym., San Francisco, Aug. 8-11, 1979, pp. 412-420.

Gerlach, S. A. 1981. Marine pollution, diagnosis and therapy. Springer-Verlag, Berlin, 218 pp.

Gold, H. J. 1977. Mathematical modeling of marine systems. John Wiley & Sons, Wiley Interscience, N. Y., N. Y., pp. 1-38, 61-99.

Goldsmith, V. 1974. Wave-climate model of the Mid Atlantic Shelf and Shoreline. VIMS STRAMSOE, #38, Gloucester Pt., VA.

Goldsmith, V. 1977. Wave-climate model of the Baltimore Canyon. VIMS STRAMSOE, #106, Gloucester Pt., VA.

Goodnight, J. H. 1979. MAXR analysis technique. In: SAS User's Guide, 1979 edition, pp. 391-392.

Green, R. H. 1979. Sampling design and statistical methods for environmental biologists. Wiley Interscience, N. Y., N. Y., pp. 9-10, 206-209.

Gross, M. G. (ed.). 1976. Middle Atlantic Continental Shelf and the New York Bight. Proceedings of Symp., Amer. Mus. Nat. Hist., 3-5 Nov. 1975. Section 2, Physical Processes, pp. 20-68; Section 3, Geological Processes, pp. 69-149.

Hansen, D. V. 1977. Circulation. MESA New York Bight Atlas Monograph No. 3. New York State Sea Grant Institute, 23 pp.

Harris, W. H. 1974. Sewage sludge expansion, migration, accumulation, and identification, Nassau Co., New York Inner Continental Shelf. U. S. Congress, Senate, Committee on Public Works, Subcommittee on Environmental Pollution; Sewage sludge hazard to Long Island beaches: Hearing, 93rd Cong. 93-HS2, pp. 297-330.

Hatcher, P. G. and L. E. Keister. 1976. Carbohydrates and organic carbon in New York Bight sediments as possible indicators of sewage contamination. Middle Atlantic Cont. Shelf and the New York Bight, Special Symp., Vol. 2, pp. 240-248.

Hatcher, P. G., L. E. Keister and P. G. McGillivary. 1977. Steroids as sewage specific indicators in New York Bight sediments. Bull. of Env. Contamination and Toxicology, 17(4): 491-498.

Hatcher, P. G. and P. G. McGillivary. 1979. Sewage contamination in the New York Bight. Coprostanol as an indicator. ES&T Res. 13(10): 1225-1229.

Hershelman, G. P., et al. 1981. Metals in marine sediments near a large California Municipal outfall. Mar. Poll. Bull., 12(4): 131-134.

Hess, K. W. 1976. A three-dimensional numerical model of the estuary circulation and salinity in Narragansett Bay. Estuarine and Coastal Mar. Sci., 4: 325-338.

Hinson, M. O. 1979. Model summary tables. In: Basta & Bower (eds.). 1979. Analyzing natural systems. Resources for the future, Washington, D. C., Appendix 7A, pp. 108-140 (unpublished).

Hinson, M. O. and D. J. Basta. 1979. Analyzing surface receiving water bodies. In: Basta & Bower (eds.). 1979. Analyzing natural systems. Resources for the future, Washington, D. C., Ch. 7, pp. 57-71 (unpublished).

Hirsch, A. 1981. The impact of ocean pollution. EPA J, 7(3): 16-20.

Hopkins, T. 1983. Mathematical modelling in the Philadelphia Dumpsite; its application to monitoring. Presentation at the Second Annual Northeast Monitoring Program (NEMP) Workshop, Milford, CT, 22-24 February 1983. Proceedings in press.

Ingham, M. (Ed.). 1982. Summary of the physical oceanographic process and features pertinent to pollution distribution in the coastal and offshore waters of the northeastern United States, Virginia to Maine. NOAA Tech. Memo., NMFS-F/NEC-17. pp. 12, 24, 42, 44, 45, 61, 68-79, 80-97.

Kamlet, K. S. 1981. The oceans as waste space: the rebuttal. Oceanus, 24(1): 10-18.

Kavanaugh, M. C. and J. O. Leckie (eds.). 1980. Particulates in water, characterization, fate, effects, and removal. American Chemical Society, Washington, DC, 49 pp.

Kelch, W. J. and J. S. Lee. 1978. Modeling techniques for estimating fecal coliform counts in estuarines. Jo. of Water Poll. Control Fed., 50: 862-868.

Kim, G. 1983. On a differentiability of four subregions of the New York Bight; based on 1980 summer monitoring data. Presentation at the Second Annual Northeast Monitoring Program (NEMP) Workshop, Milford, CT, 22-24 February 1983. Proceedings in press.

