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Seminar Series No. 1

Narragansett Bay: Issues, Resources, Status and Management

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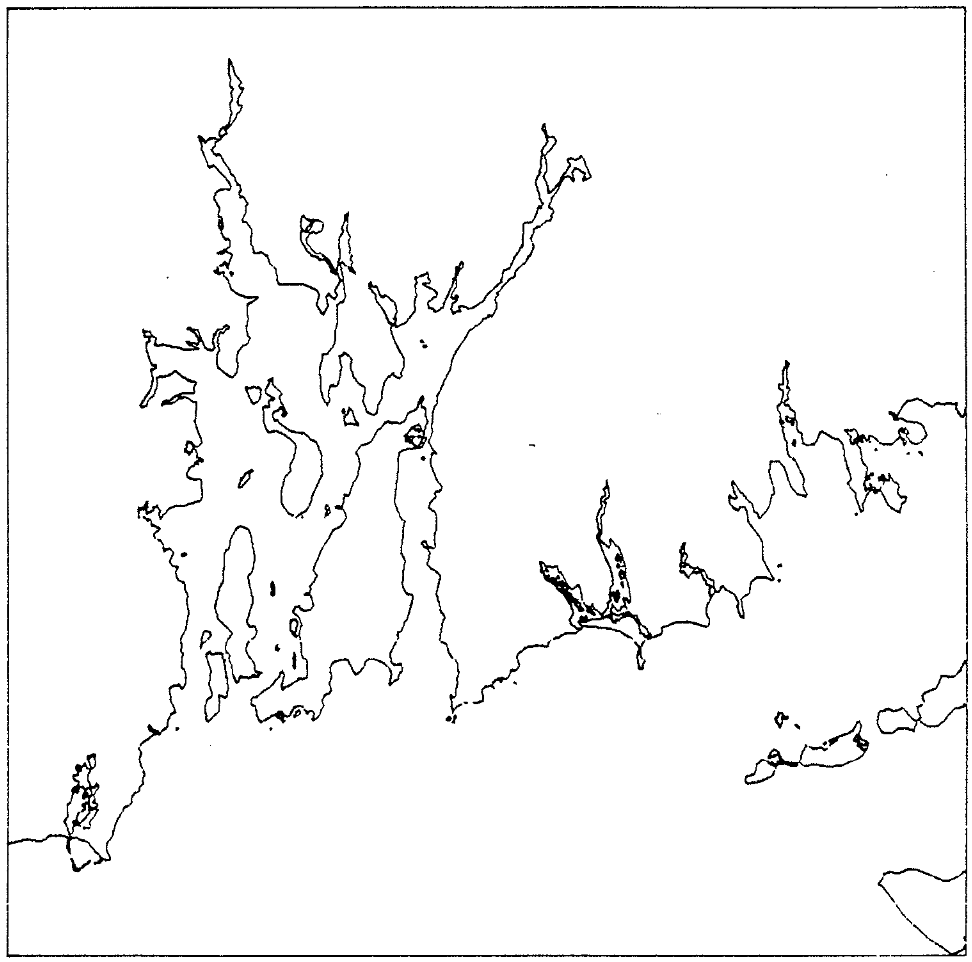

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National Oceanic and Atmospheric Administration
NOAA Estuarine Programs Office

NOAA Estuary-of-the-Month
Seminar Series No. 1

Narragansett Bay: Issues, Resources, Status and Management

Proceedings of a Seminar
Held January 28, 1985
Washington, D.C.

U.S. DEPARTMENT OF COMMERCE
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The NOAA Estuarine Programs Office

and

The U.S. Environmental Protection Agency

present

AN ESTUARY-OF-THE-MONTH-SEMINAR

NARRAGANSETT BAY

ISSUES, RESOURCES, STATUS AND MANAGEMENT

January 28, 1985

U.S. Department of Commerce
14th and Constitution Avenue, N.W.
Room 6802
Washington, D.C.

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PREFACE

These proceedings represent the presentations made at a seminar on Narragansett Bay co-sponsored by the National Oceanic and Atmospheric Administration's Estuarine Programs Office and the Environmental Protection Agency.

Many issues concerning the health and value of the Bay are considered in these papers which deal with subjects ranging from waste crankcase oil disposal to sociological concerns involving the perceptions of this body of water held by the various citizen user groups. This volume, then is a kaleidoscope of information through which we can see those areas in which we are knowledgeable and those in which additional data are needed. Many questions are addressed and many more are posed by the participating investigators. These proceedings, then are designed not only to simply report on the various presentations, but to stimulate future avenues of investigation.

The Estuarine Programs Office (EPO) wishes to thank Dr. J. B. Pearce, who coordinated this effort, and all those who gave their time to travel to the meeting, prepare their papers, and comment on the final edited versions. EPO welcomes your comments or suggestions on this or any other volume in this series.

INTRODUCTION

DR. JOHN B. PEARCE

Today's seminar is the first in a series that will be sponsored by the NOAA Estuarine Programs Office (EPO), and, as you can see from the agenda, there will be speakers dealing with a number of aspects of Narragansett Bay. These subjects range from the major issue, resources at risk, to the status of the habitat, resources, and future management options.

It's my responsibility to make a few introductory remarks. I would start out by saying that this seminar is not necessarily unique. There have been several generic estuarine seminars and a number on specific estuaries. What is unique about the present one is, that for one of the few times in history, a major Federal agency, the National Oceanic and Atmospheric Administration, has seen fit to establish a single office, the EPO, that will be responsible for coordinating estuarine studies within NOAA and for furthering cooperative research and monitoring by Federal agencies, the states, and the academic community. The seminar series will be one aspect of this effort.

The major activities of the Estuarine Programs Office fall into two general areas. As I said, coordination of studies, and then, the fostering of cooperative activities. But there is a third area that is equally important: the communication of activities that are ongoing within NOAA, the Federal agencies, and the states, to a range of user groups and scientists who are involved in estuarine studies.

I have before me on the podium a number of publications that have come to my office in just the last day or two. We have one here that was put out by the NOAA Sanctuary Program: "Narragansett Bay National Estuarine Sanctuary Management Plan." Another one that just arrived by Dr. Josselyn, who is with San Francisco State University, is called "Wetland Restoration and Enhancement in California."

Another document that arrived from the San Francisco Bay area is called "A Marsh Guide, Restoration in San Francisco Bay." And then, finally, at a meeting that I attended last Friday morning, in this very building, the U.S. Geological Survey furnished me a document called "Geological Principles for Prudent Land Use."

The importance of these publications is that in all of the years that estuarine studies have been underway--for well over a century--there's been little opportunity and little effort made to bring together the range of products that are being produced so that states, local governments and the academic community could use these materials to the greatest degree possible.

We thought it fitting therefore, that as the Estuarine Programs Office begins its second quarter of activity, we recognize this milesone with a seminar dealing with one of the estuaries that will be of concern to EPA, NOAA, and a range of other Federal and state agencies. So, today, we have brought together scientists from Narragansett Bay who will be talking about the major issues and opportunities for research and management in the Bay.

Having set up the schedule for the day, it seemed most fitting to bring before us a person from Congress, Congresswoman Claudine Schneider, who will make a few remarks concerning her understanding and thoughts on Narragansett Bay in particular, and estuaries in general.

Congresswoman Schneider has had a long interest in Narragansett Bay and other estuaries and will, I'm sure, be able to enlighten us to a considerable degree before we begin to hear from the academic and government scientists who will be involved in future Narragansett Bay studies. Congresswoman Schneider.

OPENING REMARKS

U.S. Representative Claudine Schneider (R/R.I.)

CONGRESSWOMAN SCHNEIDER: Thank you, Jack. I very much appreciate the opportunity to be here, and I appreciate the fact that NOAA and EPA have decided to come together to join forces and work for the best interests of Narragansett Bay.

There is very little question that Narragansett Bay and the other estuaries around the country are of significant value. When we recognized that eighty percent of our living marine resources all have lived at one time or another in estuaries, we can better appreciate their value. In the State of Rhode Island, we are quite fortunate to have Narragansett Bay. But unfortunately, we are extremely unfortunate to have the Bay in its present state.

We recognize the value of the Bay, its economic value, and its value to tourism. When you think about the fact that there are ten thousand jobs in the tourist industry alone and that they contribute approximately seven hundred and fifty million dollars a year to Rhode Island's economy, it's rather overwhelming. When you also acknowledge that on any one summer day you can find approximately forty thousand boats out on Narragansett Bay, and the beaches are utilized by approximately two million people, you can quickly understand the importance of maintaining the high quality of the Bay.

Not only are the Rhode Islanders recipients of the many virtues and values of the Bay but, when you acknowledge the fact that one-fourth of our entire Nations's cherrystone and little neck clams come from that Bay, then you can get pretty enthused about wanting to maintain its quality, even if you live here in Washington, D.C.

We have had a whole series of problems with Narragansett Bay. Some of my good Rhode Island friends will be elaborating on them later this morning. But just to touch on a few: Our sewage treatment facility has been in worse shape than many other sewage treatment facilities across the country. It has been responsible for the closure of seven miles of shellfish beds. There's nothing more discouraging than to open up the Providence Journal and see a drawing or a sketch of Narragansett Bay and see three-fourths of the Bay, colored or shaded in, saying that this area is closed to shellfishing.

Now, of course, we know that everybody doesn't follow the ban. We know that some people are real anxious to get in there and pick up some of those cherrystone clams and to go after some of those little necks. But the fact remains, what is happening to those people's health? What is the impact of the food that is being eaten on the food chain? These are some of the questions to which I hope we will find answers in the very near future.

Not only do we have the problem of Narragansett Bay's difficulties with the sewage treatment facility, but also the industrial polluters all along Narragansett Bay have, unfortunately, been coming very slowly to the realization that it is far better to avoid pollution now than to have to clean it up later.

Ten thousand pounds of toxic waste go into the Bay every day. Last year, we had a battle when the Congress considered extending the deadline for the electroplating industry, an industry that is very important to Rhode Island. And, quite frankly, their proposal to extend that deadline for a year I believe would have been devastating not only to the environmental quality of the Bay, but also to the other jewelry manufacturers and electroplaters who had been good citizens and invested thousands of dollars purchasing the necessary pollution control equipment.

Fortunately, we were able to compromise for a six month extension, which expired this last January. So for those of you in the audience who are from the Environmental Protection Agency, I will be looking to all of you to make sure that EPA enforces that deadline and makes sure that Rhode Island electroplaters comply with the regulations that have been implemented.

If the pretreatment plants for just this one industry could reduce the toxic load in the Bay by two to six thousand pounds a day, that's very, very significant when we're talking about the degree to which this one industry contributes to pollution.

Last year I was successful, along with other members of the delegation and a good cooperative team, in securing a million dollar grant for a study of the Bay's pollution problems. Two specific and important efforts are going to be made in this study. One project will measure the amount of the toxic substances in the sediments and in the marine life, the other will determine the sources of various pollutants. Finally, the degree of impact on the various Bay ecosystems will be evaluated.

We need to find out what the status of Narragansett Bay is. If we're spending money to attempt to clean up the Bay, then we had better find out what the sources are of the mess that we're attempting to clean up. How is it impacting the food chain? Are things getting any better due to the measures that we are taking? What is the best remedial action that can be taken at this time?

Needless to say, there is a whole spectrum of groups that are interested in cleaning up the Bay. Everybody from NOAA and EPA to the University sector to environmental group: "Save the Bay", and many others. Obviously, the citizens of Rhode Island and many of the other people that I keep meeting who claim to be my constituents because they live in Little Compton or Newport for a couple of weeks, are all very interested in the quality of the Bay resources.

I think it's important that this particular working group be aware that your life blood, or should I say more directly, your money, is on the line. If your feel at all comfortable at the prospect of having the continuing financial resources to continue this project and others, I would suggest that the more cooperative your efforts can be, the more closely EPA and NOAA work together, and the more speedily you get your act together, the more you can be assured that you will have champions in Congress who are going to fight for those financial resources.

You are all probably aware, at least those of you from NOAA, that there is a proposal right now to cut three hundred million dollars from your budget. That might mean that one out of every three of you NOAA employees that are sitting in the room right now might not be here. The fact remains that Congress is very, very serious about reducing this deficit.

If we have to contend with Federal agencies that are more interested in fighting for their turf--and we know that situation all too well because Congressmen are responsible for doing the same--then I think that the vitality of such programs as this Estuarine Program, is going to be on the line.

So, my friends from Rhode Island, my friends from the University sector, and citizens groups, I expect all of you to put the pressure on the Federal Agencies to ensure that NOAA and EPA can work together and as quickly as possible to continue to enjoy the complete support of the entire delegation because Narragansett Bay, as I have pointed out, is one of the most valuable assets we have, not only to the State of Rhode Island, but also to our country. The living marine resources are a top priority to all the people in this room.

There is very little question that cooperation has to be the keyword of your discussions for the rest of today. And this cooperative research and monitoring effect, I am confident, will be successful as long as we have full cooperation from everyone.

Thank you for your participation here today. I commend Jack for his leadership in pulling together this conference and commend my Rhode Island colleagues for taking the time and energy to come to Washington to help to better inform and educate those with whom we need to work in order to improve the water quality in our state. I look forward to working very closely with all of you and being at the forefront to assure that the financial resources will be there in order to ensure that our natural resources ensue.

DR. PEARCE: I think it's safe to say that the bureaucracy has its marching orders, because it's not just from Congresswoman Schneider that I hear these sorts of statements. We live in a world where, in fact, we are going to have to look more closely to determine what the principal issues are and how society, and particularly the scientific community, can deal with some of the real problems that we have in terms of estuarine research and management.

To this end it should be noted that this audience represents a wide range of people. We have the president of the Estuarine Research Federation with us today and individuals heading up major groups and agencies. I know, through conversations with these people, that everybody is very anxious to begin to direct the full capabilities of the Federal and state agencies to some of the problems at hand.

I want to thank Congresswoman Schneider for her excellent remarks. Certainly, we all owe a debt to Eric Schneider, who had the foresight months and even years ago, to see the importance of estuaries and to try to focus the attention of NOAA on these areas.

OVERVIEW

Dr. Scott Nixon

DR. NIXON: We have with us today, Dr. Eva Hoffman, who is working for EPA as the Director of the Narragansett Bay Study. We have with us Bob Bendick, the head of the Rhode Island Department of Environmental Management. We have Malcolm Spaulding, who runs an environmental consulting company and also serves as a professor in the Ocean Engineering Department at the University of Rhode Island and Dr. Neils Rorholm, a University professor of Resource Economics. I can claim that I have my NOAA hat on as the Sea Grant Coordinator from the University of Rhode Island. So, in this group today, we have many of the people who will be involved in future work on Narragansett Bay.

I can tell you from having attended a great many meetings during the past weeks, that we are getting as coordinated and integrated as it's possible to be. However, I hope all of you will be a little patient and tolerant with us today. We are the guinea pigs in this seminar series, and we've had some doubt as to who our audience was going to be. Certainly, none of us expected an audience of this size.

Narragansett Bay comes close to following the outlines of the State of Rhode Island and much of our small state is taken up by this body of water. Another thing that is immediately apparent upon examination is how much of an urban estuary Narragansett Bay is. I'd also like to point out that Narragansett Bay is a bit different from some of the other estuaries you may know about in that most of its freshwater inputs are dammed. What happens is that the freshwater flows down, goes over that dam, and immediately achieves a relatively high salinity of twenty parts per thousand or more. As a result, we don't have a long mixing zone with intermediate salinities going from freshwater up to twenty-five or thirty parts per thousand as you have in Chesapeake Bay, Delaware Bay, and many other areas. Bear in mind that our major point-source discharges of pollutants in Narragansett Bay flow into relatively high salinity water without the turbidity or meso-haline mixing zone commonly found in estuaries. That situation may be important in terms of the way some of the pollutants behave in the Bay and the way in which they're transported compared to transportation in other systems.

The average depth of the Bay is eight to nine meters. However, the West Passage is relatively shallow, while the East Passage is quite deep. The Upper Bay and Mt. Hope Bay are fairly shallow. There is also a dredged channel which goes on up the Providence River to the Port of Providence and another, lesser, channel, which goes toward Fall River.

To give you another perspective, I'll compare Narragansett Bay with some other estuaries with which you may be more familiar. A transect across the mouth of different systems, including Narragansett Bay, and some shallow systems such as Delaware Bay, the Chesapeake Bay mouth, and New York Bay emphasize these differences. I don't know how familiar you are with places like Barataria Bay in Louisiana, a very shallow coastal lagoon, or Mobile Bay, Alabama, also very shallow but with a deep channel on one side.

Narragansett Bay is fairly narrow and quite deep, and that configuration has some implications for the circulation that Malcolm Spaulding will describe this afternoon.

When one compares the general area of the watershed, the approximate surface area, mean depth, the mean tidal range, and the flushing time--a very approximate estimate of the flushing time--for a number of estuaries around the United States, the thing that becomes clear right away is that Narragansett Bay is a fairly small estuary compared to Delaware Bay, the Chesapeake Bay, or even to the Potomac.

The mean flushing time for Narragansett Bay is thought to be about twenty-seven days. It varies as a function of the freshwater input and ranges, we think, somewhere between ten days at the extreme high freshwater input to perhaps fifty days during summer drought periods. These are very uncertain numbers because we've never really conducted the research you need to nail that down even though this figure is a critical number for understanding how pollutants behave. The same thing is true for most of the other estuaries. We don't know their flushing characteristics very well. In fact, if you look through the literature, you can find a good bit of disagreement about how large they are. We have a lot to learn even about basic physical descriptions of many of these systems.

Another important thing about Narragansett Bay is that it does not get very much freshwater input compared to other estuaries, about forty cubic meters per second. That was the current thinking until about a year ago when Michael Pilson took a close look at the freshwater input question. It turned out that the freshwater input was really more like a hundred cubic meters per second on the annual average. But even at that rate we aren't getting very much freshwater in Narragansett Bay compared to Long Island Sound, Delaware Bay, New York Bay, or most of the other major estuaries in the U.S.

If we plot the annual temperature excursion versus the annual salinity excursion for Narragansett Bay we can see that the Bay usually goes from about zero up to about twenty degrees in the summer in the middle of the Bay. There's very little change in salinity during the year in the middle of Narragansett Bay. The salinity stays high and very constant, between twenty-five and thirty parts per thousand. It's a high, constant salinity environment.

In the Providence River, of course, the freshwater and the sewage come in and we do get some salinity variation. But even there, it's relatively salty at twenty to twenty-five parts per thousand most of the time. That's important to remember when you hear about a lot of the other estuaries in the coming sessions where there's much more of a salinity gradient, more freshwater, lower salinity, and more stratification. Narragansett Bay is relatively well mixed vertically. We don't get a strong fresh water lens on top that isolates the surface and bottom water except up in the Providence River. It's fortunate that we don't because that helps keep the bottom waters more oxygenated than they might otherwise be if we had a lighter layer of freshwater isolating the deep water from the atmosphere.

What kind of a Bay do we have? What does it really look like? I though I'd give you a little quote by the Reverend Denison, who wrote in 1880 in a book called Picturesque Narragansett Sea and Shore: "Excursions on the Bay are a part of the life of Rhode Island. Perhaps no sheet of water on our New England coast is more alive through the summer season with excursionists and pleasure parties to Narragansett Bay as no other affords equal attractions. All the people of the state must annually enjoy their view of this beautiful inland sea on the shores of the Atlantic making sure they feast on fish and luscious bivalves. Great multitudes come from all the neighboring states and from the distant parts of our country, including visitors from other lands, to gaze on the tranquil waters, the emerald islands, the romantic shores, the ocean-swept beaches, and visit our famed Newport, Providence, and other historic towns." Allowing that the Reverend might have been a bit carried away, this kind of description of Narragansett Bay appears again and again. In fact, it was a very popular summer resort. The Bay was covered with steamers and excursion boats. We had, as you'll see in a moment, hotels all the way up and down the Providence River where people went and spent their summers. The newly prosperous middle class from the industrial centers in Providence took full advantage of the Bay, and we took fish and shellfish out of the Bay all the way up into the Seekonk River.

Let's get a little better comparison as we go to a particular spot on Narragansett Bay that the Reverend chose to describe in more detail. He says, "Field's Point, so named for the former proprietors of the land, is alive, conspicuous and beautiful, jutting out from the western shores of the Bay just below Providence, readily reached by boats and carriages and is a very popular resort in the summer for the people in the city who wish to secure a shore dinner and a sniff of the sea breezes without having time to run far down the Bay. Excursion steamers usually stop at this point on their Bay trips. On this eminence stand Old Fort Independence." The spot the Reverend was talking about is now the site of the largest sewage treatment plant in the state, Field's Point. I doubt that anybody would want to sit out there to "sniff the breezes" these days. We've certainly come a long way from the Reverend's descriptions, and, though we might still claim that most of Narragansett Bay is beautiful and it still has some emerald spots on its isles, it's nowhere near what it was at the turn of the century. When the Field's Point plant was built, about 1900, it was one of the finest in the country. The City of Providence sent experts abroad, throughout Europe, to find the best technology for building sewage treatment plants. They attempted to treat the waste in as economically and in as environmentally sound a manner as possible.

What kind of a Bay do we have now in terms of pollutant inputs from facilities such as Field's Point and those other sewage treatment plants? It's not easy to compare the pollution loadings of different estuaries. To give some perspective, I have plotted the nutrient inputs to a variety of different ecosystem types. For an illustration, I've used a log-log plot as annual nitrogen input per unit area as a function of phosphorous input. It seems that the amount of nitrogen and phosphorous applied per unit area in most estuaries, including Narragansett Bay, is even greater than our most intensively fertilized agriculture.

I tried to do the same sort of thing with heavy metals. It's much more difficult to do that because there are very few estuaries in which we know how much heavy metal we're actually adding. That might surprise some of you; but we don't know the inputs of most pollutants to most estuaries very well.

Narragansett Bay, as you might expect, since we have a lot of heavy industry, a lot of old industry, and a lot of metal-working industry, receives a lot of metal pollution. Not just lead and copper, but a whole mix of these heavy metals is injected into the Bay at very high rates. This input has been going on for long time as cores from the sediments, as well as other techniques demonstrate.

A meter-deep layer of the sediment in upper Narragansett Bay, including the amount of organic carbon, organic nitrogen, organic and inorganic phosphorous, and a number of heavy metals shows that many of these metals are above background levels as far back as the early 1800s. That shouldn't surprise us too much. Narragansett Bay was the scene of the start of the industrial revolution in the United States. It began in Woonsocket and in the city of Providence, with the development of the cotton industry, and rapidly spread with the manufacture of steam engines which drove the entire early stage of the American industrial revolution. We've been a heavy metals, heavy industry center longer than any other estuary along the Atlantic Coast and certainly far longer than the west coast on Gulf coast systems have been.

The nutrients don't show up there in spite of the fact that we've had a high population, well over a hundred thousand people, for many, many years, simply because these materials are recycled in the Bay (put up into the water column and gradually washed out). They don't build up in the sediments as much as metals and hydrocarbons do. The Narragansett Bay sediments also are heavily impacted with hydrocarbons, especially in the upper Bay. Even in the lower Bay we have a significant amount of petroleum in the sediment. We probably have better data of petroleum hydrocarbons around the sediments of Narragansett Bay than any other estuary, and it's probably the one material we have more information on than any other in the Bay because of the work that Jim Quinn's lab has done over the years.

Even the data base for dissolved oxygen is much weaker than it really ought to be. While bottom waters in the lower bay are well oxygenated even during summer, the Providence and Seekonk Rivers have definite low-oxygen problems, often well below four milligrams per liter. In fact, we often get down to less than one milligram per liter with anoxia at certain times. We also know that Mt. Hope Bay has some low-oxygen problems in the summertime. These low-oxygen conditions over rather large areas of Narragansett Bay appear to come about because of the BOD loadings from sewage treatment plants and even more importantly, from the nutrient loading from those treatment plants which stimulates a large amount of phytoplankton production. Large blooms in these areas of the Bay put large amounts of organic matter on the bottom where it decomposes.

Because the water is stratified in parts of the upper Bay, this decomposition depletes the oxygen in the bottom waters. One of the nice things about low-oxygen conditions is that they are an unambiguous disaster. You can quibble over how much copper or oil is harmful to the sediment, but I don't think anybody wants to maintain that it's good idea to have oxygen concentrations less than a milligram per liter.

The nutrient levels in Narragansett Bay are not as high as you might imagine they would be. The inorganic nitrogen usually gets up to around ten micromolar. One of the points that's important to note about Narragansett Bay is that in the summertime in the lower Bay, essentially all of the inorganic nitrogen in the water is depleted. One of the important things that determines the productivity of the Bay is the way in which nutrients are recycled. Much of that recycling takes place in the sediments. As we've learned in the last ten years or so, there is a very strong interaction between what happens on the bottom and what happens in the overlying water in estuaries like

Narragansett Bay. Much of that is in terms of returning nutrients which are very rapidly taken up and used by the plankton. Up in the Providence River the nutrient levels are always high, even in the summertime, up above ten or more micromoles dissolved inorganic nitrogen per liter. It's a very enriched area and never nutrient depleted. Phosphate concentrations in the Providence River go roughly from two to eight micromoles per liter, a high phosphate level for a marine system.

Even in lower Narragansett Bay we never deplete the phosphate. It may get down to half-a-micromole or so and maybe up as high as three or four micromolar in the Bay. You can compare that with Chesapeake Bay, for example, where there are very few places where it gets above one micromole phosphate. Other places, like the Pamlico River in North Carolina, may get up to seven or eight or more micromolar. Of course, you have phosphate mining going on along the Pamlico. But Narragansett Bay is a high phosphorous-low nitrogen system that is probably nitrogen limited. We also have a strong seasonal cycle in all these nutrients, which is fairly regular from year to year.

Another important thing about Narragansett Bay is that the water is relatively clear compared to lots of estuaries. In upper Narragansett Bay we have an average extinction coefficient of about $0.76m^{-1}$, mid Bay $0.67m^{-1}$, Bay $0.58m^{-1}$.

In the Pamlico River the-K values may be $1.0 - 1.5^{-1}$. In mid-Chesapeake Bay they have a range of 0.68 to $1.13m^{-1}$. When we combine the high nutrients and that clear water, what we get is very abundant populations of phytoplankton in Narragansett Bay. It's important to make the point that Narragansett Bay is a phytoplankton-based system. We have a strong seasonal cycle. We have very little, essentially no, sea grasses in Narragansett Bay. We did have some in the coves and enbayments prior to the wasting disease in the 1930s, but it has never really come back to any extent.

Likewise, we have some very limited areas with kelp in them in the lower Bay, but they really contribute very little to the total productivity of Narragansett Bay. We're talking about a phytoplankton-based system which has a strong, characteristic winter-spring diatom bloom often beginning as early as December, though in recent years it has been occurring later and later. There are secondary blooms during the summer. Most of the productivity in Narragansett Bay now occurs in the summertime rather than in the winter-spring as it used to, so we're definitely having major changes in the Bay flora. The dominant species also changes from year to year, perhaps from eutrophication, perhaps from changes in the climate, a warming of the Bay, or something else. But it's clear that we've had some major shifts in the way the productivity of the Bay is distributed through the year and the form in which it comes.

We also have some flagellates which bloom in the early summer. But so far the Bay has been spared toxic blooms of any consequence, though they were reported in the early days of the 1800s. Even up in the Providence River where there may be peaks of over a hundred micrograms per liter, it is more common to have twenty or thirty micrograms per liter. We don't have anything to rival the impressive performance of the Potomac's blue-green algal scums. One of the things that probably saves Narragansett Bay and the Providence River from blooms like the Potomac is that we have a high salinity river, and blue-green algae don't live well in high salinity water.

Narragansett Bay appears to have a primary production of 310 grams carbon per square meter per year. That's the only published estimate, and that's only from one year's data. It shows that the Bay falls essentially in the standard range of two hundred to four hundred $gCm{-2}y^{-1}$ we find for almost all estuaries. I'm told that Narragansett Bay has been going up in recent tears and we're now closer to four hundred or four hundred fifty $gCm{-2}y^{-1}$, but those data have not been published.

I think it's safe to say that we know relatively little about variability all around the Bay. Most of our knowledge comes from the lower West Passage and the middle of the Bay, where the marine laboratory has worked since the second World War.

It's very difficult to compare zooplankton in different estuaries because every estuary samples them differently with different sized nets. Needless to say, we have a dominant copepod population in Narragansett Bay. The Durbins calculate that the approximate zooplankton production in the Bay is about twenty-five grams carbon per square meter per year. But it's extremely hard to measure secondary production in these of environments.

We have fish larvae in Narragansett Bay; some years ago one of the more intensive fish larval studies ever done was carried out for two years in Narragansett Bay as part of a nuclear power plant siting study.

There are lots of winter flounder larvae and sand lance larvae. It is extremely important as a nursery area, at least based on the abundance of the ichthyoplankton all around the Bay and up in Mt. Hope Bay as well. There are also ichthyoplankton up in the Providence River. It's difficult to get good numbers on current fisheries landings from Narragansett Bay. Our major fishery in the Bay is, as Claudine Schneider said, for clams. In the old days Narragansett Bay used to be a very productive oyster fishery, but that hasn't been true since the 1920s or 1930s. At that time, oysters were brought up from Chesapeake Bay and put on the bottom of Narragansett Bay and grown out there. That was very profitable. We had leased grounds over a large part of Narragansett Bay.

Before that we had a very productive natural oyster fishery until probably the late 1800s when pollution and over-fishing wiped it out. But even with our clam fisheries doing very well, Narragansett Bay can't claim to compete with places like Chesapeake Bay or some of the Gulf Coast estuaries like Barataria Bay.

In the past we have been able to get up to over a hundred kilograms per hectare yields when the Bay was very intensively harvested as a coastal fishery. At present, most of our finfish people go offshore and I guess the economics and all are better for working there than they are in the Bay. And there's also, of course, a very popular recreational fishery in Narragansett Bay.

In certain years there are a lot of menhaden in Narragansett Bay, and the porgy boats come in from New Jersey and sometimes even from North Carolina. There are the standard conflicts between the recreational and the commercial fishermen, about menhaden interacting with bluefish and striped bass.

I think I'll stop at this point and simply make the point that we have taken a lot of samples from Narragansett Bay. Most of them have come from the middle West Passage of the Bay. We've tried to do a lot of laboratory work on some of the major species from the Bay over the past twenty or thirty years, and we have, I think, a reasonably good state-of the-art ecological systems computer model of the Bay.

We also have developed unique living models of Narragansett Bay in the MERL tanks, or big mesocosysms. We've begun to use these to experiment with the whole ecosystem of Narragansett Bay. I think we're now at a point where we can bring the three most important kinds of research together, as we must to understand the estuary. We need to bring samples from the field (what's out there, what's coming in, how is it changing over time?) together with computer studies which enable us to numerically synthesize a lot of measurements. The models help to put the pieces together and see if they make sense. The experimental capabilities in MERL make it possible for us to get beyond descriptive natural history to creating predictive ecology.

I think we're probably in better shape to do that in Narragansett Bay than any other place I know of. We're far from understanding the Bay, but I think we've made a good bit of progress since the end of the last World War anyway.

I'd be happy to answer any questions.

QUESTION: To a lay person it sounds like you have a lot of information on the Bay. Can you just outline the areas which you feel the information is most lacking?

DR. NIXON: We don't know very much about the East Passage of Narragansett Bay. We know almost nothing about pollutants in the sediments or how they have accumulated there. That would help, as would a description of the long-range transport process.

We know almost nothing about how Mt. Hope Bay and Narragansett Bay interact. We know that a good bit of pollution enters from Fall River and upstream into the Taunton River. Our friends in Massachussets are trying hard to clean up. Nonetheless, a lot of material enters and we have no idea how much of it gets from Mt. Hope Bay into Narragansett Bay.

QUESTION: Do you have good information on point-sources?

DR. NIXON: I think so. My own feeling is that we're in fairly good shape on point-sources for Narraganset Bay, which is not to say that we can't learn more. But as you'll hear from Eva Hoffman's talk, we've learned a lot in the last five years, and we have begun to get some estimates of what's coming over the dam from up stream, and what's coming out of the treatment plants. The storm water discharges and storm water river flows have always been tremendous problems. There's forty-five or so storm overflows into the Providence River and certainly nobody has measured those or knows their behavior very well.

We have a good first-order estimate on the point-source inputs. But we're having a hard time separating the anthropogenic inputs from natural variation in the system. We know we've seen change in the Bay, but we don't know how much of it is from pollution inputs. We also don't know very much about how the various pollutants get on and off particles and how particles are transported around Narragansett Bay.

We have a hard time making predictions about how the Bay is going to respond to increasing or removing even simple things like nutrients. I think the last experiments we did with the MERL tanks showed we did an abysmal job of predicting what was going to happen. We were surprised at every turn. In fact, every time we've done an experiment we've been surprised.

I think these results force us to be fairly humble about making very firm predictions about what is going to happen. Certainly, we aren't in position to do a good job of tying secondary production, the level the citizen is concerned about, to pollution inputs. People don't care about diatoms; they care about striped bass, bluefish, flounder, clams, and so forth. We need to do a lot more work to learn how to tie those higher trophic levels to changes in the pollution inputs to changes in the primary production or changes in zooplankton. That's where the really toughest problem is at the moment.

QUESTION: You referred to MERL tanks. What are they?

DR. NIXON: The MERL tanks are a series of twelve large tanks or mesocosms. They're five meters deep, two meters in diameter. They hold thirteen cubic meters of water. And we have natural sediment community in the bottom so that we can look at sediment-water column interactions. It's a unique experimental facility that EPA built at Narragansett Bay some years ago. It was Eric Schneider's farsightedness and courage, if I may say so, that enabled us to go ahead and do what seemed to be a crazy and perhaps extravagant thing at the time. Time, I hope, has borne the wisdom of that approach.

MERL makes it possible to do experiments at the ecosystem level for coastal marine waters. Before that, we had to tear things apart--put phytoplankton in culture, put zooplankton in culture, take animals out of the bottom, do experiments, and work on them. However we had to make guesses or assumptions about how they all fit back together again. In the MERL system, we do experiments with the whole functioning system, or at least a lot of the whole functioning system with a lot of complexity. We've done a number of things: added oil; simulated storms; added various radioactive materials to see how they behaved; added nutrients; put in thermoclines; and simulated acid waste dumps, etc.

THE BAY AND THE ECONOMY

Dr. Neils Rorholm

DR. RORHOLM: I have it easy because I don't have to give you hard information, but simply get agreement in the room about what value is, and that seems to be a relatively simple matter. What is the value of that resource you refer to as Narragansett Bay? I am assured that you will all go away with your own definition of it, and that's the wonderful thing about being in the social sciences.

We will be talking about two concepts in dealing with the Bay and the community, which in this case, is the State of Rhode Island: one is value and one is impact. They are not the same, although we frequently use value in very general terms.

Briefly, value is based on the "willingness to pay" which is the ability to pay for the item and also to pay the other associated expenses.

So if we're talking about the value, for example, of the Narragansett Bay quahog resource, the harvest may be somewhere around sixteen or eighteen million dollars. Many people call this amount the value of the resource. But it isn't because it costs money to harvest the clams. So first, you have to subtract the operating expenses and then subtract the opportunity costs of the labor and management involved. Then you get the value of the resource or the amount that a private firm could afford to pay as a lease to have the sole use of that resource.

What we'll talk about today more than value is impact. What is the impact of the Bay being there, a multiple-use resource, on the surrounding countryside? We'll be talking about the outputs even as Scott talked about the inputs and our numbers will not be nearly as good.

The 1967 data were based primarily on an input-output study that was funded by then ESSA and, subsequently, by the Federal Water Pollution Control Administration, to arrive at estimates of the economic impact of Narragansett Bay.

Now, look at the title "Estimated Primary Annual Expenditures or Revenues." In other words, they can be both. A cost to someone is a revenue to someone else. So don't get too concerned about whether something is a cost in a national benefit accounting sense or whether it's a revenue. Whatever they are, they are of benefit to some people.

The Navy, of course, has had a powerful long-term influence on the economy of Narragansett Bay. You can see the drop between 1967 and 1983 from about two hundred and fifteen to eighty-eight. Now, the eighty-five percent decrease is computed in the following way:

ESTIMATED PRIMARY ANNUAL EXPENDITURES
OR REVENUES CAUSED BY NARRAGANSETT BAY
1967 AND 1983

	1967 ($1000)	1983 ($1000)	CHANGE (PERCENT)
Navy, except Education	215,808	98,226	-85
Marine Ed, R and D	35,711	270,163	+155
Marine Transportation	48,174	194,542	-36
Bridges	1,088	6,854	+113
Commerical Fishing	2,208	40,678	+522
Marine Industry	60,006	454,731	+156
Marine Recreation	26,303	198,513	+155
Waste Disposal	7,200	25,336	+19

CHANGE IN PERCENT IS NET OF INFLATION AS MEASURED BY CONSUMER PRICE INDEX (296.3)

First, we take the Consumer Price Index and assume that the Navy's spending has stayed the same up until 1983. The Price Index is normally kept at 1967 equals a hundred, as in this case. Then for 1983, it is very close to three; very close to three times as much. So we would be up around six hundred thousand. Then we take the numbers that we get today and if that was zero, then of course the percentage decrease would be a hundred percent. This simply means that there's only fifteen percent of it left. And it should be read in that way.

There's some indication that maybe there'll be some increases there later, but we'll come back to that. Marine education and research and development are also heavily influenced by the Navy. Incidentally, as you can see on the note down below, the percentage of increase or decrease that is listed is the net of inflation as judged by the Consumer Price Index. So these represent what we call real changes. The Navy is dominating but, in addition, you have the university laboratories, the parts of DEN that are marine related, and some industries that are involved in research and development.

Marine transportation has increased much less, although it has increased. We are concerned primarily with freight and the carrying of freight.

It may seem silly to list bridges, but let's face it, the bridges wouldn't be there if the Bay weren't there. For that matter, perhaps Rhode Island would not be there if the Bay were not there, for the Bay is all important to Rhode Island.