Koditschek, L. K. and P. Guyre. 1974. Anti-microbial resistant coliforms in New York Bight. Mar. Poll. Bull., 5: 71-74.

Klienbaum, D. and L. Kupper. 1978. Applied regression analysis and other multivariate methods, Duxbury Press, North Scituate, MA, pp. 235-242.

Klinkhammer, G. P. and M. L. Bender. 1981. Trace metal distributions in the Hudson River estuary. Est., Coastal and Shelf Sci., 12: 629-643.

Lear, D. W. and M. L. O'Malley. 1981. Effects of ocean dumping on a temperate midshelf environment. In: Ocean dumping of industrial wastes, Plenum Pub. Corp., N. Y., pp. 485-202.

Lear, D. W., M. L. O'Malley, W. C. Muir, and G. Pence. 1982. Environmental effects of sewage sludge at the Philadelphia Dumping Site. In: Ecological stress and the New York Bight; science and management. G. F. Mayer (ed.). Estuarine Research Federation, 481-494.

Leedertse, J. J. 1972. A water quality simulation model for well mixed estuaries and coastal seas: Vol. IV, Jamaica Bay Tidal Flows, Pub. No. R-1009-NYC. The Rand Corporation, Santa Monica, CA.

Leedertse, J. J. and E. C. Gritton. 1971. A water quality simulation model for well mixed estuaries and coastal seas: Vol. III, Jamaica Bay simulations, Pub. No. R-709-NYC. The Rand Corporation, Santa Monica, CA.

Leedertse, J. J. and S. Liu. 1974. A water quality simulation model for well-mixed estuaries and coastal seas: Vol. VI, Simulation, observation and state estimation, Pub. No. R-1586-NYC. The Rand Corporation, Santa Monica, CA.

Lewis, D. J. and T. K. Sawyer. 1979. Distribution of Acanthamoebae (Amoebida:Acanthamoebidae) in sediments from an offshore disposal site. J. Protozool., 26(3), Pt. 1, p. 20A.

Major, G. A., et al. 1981. A prototype system for monitoring offshore marine pollution. Report CSIRO, Div. Fisheries and Oceanogr., Australia, #34, 60 pp.

Malone, T. C. 1982. Factors influencing the fate of sewage derived nutrients in the Lower Hudson Estuary and New York Bight. In: Ecological stress and the New York Bight. G. F. Mayer (ed.). Estuarine Research Federation, pp. 389-400.

Martin, J. 1977. Computer data base organization. Prentice Hall, New York, Part 1, pp. 22-125; Part 2, pp. 306-331.

Mayer, G. F. (ed.). 1982. Ecological stress and the New York Bight; science and management. National Oceanic and Atmospheric Administration, Office of Marine Pollution Assessment, Stony Brook, NY. Estuarine Research Federation, Columbia, SC, pp. 213-224, 249-262, 281-298, 389-400, 481-494 and 631-654.

Martinez, A. J. 1980. Primary amebic meningoencephalitis (PAM) and granulomatous amebic enchephalitis (GAE): epidemiological and clinico-pathological considerations. Proc. 2nd Int. Conf. on Biol. and Pathogncty. of Small Free Living Amoebae, U. of FL, Gainesville.

Munday, J. 1983. Remote sensing/LANDSAT analysis; their application to long-term broadscale monitoring. Presentation delivered at the Second Annual Northeast Monitorng Program (NEMP) Workshop, Milford, CT, 22-24 February 1983. Proceedings in press.

O'Conner, B. Klotz, and T. J. Kneip. 1982. Sources, sinks, and distribution or organic contaminants in the New York Bight ecosystem. In: Ecological stress and the New York Bight; science and management. G. F. Mayer (ed.). Estuarine Research Federation, pp. 631-654.

O'Connor, J. and R. L. Swanson. 1982. Unreasonable degradation of the marine environment - what is it? Oceans, Sept. 1982, pp. 1125-1132.

Office of Ocean Resources Coordination and Assessment. 1981. A data base for estimating pollutant discharges into coastal and ocean water of the United States. National Oceanic and Atmospheric Administration/ORCA, Washington, DC (mimeo).

O'Malley, M., D. W. Lear, W. Adams, J. Gaines, T. K. Sawyer and E. Lewis. 1982. Microbial contamination of continental shelf sediments by wastewater. J. Water Poll. Control Fed., 54(9): 1320-1323.

Ralston, A. (Ed.). 1983. Encyclopedia of computer science and engineering. Van Nostrand Reinhold Co., New York. pp. 1364-1553.