Commercial fishing has increased a good deal, five hundred and some percent. I should emphasize here that those are not necessarily fish caught in the Bay. As a matter of fact, these are landings in Newport plus shellfish harvests.

Those of you who deal with fisheries statistics know that they are not all that easy to come by any more. It took a couple of telephone calls and I could find out what the 1982 landings were of shellfish, hard shell clams, and what the landings in Newport were.

Marine industry is also a composite of shipbuilding. Some boat gear may be involved, which is also included in marine recreation. Shipbuilding, as I said, oil and gas service companies, instrumentation people, and the like are included in this fairly healthy sector.

I've been accused of saying that the largest use of Narragansett Bay was as a sewer. It should be recognized that to the extent that people dump pollutants in the Bay, the Bay is performing a service because we're talking about Bay outputs.

I'm not saying that in any sense the Bay is assimilating these materials. As long as people dump in the Bay, then that is a service the Bay is performing. It is measured here, in the first case, as precisely this opportunity cost. What would it cost in 1967 to prevent the pollution of the Bay? It was determined that it would take about three hundred million dollars to prevent pollution from passing through Field's Point Sewage Plant and perhaps another plant to pay off of bonds plus the operating expenses. So these figures are real, but their definitions are different. Therefore, you don't see them added up. If you did add them up, you'd come to about 1.3 billion dollars.

Narragansett Bay, we believe, accounts for something like fifteen percent of the total personal income in the State of Rhode Island. The gross state product right now is about fourteen billion with personal income around eleven billion. This adds up in direct numbers to 1.3 billion. Earlier studies indicated that the appropriate income multiplier to use is 1.1, 1.2, or a similar figure. We end up with anywhere from 1.5 to 1.8 billion dollars of personal income effect from the Bay.

After the artist was through with the work, I got to thinking that it was possible to view the recent past with which we are perhaps more interested and concerned, in a slightly different way. I designed this graphic in which we have 1967, 1983, as we did before. Then dividing this into two periods, 1967-1969 and 1979-1983, I computed what would be called the internal rate of return. For those of you who are familiar with business planning, our business people use internal rate of return quite a bit to see what annual yield a certain business decision or business investment would generate.

It's the same as a compound interest rate. In other words, if you put your money in the bank and left it there and you had "x" amount of dollars later, you could compute the interest rate they really paid you over a period of years.

ESTIMATED PRIMARY ANNUAL EXPENDITURES
OR REVENUES CAUSED BY NARRAGANSETT BAY 1967 AND 1983
PLUS ANNUAL REAL % CHANGES FOR TWO PERIODS

	1967 ($1000)	1983 ($1000)	1967-79	1979-83
Navy, except Education	215,808	98,226	-14.3	-0.2
Marine Ed, R and D	35,711	270,183	7.3	0.8
Marine Transportation	48,174	194,542	2.7	?
Bridges	1,088	6,854	5.6	0.8
Commercial Fishing	2,208	40,678	14.7	1.8
Marine Industry	60,006	454,731	9.2	?
Marine Recreation	26,308	198,513	3.6	4.3
Waste Disposal	7,200	25,336	1.0	?
An % change in gr. state product, constnt dollars		1.6	-0.6	

? = no data for this period

As benchmarks we can see that the gross state product during the 1967-1979 period changed by 1.6 percent a year in real terms, a positive 1.6 percent per year change above inflation. You can also see that in 1979-1983 the change was a negative .6 of one percent. In all fairness, we should say that if it had been possible to have data for 1984, then the result probably would not have been negative. But let's say it had been zero or some fraction of one percent gain. It would not have made a major difference here.

So you can see something which I think impressed those of us who were intimately involved with the Bay during those years--1967 to 1979 was the growth period except for the Navy. We had, of course, the military pullout in the early 1970s, which dropped that figure to a negative rate of growth. But you can see a very good increase in marine education and research. For bridges, it's simply saying that you people are driving a lot around the Bay. Commercial fishing also showed substantial increases. If you look at details you may ask: "Is that a real number?" It consists not only of increased landings, from our offshore water, but also consists of increases relative to, for example, Massachusetts, or some ports in Massachusetts by fisherman shifting to this port to offload. So is that increase balanced off by a loss to Massachusetts? Even in a national benefits sense, it's not. The fishermen received increased production and marketing efficiency by changing their unloading places trying to avoid, what many thought to be, questionable weighing and accounting practices that prevailed elsewhere.

So the numbers are real and there are real reasons behind them. But I should emphasize again that in the commercial fishing increases or total numbers or combinations of fish, we have in no way accounted for the menhaden. We have in no way accounted for the relatively small edible fish catch in the Bay. It's certainly valuable to those who are involved in it. But we have not accounted for that. It would have to be done on a man-to-man basis.

Marine industry, shows a fairly nice growth; marine recreation, a steady growth. Waste disposal, expenditures to control the increase in loadings that follow with all these increases in economic activities bears out why some people are concerned. This growth is one percent less than the built-in gross state product growth. With more and more of the industry locating around the Bay, a problem is created.

For the last period I was surprised to see a real decline in the Navy, but it's based on the Navy's own data.

The marine research and education has leveled off. The three question marks that mark Marine Transportation are down there because I did not have the opportunity to redo the study that Joe (Ferrel) and I did for the 1979 numbers. For transportation, marine industry, and waste disposal, that's a big job to do. So in the early 1983 data, I've simply brought it up by the producers' price index from 1979 to 1983 for the four-year period, which does not make a great deal of difference.

You can see again that there are consistent increases in the traffic around the Bay. Tourism certainly is responsible for part of that growth. The commercial fishing industry is still holding up well in its growth compared to the general economy.

Marine recreation seems to have taken an upswing. That number, 4.2, is probably excessive. It is accounted for, I believe, by the fact that the data for 1983 is quite a bit better than the data that we had for 1979. The latter was a more thorough study.

So, in sum, what we have here is a multiple-use resource. This means there'll be conflicts. Nobody is ever going to agree on what the value of the Bay is. If we were to conduct a study following the Federal Government guidelines as administered by the Water Resources Council, then we could come up with a reasonably good number. As a matter of fact, I think it should be done because the policy-makers are going to have to make tradeoffs. They're going to have to make decisions about who gets what when there are conflicts in use. Believe me, Narragansett Bay is full of them.

In the old days, the market process through the notion of willingness to pay, took care of establishing value very nicely. The reason that we don't accept the market process anymore is not only for aesthetic reasons and because we feel that such things as recreation are important. But also, after having looked at the economic aspects of Narragansett Bay, I've become more and more convinced that one of the greatest economic assets found in the Bay is its impact on the living and working environment of the area.

I said this to a group of land developers some time ago and, to my surprise they agreed. Industry doesn't locate any more simply by the traditional labor force, transportation, and nearness to market criteria. They want very much to be located where middle and upper management want to live. They want clean communities, proximity to receation, and good educational systems.

I will simply say then, that it is hard to over-value the importance of the Bay to the state and thereby to its economy. Let me just very quickly outline the sort of concentrations of uses that we tend to see in the estuary.

The Navy, of course, is very heavily involved. First of all, in the Navy War College and Officer Candidate School and the various research establishments on Aquidneck Island and the Naval Underwater Research Center. To my great disappointment, this area has not turned into a fishing port, which I hoped it would, because I think there would even have been room for a fishmeal plant. The Southern New England fishing industry desperately needs a fishmeal plant because they have to truck their products up to Gloucester or some location in Maine. When you begin trucking operations, value increases.

There's still some firms left in the former military areas, but there's now a Newport shipbuilder buying space and increasing his shipbuilding. General Dynamics also has part of this area for building parts of submarines,and In Coddington Cove, Direktors' Shipyard is working on a multi-million dollar Coast Guard contract.

So, as I said, there's some increases in this region. These areas are relatively free of conflict. The shellfishery, of course, is very heavy, especially in Greenwich Bay. The finfishery is generally down in the passages. The menhaden fishery can be almost anywhere depending upon their location.

Of course, the general tourism and beach recreation is very heavy on the southern shore. People don't really use beaches in estuaries very much because they're not very exciting. So they are what I call mother and child beaches. As such, I think they are tremendously important as a place to go with children. It would be extremely important to some of the inner city areas if some beaches of that type could be brought back to some of the places in which they have been eliminated. It's not the beaches that are involved when people talk about going to the beach for a weekend.

Boating has a base for marine recreation, in Greenwich Bay, which has a tremendous concentration of boats. The resident concentration of boats is growing. This growth involves mostly visiting yachts and boats of various types here in Newport.

Marine transportation: I'm happy to say that I looked through the fog one day and saw an aircraft carrier coming toward me right along the shore. The water is very deep, and although the channel is offshore there is no law saying that big ships have to stay in the channel so that the little ones can sail safely outside. But that type of situation is perhaps a good thing to think about. How simple it really would be and how much it would lessen conflict between marine transportation interests and recreational boaters.

There are many types of regulations or agreements that would be fairly simple, but because of a lack of data to argue them and because we're not used to that kind of regulation, the conflicts go unresolved year after year. What are the major conflicts? The major conflicts are, aside from those caused by pollution, with fisheries, with swimming, with boating, and with all of the others. There's very little conflict between recreation and industry in the Bay. The conflicts are within the users themselves; the minute an activity becomes popular, the minute an avocation becomes the thing to do, because it is profitable, or is otherwise beneficial, the area attracts more people because of the state's location adjacent to major population centers.

These are the major conflicts and they are extremely difficult to handle. The state needs to find out what the value is, in the sense that I defined it earlier, that various users of the Bay provide to the state as a whole, recognizing that there are tradeoffs. The people are not benefiting from tourism in Newport during this time when the price index has risen three times, and they are paying twelve-and-a-half times what they used to pay to keep their boats and are receiving increase in services. You see, that's the flipside of economic development.

QUESTION: You talked about value, willingness to pay to keep your resource. How do you handle that when, say, some local, state or Federal Government pumps a lot of money into the area and the value to the people who are using the resource remains the same for the fishing industry or the recreation industry?

DR. RORHOLM: That is a nice one. I think as I got it, it was: "how do you handle the concept of value if the Federal or the state and/or the state governments put quite a bit of money into use and its value stays the same." Is that correct?

QUESTION: In order to keep the value, yes. Here the fishing industry still maintains the same amount of fish, but they are pumping a lot of money into development to maintain it. How do you define the value in that case?

DR. RORHOLM: You don't really change the definition of the value. What you're doing is this: Because something has happened, something's causing this input of money--let's say it's pollution--that is not being paid for by industries or households who are dumping into the Bay. Now, government sometimes makes the decision that instead of forcing these people to stop pollution and forcing the fishing industry to suffer they will support the fishing industry.

So what you're doing is changing the input mix for the resource in order to keep the value flowing. That is simply a transfer. You choose not to tell people not to dump this negative value, the cost, into the Bay. But instead, you choose to compensate the fishing industry so that it benefits not because of anything the fishing industry did, but because of something someone else did. This situation does add to the complexity, but doesn't change the concept of value.

QUESTION: But in any case, you may be pouring more money into the resources than you are pulling out; does the value remain the same?

DR. Rorholm: Yes, but then we have to get at the business of values to whom? I was talking about value to the State of Rhode Island; we want to know the value to the Nation as a whole. You're now moving money around from one place in the Nation to another. Presumably, analyses are being done of some type that make it more desirable to move it one way than another way. Those are tradeoffs that are made in order to sustain the national value. None of it may go to Rhode Island; all of it may.

To determine value of resource you must first define the area of concern. Then, are you talking about value to all people in this area or to one group? One group can lose and another one may gain. So all of these things have got to be considered. The concept of value stays the same.

QUESTION: I guess my question is: Is that the value or the willingness to pay for a resource?

DR. RORHOLM: In that present use?

QUESTION: The willingness for someone to pay to maintain the resource?

DR. RORHOLM: To whoever you're asking the question; value to whom? If we're talking about a commercial case, it's very simple. A firm bidding for a piece of land will bid the value to the firm for having control of that land. You can express that as a rent or we can capitalize it for a single amount of money using the going interest rate.

Now if government makes the decision of value to the people, then it's value to the people, as interpreted by the government, reflects how they feel their responsibilities lie to the people and to their welfare. Terms such as "health and general welfare," and "economic well-being," are used. They are not all as easy as measuring salinity. But that has to become the measurement.

Ultimately, you will not get a single number. The result will be many numbers, and the decision to go ahead with one program or another is a political decision. I'm not saying that in the pejorative sense because I happen to feel that this how we make decisions in this country. Someone has got to make the ultimate tradeoff. There is no magic number that can say, "this is where we should go or that is where we should go." We can do our best using the research and studies that provide information. Then the decision may ultimately have to take responsibility for the tradeoff and say, "Given our objectives as they are at this time, here's what we should do."

QUESTION: Both you and Dr. Nixon have mentioned that there are problems with fishery count systems. What, specifically, are the problems with traditional statistics?

DR. RORHOLM: I really don't know what they are, but I will certainly say that the statistics are not being readily released. I don't remember the names of the publications but some of them are not coming out, and some of the ones that are published are very late. If you call the local office, for example, where presumably the statistics are gathered, you're told that you can't really get the answers there, you have to call Woods Hole.

AFTERNOON SESSION

DR. PEARCE: There will be seminar coming up on Long Island Sound, probably sometime in March. In addition to the seminar on Long Island Sound, there will be a seminar on the use of remote sensing to collect data and demonstrate long-term status and trends in estuaries. That seminar is planned for later on in the spring.

Finally, Dr. Kent Mountford from the Annapolis office of the EPA and myself have been talking about organizing a seminar which would concentrate on certain anthropological and historical aspects of estuaries. Those of you who were here this morning undoubtedly heard Dr. Scott Nixon talking about some of the early observations made on Narragansett Bay and related waters. It's quite possible to find similar statements that were made about many other estuaries. Professor Goode, an outstanding fishery biologist who lived at the time of the Civil War, wrote numerous reports on Newark Bay. At that time Goode was saying that fish from the area could no longer be sold. It wasn't because they had large amounts of PCBs in their tissues, but because these fish were tainted with what was called coal oil or kerosene from the early oil refineries.

There are many historical records that go back in time. If people in the legislatures, the regulatory branches, and so on are made aware of some of the observational aspects recorded by the early scientists, it would be possible to begin to develop a historical record on the deterioration and change in estuaries and to change their views. Hence, it seems quite reasonable to have a seminar on this subject, which moves away from purely numerical type of scientific information into some of the anecdotes that were brought to us by historians.

DR. NIXON: The next speaker is Dr. Eva Hoffman, who is at the Graduate School of Oceanography at the University of Rhode Island and who has also been put in charge of coordinating the Narragansett Bay Estuarine Study. She's been working on large projects funded by NOAA, by EPA, and other agencies involving the pollutant inputs to Narragansett Bay. She probably knows more about what goes into the Bay than anybody else.

POLLUTION INPUTS

Dr. Eva Hoffman

DR. HOFFMAN: I'm going to tell you a little bit about the research I've done around Narragansett Bay in the past. This will lead to discussions of the future, later on this afternoon. This has been my main academic interest over the last six years.

First of all, I'd like to credit those people who have funded my research which first began with a grant from the Environmental Protection Agency, Narragansett Lab. It then proceeded with the Office of Marine Pollution Assessment funding and continues with money from the state.

Actually, I began to look at the sources of pollutants in Narragansett Bay in 1979 on an Environmental Protection Agency grant involving response to oil spills.

Our preliminary findings were used to obtain funding through NOAA, and now we're beginning to use some of the data that we collected under the NOAA grant to evaluate some of the findings using state funds.

This report will summarize our research and previous data on the sources of pollutants in Narragansett Bay. First, we will discuss each source and the methods used to assess its magnitude. Second, we will combine the data to evaluate the relative importance of the various sources. Third, we will examine possible applications of these data to water quality management issues. Finally, we will explore future research requirements.

URBAN RUNOFF

As a first step in the evaluation of the annual pollutant loads generated by urban runoff, it is necessary to have loading rates (such as mass/drainage area/time) which can be applied, with some degree of confidence, to the drainage area in question. In the case of petroleum hydrocarbons, there were no data available which could provide this information since previous studies had been done in areas with mixed land use types (11, 12, 13, 14, 15). These studies could be used for specific water bodies, but the results were not universally applicable. There were even fewer studies on polycyclic aromatic hydrocarbons (PAHs, priority pollutants which are suspected carcinogens) in urban runoff (15, 16, 17, 18). There were appropriate urban runoff loading factors for metals and these data have been expanded by this study and by the National Urban Runoff Program (NURP, 19).

We needed to assess the amount of hydrocarbons and PAHs in the urban runoff entering Narragansett Bay which led us, as

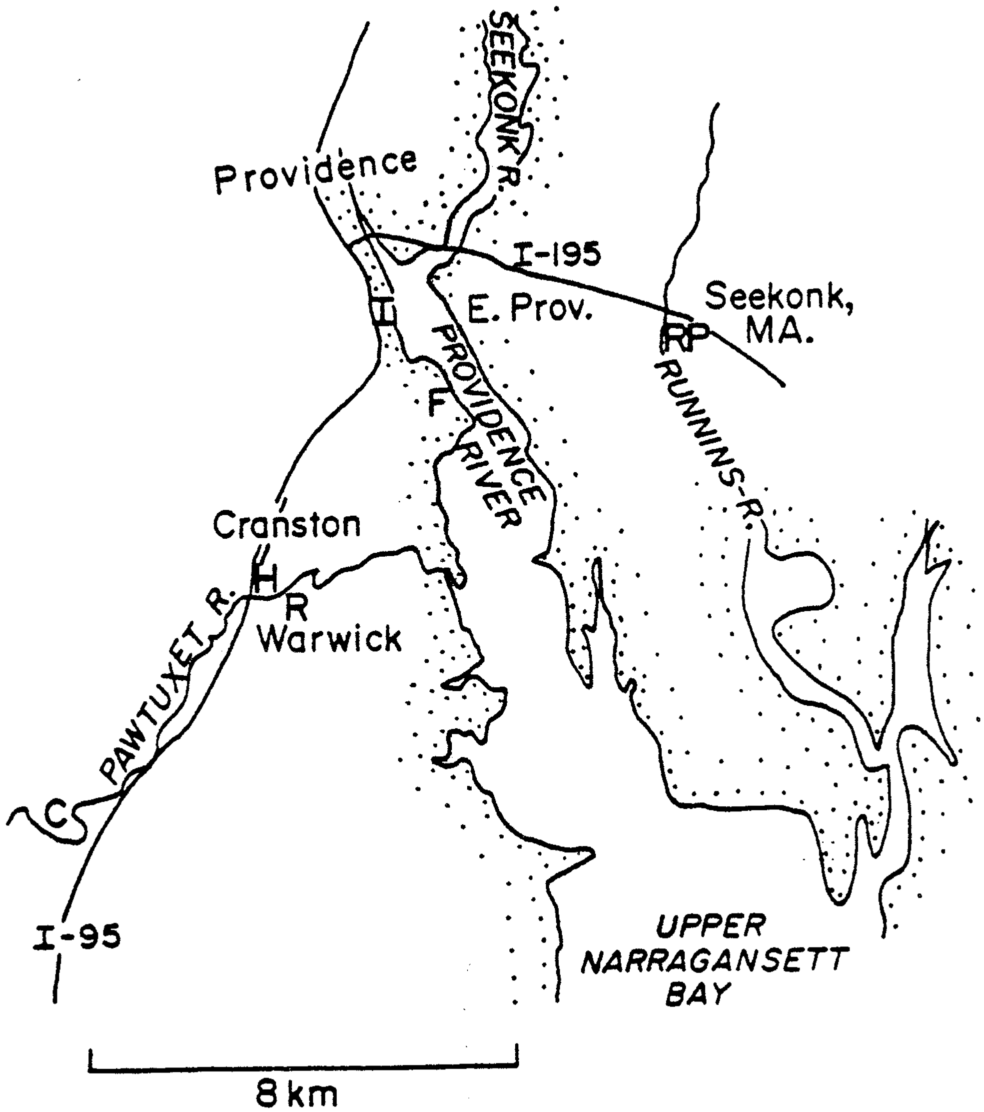


Figure 1: Urban runoff sampling locations. R = residential area drain; C = commercial area drain; I = industrial area drain; H = interstate highway drain; RP = retention pond studied; F = Fields Point Wastewater Treatment Facility.

Table 1

Urban runoff loading factors as a function of land use.

(kg/km^2 of land use/yr)

Annual rainfall = 121 cm/yr

Pollutant	Residential (single family suburban)	Commercial[a] (shopping mall)	Industrial (heavy)	Highway[b] (8 lane)
Petroleum hydrocarbons (HC)[c]	180	580	14000	7800
LMW-PAHs[d]	0.009	0.100	2.42	1.220
HMW-PAHs[d]	0.258	0.589	3.97	16.9
Fe[e]	135	166	856	915
Mn[e]	49.6	8.6	65.8	513
Cu[e]	3.0 (8)	3.0 (22)	35.3	146
Pb[e]	22.4 (36)	43.6 (82)	166	2250
Cd[e]	0.18	0.69	0.85	2.48
Zn[e]	43.5 (34)	n.d. (177)	639	7020
Suspended solids (TSS)	4400(12200)	32400(54300)	548000	424000

[a]for more detail see Hoffman, Latimer, Mills and Quinn 1982; (20)

[b]for more detail see Hoffman, Latimer, Hunt, Mills and Quinn 1984; (21)

[c]Hoffman, Mills, Latimer and Quinn 1983; (10)

[d]LMW-PAHs are lower molecular weight polycyclic aromatic hydrocarbons having two rings; HMW-PAHs are higher molecular weight polycyclic aromatic hydrocarbons having 3 or more rings; Hoffman, Mills, Latimer and Quinn 1984; (22)

[e]Hoffman, Latimer, Hunt and Quinn 1983; (23)

n.d. not determined;

Values in parentheses are loading factors as projected from National Urban Runoff Program (NURP). (19)

organic geochemists, to conduct a study of our own. The experiment was designed to examine hydrocarbons and PAHs in runoff as a function of land use in a manner similiar to those used for other components of the NURP studies. The sampling locations relative to Narragansett Bay are shown in Figure 1. The results of our study, derived from 21 storm events for organics, and 12 storm events for metals, are given in Table 1. Where available, runoff loading factors generated by the NURP studies are included for comparison.

Inspection of our data reveal a strong dependence of urban runoff pollutant loading on land use. Often differences of several orders of magnitude are involved. The urban runoff loadings for HMW-PAHs, Fe, Mn, Cu, Pb, Cd, Zn and suspended solids (TSS) were highest at the interstate highway locations. Even though highways represent only a very small proportion of the land use in some locations, they become increasingly important near urban areas. Since the loading factors are high, the highway land use can become an important part of the total urban runoff loads to urban water bodies. Highways were not studied separately in the NURP program.

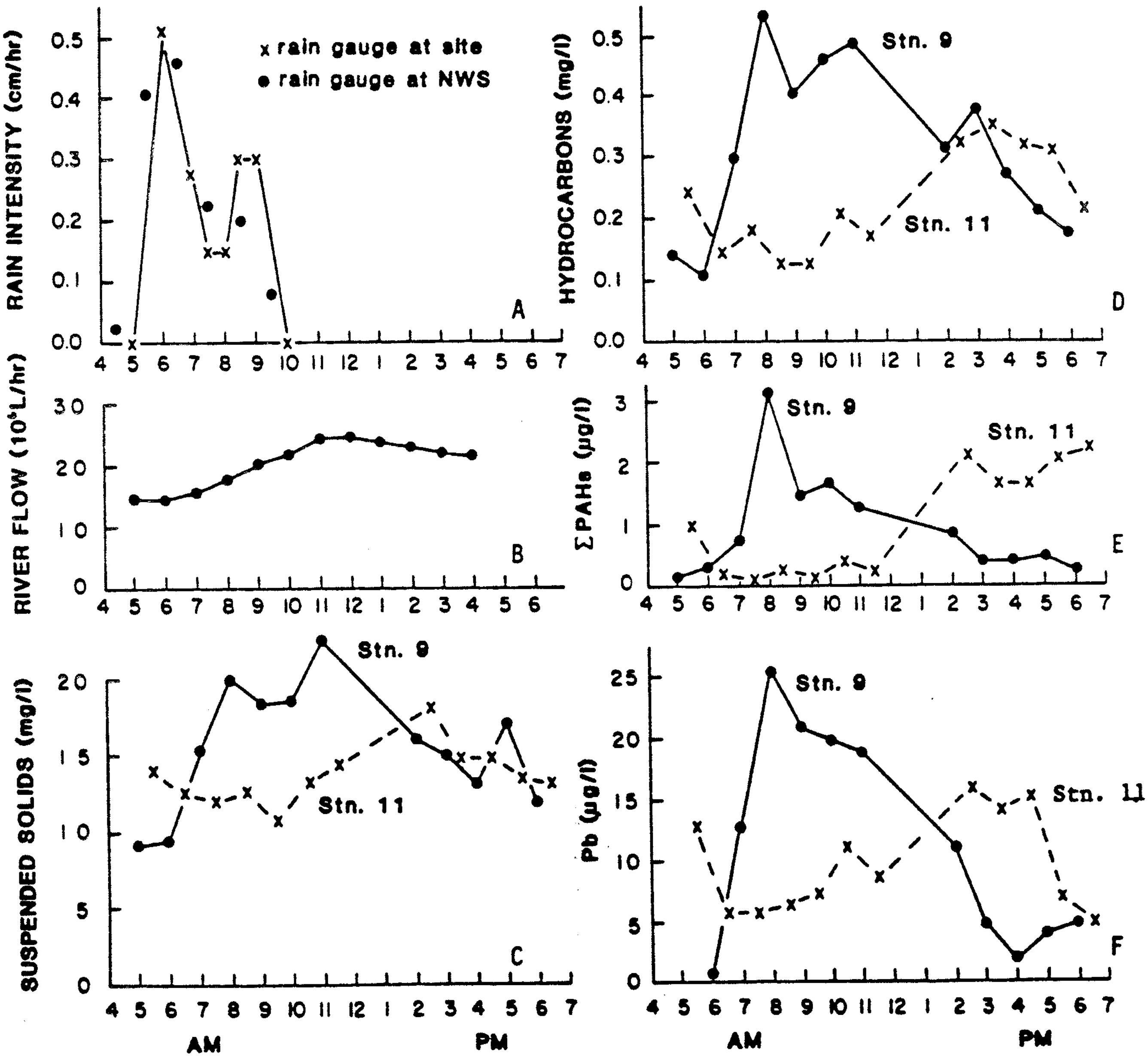
Loading for petroleum hydrocarbons and LMW-PAHs was highest at the industrial location. Our collection site, admittedly, could be termed "heavy industrial" since it was located in the Port of Providence area. These values, then, were not typical of newly developed industrial parks which would have loadings similar to our commercial location. (Commercial land use and industrial land use were combined in the NURP studies (19) which, in our view, would be satisfactory for light industry, but inappropriate for heavy industrial areas as illustrated in Table 1).

The next step was the combination of the urban runoff loading factors with land use data for the specific drainage basin of interest. This would seem, at first inspection, to be a trivial matter, but hidden pitfalls exist for the unwary scientist (55). To give only a few examples: (1) poor choice of land use categories (categories for urban planning purposes may not be the best for urban runoff studies--i.e. the utility category can include both power line right-of-ways (open land) and power plants (heavy industry); (2) land uses as a function of drainage basin are most frequently derived using topographical maps which may or may not represent locations to which the storm sewers actually carry the water.

About a year ago we decided to see how well we could predict actual urban runoff mass discharges to a water body. We decided to use the Pawtuxet River as a test case. The rainfall rate, river flow rate, and concentrations of a number of components known to be present in urban runoff are presented in Figure 1a. At Station 9, all of the urban runoff components (suspended solids, Figure 1a,C; total hydrcarbons, Figure 1a,D; PAHs, Figure 1a,E; and Pb, Figure 1a,E) had peaks in concentration at 8 a.m. due to the first flush of urban runoff. Suspended solids and total hydrocarbons had another concentration peak at 11 a.m., perhaps in response to the second rain pulse. In the PAH and Pb profiles, this second pulse resulted in only a shoulder at Station 9. The urban runoff flush as evidenced by the peaks in concentration at 8 a.m. for Station 11 samples for all of the illustrated components at 2:30-3:30 p.m., a delay of six and a half to seven and a half hours. This observation is consistent with the time of travel between the two stations. The time of travel between Stations 9 and 11 at the rate of 14.9 x 10^6 l/hr (146 cfs) is 9.33 hours; at the rate of 24.9 x 10^6 l/hr (246 cfs) the time of travel is 5.56 hours. Considering that the average flow rate between 8 a.m. and 3 p.m. was 23.0 x 10^6 l/hr, the theoretical time of travel between the two stations is approximately 6.3 hrs, in good agreement with the 6.5-7.5 hour lag observed in our concentration data at the two stations.

This storm event afforded us the opportunity to properly evaluate the application of urban runoff loading factors developed as a part of the NOAA study. Since three of the four land use loading factors were determined at sites in the Pawtuxet River basin, the Pawtuxet River was a logical choice to determine the applicability of these loading factors to river water quality calculations.

We compared the predicted urban runoff load to the Pawtuxet River during our monitoring period with the actual loads for these components. For Station 9, the predicted and actual discharge rates agreed within a factor of 2 for 4 of the 5 urban runoff components. All of the rates agreed within factor of 3 at Station 9. The actual and predicted rates were neither routinely higher or lower than each other.



RAIN INTENSITY (cm/hr)
x rain gauge at site
• rain gauge at NWS
A
RIVER FLOW (10⁶L/hr)
B
SUSPENDED SOLIDS (mg/l)
Stn. 9
Stn. 11
C
AM
PM
HYDROCARBONS (mg/l)
Stn. 9
Stn. 11
D
ΣPAHs (μg/l)
Stn. 9
Stn. 11
E
Pb (μg/l)
Stn. 9
Stn. 11
F
AM
PM

Figure 1a

These data can also be used to evaluate how important urban runoff components are to the water quality of the river following rain storms. At Station 9, the dry weather background corrections were minor for all the HMW PAHs (except benzo(a)anthracene) and for HC, Pb, and Zn. The corrections were severe for Cd and Cu suggesting that these metals were not greatly influenced by urban runoff inputs. Thus at Station 9, 85 percent of the HMW PAHs, 79 percent of the HC, 82 percent of the Pb, and 63 percent of the Zn was due to wet weather input. Only 18 percent of the Cu and 19 percent of the Cd could be attributed to urban runoff inputs.

Having determined loading factors and found land use statistics, we could then calculate urban runoff loads to the water body of interest for areas which are newly developed. However, the situation in Providence and other older cities of the Northeast which have combined sewer systems collecting both wastewater and urban runoff, leads to complications with the calculations. In the 1890s, at the time of its original construction, the combined system in Providence was considered innovative because it collected urban runoff, recognized even then to contribute to water pollution. The runoff did not contain automotive-related pollutants but horse-related ones. A schematic of a typical combined sewer system is given in Figure 2.

In these systems, urban runoff has at least three choices: (1) it can travel down the street to the nearest water body via overland transport; (2) it can travel to a catch basin that is tied into a separate storm sewer usually taking the runoff to the nearest water body; or (3) it can travel to a catch basin that is tied into a combined sewer system. Once in a combined system, it can travel to a sewage treatment plant, which may or may not be in the same drainage basin, or can overflow the system via a combined sewer overflow, usually, in the drainage basin of origin. As a first step, it is necessary to subdivide the land use statistics into subdrainage areas so that loading rates for the areas served by storm drains can be calculated independently of areas served by combined sewers. For Providence, this was done by tedious planimetry and lots of student help using a land use map superimposed on a city sewer map (24). Estimation of the amount going into combined sewers is not a difficult calculation once the land use characteristics for these areas are available. The more difficult question is: Where does the runoff go once it gets into the system? Does it overflow the system close to the source? Does it go all the way to and through the treatment plant? Does it go to the treatment plant only to be bypassed around the plant? Once the runoff goes into a combined system it is mixed with unknown proportions of raw sewage; how much of this sewage overflows along with the runoff during rain events?

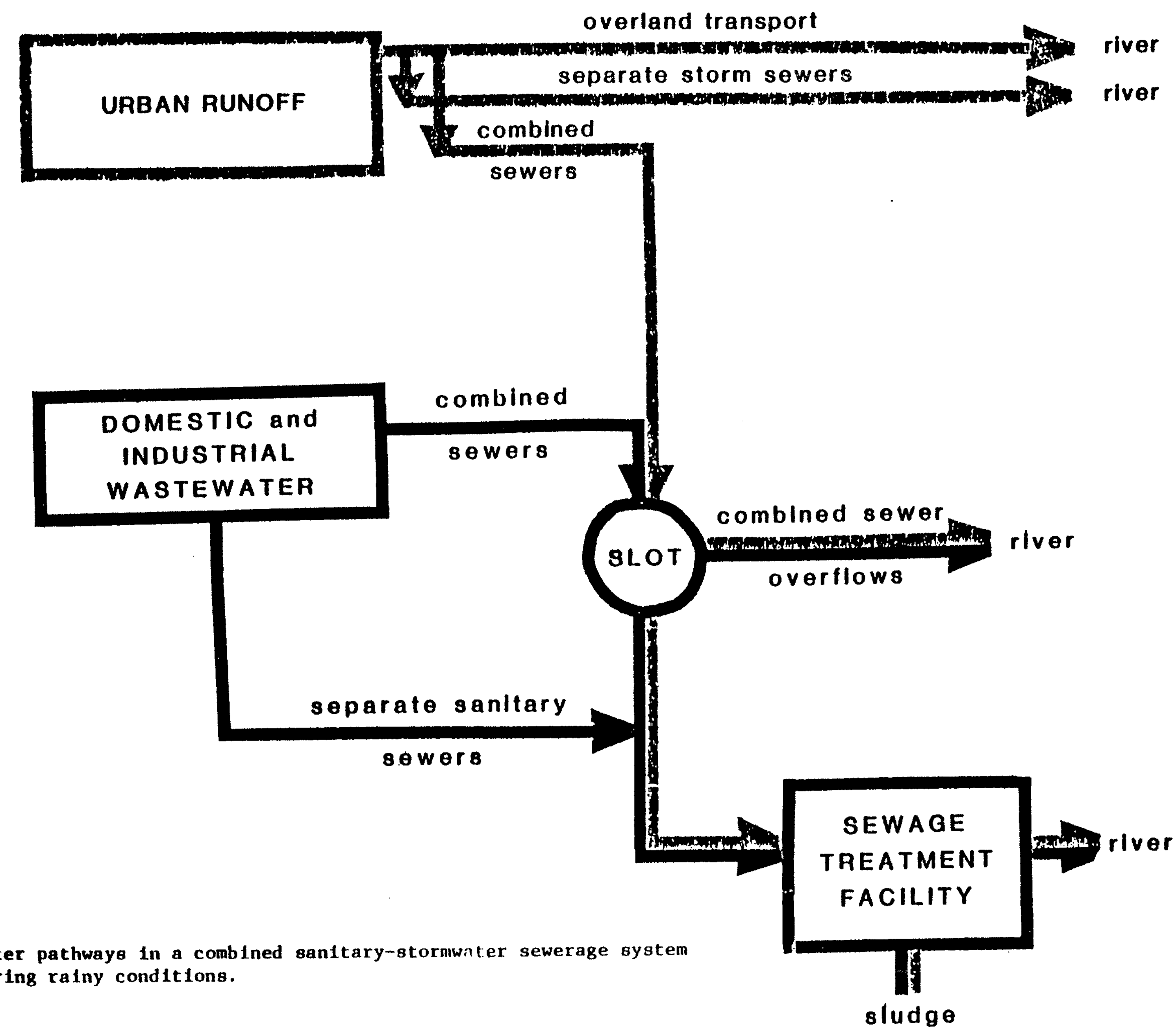


Figure 2: **Water pathways in a combined sanitary-stormwater sewerage system during rainy conditions.**

There are two basic approaches to answering these questions: (1) monitor each overflow individually; or (2) model the system. The city of Providence has been divided into nine combined sewer overflow (CSO) drainage districts. Preliminary design projects for two of these districts have been contracted and include at least flow monitoring of each CSO in two districts and some pollutant determinations on other selected CSOs. These two projects cost in excess of $1.2 million. Although we now have some ideas concerning the nature of CSO discharges in two districts, the data are not useful in assessing the problems in the other seven districts of the city. The monitoring of each of the 65 overflows in Providence would be difficult logistically and very expensive.

Modeling of the sewer system is a much less expensive way to estimate how important CSOs are in context with other sources. It is also an inexpensive method to assess whether extensive design and monitoring studies are warranted.

There have been three modeling efforts for Providence's combined sewer system: one model estimates CSOs by difference between total flows entering the system and the amount which gets all the way to the plant (25); two other models estimate CSOs by calculating the sewage and runoff flows in each district, sending all of it to the plant until the capacity of the connector pipes in the district are reached, while the rest is discharged through the local CSO (24,26). The annual predictions of each model are given in Table 2. Reconciliation of the modeling results await future study when plant flow monitoring devices are accurately calibrated and more reliable. There is, obviously, some uncertainty in amounts of runoff and sewage discharged by CSOs in Providence.

All three of the system models predict that some fraction of the runoff goes to the treatment plant although one did not report its magnitude. We monitored the influent and the effluent of this plant during three rainstorms to evaluate the impact of urban runoff in the plant (27). The results of this study are summarized in Table 3. Urban runoff was found to affect the plant in two ways: (1) by increasing the loads of pollutants during storms and (2) by producing elevated flow rates which are sometimes sufficient enough to produce hydraulic overloadings of the secondary treatment system. Both in combination produce higher mass discharges from the plant in wet weather than during analogous dry periods. It is likely that each treatment plant receiving storm water discharges will behave differently in this aspect.

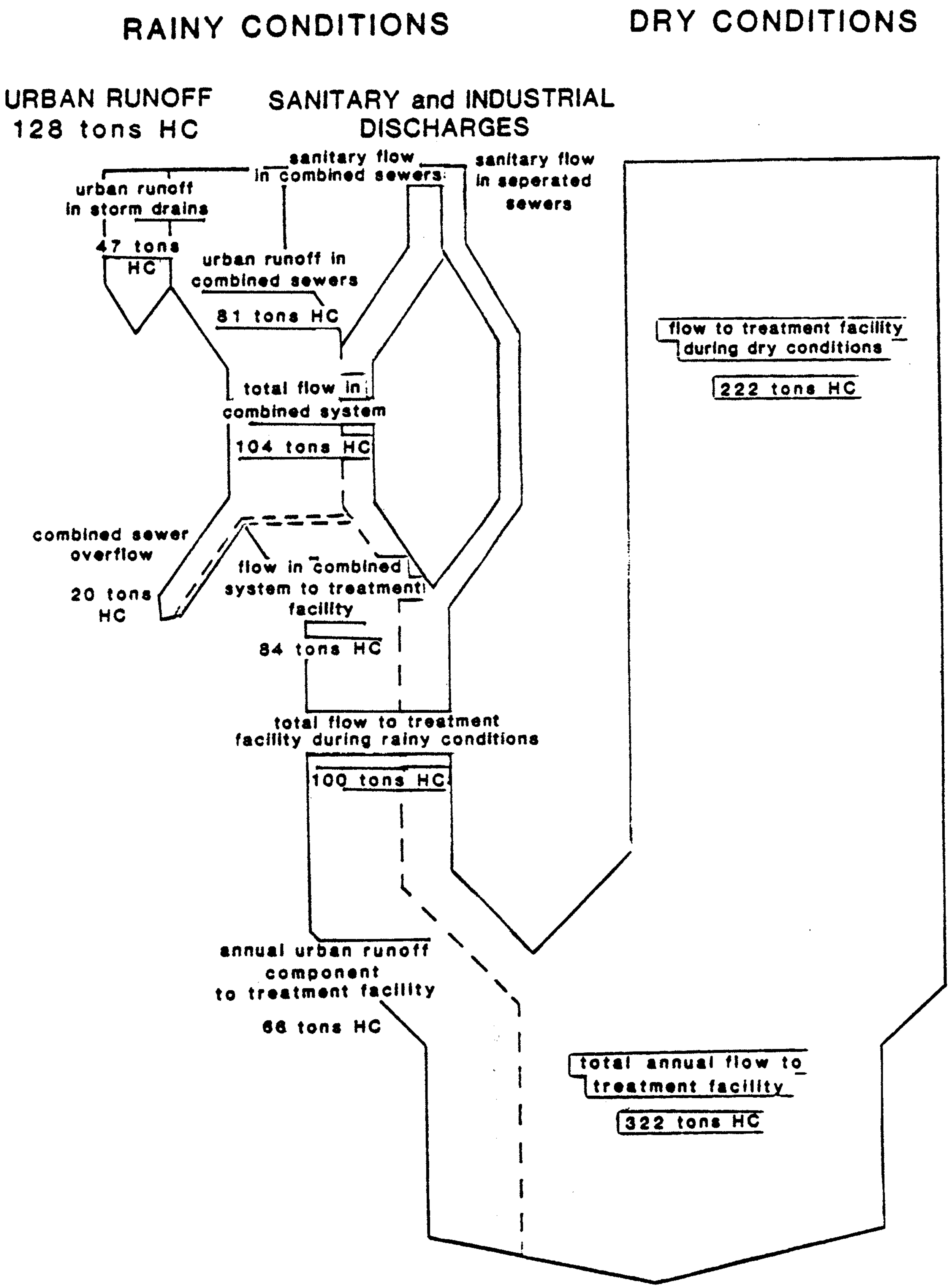


Figure 3: Estimated urban runoff and sewage pathways in the combined and separated sewers of Providence: Annual mass loads for hydrocarbons.

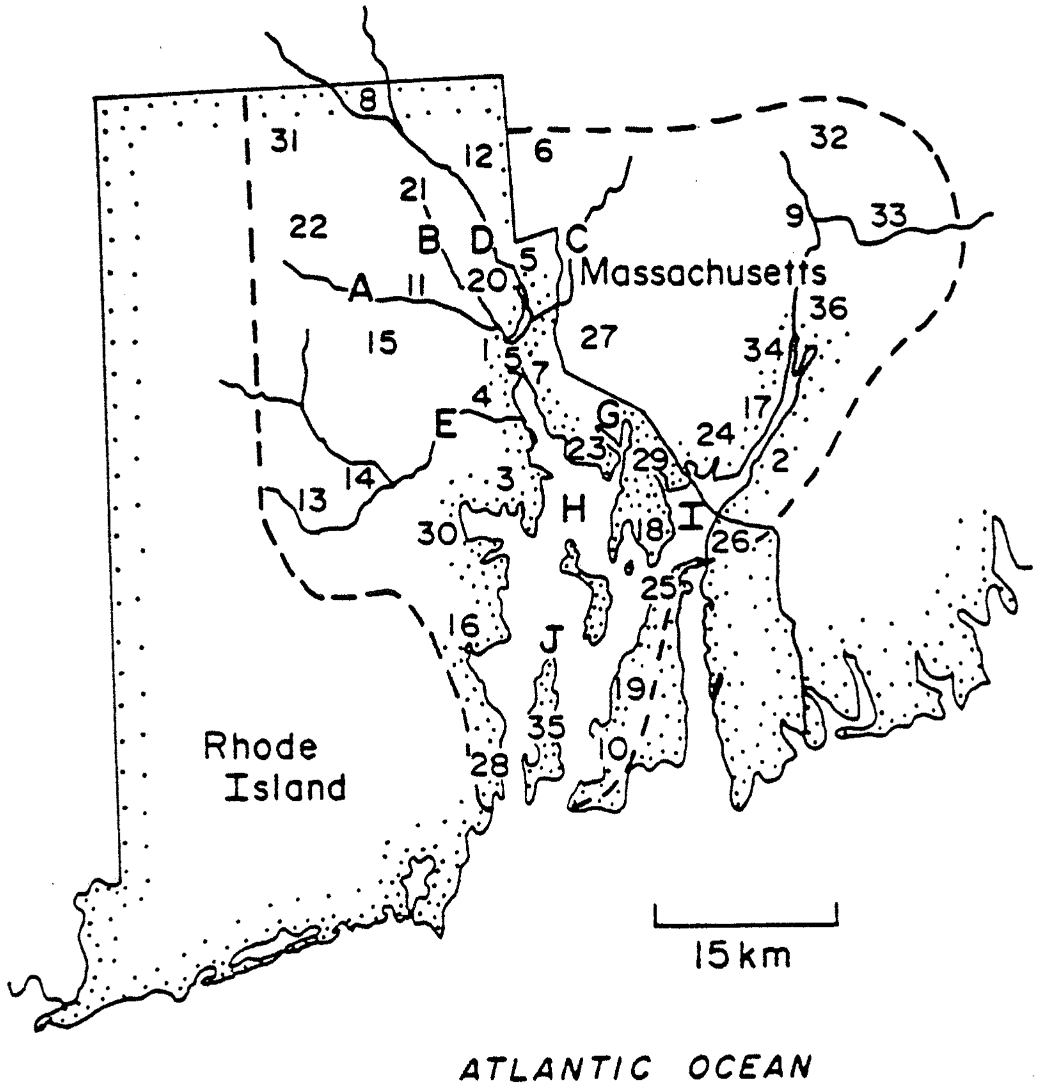


Figure 4: Narragansett Bay watershed (dashed line indicates the limits of the water pollutant inventory estimated in this study). Letters are the receiving waters considered: A = Woonasquatucket River; B = Moshassuck River; C = Ten Mile River; D = Blackstone-Seekonk Rivers; E = Pawtuxet River; F = Providence River; G = Runnins, Barrington, Warren and Palmer Rivers: H = Upper Narragansett Bay; I = Mt. Hope Bay and Taunton River; and J = Lower Narranganset Bay. Numbers are cities and towns in the watershed (listed in descending order): 1 = Providence; 2 = Fall River; 3 = Warwick; 4 = Cranston; 5 = Pawtucket; 6 = The Attleboros; 7 = E. Providence; 8 = Woonsocket; 9 = Taunton; 10 = Newport; 11 = N. Providence; 12 = Cumberland; 13 = Coventry; 14 = W. Warwick; 15 = Johnston; 16 = N. Kingstown; 17 = Somerset; 18 = Bristol; 19 = Middletown; 20 = Central Falls; 21 = Lincoln; 22 = Smithfield; 23 = Barrington; 24 = Swansea; 25 = Portsmouth; 26 = Tiverton; 27 = Seekonk; 28 = Narragansett; 29 = Warren; 30 = E. Greenwich; 31 = N. Smithfield; 32 = Raynham; 33 = Freetown; 34 = Dighton; 35 = Jamestown; 36 = Berkley.

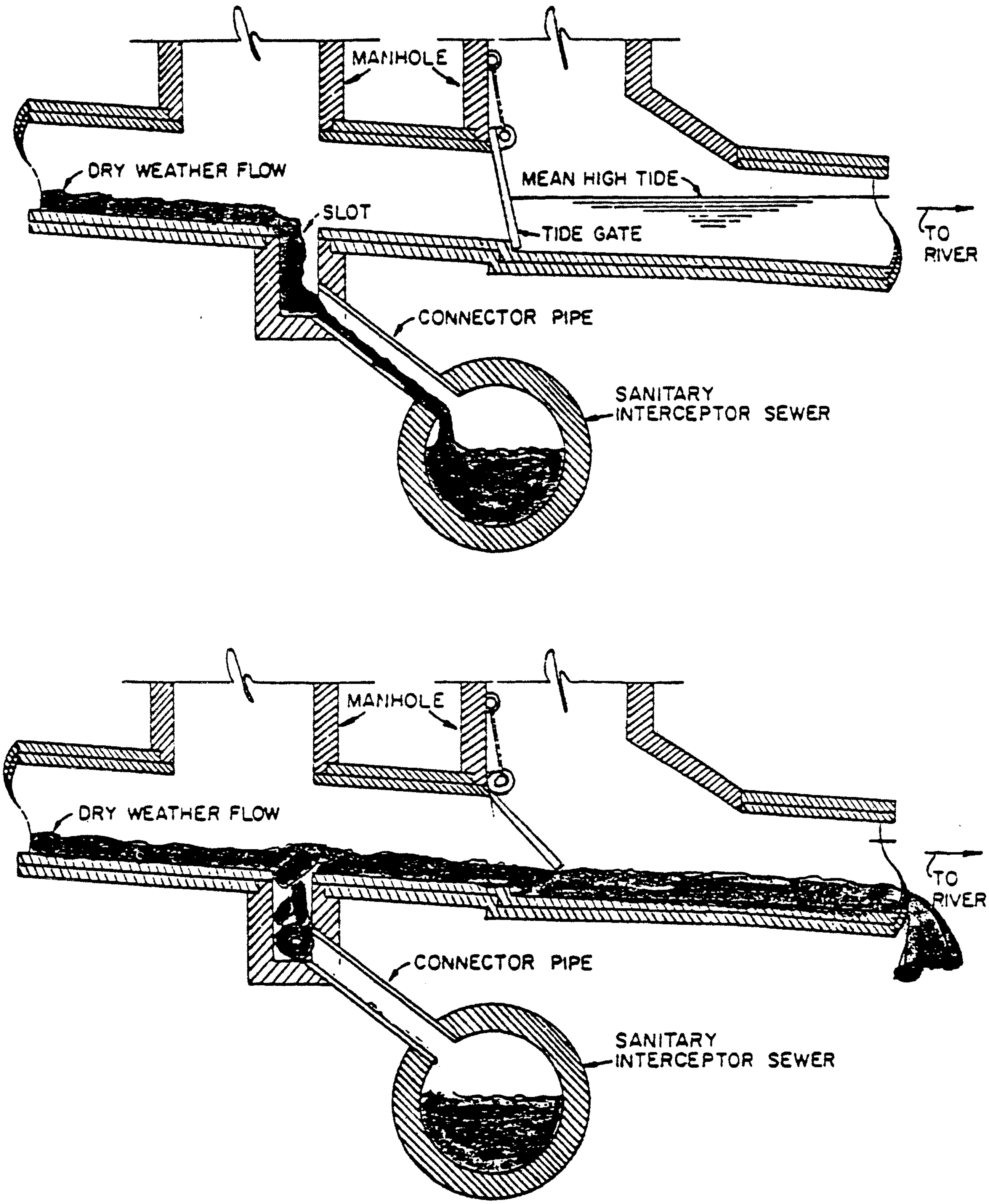


Figure 5: Typical combined sewer overflow structure in Providence. The top shows a properly functioning combined sewer overflow. The bottom illustrates a poorly maintained slot stucture which leads to continual discharges even during dry conditions.

Table 2

CSO discharges in the

cities of Providence, Pawtucket and Central Falls

Model	Hoffman (25)	Martin (24)	Metcalf and Eddy (26)
		10^9 l/year	
Wet conditions, Providence			
City-wide urban runoff	13.8	14.5	not given
Urban runoff to storm drains	5.0	5.3	" "
Urban runoff to CSO's	1.7	6.4	6.0
Urban runoff to POTW	7.1	2.8	not given
Sanitary out storm drains	0	0	" "
Sanitary out CSO's	1.5	0.1	" "
Sanitary to POTW	11.8	5.6	" "
Wet conditions, Pawtucket and Central Falls	(54)		
Urban runoff to storm drains	3.1		
Urban runoff to CSO's	3.5		
Urban runoff to POTW + bypass	4.1		
Sanitary out storm drains	0		
Sanitary out CSO's	0.85		
Sanitary to POTW + bypass	1.0		
(Total bypass)	(1.1)		

Table 3

Fields Point Wastewater Treatment Facility

Annual Mass Discharge Rates

(tons/year)

EFFLUENT:

	Dry conditions	Excess during rainy conditions	Total annual discharge: This study	Total annual discharge: Other data
TSS	4380±1720	1480 ± 1450	5860 ± 3170	4580[a]
HC	210 ± 69	48.0 ± 50.0	258 ± 119	226[b]
LMW PAHs	0.95± 0.51	0.040 ± 0.050	0.99± 0.56	-
HMW PAHs	0.098± 0.032	0.030 ± 0.029	0.13± 0.06	-
Cu	73.7 ±15.3	0.57 ± 0.13	74.3 ±15.4	41.9[c], 73[a]
Ni	94.9 ± 2.6	0.58 ± 0.83	95.5 ± 3.4	68.9[a]
Cd	0.12 ± 0.07	0.0029 ± 0.0010	0.12± 0.07	0.34[a]
Pb	1.7 ± 1.0	0.18 ± 0.002	1.9 ± 1.0	4.8[a]

INFLUENT:

	Dry conditions	Excess during rainy conditions	Total annual discharge: This study
TSS	8470±2300	1450±1380	9920±3680
HC	412± 251	17.5± 2.3	430± 263
LMW PAHs	1.67± 1.34	0	1.67± 1.34
HMW PAHs	0.13± 0.093	0.063±0.014	0.193±0.107
Cu	112± 23	0	112 ±23
Ni	158± 83	0	158 ±85
Cd	0.25± 0.18	0.003±0.004	0.25 ±0.18
Pb	2.0 ± 0.1	0.51± 0.19	2.5 ± 0.2

[a] State of Rhode Island, 1982 (28)

[b] Van Vleet and Quinn, 1977 (7)

[c] C. Hunt, MERL, URI, Personal communication, 1983. (29)

In summary, to produce urban runoff estimates for Narragansett Bay, we monitored storm drains serving different land uses; we modified land use data, if necessary, to make them useful for water quality planning; we estimated how much urban runoff did not go to the drainage basin of origin but went to a treatment plant instead; and we estimated how much runoff mixed with sewage and was discharged by CSOs. An example of urban runoff pathways for hydrocarbons in the city of Providence is illustrated in Figure 3. Similarly, we calculated the urban runoff expected from each of the 36 cities and towns surrounding the Bay (see Figure 4). These total Narragansett Bay watershed calculations for a variety of different pollutants are presented later, in the pollutant inventories.

DRY WEATHER CSO DISCHARGES

In the past, frequent clogging of the CSO structure with debris resulted in discharges of sewage from the CSOs even during dry weather conditions (see Figure 5). If the discharge is from an industrial area of town, this overflow will have industrial waste in it. If it's a residentil part of town, then these will be residential waste combined with the urban runoff. So it's difficult to go out in the field and actually monitor every one of these combined sewer overflows.

Now, this is what the flow looks like in dry conditions. This is without urban runoff. It's a fairly simple matter to sit down and monitor. Hopefully in dry conditions, these systems are not supposed to be overflowing.

This is the way a slot structure works in the City of Providence. Basically you have dry weather flow that comes to this office, drops from the combined sewer overflow into the interceptor that takes it to the plant. Then you have a tide gate here to prevent entering of river water back into this system.

There are a couple of things that happened in the City of Providence. First, of all, a good number of these tide gates that are supposed to be here are not. What happens is that at every high tide river water enters into the system, mixing with the dry weather flow and the result is an extra amount of water going to the sewage treatment plant.

There's two reasons why this is detrimental. First of all, it's extra water, but it's cold water and the biological treatment processes don't like the cold water. If you're talking about the Providence River, it's saline water and the biological processes don't like salinity either. The result is poor treatment at every high tide.

I noted the condition (Figure 5B) in which you have tires and logs and beer cans plugging the structure so that the dry weather flow does not go where it's supposed to, but instead discharges to the river. This is what I was observing.

The city had taken the device that could be used for sewer element and had allocated it to something a little more visible for the citizenry, i.e., downtown cleanup.

During 1975, nine out of the 65 CSOs in the city were found with dry-weather disccharges totalling about 47 x 106 1/d (12.5MGD) (30). When systematically inspected again in 1980, 18 CSOs were flowing during dry weather (plus another three intermittently) with a total flow of 86 x 106 1/d (22.8 MGD) (31).

The discharge rate of pollutants to receiving waters due to these dry weather overflows can be estimated although actual chemical analysis of these dry weather flows are rare. Until more complete data are available, calculation of loading rates requires one of three assumptions: (1) the concentrations of pollutants found at one dry weather discharge can be projected to the total using the individual CSO flow rates; or (2) the average concentrations of pollutants in raw sewage arriving at the treatment plant can be combined with CSO flow rates to estimate loadings; or (3) the concentrations of pollutants in dry weather CSO discharges are a function of the industrial discharges in that part of the city. Thus data on the chemical nature of the sewage in industrial areas can be combined with the flow rate of the CSO serving that district.

As examples, the petroleum hydrocarbons and copper loads of dry weather CSO discharges in 1980, estimated by each assumption, are given in Table 4. All of these calculations suggest that dry weather CSO discharges could have been a significant contribution to the Narragansett Bay pollutant inventory at that time.

We are pleased to note, however, that before an in-depth survey of the chemical composition of each of these discharges could be conducted, the Narragansett Bay Commission launched a vigorous inspection and maintenance program in 1982 which has eliminated most of these discharges.

Table 4

Estimated hydrocarbon and copper input rates from dry weather CSO discharges.

Metric Tons HC/yr

River	Flow 10^6 l/d	Assumptions (see text) 1*	2**	3***
Providence	58.5	299	64	130
Seekonk	3.9	20	4	-
Moshassuck	9.6	49	11	-
Woonasquatucket	7.2	37	8	3
Σ		405	87	133

*Concentration of dry weather discharge HC = 14 mg/l (Pruell); (32)

**Concentration of raw sewage HC = 3.02 mg/l (Hoffman et al.); (27)

***Concentrations of industrial discharges range from 12.2 mg/l to 1.0 mg/l (Hoffman). (33)

Metric Tons Cu/yr

River	Flow 10^6 l/d	Assumptions (see text) 1*	2**	3***
Providence	58.5	17.2	26.9	74.6
Seekonk	3.9	1.2	1.8	-
Moshassuck	9.6	2.8	4.4	-
Woonasquatucket	7.2	2.2	3.3	0.4
Σ		23.4	36.4	75.0

*Concentration of dry weather discharge Cu = 0.81 ± 0.40 (this study)

**Concentration of raw sewage Cu = 1.26 mg/l (Hoffman et al.); (27)

***Concentrations of industrial discharges range from 10.10 mg/l to 0.16 mg/l (Hoffman). (33)

The city knew about these conditions since 1973, and I found it amazing that the situation had persisted for so long. When our data was presented to the City of Providence, we suggested that perhaps the clogged slots should be maintained. In the audience was the executive director for the state commission which was preparing to take over the plant. The state had become concerned over the continual problems with the Providence sewer system and had finally decided that they were going to run it themselves.

So sitting in the back of the room was the executive director of this newly formed commission. The minute that the state took over, he formed a collection system team and they started cleaning the slots. So I'm happy to report today that the values on Table 4 are no longer operative. We don't have any dry weather flows in the City of Providence any more, at least on a continual basis, because each slot is now inspected on a weekly basis.

Sporadic overflows still occur at Ocean Street since the diverson structure (underneath the high speed lane of Interstate 95) is difficult to properly maintain. Even this sporatic discharge will be eliminated upon completion of the North Channel dryweather CSO diversion structure in 1985. Our calculations indicate that this program has been very worthwhile considering its relatively low cost. These discharges were <u>not</u> included in the current pollutant inventory but should be included if historical considerations become important or if vigorous maintenance is discontinued.

SEWAGE TREATMENT PLANTS

The estimation of the pollutant inputs of municipal treatment plant effluents into water bodies is a relatively easy calculation compared to urban runoff inputs. The simplicity is due to the fact that: (1) plants are monitored for a variety of contaminants on a routine basis as a requirement of the National Pollutant Discharge Elimination System (NPDES) permits (28); and (2), there is no doubt into which water body the discharge is going. There are 20 sewage treatment plants in the Narragansett Bay drainage basin. Of the 20, four of them are served, at least partially, by combined sewers. The daily loading rates for TSS and selected metals are given in Table 5.

However, hydrocarbons, PAHs and most other organics are not routinely measured as a part of the NPDES monitoring program. The estimation of these contaminants requires a number of assumptions. We have monitored the effluent of several sewage treatment plants for hydrocarbons and PAHs. The concentration ranges and discharge rates based on population are variable from plant to plant in Rhode Island (see Table 6). Therefore, both units seemed to be unsuitable for use in describing the

Table 5

Discharge rates of solids and selected metals from Narragansett Bay basin sewage treatment plants.[a]

Plant	Receiving water	kg/d					
		TSS	Cu	Ni	Cd	Pb	Zn
N. Attleboro	Ten Mile River	57.1	1.44	1.86	-	0.32	-
Attleboro	Ten Mile River	128	8.27	6.64	4.04	3.29	-
Woonsocket	Blackstone River	648	1.80	3.06	-	-	-
Blackstone Valley*	Seekonk River	7672	14.6	15.0	1.12	7.7	-
Providence[b]*	Providence River	16100	204	262	0.329	5.21	206
E. Providence	Providence River	424	0.97	1.78	-	-	-
Smithfield	Woonasquatucket River	235	-	-	-	-	-
Cranston	Pawtuxet River	922	1.03	5.27	0.58	0.36	-
Warwick	Pawtuxet River	225	0.19	0.77	-	-	-
W. Warwick	Pawtuxet River	465	1.63	-	-	-	-
Warren	Warren River	209	-	-	-	-	-
Bristol	Upper Narragansett Bay	679	0.50	-	-	-	-
Taunton	Taunton River	263	4.02	0.23	-	0.44	-
Somerset	Taunton River	174	-	-	-	-	-
Fall River*	Mt. Hope Bay	2570	5.04	-	-	-	-
East Greenwich	Greenwich Cove	225	0.34	-	-	-	-
URI Bay Campus	Narragansett Bay	2.5	-	-	-	-	-
Quonset Pt.	Narragansett Bay	99.5	0.53	1.65	-	-	-
Jamestown	Narragansett Bay	27.3	0.27	-	-	0.029	-
Newport*	Narragansett Bay	2500	16.7	34.2	-	0.404	-

[a]NPDES monitoring inputs unless otherwise indicated;

[b]Hoffman, Carey, Mills and Quinn. (27)

*combined system.

- data not available.

Table 6

Petroleum hydrocarbons in sewage treatment effluents.

Narragansett basin plants	Mean conc. HC (mg/l)	Mass discharge (g/cap/d)	Mean (HC conc./ TSS conc.) (mg/mg)
Providence*(wet)[a]	3.46	3.5	0.022
Providence*(dry)[a]	2.23		0.034
Cranston[b]	0.18	0.10	0.019
Warwick[b]	1.41	0.25	0.046
West Warwick[b]	5.0	0.95	0.066
Mean ± s.d.	2.4 ± 2.1	1.2 ± 1.6	0.039 ± 0.020
Other plants:			
Seattle*[c]	3.4	3.1	0.024
S. California[d]			
JWPCP	16.3	6.0	0.081
HYP 5 mi	6.1	4.6	0.075
HYP 7 mi	341	4.6	0.043
OCSD	7.8	3.3	0.056
CSD	12.3	4.4	0.084
Mean ± s.d.	64.5 ± 135.5	4.3 ± 1.0	0.061 ± 0.024

*Plants served by combined systems;

[a] Hoffman, Carey, Mills and Quinn; (27)

[b] Unpublished data; (35)

[c] Barrick (36)

[d] Eganhouse (37)

non-monitored plants in the basin. We observed, in our studies, that poor treatment of solids was often accompanied by poor treatment of hydrocarbons. Surprisingly, the HC/TSs ratio varied little among monitored Rhode Island plants and was also fairly consistent nationwide.

Average concentrations of PAHs at the four monitored facilities revealed that Providence, with its combined system, had concentrations higher than those served by separate sewer systems. Therefore, we used the Providence concentrations for facilities with combined systems and the average concentrations of Warwick for the separated systems (see Table 7).

It should be noted here that even superficial inspection of Tables 5 and 7 shows that Providence has the highest mass discharges of the plants in the Narragansett Bay basin.

QUESTION: What is the type of treatment at Field's Point?

DR. HOFFMAN: It's secondary.

QUESTION: Advanced secondary?

DR. HOFFMAN: It's an activated sludge secondary treatment.

Analyses of these pollutants down-pipe from industrial sections of the city (33) revealed that industrial sources contribute most of these pollutants to this municipal treatment plant (27). Comparison of sewage treatment plants as a source of pollutants with other sources is presented later.

DIRECT INDUSTRIAL DISCHARGES

In 1972 when the National Pollutant Discharge Elimination System (NPDES) was started, industries discharging effluents into rivers and estuaries were required to apply for a discharge permit or an exemption. Usually, accompanying such an application, were analyses reports of their discharges. In 1972 an inventory of these discharges was compiled and reported in the Providence Journal (38). In order to update the data on oil and grease, we examined the NPDES quarterly discharge reports for 1980-1981 for industries in the Narragansett Bay basin. These reports were available at both EPA Regional Headquarters and the Rhode Island Department of Environmental Management. In 1982, each firm with a NPDES permit was asked to submit a full priority pollutant analysis as a part of their permit renewal application. Seeing a potential not only for full metal analyses on each discharge but also for priority pollutant results, we reexamined each file again in 1983. A summation of the results of our various file inspections is given in Table 8.

Table 7

Estimated PAHs in sewage treatment effluents.

Plant[a]	Flow (10^6 l/d)	kg/d HC	gm/d LMWPAH*	gm/d HMWPAH*
N. Attleboro	13.6	2.2	0.097	3.51
Attleboro	20.4	4.9	0.147	5.26
Woonsocket	40.4	25.3	0.29	10.41
Blackstone Valley[b]	80.2	215	1040	136
Providence[b]	210	707	2710	356
E. Providence	27.7	16.5	0.199	7.13
Smithfield	5.3	9.2	0.038	1.37
Cranston[c]	44.3	17.5	34.0	13.7
Warwick[d]	10.3	10.4	0.074	2.65
W. Warwick[e]	14.2	28.5	0.055	3.07
Warren	6.7	8.2	0.055	1.72
Bristol	9.9	26.5	0.071	2.55
Taunton	23.0	10.3	0.165	5.93
Somerset	10.1	6.8	0.073	2.61
Fall River[b]	72.6	100	936	123
East Greenwich	2.8	8.8	0.020	0.72
URI Bay Campus	0.24	0.1	0.001	0.062
Quonset Pt.	3.3	3.9	0.023	0.85
Jamestown	2.5	1.1	0.018	0.63
Newport[b]	39.8	97.5	514	67.4

*LMWPAH is lower molecular weight polycyclic aromatic hydrocarbons with two rings;

HMWPAH is higher molecular weight polycylcic aromatic hydrocarbons with three or more rings;

[a]Warwick mean concentrations used unless otherwise noted;

[b]Combined systems, LMWPAHs = 12.89 μg/l, HMWPAHs = 1.69 μg/l (Providence mean concentrations); (27)

[c]Mean Cranston concentrations; LMWPAHs = 0.768 μg/l; HMWPAHs = 0.311 μg/l; (35)

[d]Mean Warwick concentrations LMWPAHs = 0.0072 μg/l, HMWPAHs = 0.258 μg/l; (3

[e]Mean W. Warwick concentrations; LMWPAHs = 0.0039 μg/i; HMWPAHs = 0.216 μg/l. (35)

The decline in oil and grease loadings from industries discharging to the Bay and its tributaries from 1972 to 1983 is quite noticeable. There are three major reasons for this: (1) since 1972, several large industries have either gone out of business or have moved out of state; (2) since 1972, some industries have tied into local municipal treatment plants; and (3) most industries are no longer required to report full analyses on a monthly basis, except when seeking a renewal of their permit. For example, the largest discharger of oil and grease in the Narragansett Bay region went into receivership in 1982; the second largest tied into a municipal treatment facility in 1983; and the the third largest went out of business. Of the 23 industries reporting oil and grease data in 1972, seven are no longer in business here in Rhode Island. Four are tied into municipal treatment plants and only 12 still discharge directly into the local water bodies (but five of these are no longer required to report oil and grease).

The metal data in Table 8 is more difficult to interpret without knowledge of local activities. The 1972 data gave no mass pollutant loads for a power plant on the Providence River, whereas, the 1983 data included this power plant. Usually the presence or absence of data for one industry would not make a significant difference. However, the plant uses Providence River water for cooling at a flow rate of approximately 600 x 106 1/d and the water that they intake is less than pristine. Therefore, it is not appropriate to blame them entirely for the metal loads. In this case, it would have been better to analyze both the plant influent and effluent and add to the inventory only the increase between the two. This was done for a power plant on Mt. Hope Bay whose cooling water discharge averages over 3000 x 10_6 1/d (39). Even trace amounts in a flow rate that large can lead to a significant mass pollutant loading. If the power plants are excluded from the data set, a decline is observed in metal loadings from industries in the past 12 years, probably for the same reasons as the decline in oil and grease loadings.

We were especially anxious to examine the PAH data in the priority pollutant NPDES scans submitted in late 1982. However, we found that industries most frequently checked the "believed absent" box and did not analyze for PAHs. Other industries reported "less than 10 ppb" or "less than 20 ppb." Our calculations indicate that, for a waste discharge to contain more than 10 ppb of any one PAH, it would have to have a waste oil content exceeding 50 mg/1. This level is extremely high for most types of industrial discharges, although it is not unheard of. Therefore, in hindsight, the absence of PAH data is not surprising. To determine if this source of pollutant entry into local waters could be significant to the inventory, we estimated the PAH input by assuming that the oil and grease discharges had the nature of waste crankcase oil. These estimates are probably a worst case situation.

Table 8

Summary of direct industrial discharges to the Narragansett Bay basin (tons/yr).

Pollutant	1972[B] (ref. 38)	1981[B] (ref. 28)	1983[A] (ref. 28)	1983[B] (ref. 28)	1983[C] (ref. 28,39)
Oil & grease	397	161	25.9	25.9	41.3
Cd	1.0		8.3	0.07	0.092
Cr	42.0		31.2	12.11	13.1
Cu	26.6		35.9	13.4	14.9
Pb	0.6		6.9	0.01	0.04
Zn	149.1		82.8	6.8	7.3
Ni	1.0		8.8	0.01	3.0
LMWPAHs[d]			0.183	0.183	0.291
HMWPAHs[d]			0.014	0.014	0.021

[A]Total RI mass discharges as reported by NPDES (includes power plant data).

[B]RI mass discharges without power plants;

[C]RI and Massachusetts mass discharges without power plants;

[d]Calculated from oil and grease data assuming
Σ LMWPAHs = 7050 μg/gm; Σ HMWPAHs = 523 μg/gm. (32)

WASTE CRANKCASE OIL DUMPING

The improper disposal of used crankcase oil down sewers has been cited by several authors as contributing to the oil content of sewage and receiving waters (7,40). The impact of this disposal method is impossible to assess directly since it is a covert practice. Often the evidence is seen--empty oil cans in rivers and on streets, large oil stains around catch basins--but the magnitude of the problem has only been the subject of speculation. In order to address this question, we designed a survey that we mailed to 1000 Providence residents. Under the guise of asking about whether they would participate in a used oil recycling program, we added a question about their current disposal practices (41). Following this study, virtually the same questionnaire was used again in connection with a South

Carolina legislative study, querying South Carolinians about their habits in this regard (42). These two data sets in combination give us an idea of what urban, suburban, and rural residents do with their waste oil (41,42). A summary of the survey results is given in Table 9.

The joint study (43) concluded: (1) on the average, car owners changed their crankcase oil in their vehicles twice a year regardless of population density; (2) as the population density increased, the percentage of do-it-yourself oil changers decreased; (3) the disposal methods used are a function of demographic parameters; and (4) the specific practices of pouring the used oil on the road or pouring it down catch basins is clearly more utilized in a highly urban area where catch basins are convenient.

We used the survey results to predict waste oil contributions of each city and town in Narragansett Bay drainage basin. First, we classified each town into one of three categories (urban, suburban, and rural) by population density criteria to determine which of the data sets were the most appropriate for each town. We then calculated the amount of waste oil dumped down sewers or poured on roads per town using the number of vehicle registrations in each town (44). The other waste oil disposal methods could also eventually result in surface or groundwater contamination but this process would take longer and some degradation is possible. Leaks from underground storage tanks used for waste oil in gas stations are also a potential water pollution problem. However, when oil is dumped down a sewer, its transport to receiving waters is rapid. Our waste oil dumping estimates are based only on the amount of oil poured down sewers and represent a conservative value if other methods of oil disposal also contribute to water pollution.

Table 9

Used crankcase oil disposal practices. (Ref. 43)

	Urban	Suburban	Rural
Population density	>3000/mi^2	3000-500/mi^2	<500/mi^2
Percent of oil changed by owners	33.5%	39.9%	48.5%
Disposal method used by owners:	Percentage of oil volume		
Give it to service station	6.9	10.4	3.0
Put in garbage	40.7	23.4	14.0
Store at home	4.1	6.5	5.0
Pour it out or bury it in backyard	29.7	39.0	38.0
Pour it on the road	4.8	4.0	0
Pour it down sewer	7.6	2.6	1.0
Take to dump	2.8	3.9	9.0
Other	3.5	14.3	24.0

Because used crankcase oil contains metals and PAHs, we estimated the loadings expected for these constituents using literature data about the composition of used crankcase oil (32,45). The summation for the Narragansett Bay drainage basin is given in Table 10.

OIL SPILLS

Any pollutant inventory involving oil pollution assessment in the coastal zone would be remiss without a mention of oil spills. Accidental discharges of oil receive media attention. The oily seagull as a favorite of journalists is surpassed in popularity only by photos of tank trucks laying upside down in a river or grounded ships. Narragansett Bay oil spill data is available from the U.S. Coast Guard Marine Safety Office, from the Rhode Island Department of Environmental Management's Water Resources Emergency Response Section, and from the Environmental Protection Agency Regional Laboratory. A comparison of the three data sets revealed descriptions which only infrequently overlapped (46). The state team handles most truck accidents and accidental industrial discharges and the Coast Guard handles most of the tanker, barge, and fishing boat problems. Years of cooperation between these agencies have led to very little duplication of effort. The data sets used together provide a much more complete picture about accidental discharges of oil than any one separately. The amount of oil spilled and reaching water bodies in the watershed in any one year varied between 2830 gallons in 1982 to 35,587 gallons in 1976 (46). The oil reaching water bodies was only half of the total reported spilled volumes since contamination. The oil most frequently spilled in the Narragansett Bay area is fuel oil, and, in terms of volume, the largest volumes are spilled at bulk oil storage terminals followed by truck accidents and industrial discharges (46). The mean annual oil volume entering the waters of the Narragansett Bay watershed was 11,900 gallons/year or 40 tons/year.

Figure 6 is our final oil pollution budget. Please note that if it started as urban runoff, but went to the sewage treatment plant, we counted it as sewage. So you can immediately tell what kinds of factors are involved here.

For a comparison I put some of the polycyclic aromatic hydrocarbon data here, and you see a different picture for the lower molecular weight PAHs--the big source of sewage. For the high molecular weight PAHs it's urban runoff and atmospheric deposition. So even within a class of compounds the sources change.