Rassoulzadegan, F. 1982. Nutrition chez les protozoaires marins planctoniques. In: L'Institute Oceanographique, Annales de L'Institute Oceanographique, marine pelagic protozoa and microzooplankton ecology. Nouvelle Seris - Tome 58, 1982, Fasicicule supplementaire, pp. 191-206.

SAS Institute. 1979. SAS User's Guide, 1979 edition. SAS Institute, Post Office Box 10066, Raleigh, NC, 27605, pp. 391-394.

Sawyer, T. K. 1979. Species diversity among marine protozoan in sediment from a sewage disposal site. J. Protozool., 26(3), Pt. 1, p. 22A.

Sawyer, T. K. 1980. Marine amebae from clean and stressed bottom sediments of the Atlantic Ocean and Gulf of Mexico. J. Protozool., 27(1): 13-32.

Sawyer, T. K. and J. Griffin. 1982. Amibes marines plactoniques, considerations taxonomiques. In: L'Institute Oceanographique, Annales de L'Institute Oceanographique, marine pelagic protozoa and microzooplankton ecology. Nouvelle Seris - Tome 58, 1982, Fasicicule supplementaire, pp. 169-172.

Sawyer, T. K., E. J. Lewis, M. Galasso, D. W. Lear. 1982. Pathogenic amoebae in ocean sediments near wastewater sludge disposal sites. Jo. Water Poll. Control Fed., 54(9): 1320-1323.

Selli, R., et al. 1977. Aspetti scientifici dell inguinamento dei mari italiani. Accad. Naz. Lincei, (Roma), Ahi convegni, 31: 169-191.

Shuval, H. I. 1978. Studies on bacterial and viral contamination of the marine environment. Rev. Int. Oceanogr. Med., 50: 43-50.

Singh, B. N. and S. R. Das. 1972. Occurrence of pathogenic Naegleria aerobia, Hartmanella culbertsoni, and H. rhysodes in sewage sludge samples of Lucknow. Curr. Sci., 41: 277-281.

Smith, R. 1981. The early stages of contaminant dispersion in shear flows. J. Fluid Mech., 111: 107-122.

Stebbings, J. H. 1981. Epidemiology, public health, and health surveillance around point sources of pollution. Env. Res., 25: 1-7.

Stefan, H. G. and A. C. Demettracopoulos. 1981. Cells-in-series simulation of river and transport. J. of Hydrodynamics Div. ASCE, 107 (HYG): 657-697.

Steimle, F., J. Caracciolo, and J. B. Pearce. 1982. Impacts of dumping on New York Bight apex benthos. In: Ecological stress and the New York Bight; science and management. G. F. Mayer (ed.). Estuarine Research Federation, pp. 213-224.

Swanson, C. and M. Spaulding. 1979. Generation of a tidal current model for Narragansett Bay using a numerical model. Marine Tech. Rept. #61, NOAA Grant 04-6-158-44002, 10 pp.

Tracor, Inc. 1971. Estuarine modeling: An assessment. Report No. 16070 DZV 02/71, prepared for EPA, Washington, D. C. (or NITS PB-206-807), 62 pp.

Vaccaro, R. F. 1981. The oceans and U. S. sewage sludge disposal strategy. Oceanus, 24(1): 55-60.

Van Loon, J. C. and J. Lichwa. 1973. A study of the atomic absorption determination of some important heavy metals in fertilizers and domestic sewage plant sludge. Environmental Letters, 4: 1.

Van Loon, J. C., D. Ruttan, and J. Kinrade. 1973. The determination of heavy metals in domestic sewage treatment plant wastes. Water, Air, and Soil Pollution, 2: 473-482.

West, R. H. and P. G. Hatcher. 1980. Poly-chlorinated biphenyls in sewage sludge and sediments of the New York Bight. Mar. Poll. Bull., 11(5): 126-129.

Wrens, H. J. 1953. The geological and hydrographic environment of the Narragansett Bay region. Yale University, Edwards St. Lab. Tech. Rept. No. 13, 83 pp.

Zar, J. H. 1974. Biostatistical analysis, Prentice Hall, Englewood Cliffs, N. J., pp. 198-225, 263-277.

VITA

Carl Robert Berman, Jr.

Born in Ocala, Florida, 6 March 1942. Earned Bachelor of Arts degree, Experimental Psychology, Tulane University of Louisiana, August 1964. Served as a Regular Naval Officer, August 1964 to August 1969. Earned Master of Science degree, Biological Oceanography, Old Dominion University, Norfolk, Virginia, May 1977. Presently serving as Executive Officer, Division of Environmental Assessment, NOAA, Sandy Hook Laboratory, Highlands, New Jersey, with the rank of Commander, NOAA Commissioned Corps.

The author is married and has one daughter.

Carl R. Berman, Jr.
School of Marine Science
College of William and Mary