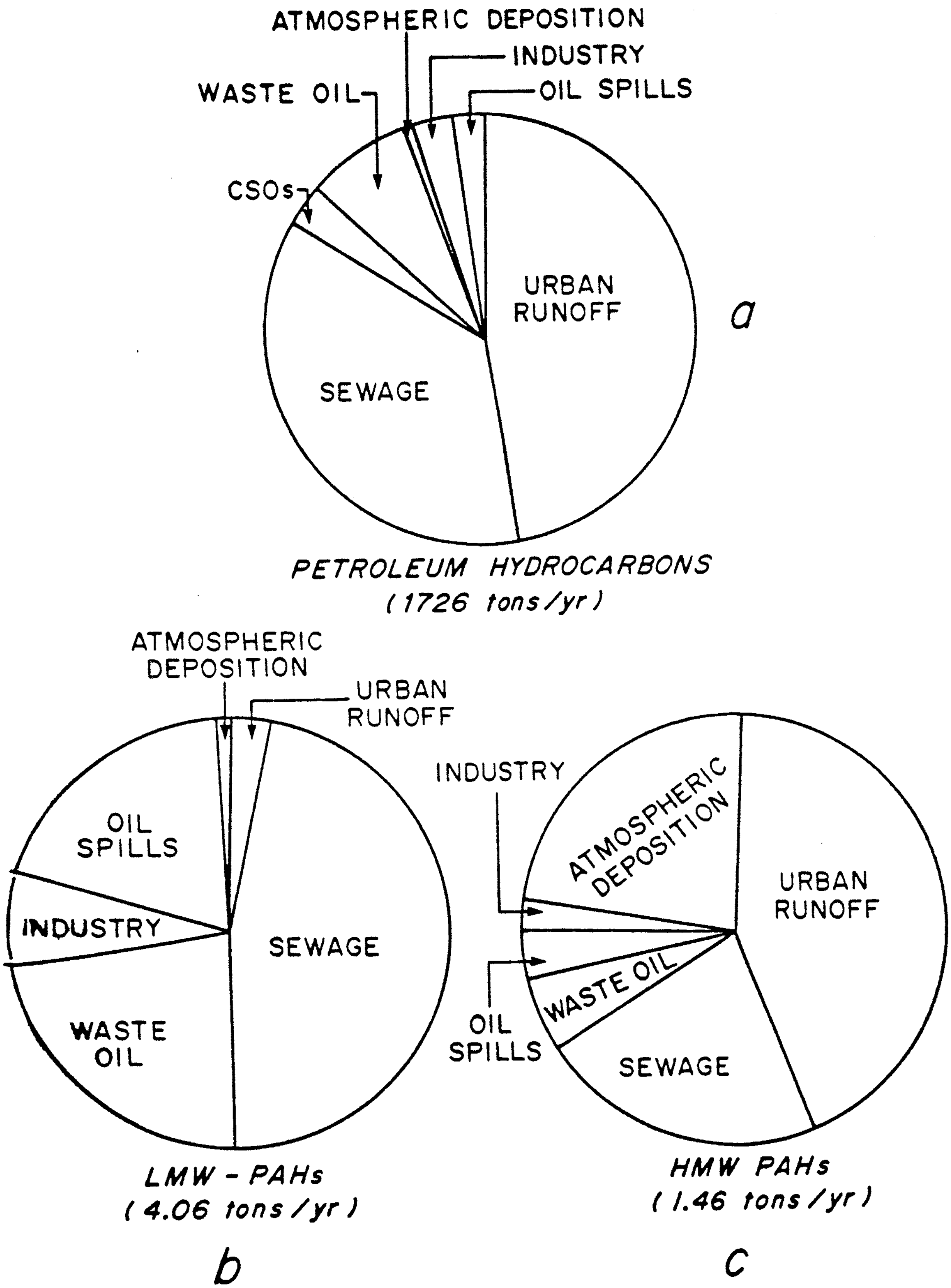


Figure 6: Pathways of hydrocarbon water pollution in the Narragansett Bay watershed. (a) Petroleum hydrocarbons; (b) lower molecular weight PAHs (2 rings); (c) higher molecular weight PAHs.

Table 10

Contributions of waste oil dumping down sewers to waters in the Narragansett Bay basin.

Pollutant	Concentration in used crankcase oil	Estimated contribution to watershed
Petroleum hydrocarbons	∿ 100%	132 tons/yr (48480 gal/yr.)
LMW-PAHs	7050 μg/gm[a]	929 kg/yr
HMW-PAHs	523 μg/gm[a]	68.9 kg/yr
Cu	28 μg/gm[b]	3.7 kg/yr
Pb	7870 μg/gm[b]	104.0 kg/yr
Fe	221 μg/gm[b]	29.1 kg/yr
Cd	0.8[b]	0.11 kg/yr
Zn	995[b]	131 kg/yr
Mn	4.0[b]	0.53 kg/yr

[a]Ref. 32

[b]Ref. 45

Now, since I know some of you are interested in metals, I wanted to show you our budget results for the metals we studied (Figure 7). In fact, urban runoff is the prime source of lead to the estuary, followed by inputs from sewage. But, again, some of this sewage is from the urban runoff. Note the lead atmospheric deposition, and the lead in waste oil.

It turns out that if you were to take the lead out of gasoline you would eliminate something like eighty-five percent of this budget. Lead in gasoline is the reason why you have it in urban runoff, in atmospheric deposition, and in waste oil. The only thing that would remain after the removal of lead from gasoline is in sewage that is not from urban runoff.

Copper in Rhode Island is mainly from the sewage treatment plants. In fact, more than half of this metal is from Field's Point. If industrial pretreatment is effective and reduces the industrial input by a half, then you've virtually taken care of half of the copper budget.

Figure 8 is a diagram of the copper budget of the Pawtuxet River. It is presented to give you an idea of how this varies from town to town, according to the land use, the industries that discharge to the river, and according to what the sewage treatment plants at each town contribute. The big pie graph on the right hand side of Figure 8 is the sum of each town. This is the copper budget for the entire Pawtuxet River. Each town in the budget could be vastly different, but if you look at Coventry, it's mainly industry. If you look at Johnston, it's mainly urban runoff. If you look at West Warwick, it's mainly sewage. The net result is a mixture of sources.

After you put the pieces together, the budget doesn't tell you what each town is doing. Therefore, you might want to have a different pollution abatement strategy for each town along the river.

These budgets are very useful for water quality management planning. If you know where it's coming from, it makes it easier to decide where you should spend your first dollars for abatement.

This presentation described research activity that I've been involved in for the last four years -- just giving you a brief glimpse of the methodology we used and the net result.

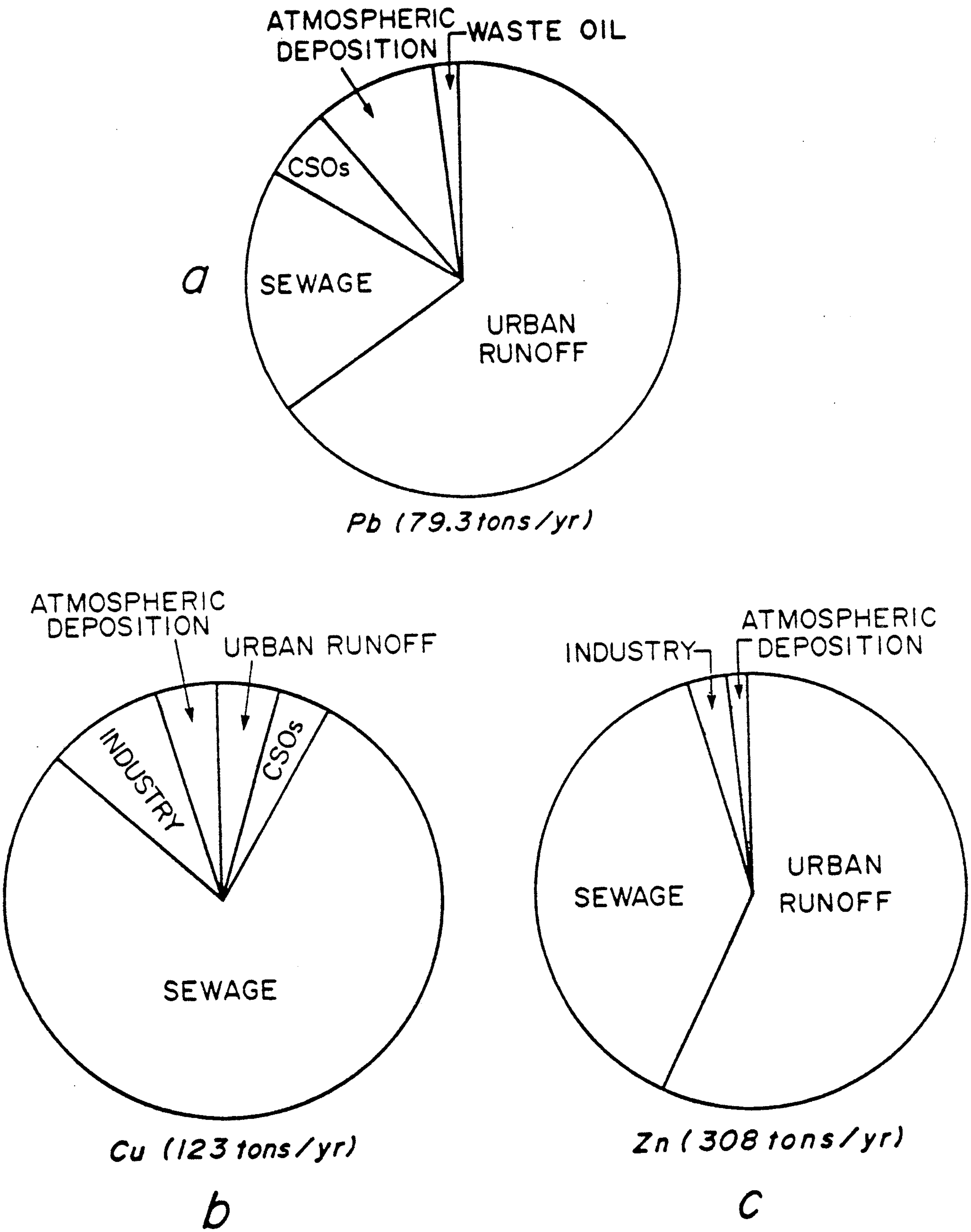


Figure 7: Pathways of metal water pollution in the Narragansett Bay watershed. (a) lead; (b) copper; (c) zinc.

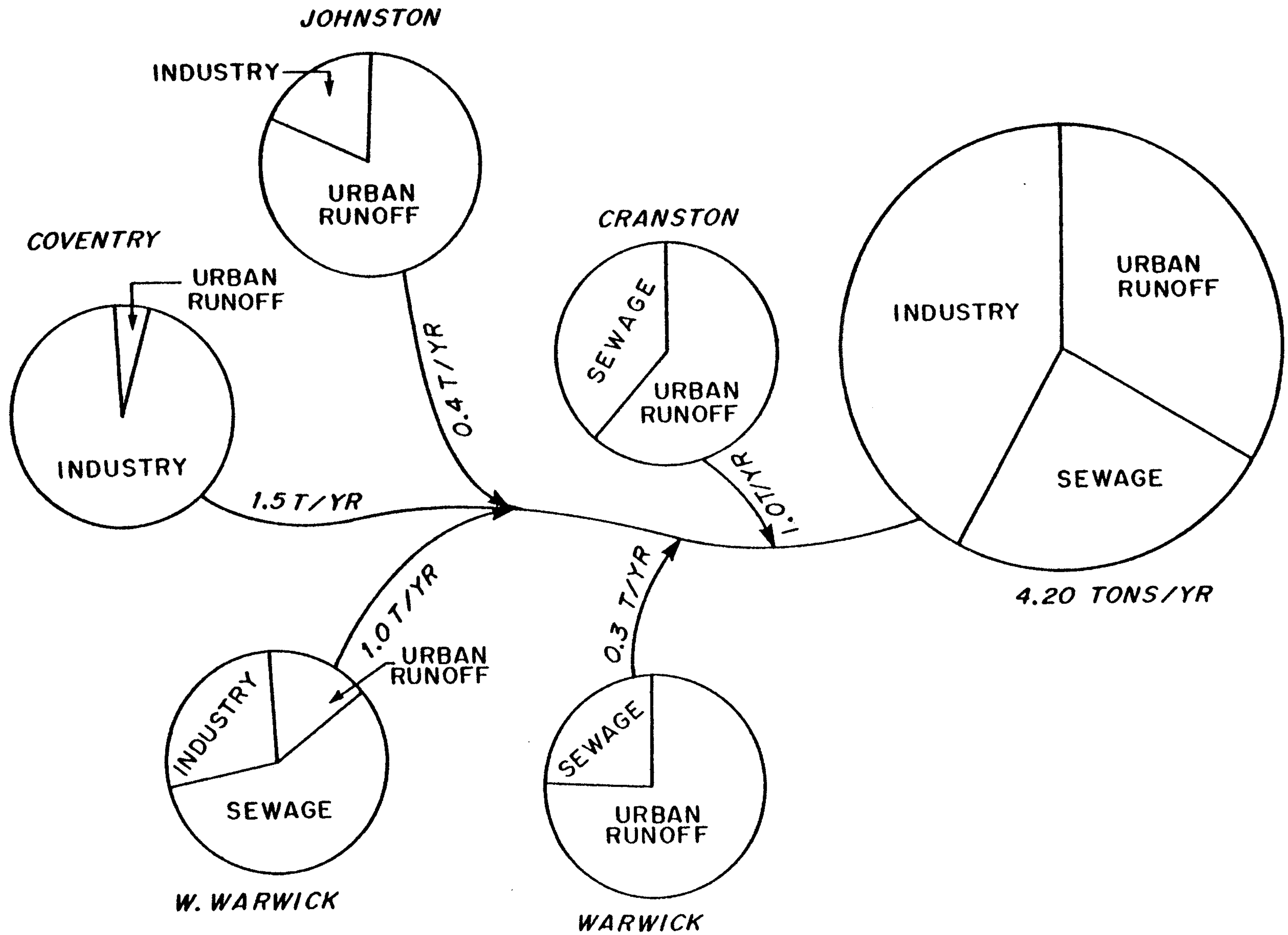


Figure 8: Sources of copper to the Pawtuxet River, variations among the different towns on the river.

DISCUSSION

QUESTION: What is the difference between particulate and dissolved hydrocarbons?

DR. HOFFMAN: It's basically an operational word. Anything that stays on a filter when you filter a sample we call particulate. It may have been associated with a particle from the very beginning or it could have become associated with a particle during its transport, and it could have been associated with the particle in the sample bottle between the time it was taken out in the field and the time it arrived at the lab.

QUESTION: Plants do have the capability of removing pretty complex organics, and I wondered what the effectiveness of this plant is?

DR. HOFFMAN: The effectiveness of removal of petroleum hydrocarbons is about what it is for suspended solids. So basically, if the plant can treat the suspended solids, it can treat the hydrocarbons. It's very interesting that when you collect the samples in the influent the makeup is about half-and-half--half particulate hydrocarbons, and half dissolved hydrocarbons according to our operational definition. But by the time they leave the plant, the hydrocarbons are predominantly associated with particles. That's because they are being mixed with the activated sludge; they are being mixed with all the particles and suspended solids within the plant itself. We have found that there is a good correlation between the removal of the solids and the removal of the petroleum. The residence time in the plant itself, in the secondary system, is really not very effective in doing any biodegradation. We saw no chemical evidence of biodegradation.

QUESTION: Does that affect the quality of the sludge your plant produces?

DR. HOFFMAN: No. The sludge comes out very oily and this condition makes it easy to burn. In fact, they want to go to incineration whenever they can get their incinerator working. And they don't need to add any oil to get it to go; it burns very nicely without it.

QUESTION: What happens to the particles that are coming from the sewage treatment plant as primarily freshwater and mixing with twenty parts per thousand sea water?

DR. HOFFMAN: Good question. We're going to look at that in the future. These studies were all done from the source-point of view. I haven't been out on Narragansett Bay since I was a graduate student, back in 1974. So I can't answer those kinds of questions at the moment. There is evidence from previous studies that fifty percent of the hydrocarbons settle out in the Providence River estuary and fifty percent are transported further downstream.

QUESTION: In estimating your point sources what data do you use?

DR. HOFFMAN: We did monitoring of our own for a number of the sewage treatment plants. We were fortunate to get some twenty-four hour composites from those plants that didn't have combined sewers. We analyzed about fifteen composites from three different plants along the Pawtuxet River and some grab samples from some of the others just to see if they were in the same range that the others were in. We found a good correlation between hydrocarbon concentrations in the effluent and the suspended solid in the effluent. When we didn't have data we normalized our hydrocarbon concentrations to the suspended solids concentrations. For the industry we got the data off the NPDES permit monitoring reports.

QUESTION: Have we done any recommendations on the basis of this work?

DR. HOFFMAN: Yes, we have. There are a number of ways that we can abate urban runoff. The lead was a fairly simple explanation. You take the lead out of gasoline, you solve the lead problem. For petroleum hydrocarbons it's a little bit more difficult. We found out that most of the sources for hydrocarbons were from oil drips along the road and onto parking lots. We did a survey of different service stations and garages and asked them what they found to be the most common source of oil drips and how much would it cost to fix it. The answer that we got, five out of the ten that we surveyed, indicated that it was from the valve cover seals, and the cost to repair was twenty dollars. So if you really wanted to abate hydrocarbons in urban runoff, what you should do, as part of the safety inspection by the state, is investigate whether or not oil drips are occurring in each automobile. The state already requires emissions testing for air pollutants. They could also tap on to see whether or not the car is leaking an excessive amount of oil in the process.

Some of the oil in urban runoff, by the way, especially in the industrial areas of town was clearly not crank case oil. It was number two fuel oil, which indicates that in industrial areas of town there are poor transfer processes. If people would exercise more care in regard to handling their oil products, this source could be eliminated as well.

QUESTION: Where does the oil come from in industrial runoff?

DR. HOFFMAN: We were at the end of the sewer. We don't know exactly how it got in there. We can only surmise, because it appeared to us that about half of it was number two fuel oil. This would indicate perhaps underground facilities were leaking into the sewer system by improper seals. Also, one of the fairly common practices in the industrial areas of the older cities is that they have floor drains in their factories and in their institutions. Whenever they have spills, they just hose down the floor. And these floor drains are hooked into the storm system.

I think that industrial pretreatment will do two things: (1) it will clean up what is going to the sewage treatment plant; and (2) it will also impact what is going through these floor drains into the storm sewer systems.

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DR. NIXON: Our next speaker is Dr. Malcolm Spaulding. He is one of the priNcipals in a company called Applied Science Associates Inc. and is also a professor of ocean engineering at the University of Rhode Island. Malcolm has been modeling estuaries and near shore shelf regions for some years.

CIRCULATION DYNAMICS

Dr. Malcolm Spaulding

DR. SPAULDING: This morning, I'm going to review the circulation and pollutant transport dynamics of Narragansett Bay. I'm going to take you through a historical perspective on that particular problem so you can see where we started and where we are now in the process of understanding the circulation and pollution transport dynamics.

I've put together an outline of the talk (Figure 1). I've already told you about the objectives. I'll tell you a little bit about the study area.

The first thing I'll do is give you an overview of the field programs and the numerical modeling studies that have been done. I'll talk about the pollutant transport dynamics in the overview sense, and then the flushing models. Then I'll tell you a little bit about the numerical water quality models, the current state or the practice thereof, a brief summary, and then some recommendations about where we need to go from here.

The area, as you've noted before, is Narragansett Bay (Figures 2 and 3). It's located in the southern New England bight. It's surrounded by a series of four coastal sea areas that interface between it and the shelf proper. Those coastal sea areas are Long Island Sound, Block Island Sound, Rhode Island Sound, and Buzzard's Bay; those areas tend to isolate Narragansett Bay from the circulation on the shelf.

If you look at Figure 2, you see that it's not simply a riverine system discharging into the ocean. What we have is a series of rivers. The two major rivers are the Blackstone, discharging into the Providence, and the Taunton River discharging into Mt. Hope Bay. The freshwater flows from these rivers however is fairly small.

Narragansett Bay could be more properly looked at as a series of interconnected channels rather than as a typical bay with a river at the head.

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OUTLINE OF PRESENTATION

- OBJECTIVE
- STUDY AREA
- CIRCULATION DYNAMICS
  1. OVERVIEW OF MAJOR STUDY EFFORTS
     - FIELD PROGRAMS
     - PHYSICAL AND NUMERICAL MODEL STUDIES
  2. LONG PERIOD WAVE FORCING
     - SEICHING
     - TIDES
  3. WIND FORCING
     - TYPICAL
     - STORM SURGE
  4. DENSITY/RIVER RUNOFF FORCING
- POLLUTANT TRANSPORT DYNAMICS
  1. OVERVIEW OF MAJOR STUDY EFFORTS
     - FIELD PROGRAMS
     - PHYSICAL AND NUMERICAL MODEL STUDIES
  2. FLUSHING MODELS
  3. NUMERICAL WATER QUALITY MODELS
- SUMMARY OF UNDERSTANDING
- RECOMMENDATIONS FOR FUTURE STUDY

Figure 1

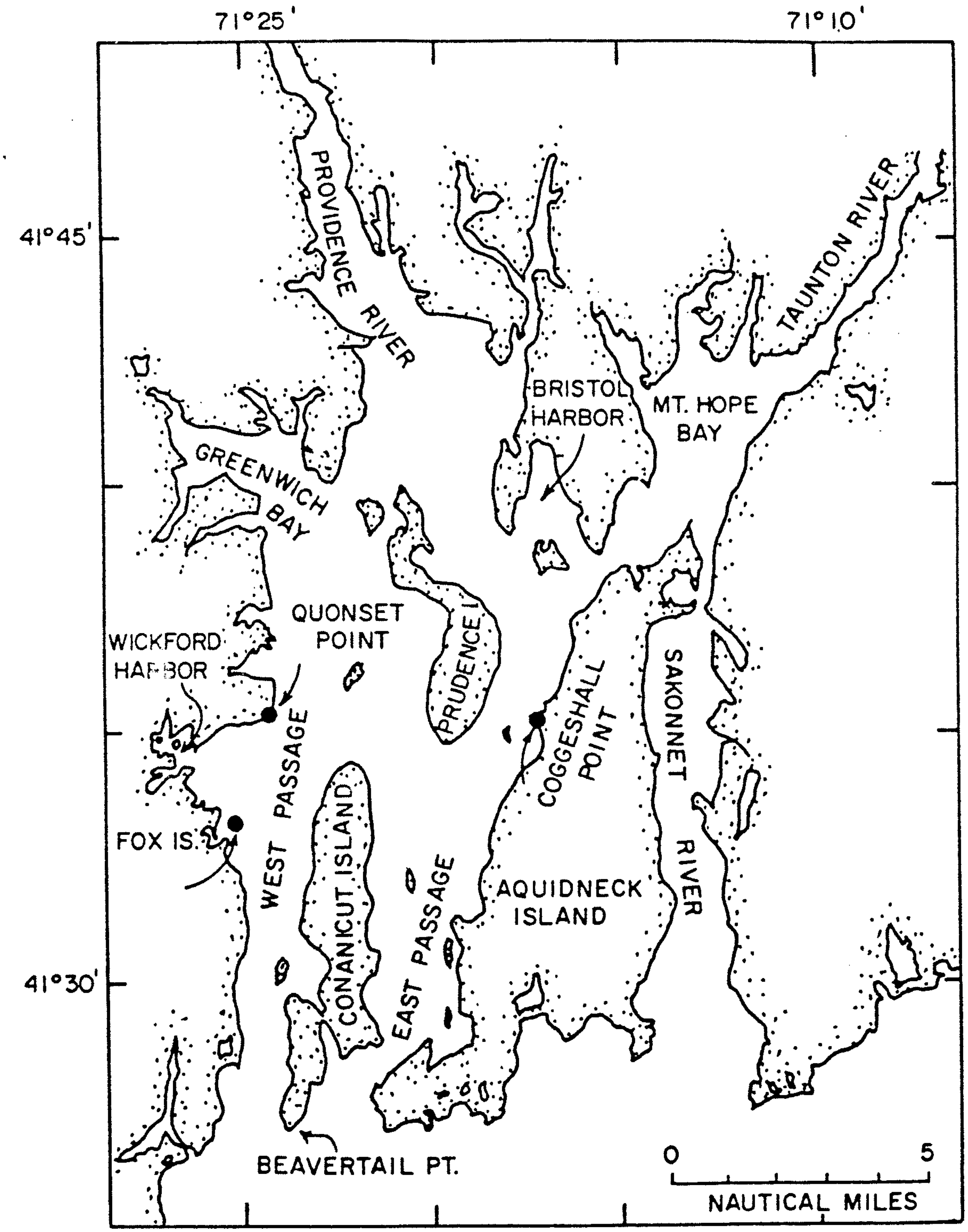
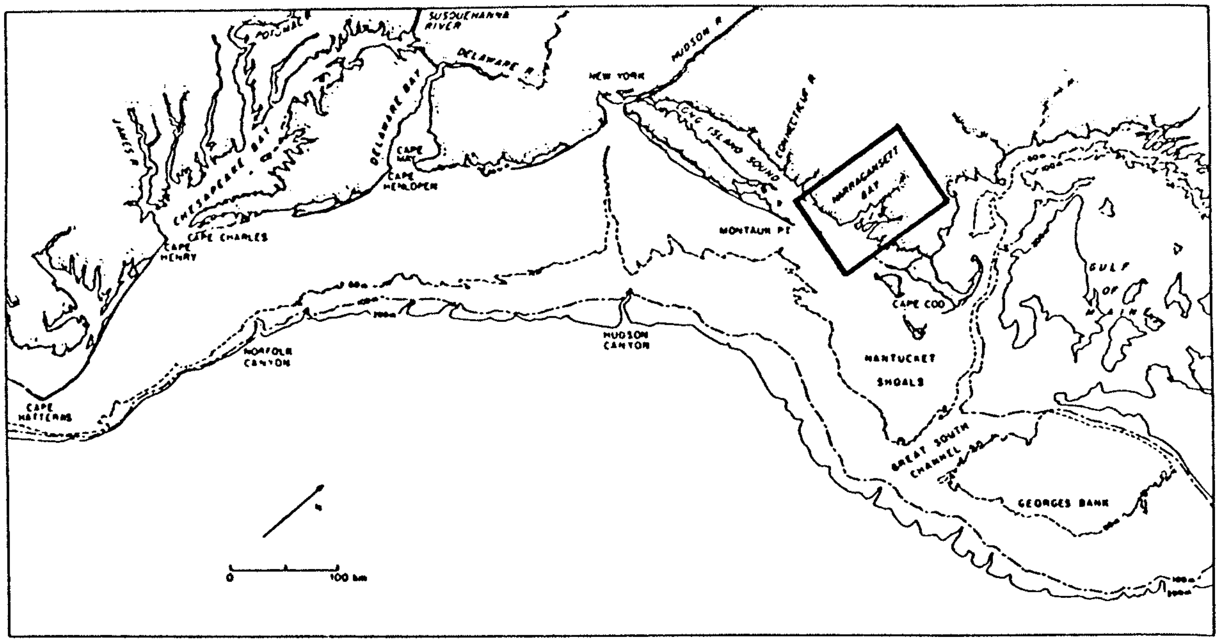


Figure 2

Narragansett Bay.



The location of Narragansett Bay in relation to the Middle Atlantic Bight and Western Gulf of Maine (after Beardsley and Boicourt; 1981).

Figure 3

In general, the depth of the East Passage is about a factor of two deeper than the West Passage (Figure 4). This deep water continues up the Bay and then goes into a narrow shipping channel. The narrow shipping channel is dredged to the head of the Providence River. It has a major impact on the circulation dynamics in the area in that the water depth here is about twice as deep as the water on either side of the channel.

The system is classified as a partially mixed estuary (Figure 5). However you can find about any estuarine type you want in Narragansett Bay if you look in the right spot. The lower estuary is well mixed. The mid part of Narragansett Bay is partially mixed, and the upper part displays many characteristics of a fully stratified system.

The mean depth is about 8.3 meters for the Bay as a whole. There is a depth differential between the East Passage and the West Passage of approximately a factor of two.

The surface area, and size of the Bay, is relatively small. It's only forty kilometers long and sixteen kilometers wide. The freshwater input is only a hundred and five cubic meters per second. There are two major sources of freshwater: the Blackstone, which discharges into the Seekonk and the Taunton which discharges into Mt. Hope Bay.

The sewage treatment plant acts as a significant source of freshwater to Narragansett Bay. Direct rainfall is also fairly large.

Tidal range in the system is about 1.1 meter. That's amplified approximately 1.3 times as one goes to the head of the Bay. There's about a twenty-minute lag between high tide at Newport and at the head of the Bay. The M2 semidiurnal tidal component is the most important. M4 and M6 tieds are also important in the Bay. It's basically a standing wave system.

The currents are typically twenty to fifty centimeters per second weighted more towards the twenty than the fifty. Experience shows that the currents in some of the selected smaller passages are at least an order of magnitude or a factor of five higher then that. The phase difference between the elevation and the currents is about eighty degrees, again, indicative of a standing wave system.

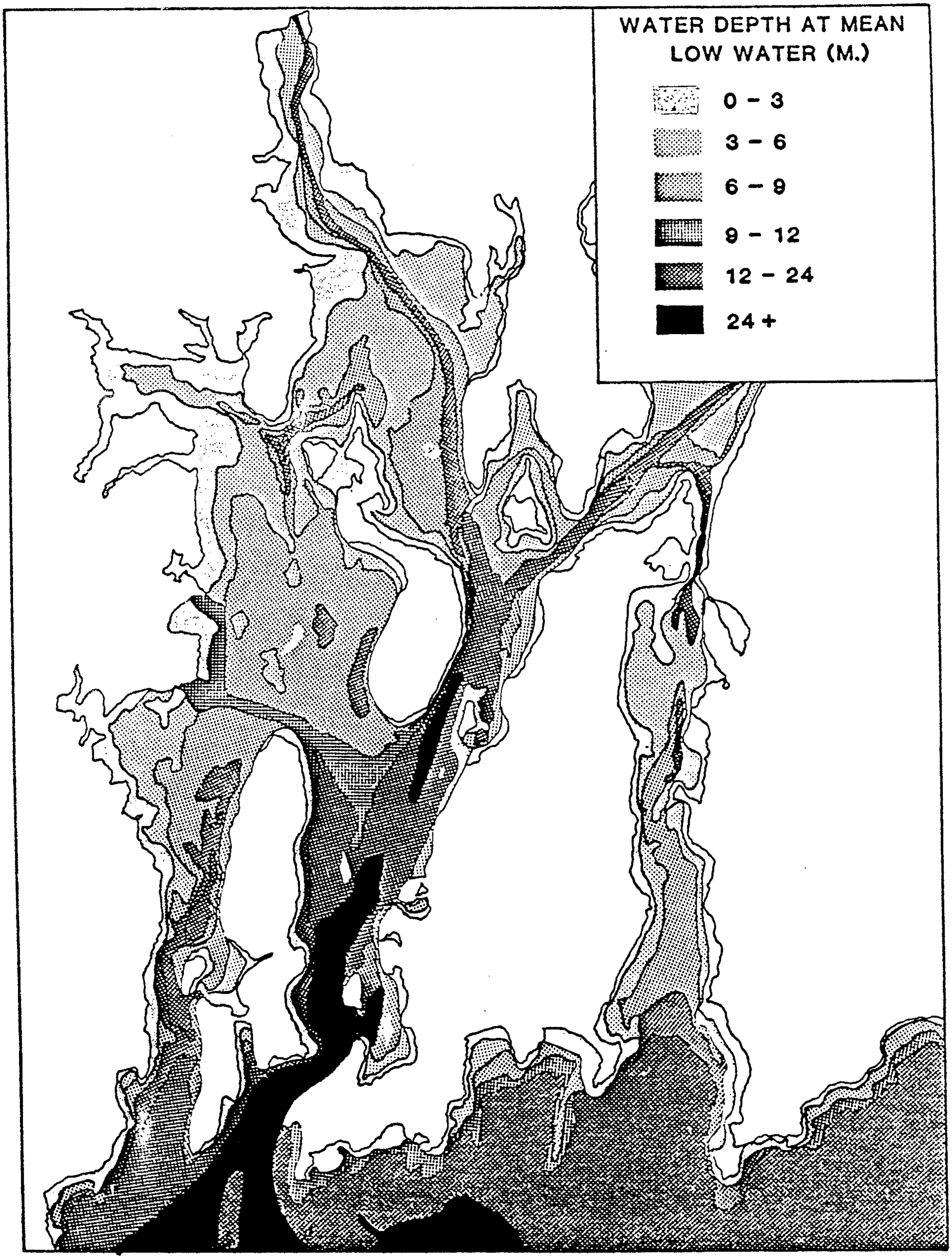


Figure 4

The bathymetry of Narragansett Bay.

Figure 5

PHYSICAL CHARACTERISTICS OF NARRAGANSETT BAY

PARAMETER	CHARACTERISTIC
● CLASSIFICATION	PARTIALLY MIXED ESTUARY
● GEOMETRY	
SURFACE AREA	328 KM^2
MEAN DEPTH	8.31 M
MEAN DEPTH - EAST PASSAGE	17.5 M
MEAN DEPTH - WEST PASSAGE	7.5 M
MEAN VOLUME	2.724 KM^3
LENGTH	40 KM
WIDTH	16 KM
● FRESH WATER INPUT	
AVERAGE MEAN	105 M^3/S
RIVERS (GAUGED)	
BLACKSTONE	21.3 M^3/S
MOSHASSUCK	1.13 M^3/S
WOONASQUATUCKET	2.02 M^3/S
PAWTUXET	9.6 M^3/S
TAUNTON	18.7 M^3/S
SEWAGE TREATMENT	6.48 M^3/S
DIRECT RAINFALL	6.52 M^3/S
● TIDAL RESPONSE	
MEAN RANGE	
NEWPORT	1.07 M
PROVIDENCE	1.4 M
AMPLIFICATION	1.3
TIME LAG	20 MINUTES
PRINCIPAL COMPONENT	M2 (12.42 HRS) M4 + M6 IMPORTANT
TYPE	STANDING WAVE
● CURRENTS	TYPICALLY 20-50 CM/S, IN SELECTED NARROW PASSAGES 150 CM/S
	-80° PHASE DIFFERENCE BETWEEN CURRENTS AND SURFACE ELEVATION

The river runoff in the system is highly dominated by seasonal variation (Figure 6). During the spring we have spring melt and substantial runoff. During the summertime we have low-flow conditions; returning to higher flows again in late winter and spring.

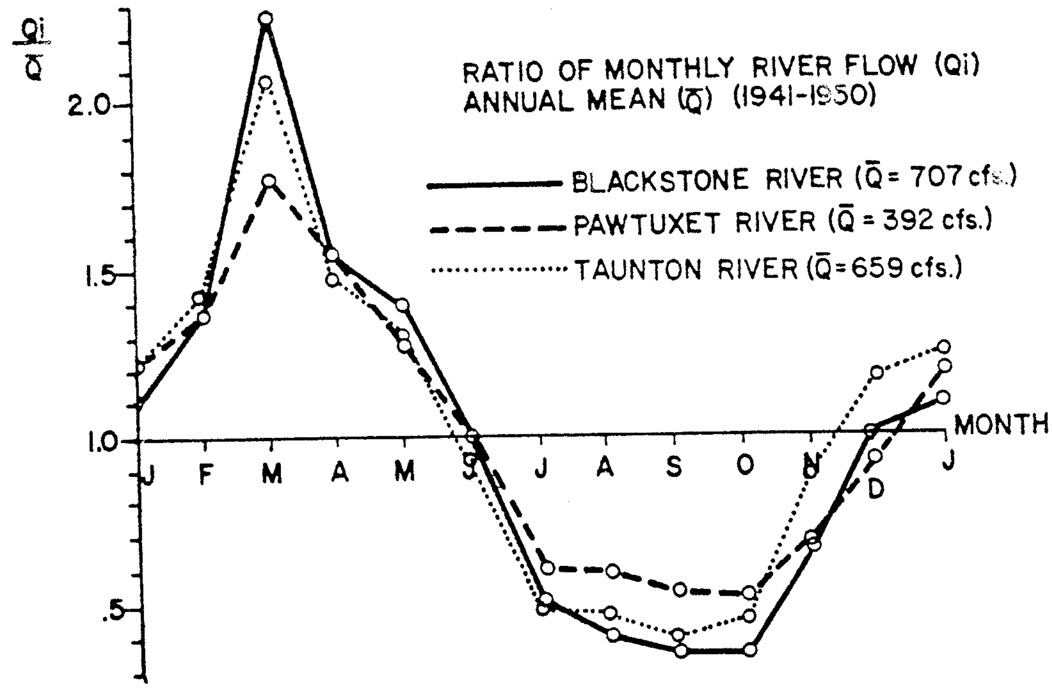
The principal forcing from the atmosphere comes from wind and the wind stresses. An energy distribution plot versus direction divided by the four seasons (Figure 7) shows that in general the wind is from the west. In the winter it's from the northwest. In the summer it's from the southwest. In general the winter winds are a factor of almost two stronger than the summer winds. The typical time for passage of weather events is about two to ten days. The most characteristic time scale is two to three days to about six to ten days.

Physical oceangraphic studies have all been done in response to some defined need in the Bay. The first one I could find on record was in 1936 (Figure 8). Haight's famous summary of the circulation in the Bay looked at current measurements at well over a hundred stations in the Bay using simple drogue techniques. Haight summarized data that was taken as early as 1844 with the bulk of the data coming from Sammons in 1930.

In 1956 and 1959 there were several salinity and temperature cruises. They were done as a part of a hurricane barrier study. In 1972 Wesiberg and Sturges, and later Weisberg, took some measurements. The first set of measurements was taken at Rome Point in the lower Bay for the potential siting of a power plant. Weisberg's subsequent study was in the Providence River for his Ph.D. thesis. He was interested in looking at wind forcing in a partially mixed estuarine system.

In 1977 an unreported NOAA National Ocean Service study involved standard circulatory survey for Narragansett Bay. It was at a time when the National Ocean Service was retiring their Ticus current meter system. Unfortunately the current data was not recoverable. However, we do have some good sea surface elevation observations from that program.

In 1980, Oviatt took biweekly salinity and temperature and water quality samples along the central axis of the Bay. More recently, a graduate student and I have been working on the circulation dynamics in Providence River. We've used six deployments, fifty to sixty day periods each and looked at seasonal variability in the forcing and response in upper Narragansett Bay.



Monthly variations in discharge for local rivers.

Figure 6

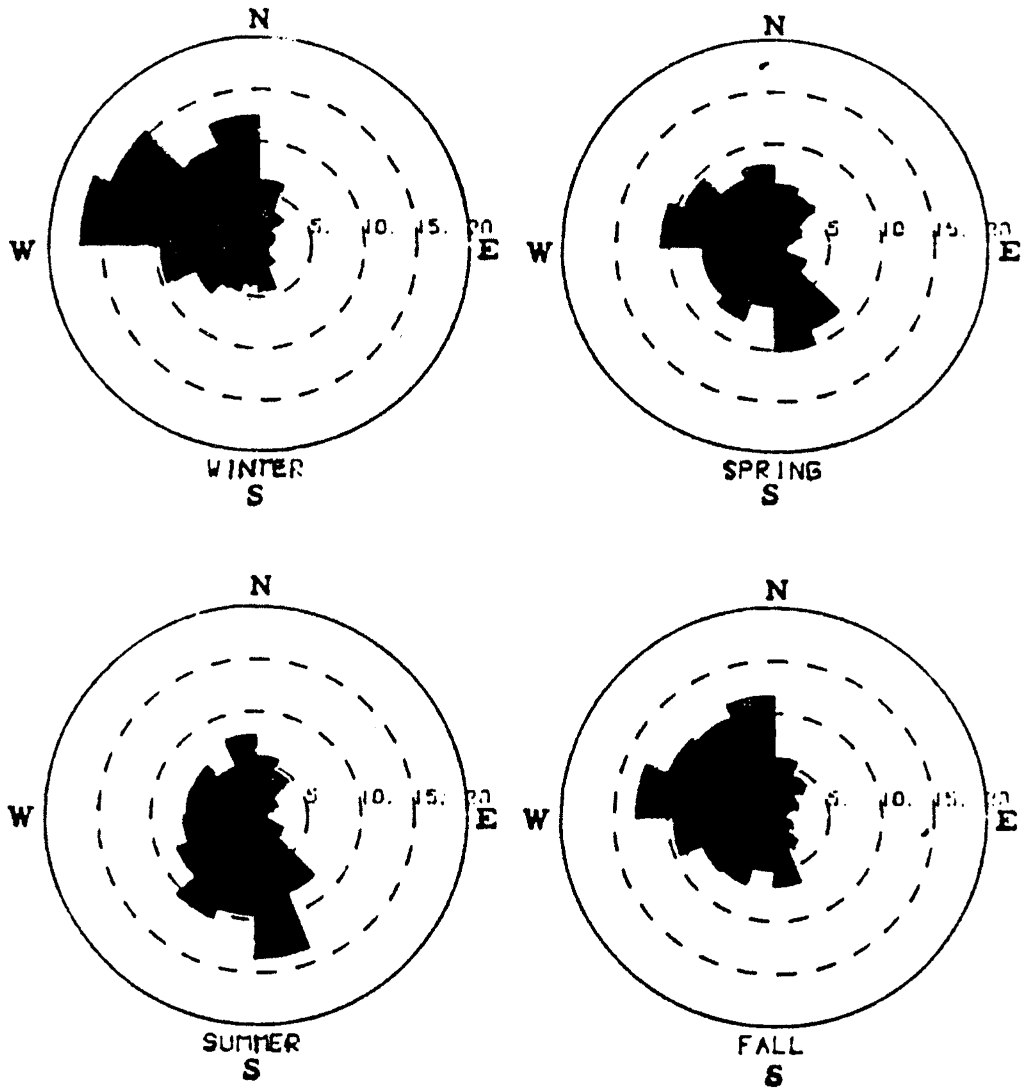


Figure 7

Seasonal variations in the directional distribution of total wind energy (velocity squared) at Green Airport based upon twenty years of observations (1960-1979). Each rose shows the percentage of total wind energy coming from each 22.5 degree sector.

Figure 8

MAJOR PHYSICAL OCEANOGRAPHIC FIELD STUDIES

REFERENCE	FEATURE
HAIGHT (1936)	- CURRENT MEASUREMENTS AT 100 STATIONS USING DROGUES - TIDAL SCALE
BLAKE (1844) MARINDIN (1874) PILLSBURY (1889) SAMMONS (1930) BOOTHE (1931)	- NARRAGANSETT BAY - USGS TIDAL CHARTS CONSTRUCTED
HICKS (1956, 1959)	- SALINITY AND TEMPERATURE DATA TWO CRUISES, JUNE AND AUGUST 1956 - NARRAGANSETT BAY - HURRICANE BARRIER STUDY U.S. ARMY CORP.
WEISBERG AND STURGES (1972)	- CURRENT MEASUREMENTS IN VERTICAL, TIME SERIES - ROME POINT - WEST PASSAGE - ROME POINT - POWER PLANT SITING
WEISBERG (1974)	- BOTTOM CURRENT MEASUREMENT 51 DAY TIME SERIES - ENTRANCE TO PROVIDENCE RIVER - WIND FORCING IN PARTIALLY MIXED ESTUARIES
NOS (UNREPORTED)	- TIDAL HEIGHT AND CURRENT SURVEY - NARRAGANSETT BAY - STANDARD CIRCULATORY SURVEY - NO CURRENT DATA RECOVERABLE
OVIATT (1980)	- BIWEEKLY SALINITY AND TEMPERATURE AND WATER QUALITY PARAMETER SURVEY - LONGITUDINAL TRANSECT FROM UPPER TO LOWER BAY - DEFINE WATER QUALITY
TURNER AND SPAULDING (1985)	- CURRENT, TIDAL HEIGHT, WIND, SALINITY, AND TEMPERATURE MEASUREMENTS, 6 DEPLOYMENTS, 15 - 60 DAYS. - PROVIDENCE RIVER - CIRCULATION DYNAMICS OF STRATIFIED ESTUARINE RIVER

Modeling work has been equally active in Narragansett Bay (Figure 9). Kurt Hess, who now works for NOAA started this work. He looked at vertically averaged circulation dynamics in Narragansett Bay, in response to tidal forcing. He verified his predictions with flow rate and surface elevation data.

In 1974, a graduate student of mine, J. Craig Swanson, and I did some work on two-dimensional vertically averaged modeling, and we refined Hess's model to a smaller grid size. In 1974 Kurt worked on looking at the steady state circulation dynamics for the area. In 1975, Hunter and I did a two-dimensional vertically averaged model for the upper Bay. In 1982, Gordan developed a three-dimensional model for the Bay.

So in terms of our understanding of the circulation dynamics, we've been about equally active in terms of field measurements and numerical modeling studies.

Now, we're going to talk about the long period wave forcing and particularly the seiching and tidal behavior of the Bay (Figure 1).

The seiching response of the Bay (Figure 10) is important to know if one would predict how the Bay might respond if driven at some other frequency. So we're interested in the free oscillation response of the Bay. Haight estimated it, using Merian's formula, at about 5.7 hours. Hess and White in their model, estimated it at about 4.8. We've done some simple analytical modeling and estimated it at between four and five hours.

The important point is that the M4 and M6, which are harmonics of the M2 semidiurnal tide, have periods that bridge this value. One is lower and one is higher than the seiching period, or its free oscillation period, producing an increase in response in that system.

Figure 11 shows the amplitude ratio of the tidal height at the head of the Providence River to the amplitude at the boundary as a function of frequency. We see that for the diurnal tidal components (O_1, K_1) and even the semidiurnal tidal components (M_2, S_2, N_2), the response of the Bay is to amplify those components very, very slightly.

However, if we look at the seiching frequency of the Bay--(Figure 10) we see that the M4 and the M6 tidal constituents seiching frequency. We expect in Narragansett Bay that the M4 and M6 components are amplified in the Bay

Figure 9

NUMERICAL CIRCULATION MODELS
NARRAGANSETT BAY

REFERENCE	FEATURE
HESS AND WHITE (1974)	2-D VERTICALLY AVERAGED NARRAGANSETT BAY (EXCLUDING MT. HOPE BAY), TIDAL AND STORM SURFACE FORCING, VERIFIED WITH FLOW RATES AND SURFACE ELEVATIONS, 926 M GRID SIZE
SPAULDING AND SWANSON (1974)	2-D VERTICALLY AVERAGED, NARRAGANSETT BAY, TIDAL FORCING VERIFIED WITH HESS AND WHITE MODEL, 370 M GRID SIZE
HESS (1974)	3-D STEADY STATE, NARRAGANSETT BAY (EXCLUDING MT. HOPE BAY), RIVER RUNOFF, VERIFIED WITH SALINITY DATA, 926 M GRID SIZE
HUNTER AND SPAULDING (1975)	2-D VERTICALLY AVERAGED, PROVIDENCE RIVER, TIDAL FORCING VERIFIED WITH HAIGHT DATA, 228 M GRID SIZE
GORDON (1977)	3-D FULLY COUPLED, PROVIDENCE RIVER TIDAL FORCING, NO VERIFICATION, 370 M GRID SIZE
GORDON (1982) GORDON AND SPAULDING (1985)	3-D TIME DEPENDENT, NARRAGANSETT BAY (EXCLUDING MT. HOPE BAY) TIDAL AND WIND FORCING, VERIFIED WITH CURRENT OBSERVATIONS, 926 M GRID SIZE

Figure 10

NARRAGANSETT BAY

SEICHING RESPONSE

REFERENCE	LONGITUDINAL * SEICHING PERIOD (HRS)
HAIGHT (1936)	5.72 MERIAN'S FORMULA RECTANGULAR BASIN, ℓ = 24 NM, D = 7.62M
HESS AND WHITE (1974)	4.8 TWO DIMENSIONAL VERTICALLY AVERAGED HYDRODYNAMIC MODEL, 926 M GRID SIZE
GORDON AND SPAULDING (1985)	3.85 - 5 ANALYTIC MODEL FOR 1-D WIDTH/DEPTH VARYING CHANNEL

*NOTE: TIDAL RESPONSE PERIODS

M4 - 6.21 HRS
M6 - 4.14 HRS

relative to other constituents. The S in Figure 11 is the linearized damping coefficient.

You can see that the amplification here for the M6 is approximately three to three-and-a-half times its value at the Bay mouth.

Now, I'll discuss some of Haight's data. Figure 12 shows their station locations.

I'm going to show some data from station (B01) (Figure 13) in these early surveys. If you look at the observations, which is the lower graph you observe a distinct double-peaked flood in the Bay and a single peaked ebb. Now, this is very unusual. In 1936, this so amazed Haight when he was writing his report that he decided to change the format of data presentation. Normally, they would present data from the two slack periods and then at the maximum and ebb periods, a total of four plots.

When Haight saw this data, he decided to use a twelve-plot presentation, to describe tidal currents in Narragansett Bay.

The origin of the double peaked flood and single peaked ebb, according to Haight, was the combination of the M2 and its two harmonics, M4 and M6. If you add those three components together for the phase relationship in the Bay, you get this distinct response (Figure 13).

The seiching period of the Bay and the M4 and M6 period relative to that seiching period leads to this well defined double peak flood in Narragansett Bay.

Now, there are essentially two kinds of tidal systems that are possible or two ends of the spectrum (Figure 14). One is a simple progressive system. In the progressive system the surface elevation and the horizontal velocity are in phase and the salinity is 900 out of phase. A progressive system is characterstic of a typical ocean area.

In Narragansett Bay and in most other closed systems, however we have a standing wave system. In a standing wave system the surface elevation and the velocity field are ninety degrees out of phase. That means that when we have high tide in the area, we have no flow. When we have zero tide height, we have maximun ebb. When we have low water, we have no flow again. When we have zero water, we have maximum flood, and the cycle repeats.

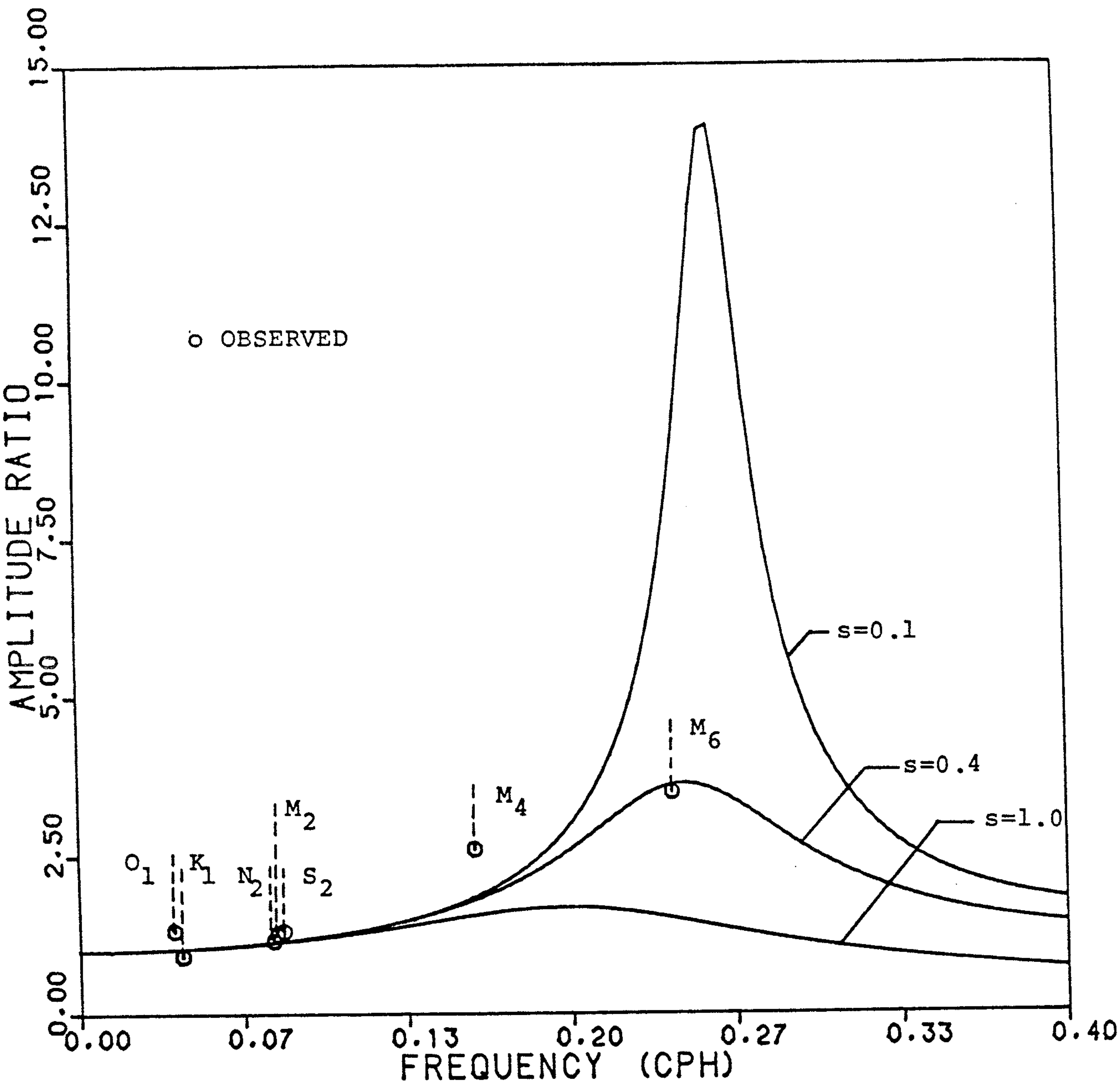
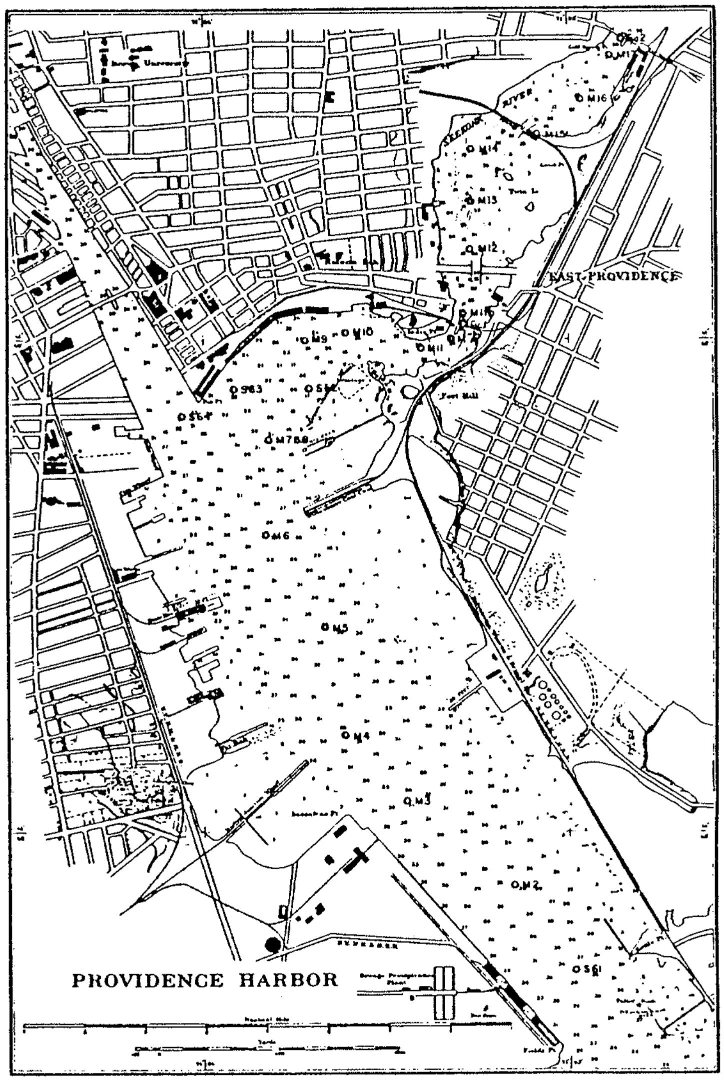
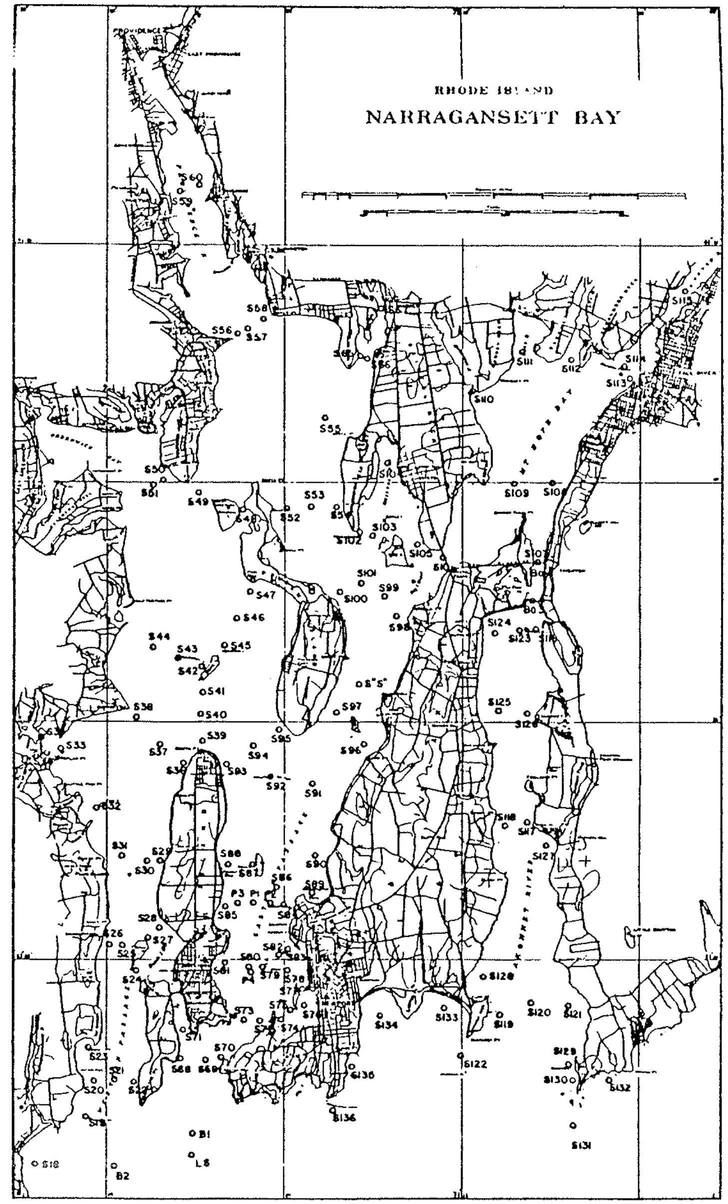


Figure 11

Ratio of surface elevation amplitude near the head of the Bay to that at the mouth as a function of frequency. Results are for s equal to 0.1, 0.4 and 1.0. Observed ratios at various tidal frequencies are also presented.

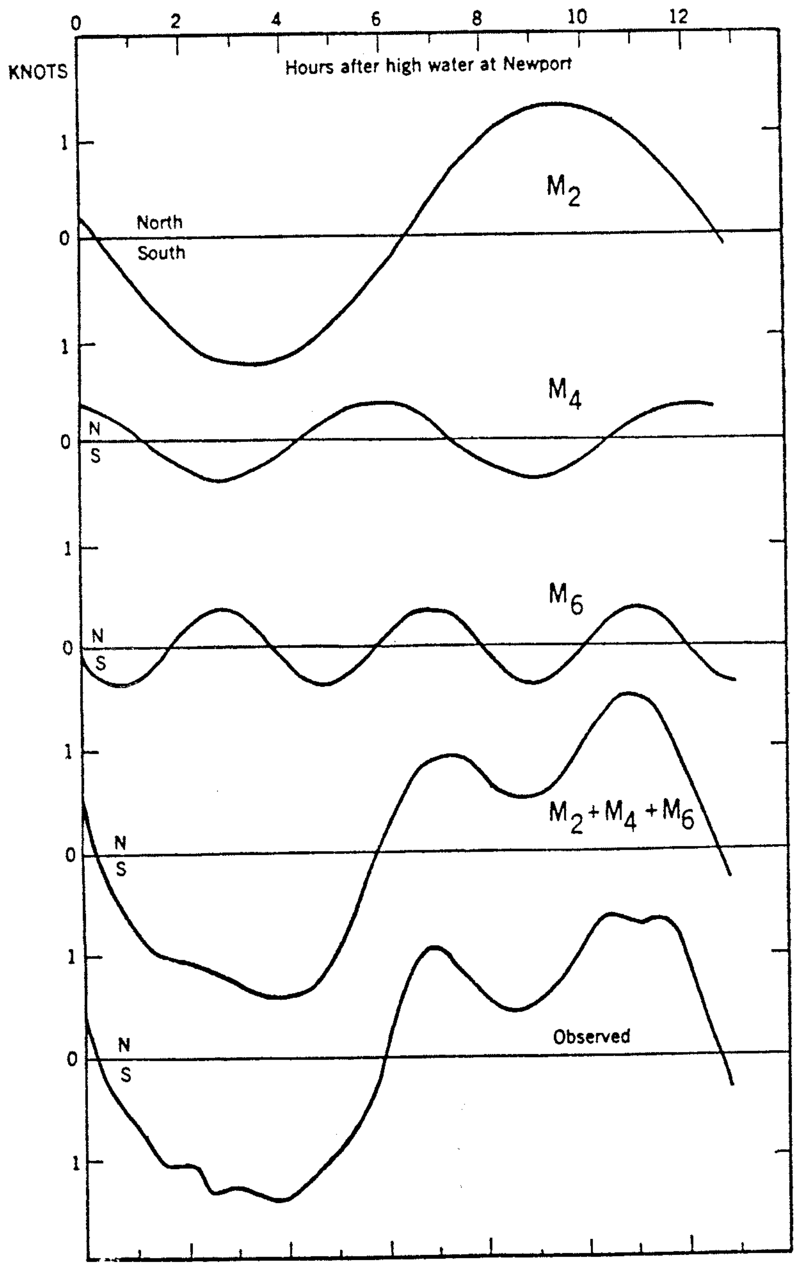


Current stations, Providence Harbor



Current stations, Narragansett Bay.

Figure 12



Combination of M_2, M_4, and M_6 currents, Station Bo 1.

Figure 13

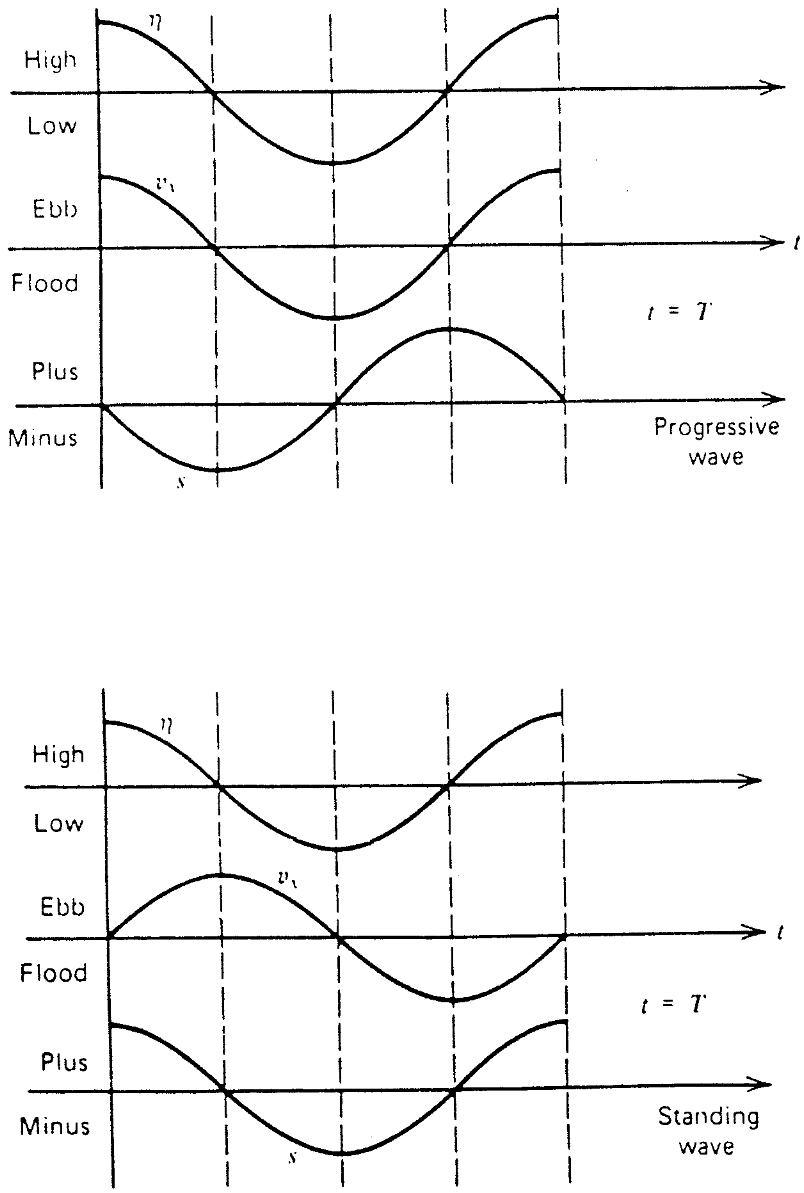

η
High
Low
v_x
Ebb
Flood
t
t = T
Plus
Minus
s
Progressive wave
η
High
Low
v_x
Ebb
Flood
t
t = T
Plus
Minus
s
Standing wave

Figure 14

Hence the phase relationship for a perfect standing wave system has the surface elevation and the current ninety degrees out of phase. For Narragansett Bay the volume is typically 80 percent.

One of the first circulation modeling efforts for Narragansett Bay was done by Hess, (without Mt. Hope Bay). He studied tidal circulation in the grid shown in Figure 15.

Figure 16 shows a comparison of Hess's model predictions with the observations for surface elevation at three key stations: Newport, Bristol, and Providence. As you can see, the agreement is quite good. Looking at Hess' model predictions and comparing them to observations of the currents at three different locations: the upper one is the West Passage; the middle one is Jamestown Bridge, which is in the lower half of the Bay on the West Passage; and then, finally, plot C is in the East Passage (Figure 17). The agreement is quite good in terms of the tide, and you can again see the characteristic double-peaked flood current.

Another interesting feature of the Bay is that if you look at the currents or the transport through the East and the West Passage, you find that there is a substantial difference: better than a factor of two (East to West) differential (Figure 18). The tidal ranges are about the same but the depths have a factor of two differential. The currents in the East Passage are higher than they are in the West.

We've done some subsequent analysis in terms of circulation from the Swanson-Spaulding model. What we did was to add Mt. Hope Bay to this system and the Sakonnet River and then significantly reduce the grid size so we could get better resolution.

These particular plots (Figure 19) were assembled, and have been distributed by the University or Rhode Island to the boating community. They give a general idea of the circulation in the Bay. The insert shows the surface elevation at one time in the tidal cycle.

Figure 20 shows the surface elevations in the Bay at zero hours, two, four, six, eight, ten, and twelve hours after high tide at Newport. These are in a tenth-of-a-foot increments in terms of surface elevations. The most interesting item is that the upper Bay, particularly the Providence River, is almost always in phase.

When it's high water in the Providence River, it's high water everywhere in the Providence River. You can't tell the difference between the upper end of the Providence River and the lower end. That's another characteristic of the standing wave dynamics of the system.

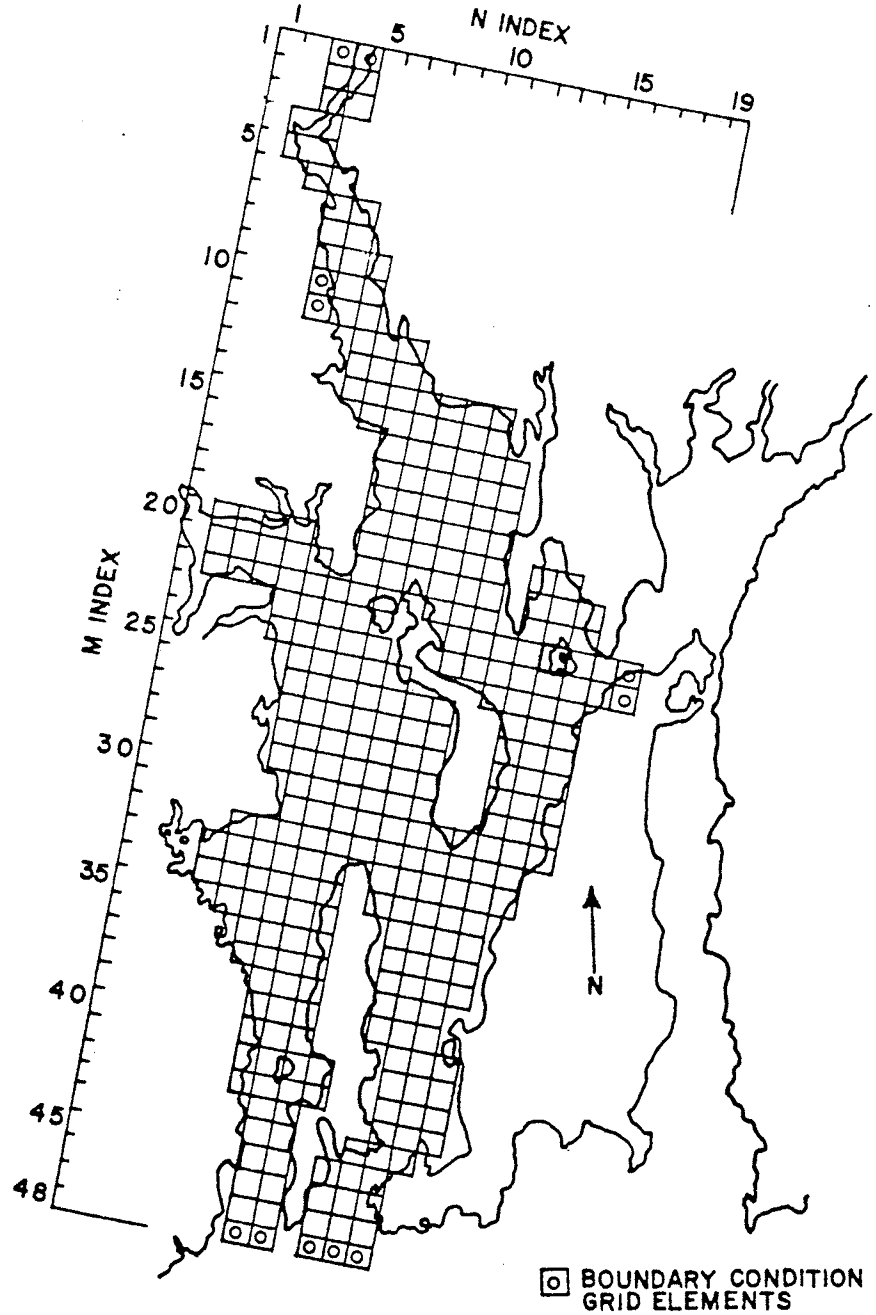


Figure 15

The grid network for Narragansett Bay.

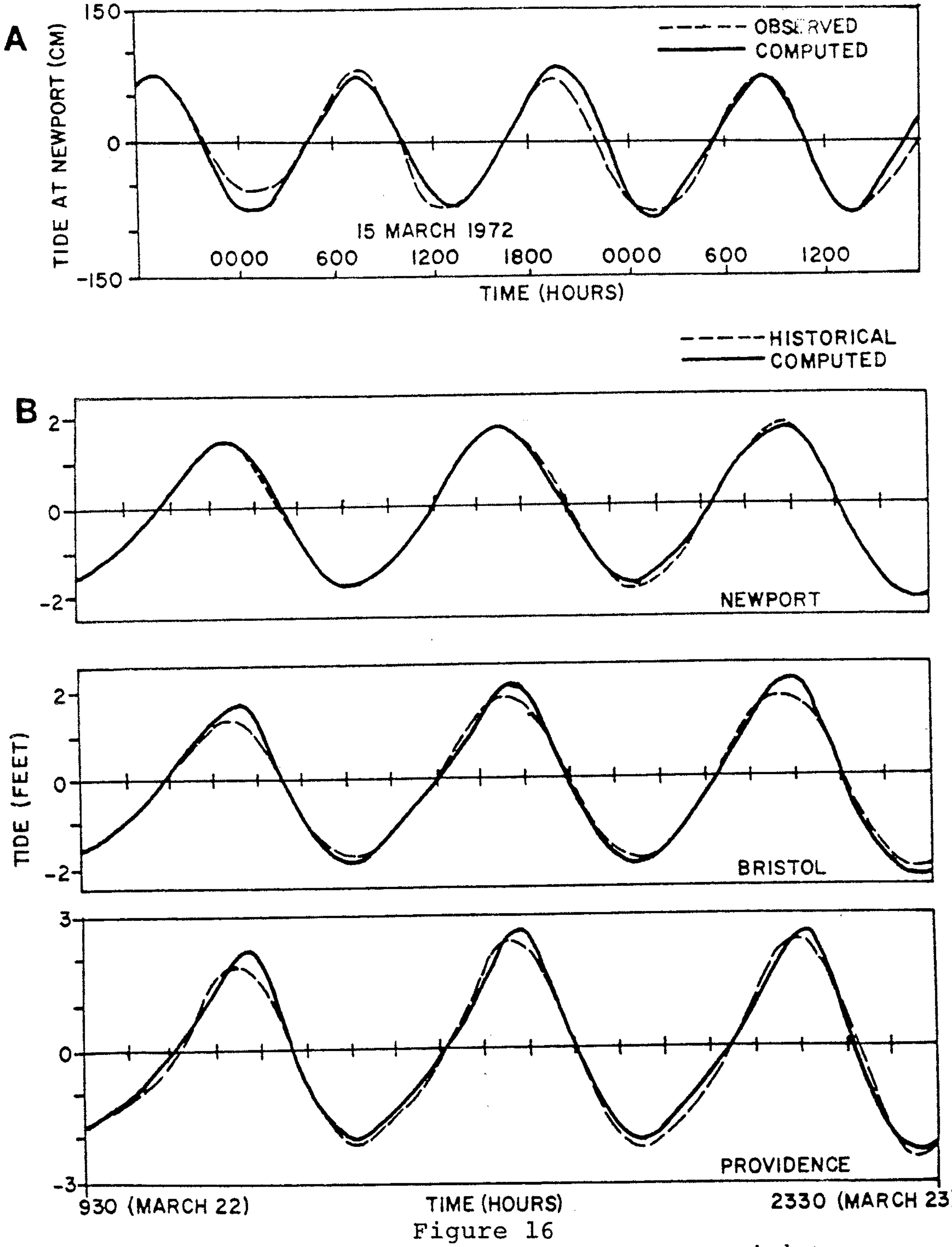


Figure 16
Comparison of observed tide at the Newport gauge and that computed by the model (A); and comparison of historical and computed tide at the Newport (top), Bristol (middle), and Providence (bottom) stations (B).

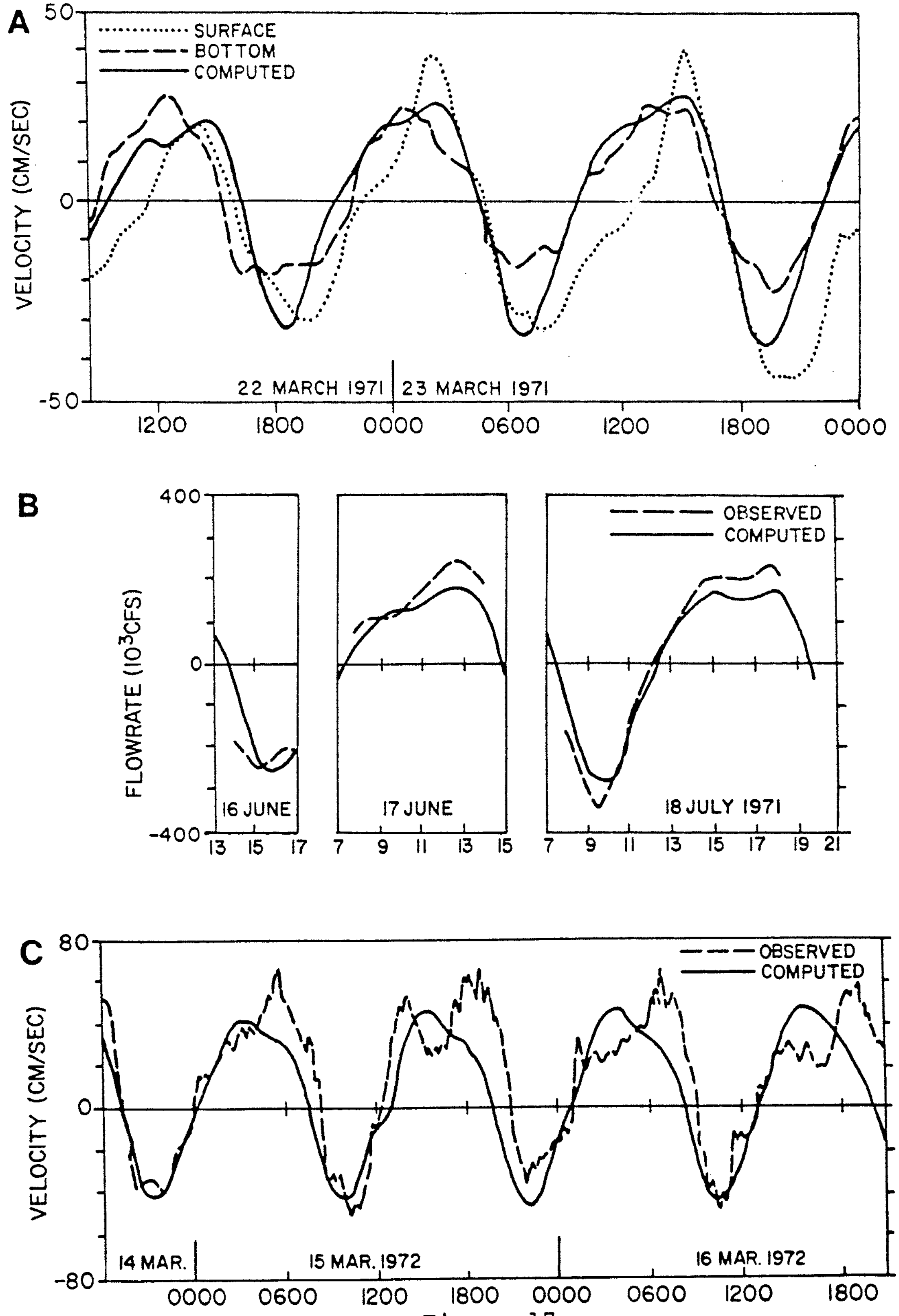


Figure 17

Comparison of observed and predicted current velocity in the west passage (A), flowrate at the Jamestown Bridge (B), and current velocity in the east passage (C).

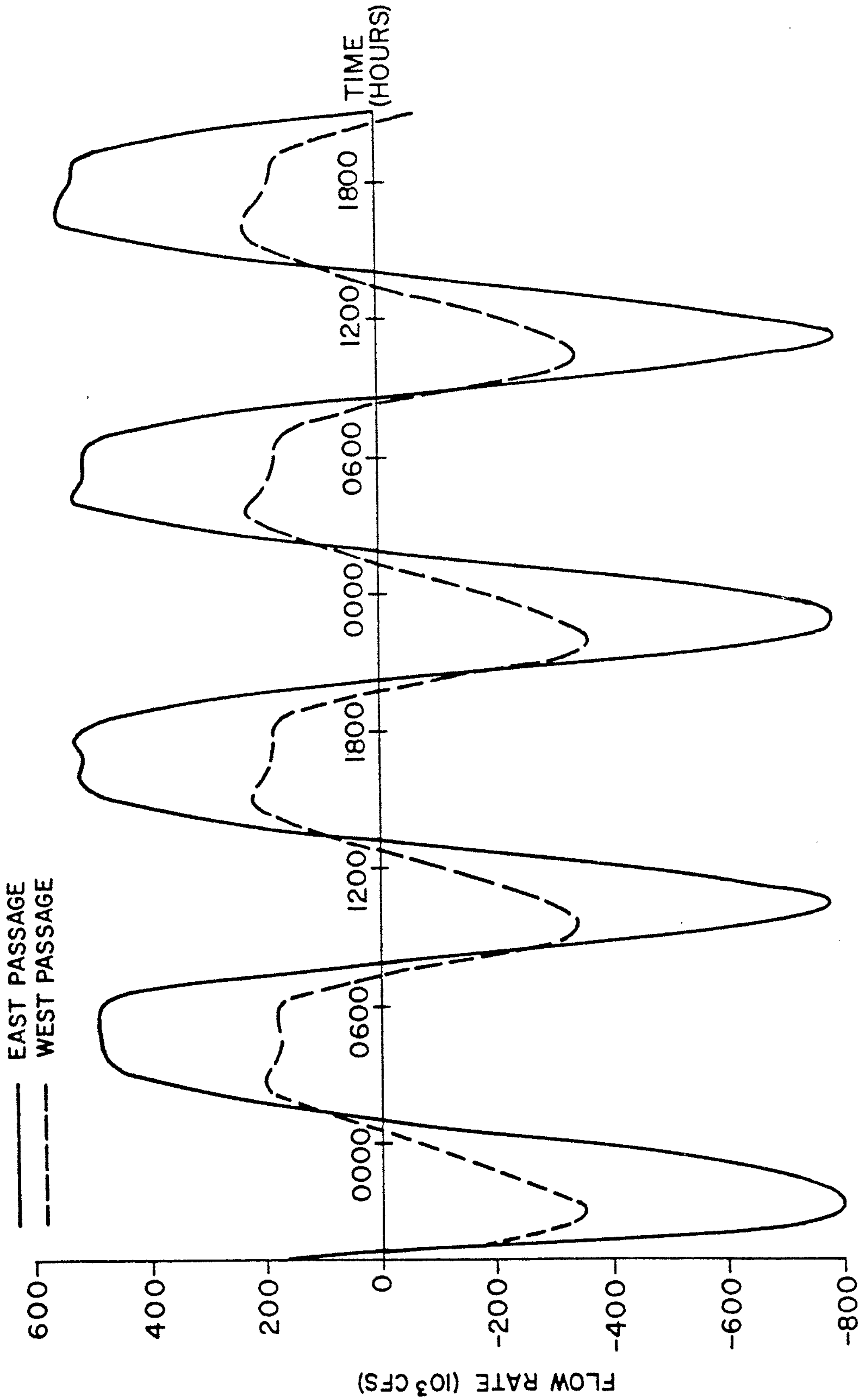


Figure 18
Predicted flowrates through the lower east and west passages for a period beginning at 1900 E.S.T., March 15, 1972.

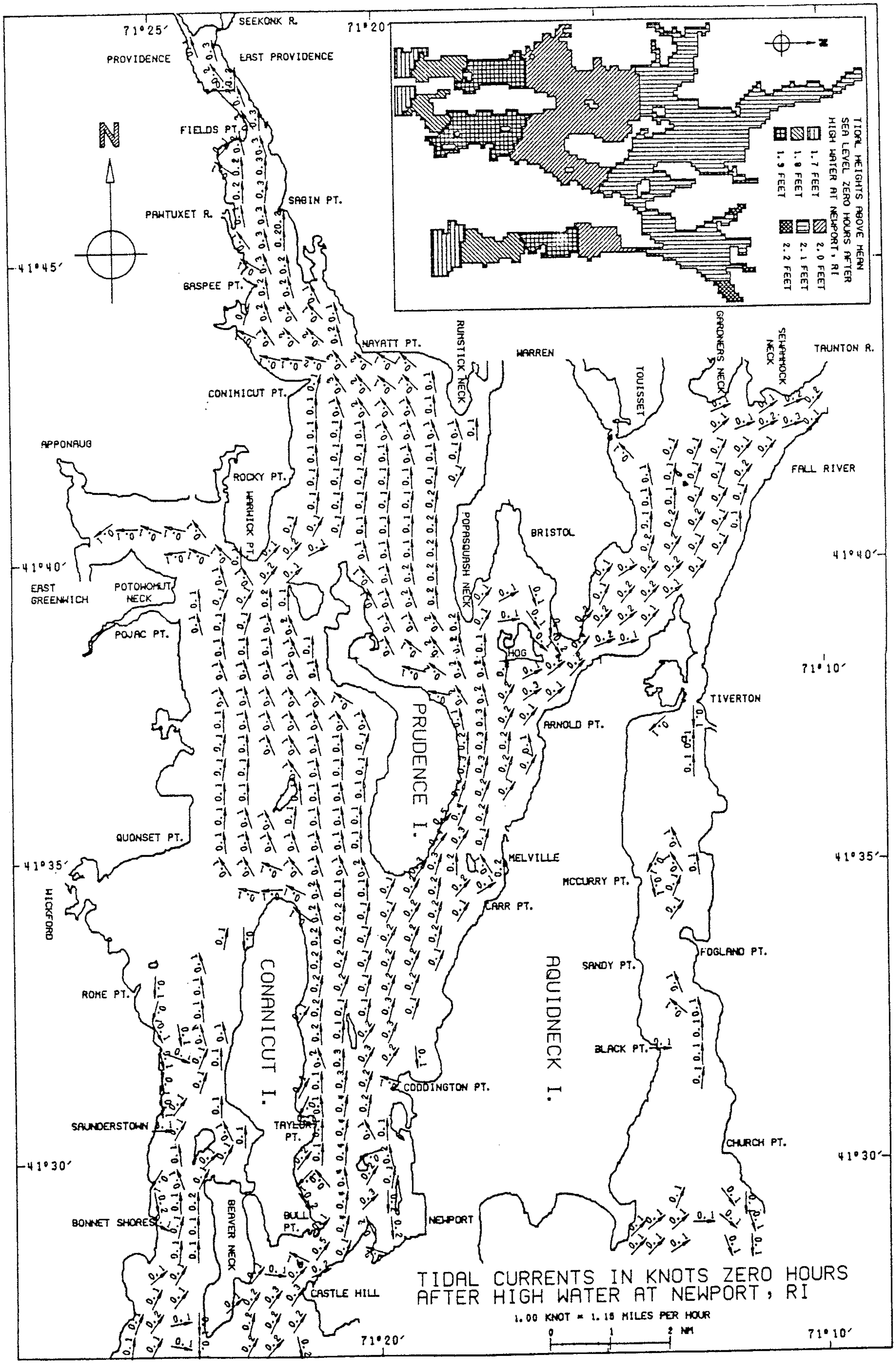
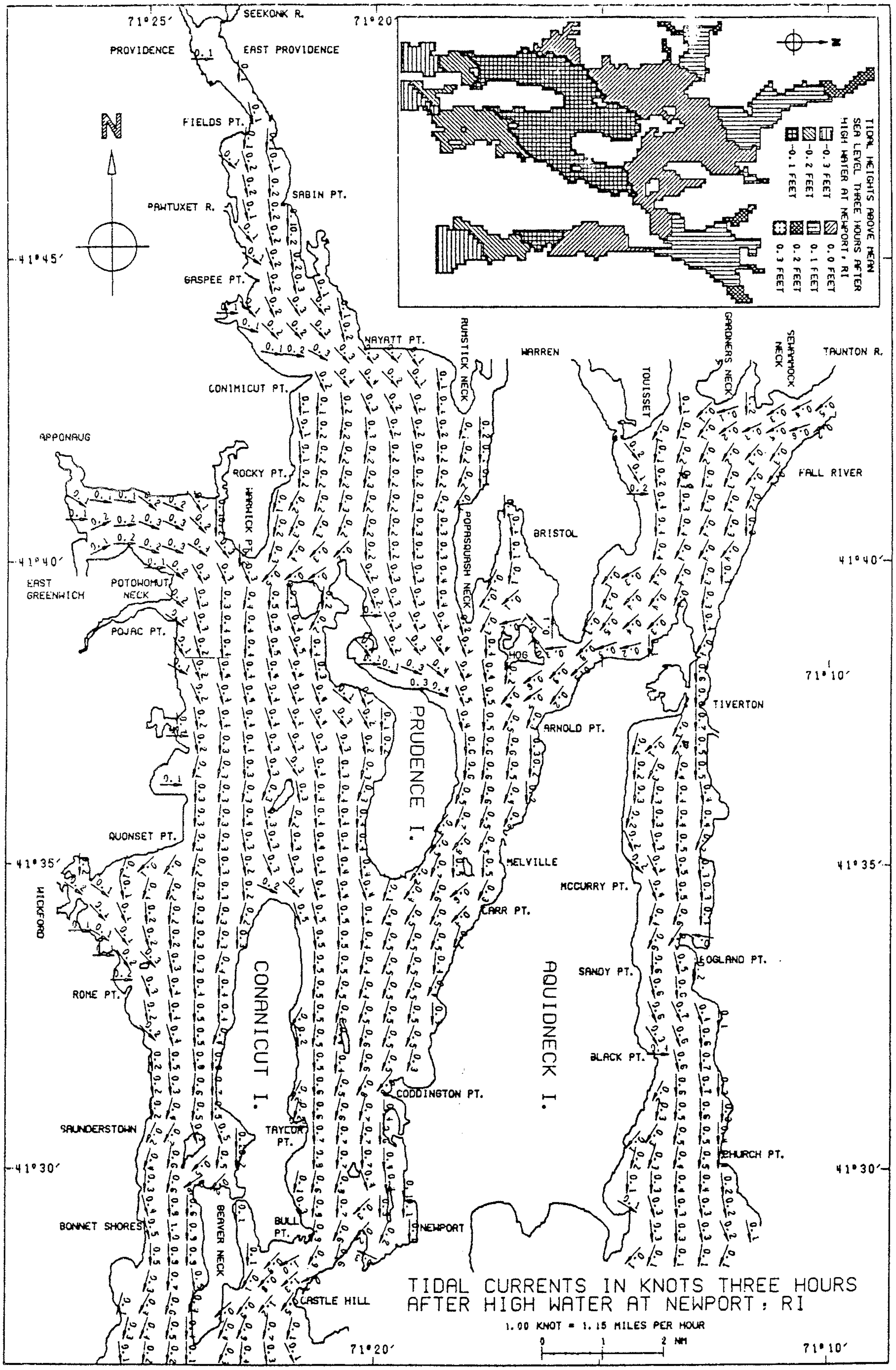

TIDAL CURRENTS IN KNOTS ZERO HOURS AFTER HIGH WATER AT NEWPORT, RI
1.00 KNOT = 1.15 MILES PER HOUR
TIDAL HEIGHTS ABOVE MEAN SEA LEVEL ZERO HOURS AFTER HIGH WATER AT NEWPORT, RI
1.7 FEET
1.8 FEET
1.9 FEET
2.0 FEET
2.1 FEET
2.2 FEET
PROVIDENCE
EAST PROVIDENCE
SEEKONK R.
FIELDS PT.
SABIN PT.
PAWTUXET R.
GASPEE PT.
NAYATT PT.
CONIMICUT PT.
RUMSTICK NECK
WARREN
TOUISSET
GARDNERS NECK
SEWAMMOCK NECK
TAUNTON R.
FALL RIVER
APPONAUG
ROCKY PT.
WARWICK PT.
POPASQUASH NECK
BRISTOL
EAST GREENWICH
POTOWOMUT NECK
POJAC PT.
HOG
PRUDENCE I.
ARNOLD PT.
TIVERTON
QUONSET PT.
MELVILLE
MCCURRY PT.
CARR PT.
WICKFORD
CONANICUT I.
AQUIDNECK I.
SANDY PT.
FOGLAND PT.
ROME PT.
BLACK PT.
CODDINGTON PT.
SAUNDERSTOWN
TAYLOR PT.
CHURCH PT.
BONNET SHORES
BEAVER NECK
BULL PT.
NEWPORT
CASTLE HILL
71°25′
71°20′
71°10′
41°45′
41°40′
41°35′
41°30′

Figure 19a



TIDAL CURRENTS IN KNOTS THREE HOURS AFTER HIGH WATER AT NEWPORT, RI
1.00 KNOT = 1.15 MILES PER HOUR
TIDAL HEIGHTS ABOVE MEAN SEA LEVEL THREE HOURS AFTER HIGH WATER AT NEWPORT, RI
-0.3 FEET
-0.2 FEET
-0.1 FEET
0.0 FEET
0.1 FEET
0.2 FEET
0.3 FEET
PROVIDENCE
EAST PROVIDENCE
SEEKONK R.
FIELDS PT.
SABIN PT.
PAWTUXET R.
GASPEE PT.
NAYATT PT.
CONIMICUT PT.
RUMSTICK NECK
WARREN
TOUISSET
GARDNERS NECK
SEWAMMOCK NECK
TAUNTON R.
FALL RIVER
APPONAUG
ROCKY PT.
WARWICK PT.
POPASQUASH NECK
BRISTOL
EAST GREENWICH
POTOWOMUT NECK
POJAC PT.
HOG
TIVERTON
ARNOLD PT.
PRUDENCE I.
QUONSET PT.
MELVILLE
MCCURRY PT.
WICKFORD
CARR PT.
ROME PT.
CONANICUT I.
SANDY PT.
AQUIDNECK I.
FOGLAND PT.
BLACK PT.
CODDINGTON PT.
SAUNDERSTOWN
TAYLOR PT.
CHURCH PT.
BONNET SHORES
BEAVER NECK
BULL PT.
NEWPORT
CASTLE HILL

Figure 19b

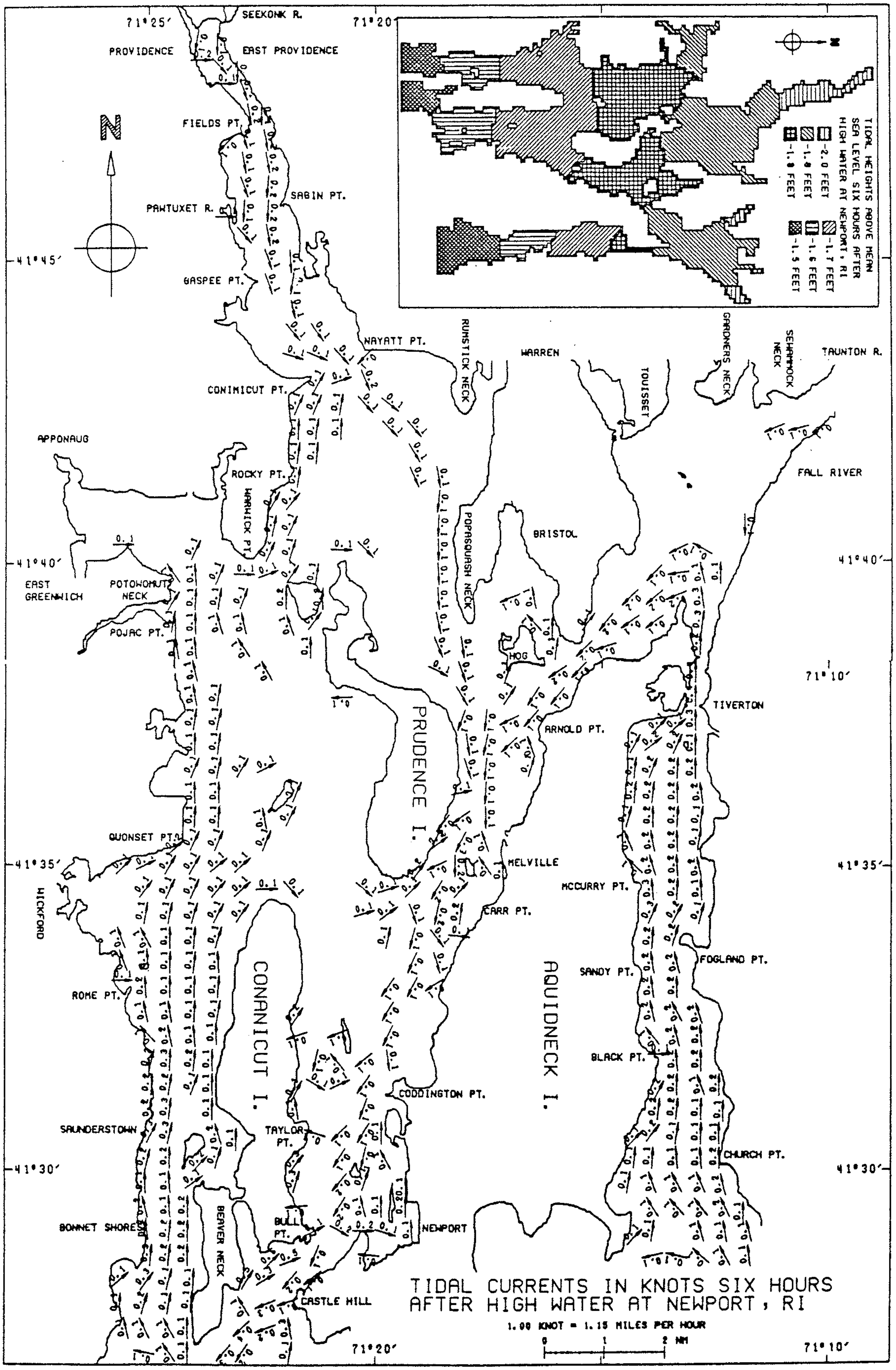
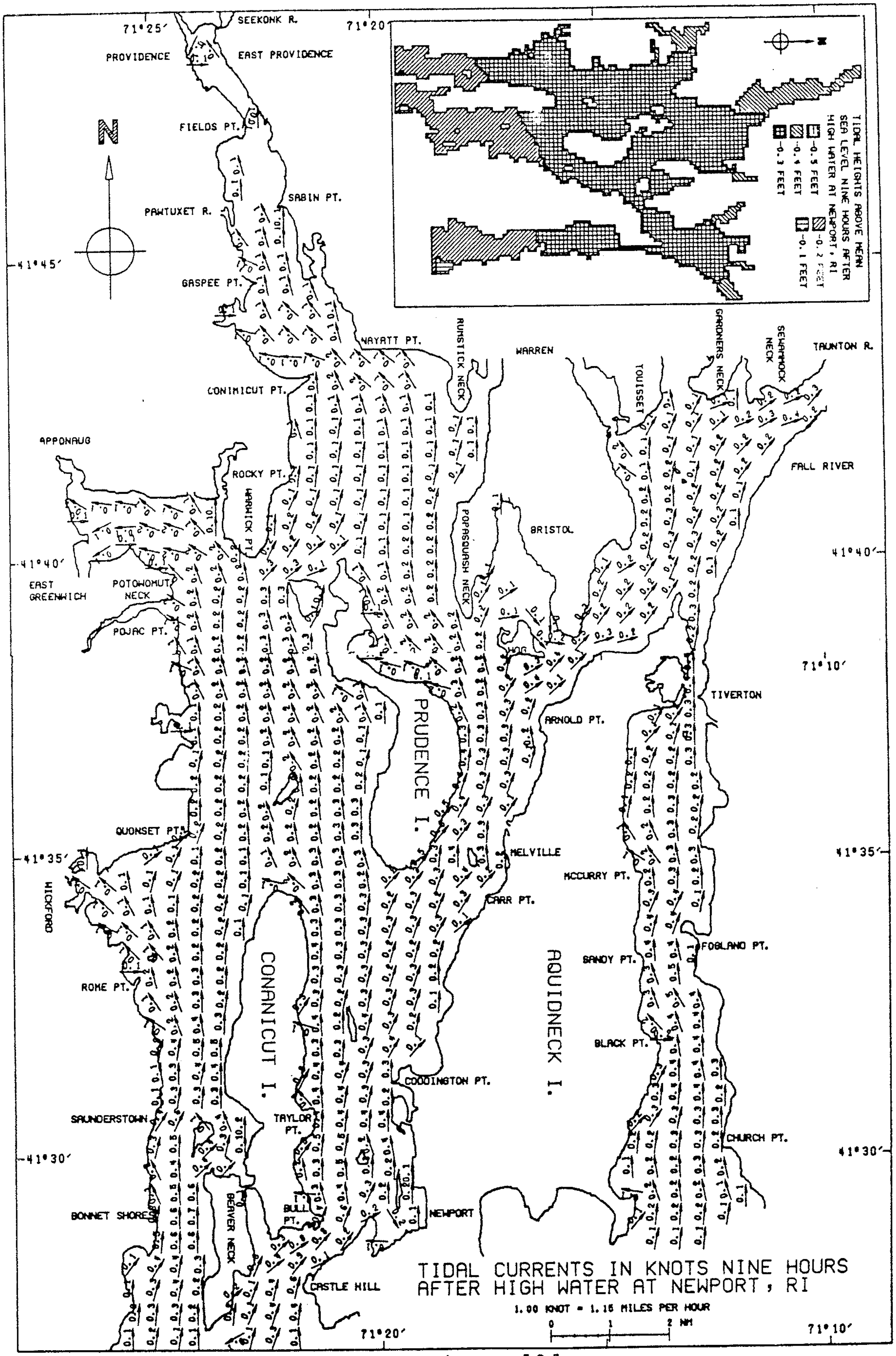

TIDAL CURRENTS IN KNOTS SIX HOURS AFTER HIGH WATER AT NEWPORT, RI
1.00 KNOT = 1.15 MILES PER HOUR
0 1 2 NM
TIDAL HEIGHTS ABOVE MEAN SEA LEVEL SIX HOURS AFTER HIGH WATER AT NEWPORT, RI
-2.0 FEET
-1.8 FEET
-1.8 FEET
-1.7 FEET
-1.6 FEET
-1.5 FEET
N
71°25′
71°20′
71°10′
41°45′
41°40′
41°35′
41°30′
SEEKONK R.
PROVIDENCE
EAST PROVIDENCE
FIELDS PT.
SABIN PT.
PAWTUXET R.
GASPEE PT.
NAYATT PT.
CONIMICUT PT.
RUMSTICK NECK
WARREN
TOUISSET
GARDNERS NECK
SEWAMMOCK NECK
TAUNTON R.
FALL RIVER
APPONAUG
ROCKY PT.
WARWICK PT.
POPASQUASH NECK
BRISTOL
EAST GREENWICH
POTOWOMUT NECK
POJAC PT.
HOG
TIVERTON
PRUDENCE I.
ARNOLD PT.
QUONSET PT.
MELVILLE
MCCURRY PT.
WICKFORD
CARR PT.
CONANICUT I.
AQUIDNECK I.
SANDY PT.
FOGLAND PT.
ROME PT.
BLACK PT.
CODDINGTON PT.
SAUNDERSTOWN
TAYLOR PT.
CHURCH PT.
BONNET SHORE
BEAVER NECK
BULL PT.
NEWPORT
CASTLE HILL

Figure 19c



TIDAL CURRENTS IN KNOTS NINE HOURS AFTER HIGH WATER AT NEWPORT, RI
1.00 KNOT = 1.15 MILES PER HOUR
0 1 2 NM
TIDAL HEIGHTS ABOVE MEAN SEA LEVEL NINE HOURS AFTER HIGH WATER AT NEWPORT, RI
-0.5 FEET
-0.4 FEET
-0.3 FEET
-0.2 FEET
-0.1 FEET
N
71°25′
71°20′
71°10′
41°45′
41°40′
41°35′
41°30′
SEEKONK R.
PROVIDENCE
EAST PROVIDENCE
FIELDS PT.
SABIN PT.
PAWTUXET R.
GASPEE PT.
NAYATT PT.
CONIMICUT PT.
RUMSTICK NECK
WARREN
TOUISSET
GARDNERS NECK
SEWAMMOCK NECK
TAUNTON R.
FALL RIVER
APPONAUG
ROCKY PT.
WARWICK PT.
POPPASQUASH NECK
BRISTOL
EAST GREENWICH
POTOWOMUT NECK
POJAC PT.
HOG
PRUDENCE I.
ARNOLD PT.
TIVERTON
QUONSET PT.
WICKFORD
MELVILLE
MCCURRY PT.
CARR PT.
CONANICUT I.
AQUIDNECK I.
SANDY PT.
FOGLAND PT.
ROME PT.
BLACK PT.
CODDINGTON PT.
SAUNDERSTOWN
TAYLOR PT.
CHURCH PT.
BONNET SHORES
BEAVER NECK
BULL PT.
NEWPORT
CASTLE HILL

Figure 19d

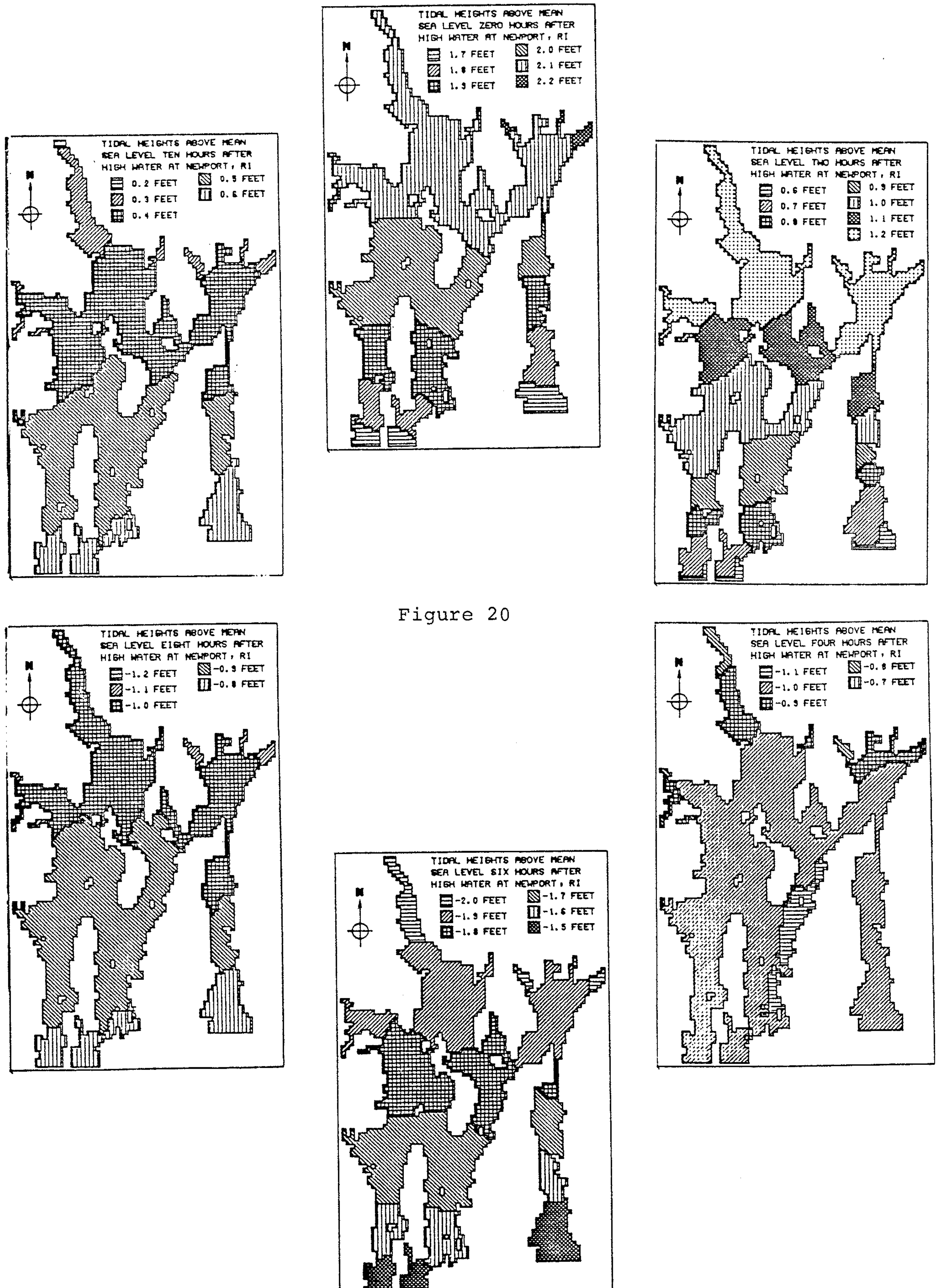

TIDAL HEIGHTS ABOVE MEAN SEA LEVEL ZERO HOURS AFTER HIGH WATER AT NEWPORT, RI
N
1.7 FEET
1.8 FEET
1.9 FEET
2.0 FEET
2.1 FEET
2.2 FEET
TIDAL HEIGHTS ABOVE MEAN SEA LEVEL TEN HOURS AFTER HIGH WATER AT NEWPORT, RI
N
0.2 FEET
0.3 FEET
0.4 FEET
0.5 FEET
0.6 FEET
TIDAL HEIGHTS ABOVE MEAN SEA LEVEL TWO HOURS AFTER HIGH WATER AT NEWPORT, RI
N
0.6 FEET
0.7 FEET
0.8 FEET
0.9 FEET
1.0 FEET
1.1 FEET
1.2 FEET
TIDAL HEIGHTS ABOVE MEAN SEA LEVEL EIGHT HOURS AFTER HIGH WATER AT NEWPORT, RI
N
-1.2 FEET
-1.1 FEET
-1.0 FEET
-0.9 FEET
-0.8 FEET
TIDAL HEIGHTS ABOVE MEAN SEA LEVEL FOUR HOURS AFTER HIGH WATER AT NEWPORT, RI
N
-1.1 FEET
-1.0 FEET
-0.9 FEET
-0.8 FEET
-0.7 FEET
TIDAL HEIGHTS ABOVE MEAN SEA LEVEL SIX HOURS AFTER HIGH WATER AT NEWPORT, RI
N
-2.0 FEET
-1.9 FEET
-1.8 FEET
-1.7 FEET
-1.6 FEET
-1.5 FEET

Figure 20

We've done some very specialized models for smaller areas in Narragansett Bay. Figure 21 is a tidal simulation for the upper Bay area, Providence River. The left boundary is the West Passage entrance, the East Passage entrance in the bottom, and the Seekonk River at the top. You see very strong currents in the center of the river and weaker currents on the sides. If I over-laid the topography and bathymetry of the area (Figure 22) you see a dredged channel feature running right up the center of the system. The channel depths are a factor of two deeper than they are on either side.

We now look at the tidal response of Narragansett Bay overall. Figure 23 shows observations of the tidal constituent amplitudes and phases for particular stations (Figure 24) which were observed by the National Ocean Survey and by investigations at the University of Rhode Island Graduate School of Oceanography and Ocean Engineering Department. As the M2 tide goes up the Bay, the amplification is about 1.3. to 1.4 at the very head of the Providence River. (Figure 23a) Up into the Seekonk it's even a little larger. The phase shift is about twenty-plus degrees for the M2. I would also point out that in the Providence River, the whole system is in phase.

Now, if we look at other constituents that have a higher frequency (M4 and M6) and is closer to the resonance period of the Bay, you see significant amplification. Before, where we had a range of 1 to 1.3 we now have a range of 1 to 3. So the amplitude of the M4 component increases by a factor of three going up the Bay as opposed to 1.3 for the M2. The M6 plot, shows exactly the same response.

We have recently completed some intensive field work in the Providence River which started in 1981 and ended in 1983. We had a total of six deployments in the Providence River (Figure 25). Figure 26 shows the deployment locations. Current measurements were from thirty to ninety days in duration. We had surface elevation, temperature, salinity, wind, and river runoff measurements for those time periods. We usually had four meters in the water, two of which recorded temperature and salinity as well as current information. Figure 27 shows a typical time service.

If we look at all the data for the tidal flows, removing the low frequency response, we can again see the M2, M4, M6 relationship, that gives us this strong double-peak flood

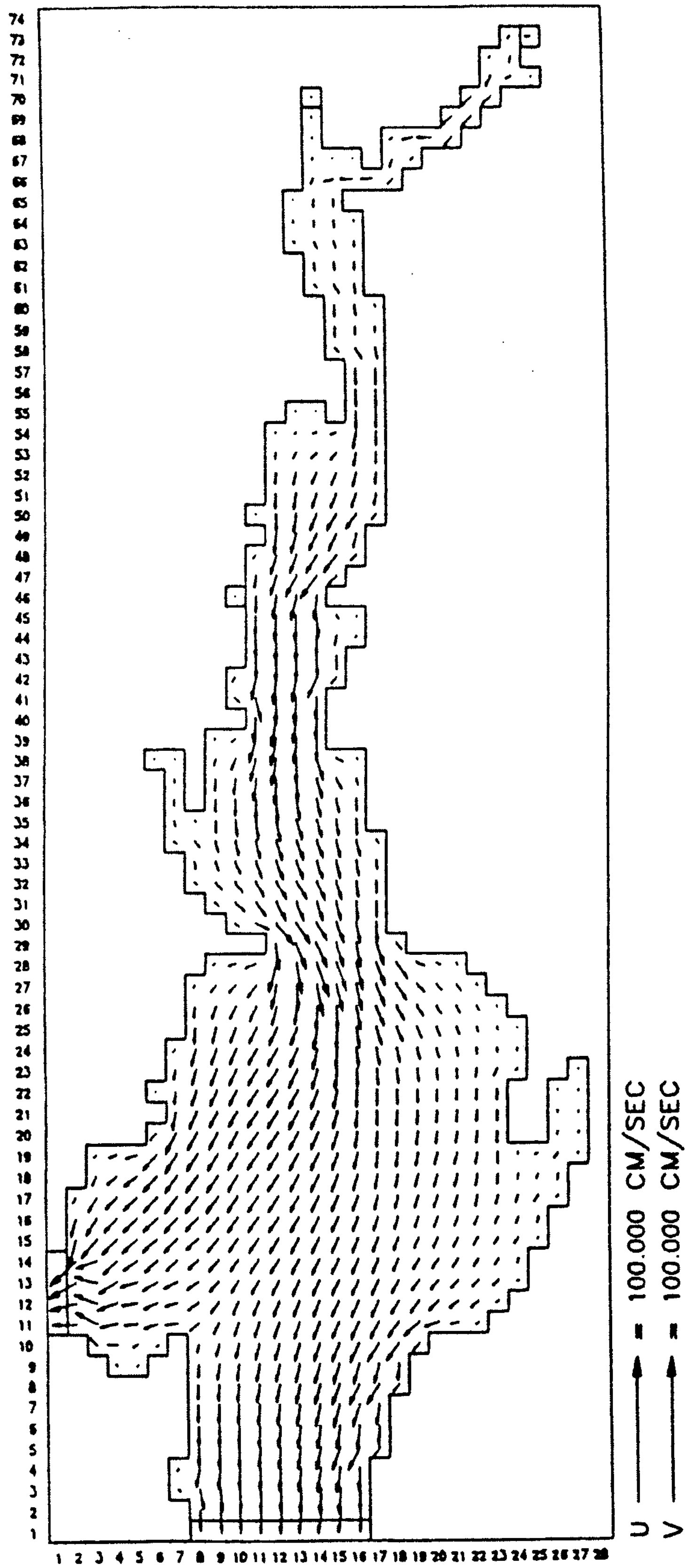


Figure 21
Model predicted tidal current pattern for maximum ebb (2.9 hours after high water at Warwick Point).

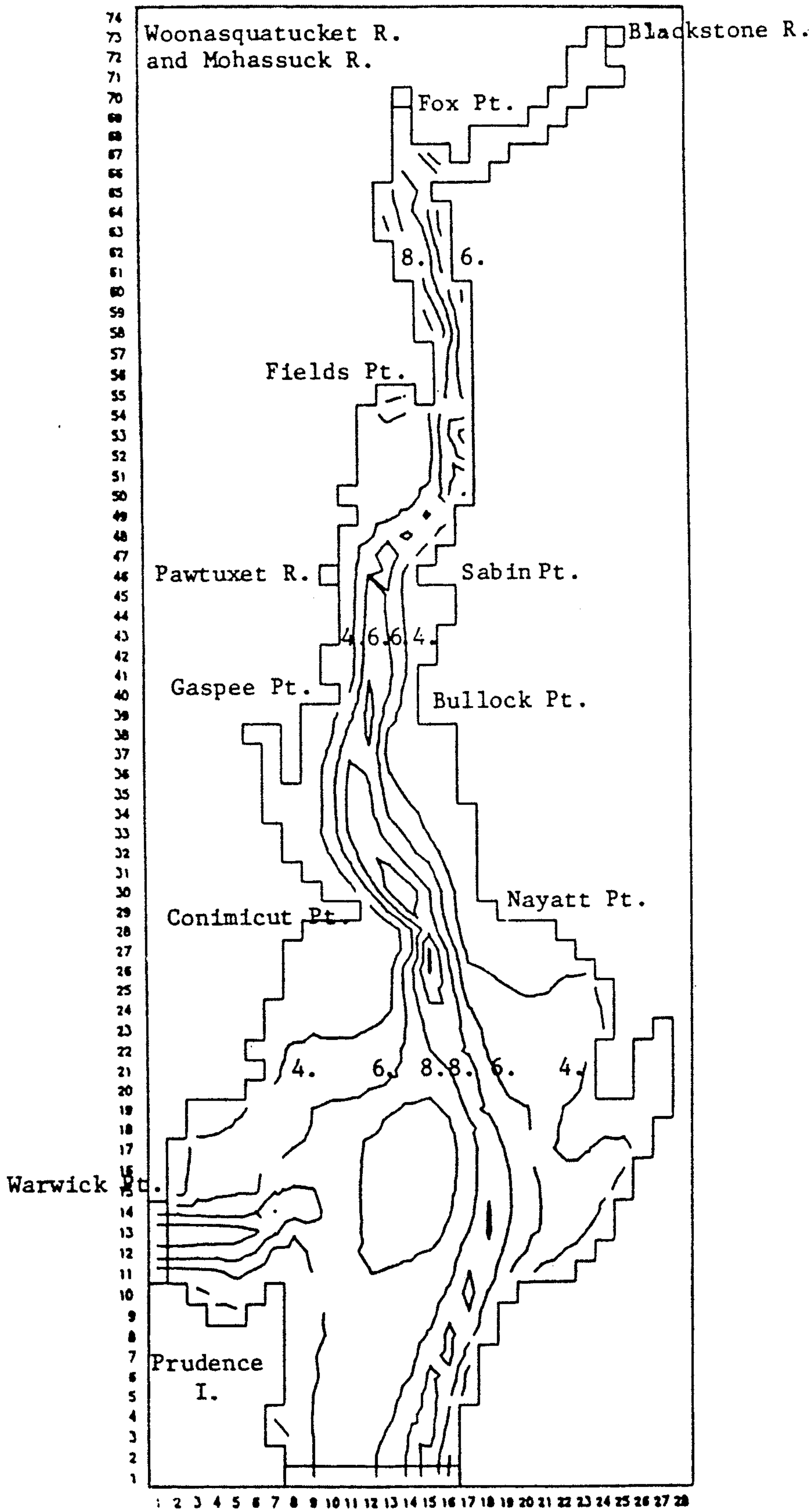


Figure 22

Bathymetry (M) for Providence study area.

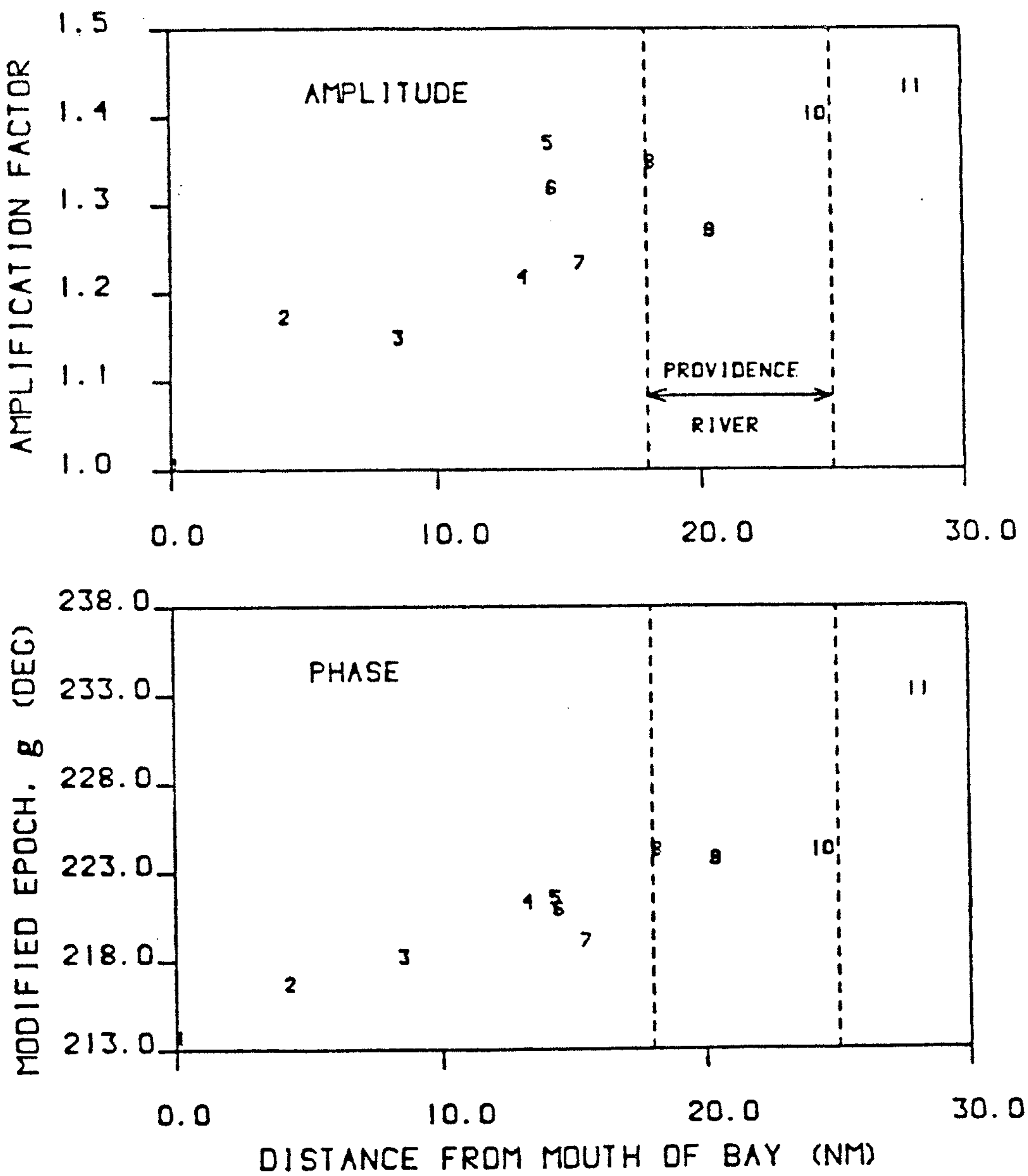


Figure 23a

M2 PHASE AND AMPLITUDE CHANGES IN THE PROVIDENCE RIVER AND NARRAGANSETT BAY.

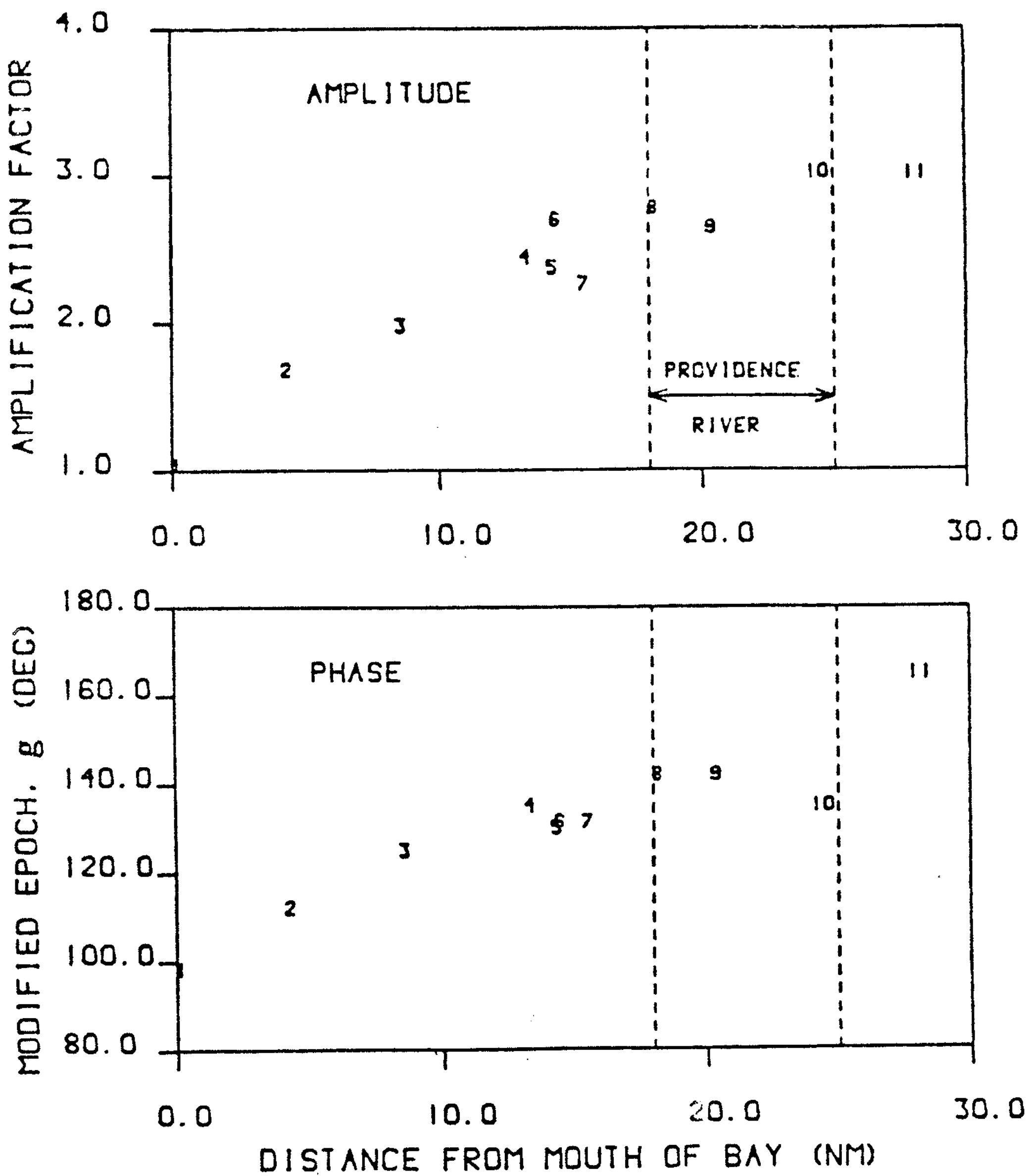


Figure 23b

M4 PHASE AND AMPLITUDE CHANGES
IN THE PROVIDENCE RIVER AND NARRAGANSETT BAY.

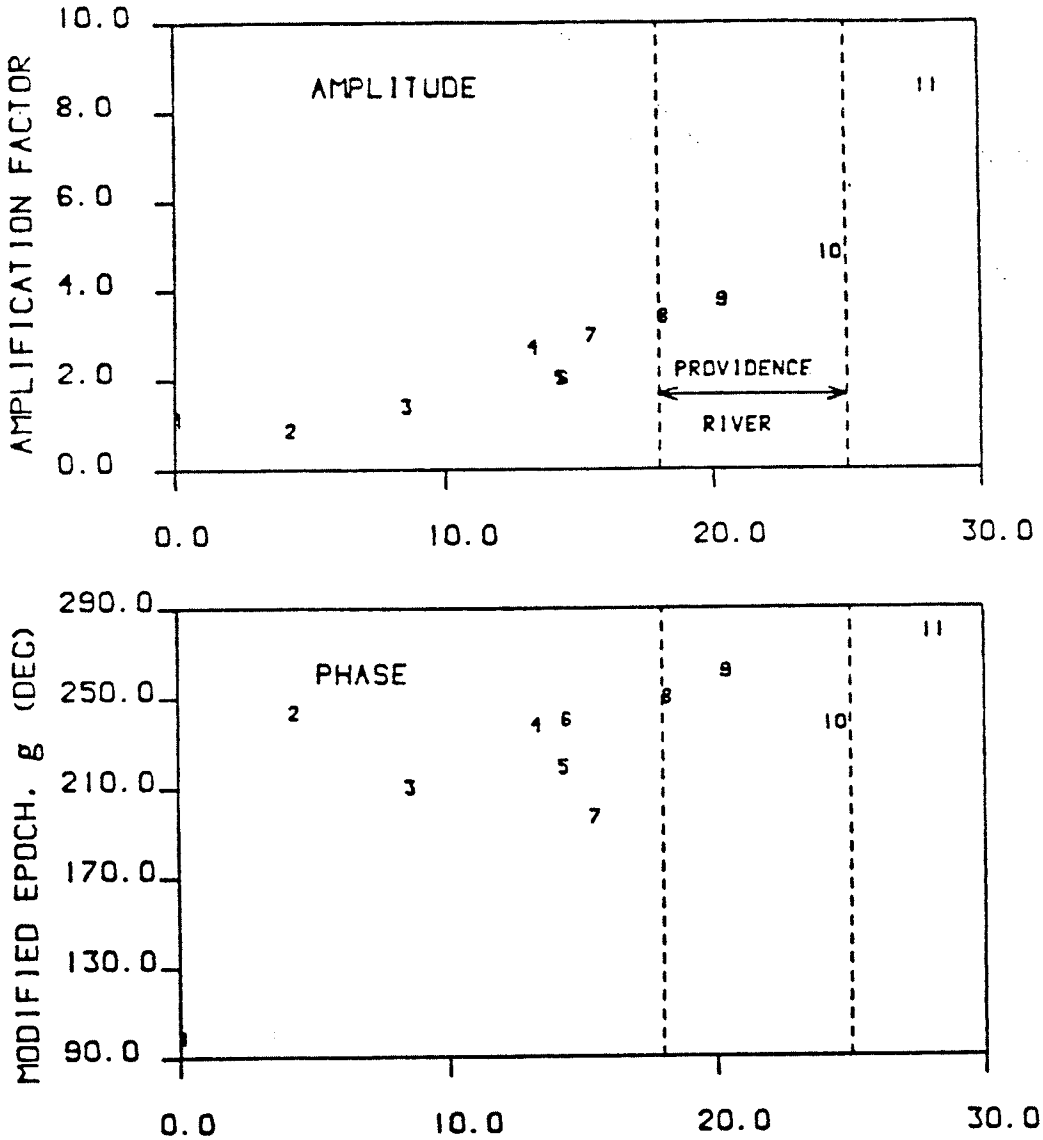


Figure 23c

M6 PHASE AND AMPLITUDE CHANGES
IN THE PROVIDENCE RIVER AND NARRAGANSETT BAY.

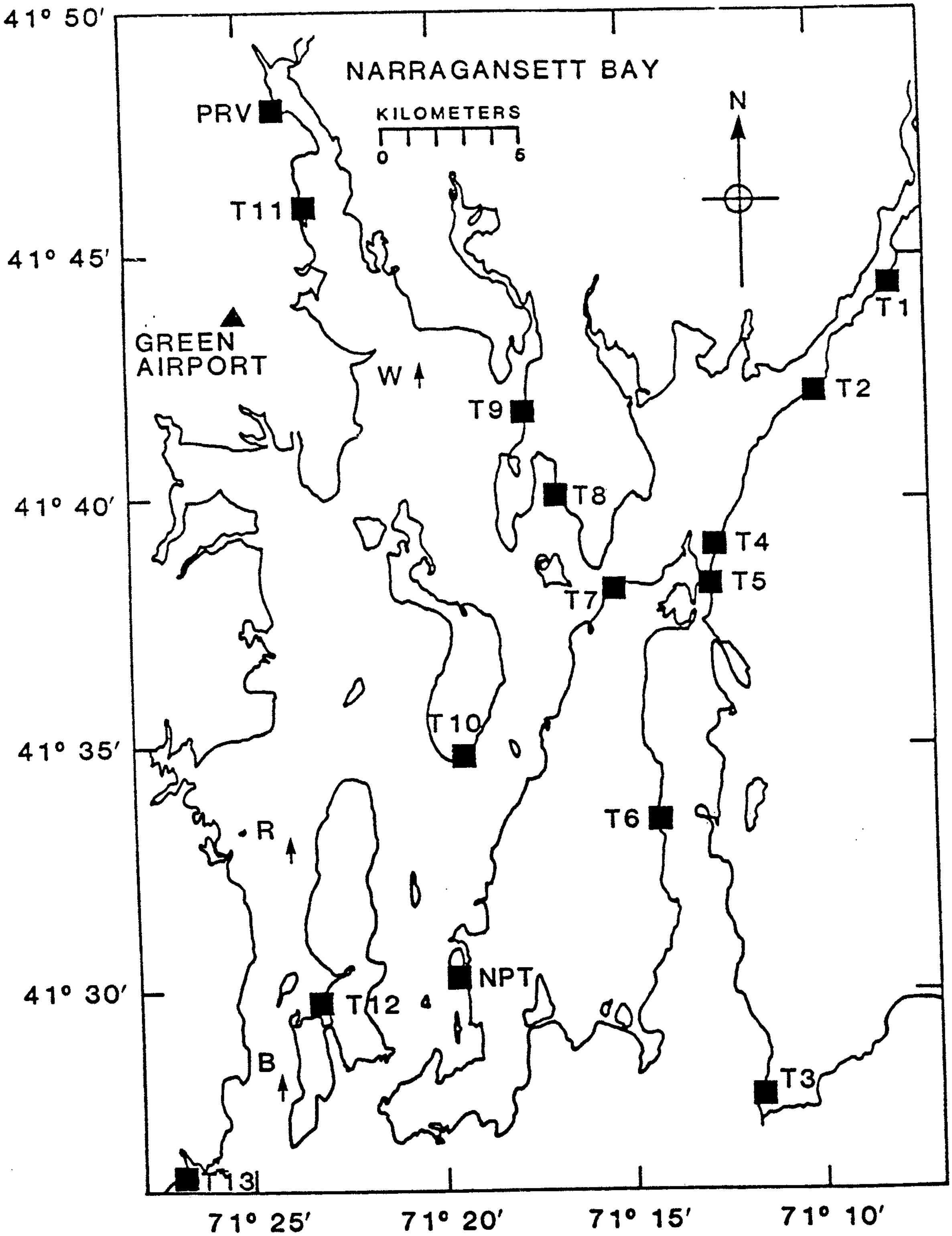
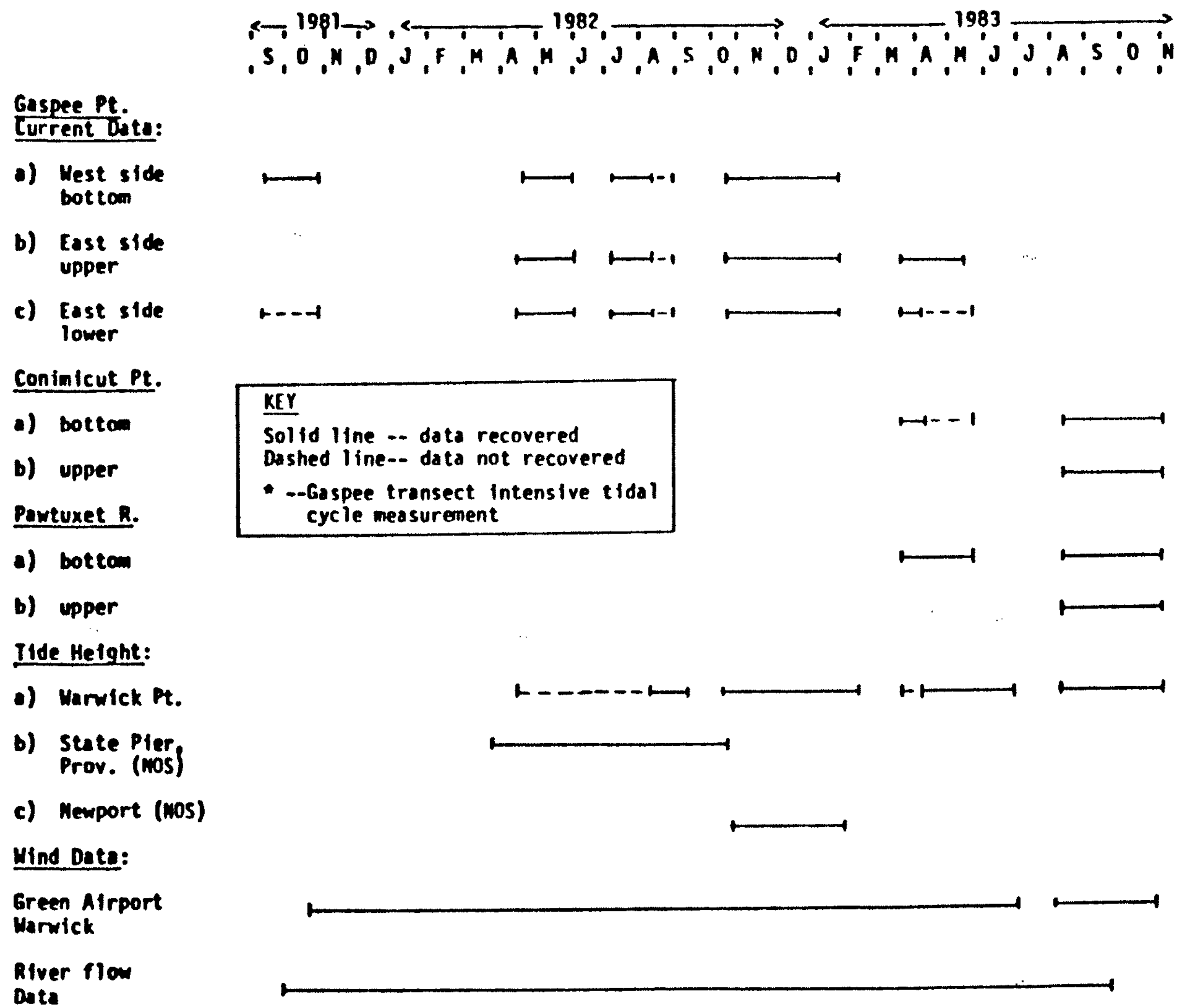


Figure 24

Location of sea level (■), current (↑) and meteorological (▲) observations.



Summary of data collected during the study.

Figure 25

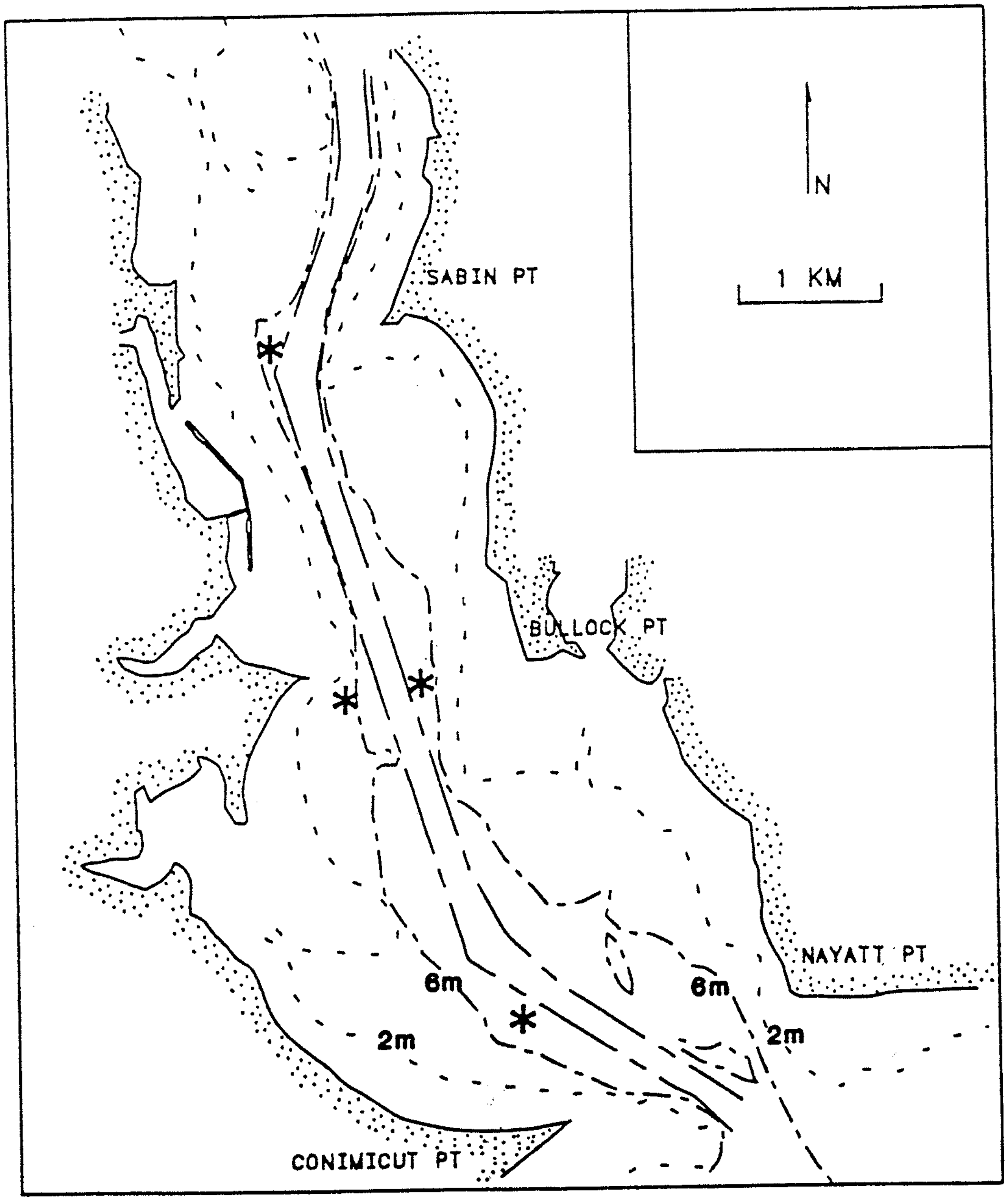


Figure 26

CURRENT METER DEPLOYMENT LOCATIONS IN THE PROVIDENCE RIVER.

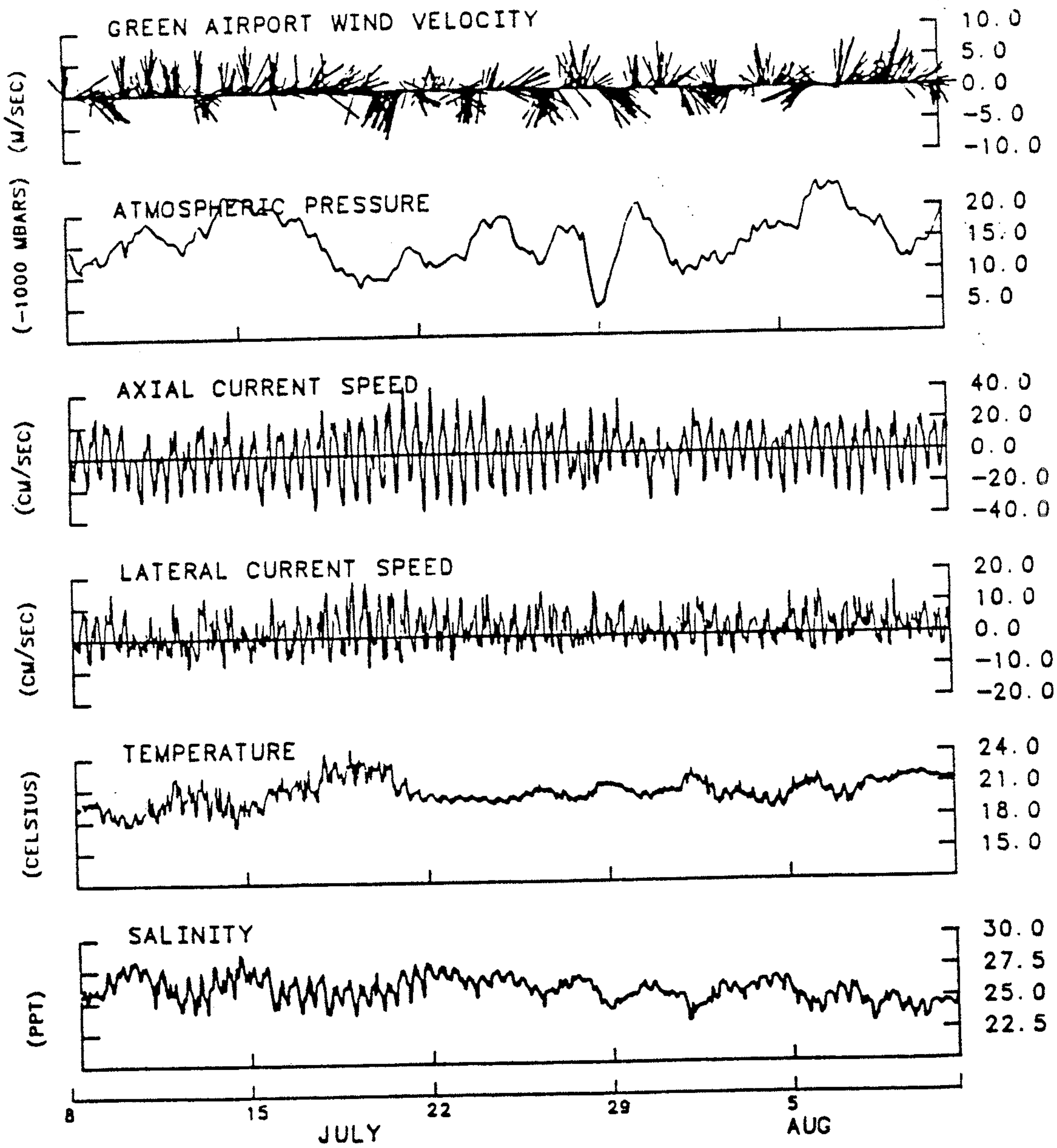


Figure 27

RECORD E1D3 CURRENT, TEMPERATURE, AND SALINITY DATA WITH CONCURRENT WEATHER DATA FOR THE PERIOD 7/8/82 - 8/11/82.

single-peak ebb in the Bay; (Figure 28) another confirmation of Haight's results. These are the longest time series that have ever been taken in Narragansett Bay.

We now look at selected surface elevation records in the Bay. (Figure 24) These were taken by the National Ocean Service in 1977 at thirteen stations around the Bay. We removed the tidal signal to looked at the low-frequency wind forcing (Figure 29).

This low-frequency response is on the order of thirty hours or longer. If you look at Figure 29 and compare the upper Bay and lower Bay stations you can't tell any difference between them. The correlation is extremely high, on the order of .975. What happens is that at low frequencies the whole Bay moves up and down simultaneously. The surface elevation in the lower Bay, the mid Bay and the upper Bay at low frequency responds simultaneously. Hence non-local forcing i.e., wind forcing on the continental shelf that causes changes in the sea level elevation at the mouth of the Bay, makes a substantial contribution to the non-tidal, low-frequency circulation in the Bay.

We looked at selected wind forcing experiments using several numerical models. We've looked at simulations for the non-local forcing case. If we look at the depth mean currents for peak inflow for non-local forcing (Figure 30), currents on the order of eight centimeters per second are predicted. The non-local forcing amplitude is typically fifteen to forty centimeters with periods on the order of a day or two.

With the model, we've also investigated, a series of simple forcing experiments where we blow the wind from a given direction. We assure that the wind remains constant. Then we watch the Bay's response. In general, the response time of the Bay to a wind event is roughly ten hours. Since it takes about three to ten days for a weather event to pass over the Bay, the Bay is always in quasi-steady state with the wind. We therefore don't have significant transient events.

We now look at steady state flows generated at selected transect (Figure 31). Figure 32 shows the transport across the transects for a series of different constant wind forcing. This plot allows you to sort out the transport as a function of wind direction for each of the nine sectors.

In order to understand what is happening, Figure 33 shows a series of simple flow direction flow direction diagrams. If the wind blows from the south toward the north, (Figure 33a) then we get flow into the West Passage, into the Sakonnet River, and no flow in the Providence River in the long term, as we should.

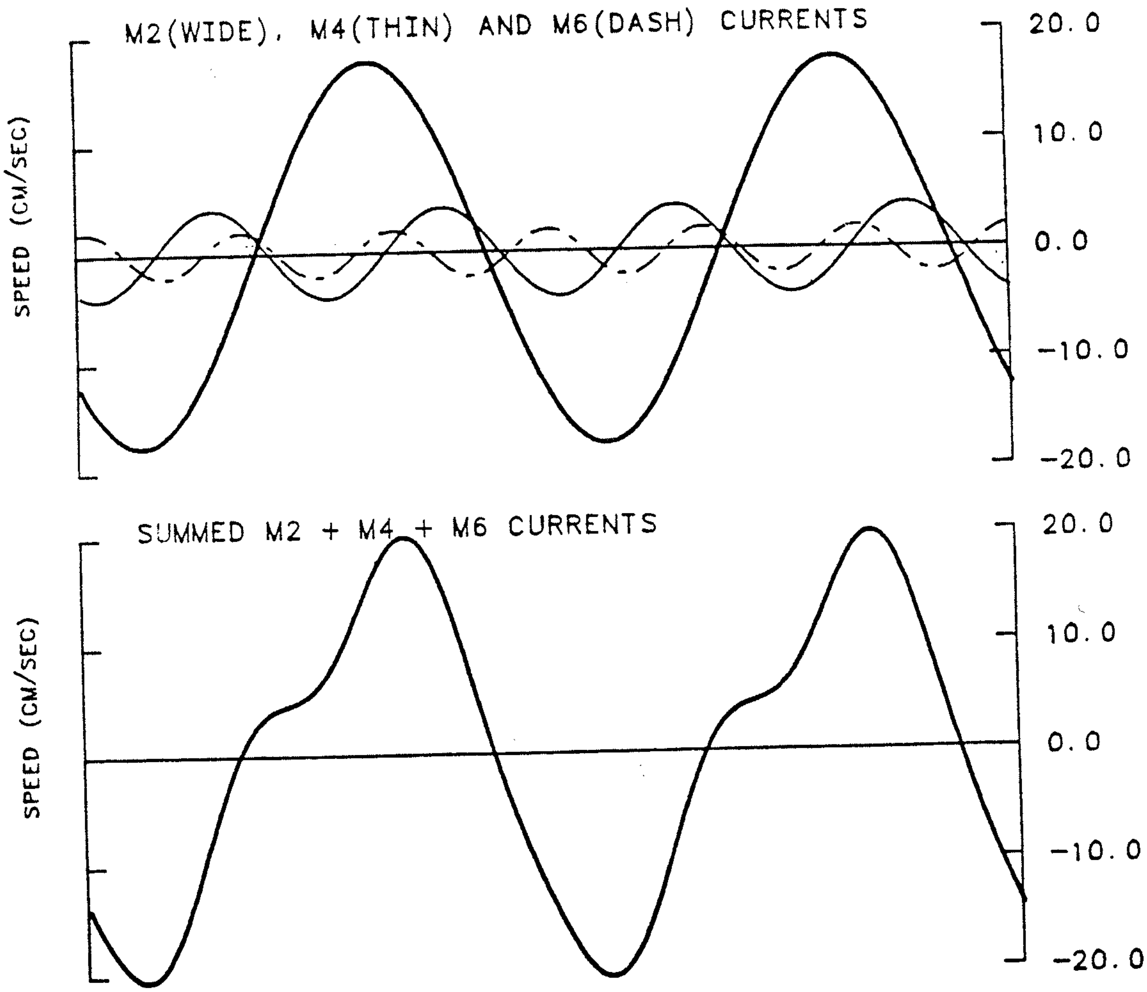


Figure 28

TIME SERIES,
OF THE M2, M4, AND M6 TIDAL CURRENTS THROUGH THE GASPEE POINT TRANSECT, FROM THE AVERAGED CURRENT METER DATA.

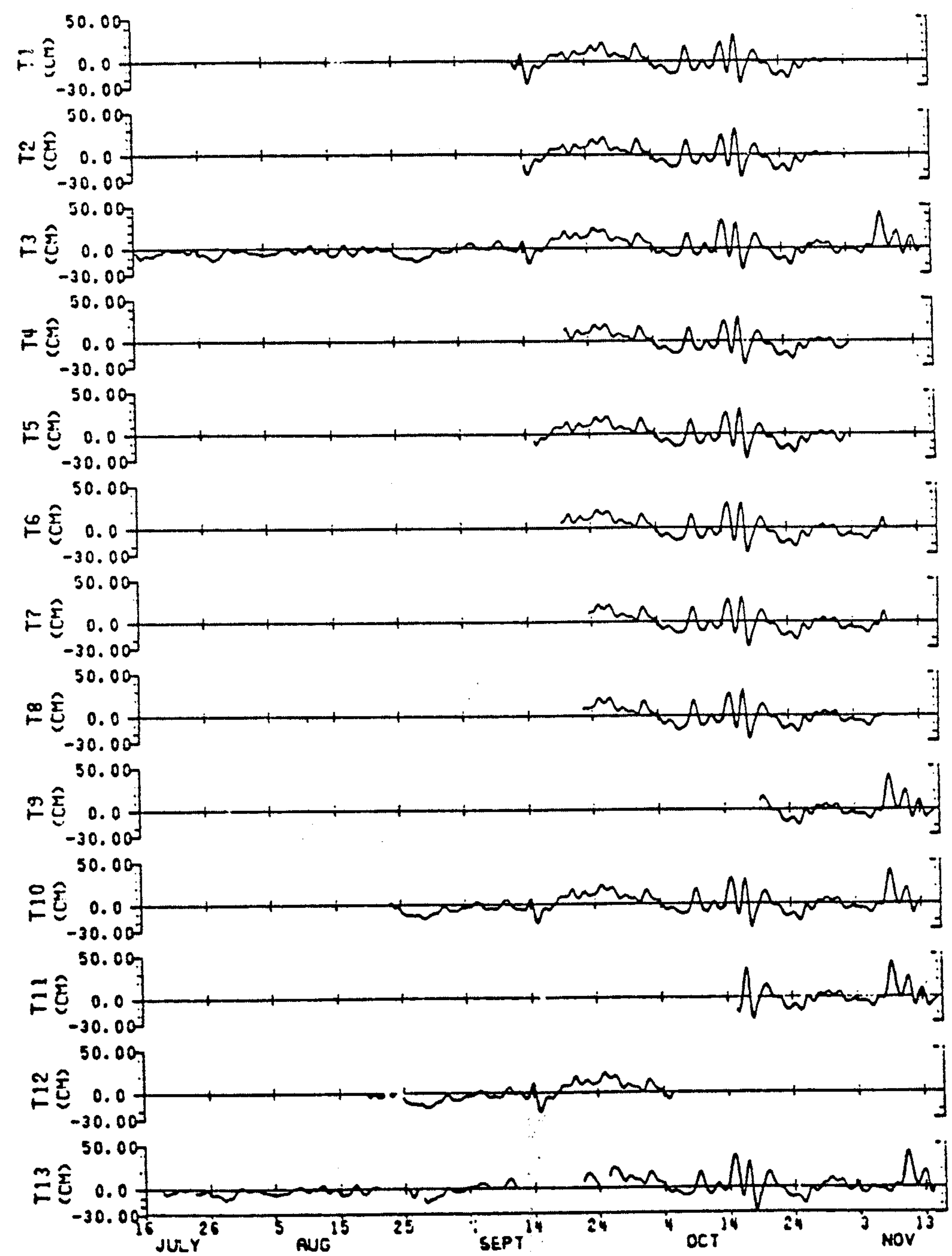


Figure 29

Low-pass filtered time series of adjusted sea level. The location of stations is indicated in Figure 3-2.

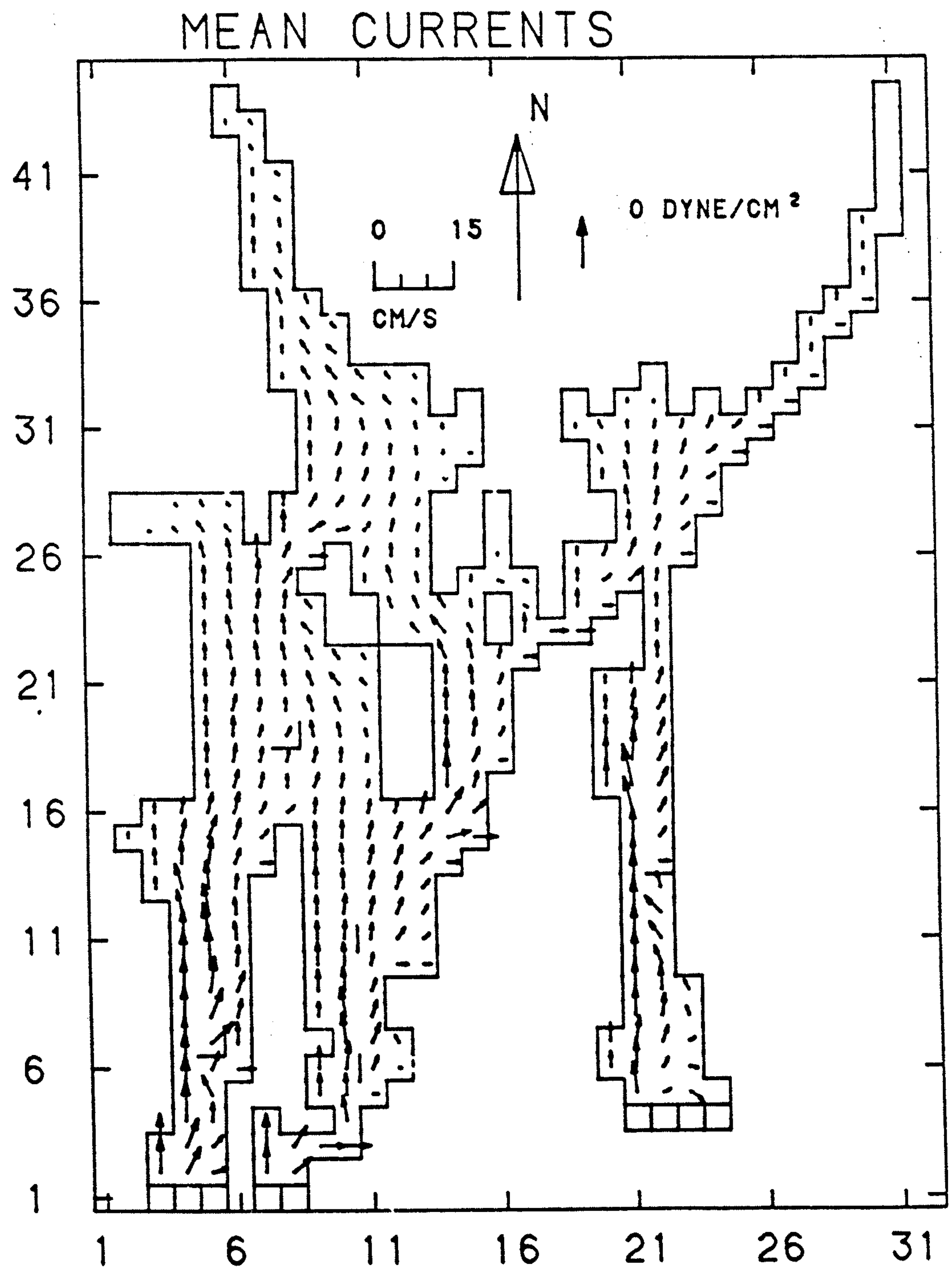
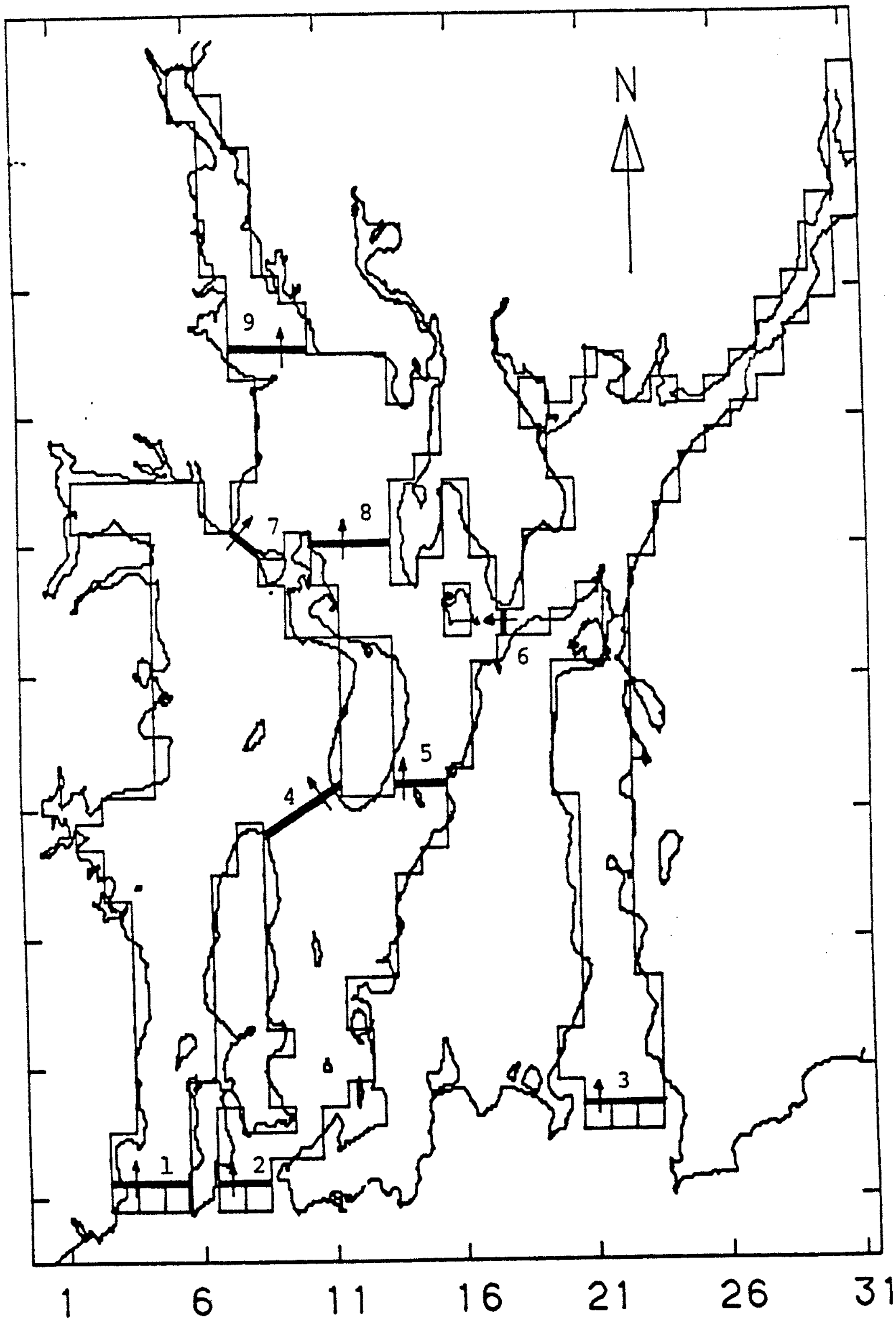


Figure 30

Depth mean currents at peak inflow for the non-local forcing experiment.



Location of cross sections used in transport calculations. Arrows indicate direction of positive transport.

Figure 31

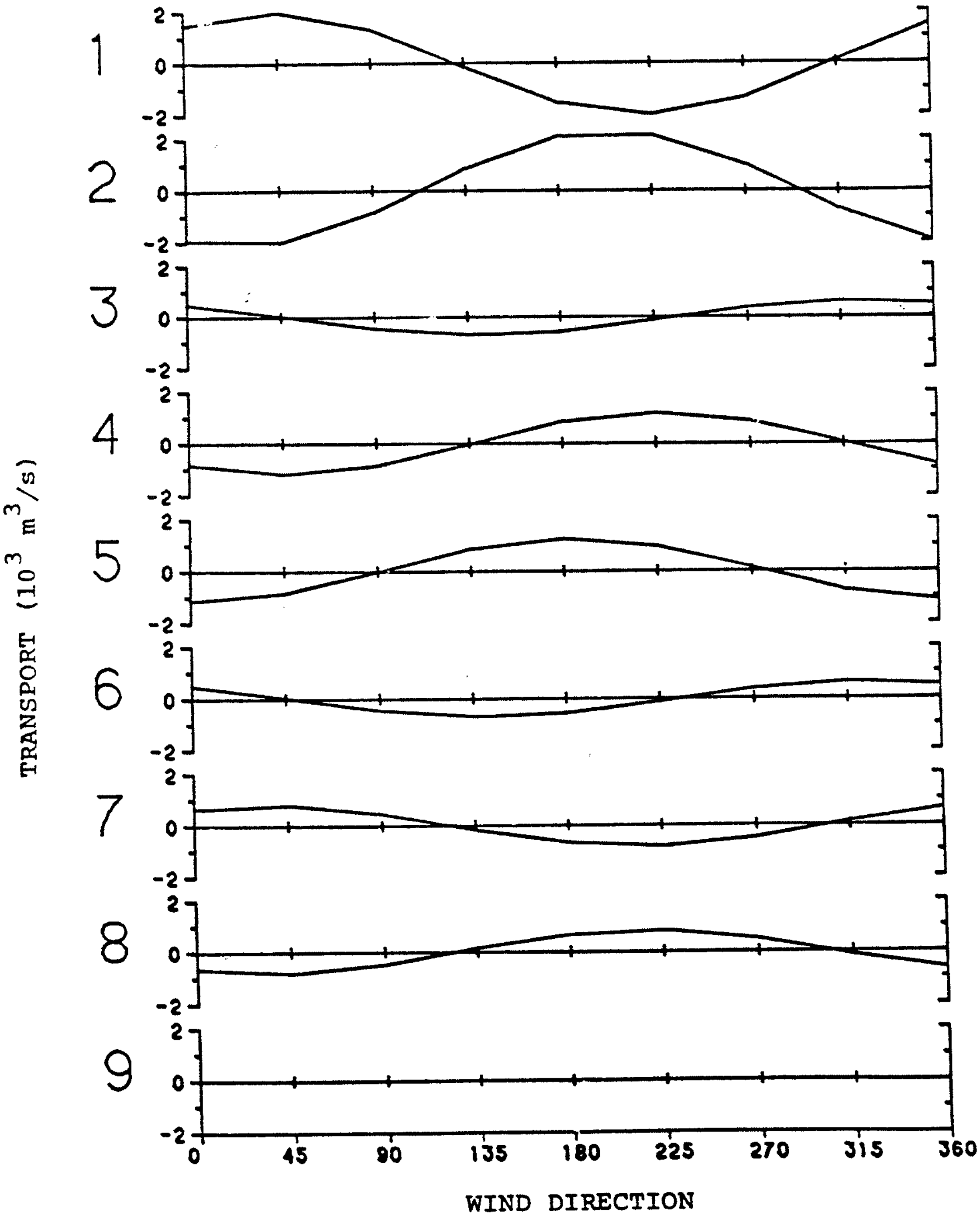


Figure 32

Transport across the 9 cross sections illustrated in Figure 3-22 as a function of wind direction. The wind stress is 1 dyne/cm^2 in magnitude.

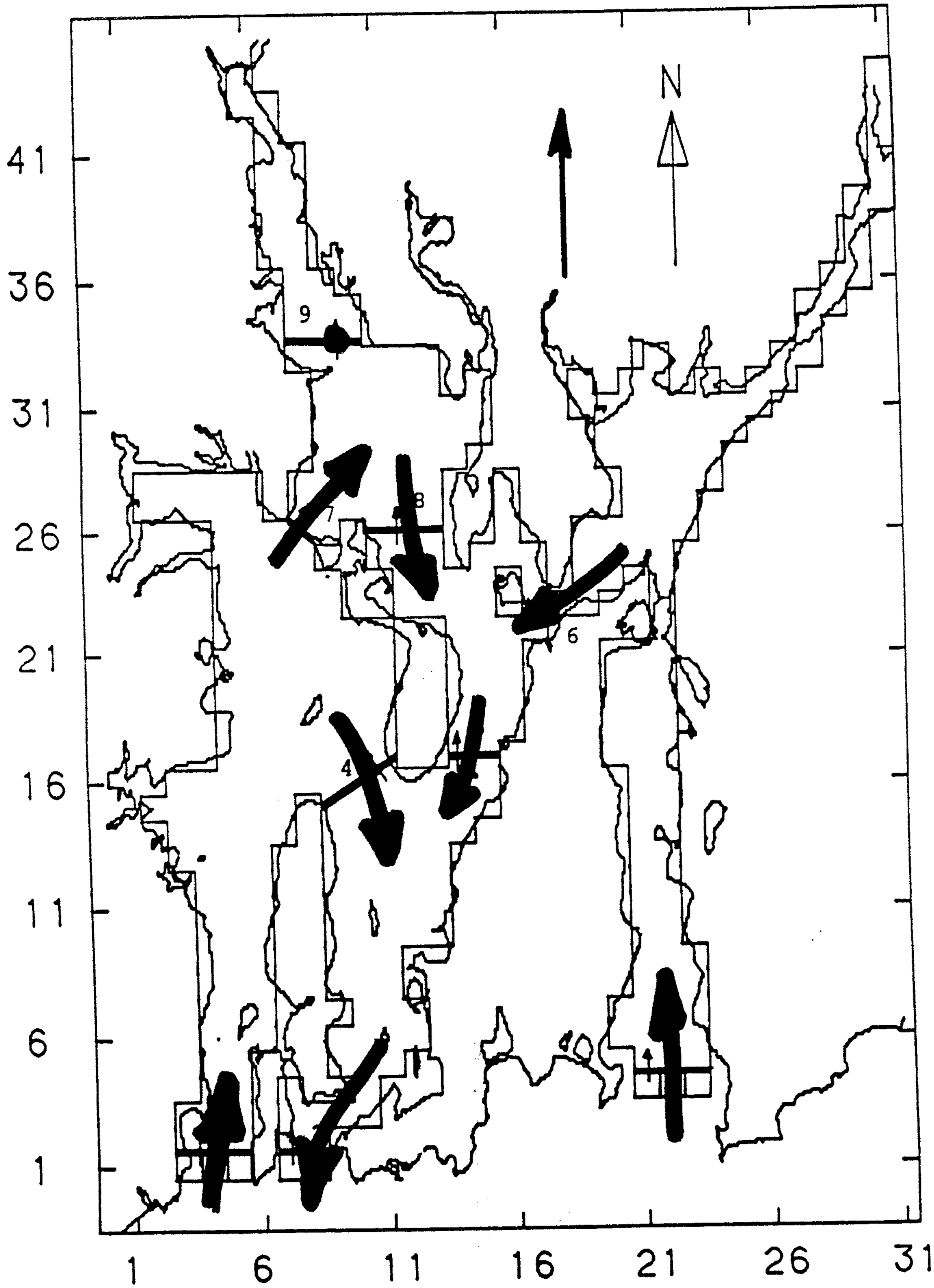


Figure 33a

Location of cross sections used in transport calculations. Arrows indicate direction of positive transport.

We get flow around Patience and Prudence Islands and then back down the Bay. We get return flow out of the East Passage of the Bay. This is an important result. The depth differential between the East Passage and the West Passage makes a difference in the Bay's wind-induced response. If we switch the wind around so the wind is blowing out of the north towards the south (Figure 33b), we get inflow into the East Passage and outflow out of the Sakonnet River and the West Passage. Again, there is no long-term transport in the Providence River.

If the wind comes from the west, which is where it normally comes from, we revert back to the northerly wind stress pattern for the East and West Passage flows. Instead of getting inflow we get outflow at the mouth of the Sakonnet River. That's because we're piling water up in Mt. Hope Bay and it's forcing water out of the Sakonnet River.

Interestingly enough, if we go to the winter case, where the winds are out of the northwest (Figure 33d), you essentially have no transport at all predicted in the West Passage of the Bay nor in the Providence River. We essentially have transport up the East passage and then back out the Sakonnet River.

Those results are model simulations. I would be delighted if we could show a comparison to observations. We don't have those so we really don't know how well the model performs.

We do have some observations in the Bay where we have wind-time series and current-time series for discrete locations, Figure 34 shows a comparison between the model predictions and observations. The results are poor. The reason for the problem is that we don't account for non-local forcing, and the model resolution is inadequate, for this particular area, to address the spatial variability of the current field.

We've made observations in the Providence River--in the center of the river at Gaspee Point. Figure 27 shows wind speed, atmospheric pressure, axial current (which is the current along the channel), lateral current, (which is across the channel), temperature, and salinity. This is at two-and-a-half meters from the surface. This is from the 8th of July to the 12th of August, a little over a month. You see strong tidal signals in the current observations. You see tidal signals in the temperature and the salinity. If you look at the salinity and temperature time series, it convinces you that sampling salinity on one day, which is what we commonly do, we could be fairly erroneous in terms of trying to understand the tidal dynamics versus the long-term behavior in the system. If you're going to take salinity observations in the bay, it is obvious that they need to be related to what's happening in the longer term in the Bay.

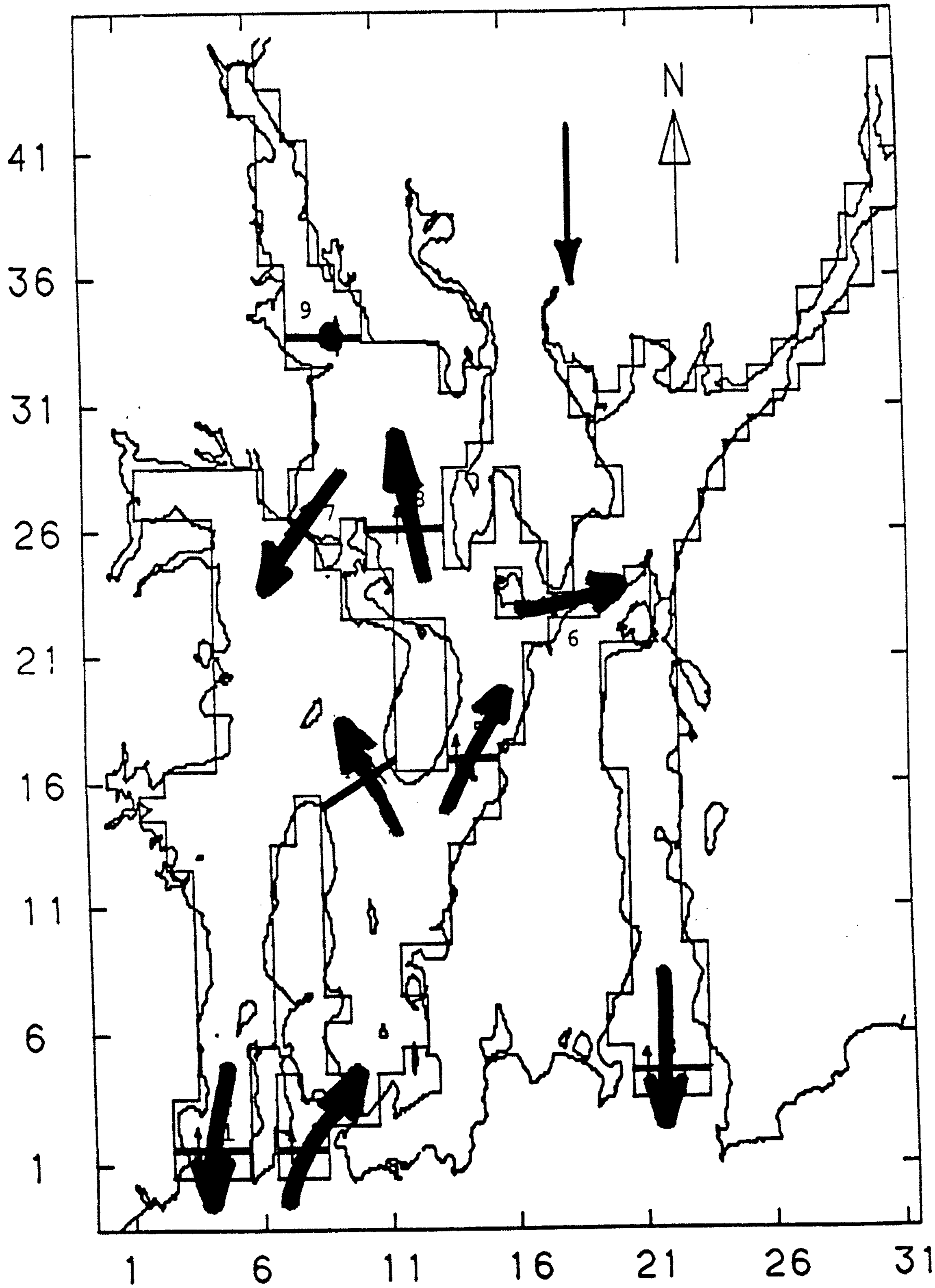


Figure 33b

Location of cross sections used in transport calculations. Arrows indicate direction of positive transport.

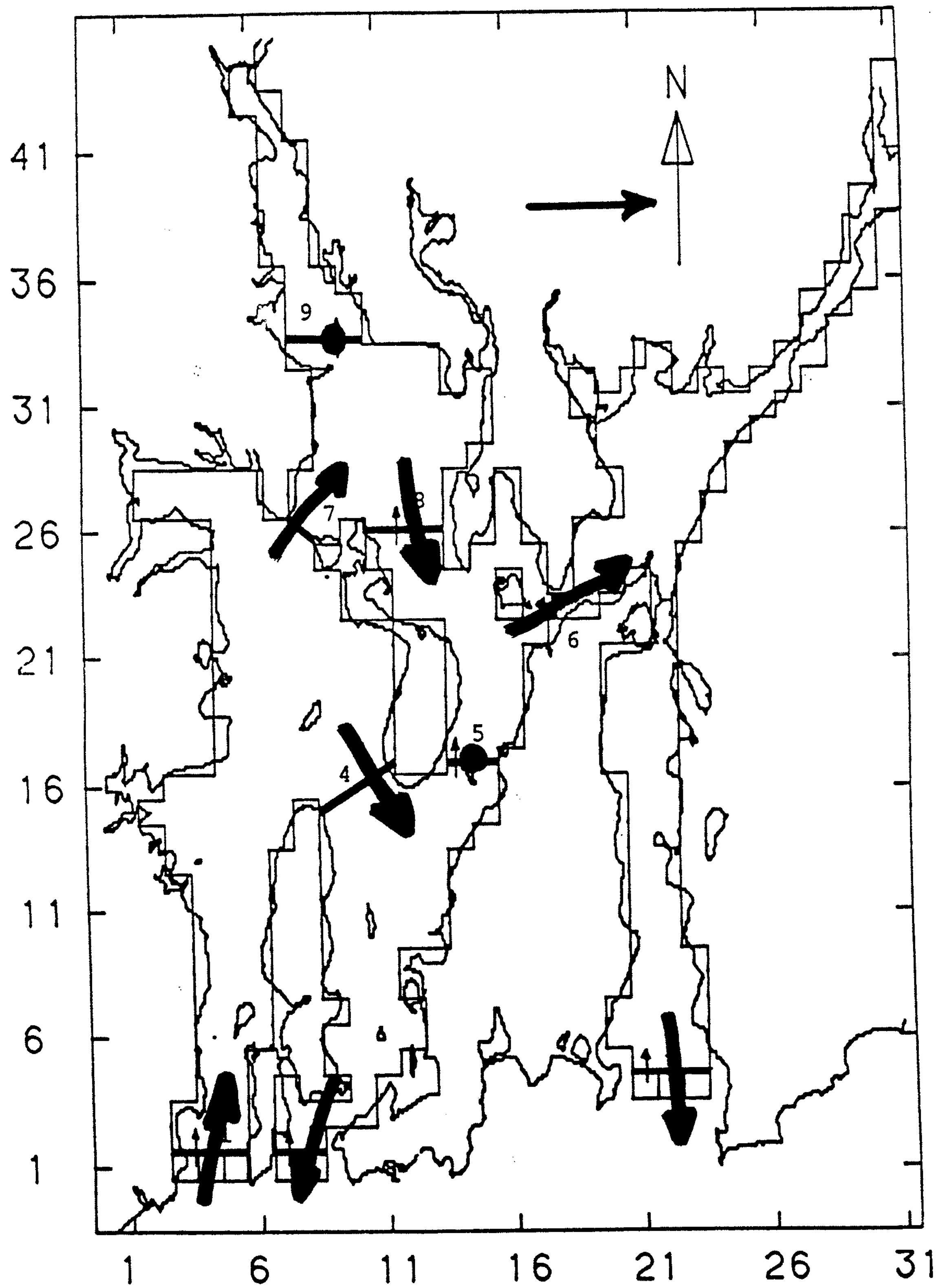


Figure 33c

Location of cross sections used in transport calculations. Arrows indicate direction of positive transport.

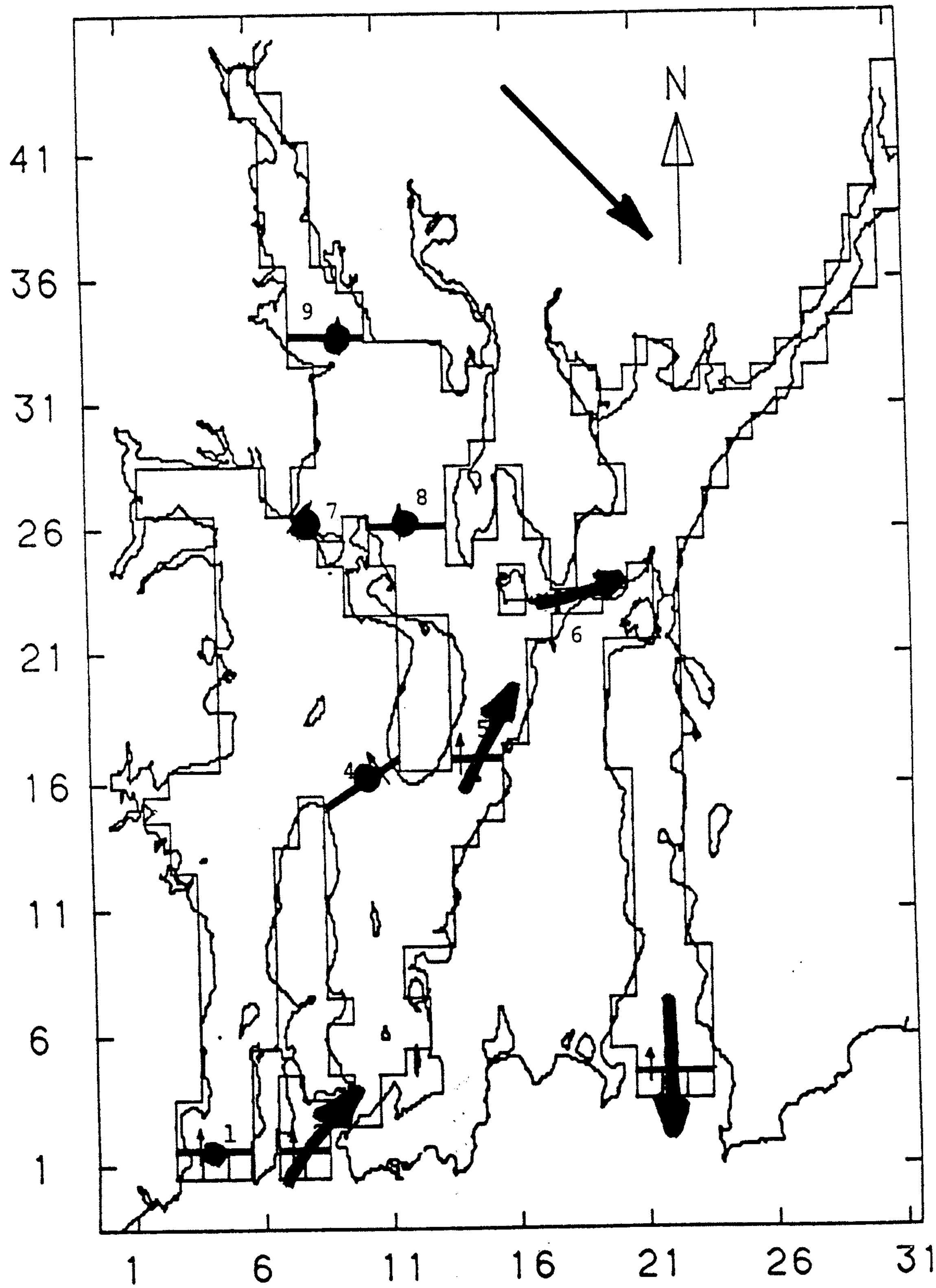


Figure 33d
Location of cross sections used in transport calculations. Arrows indicate direction of positive transport.

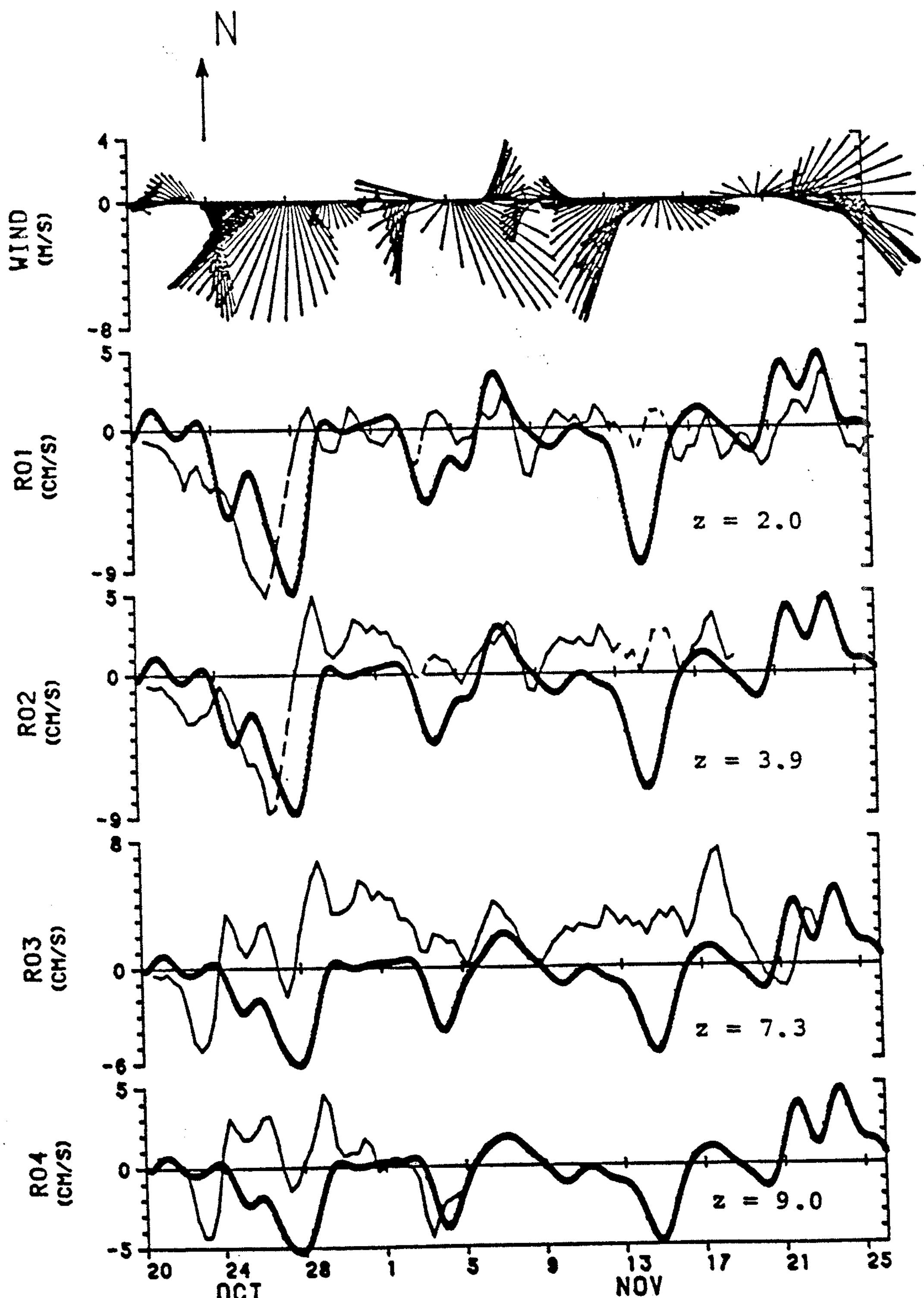


Figure 34

Comparison of observed and computed low-pass filtered currents at Station R. (Computed results are indicated by the heavy lines). z indicates the depth, in meters, below mean low water of each record. The corresponding wind time series is shown in the top panel.

Now, if we took the observations of the current at that one location and we remove the tidal signal--the tide just goes in and out of the Bay--what happens in the longer term? What does non-local forcing, the wind forcing, and the density forcing, do to the circulation?

We had three current meters in the area, including two ENDECO current meters located at two-and-a-half and five-and-a-half meters from the surface, and one Marsh-McBirney meter on the other side. We constructed progressive vector diagrams for each one of those meters over the deployment period (Figure 35) without the tide. We see a clear, long-term response. A straight line here would mean a steady current. Deviations from that straight line represent higher frequency variations. What you see is that we get excursions on the order of fifty kilometers over the study period. That's obviously not an excursion of that particular particle of water. We have significant variability in terms of the direction of the current and also in terms of its magnitude for this very narrow channel. In the case of the Marsh-McBirney, and the other two meters, they are at exactly the same depth below the surface, two hundred meters apart, horizontally.

If we now remove the mean value from this record and look at the perturbations (I have the progressive vector diagram for the perturbations), see the excursions more clearly (Figure 36). The times are the dates from the beginning of the deployment and the total distances are on the order of ten kilometers. This suggests that the wind in the Providence River is responsible for high-frequency mixing. In the long-term, the river-induced density forcing determines the circulation pattern. The variability however is very significant on spatial scales, on the order of hundreds of meters. (Figure 37)

Narragansett Bay has been impacted several times by some fairly severe storms (Figure 38). The 1938 and 1944 storms, Carol and Donna, seemed to be the important ones. Tidal surges at Providence of fifteen feet were the maximum observed. Hess performed simulations of the 1944 storm passing over Rhode Island, and he employed the model area shown in Figure 15 with the 1944 storm track coming across the Bay. (Figure 34)

He did a very good job of reproducing the observed surge height, computed versus observed (Figure 40). The lower graph shows you what the historical mean values of the tide would be, and what it is with the storm imposed.

In terms of the Bay's overall response, you can see that the amplification that one saw in the other constituents also holds true with the storm. The surge height went from about four feet at the lower Bay to nine-and-a-half in the upper Bay region (Figure 41).

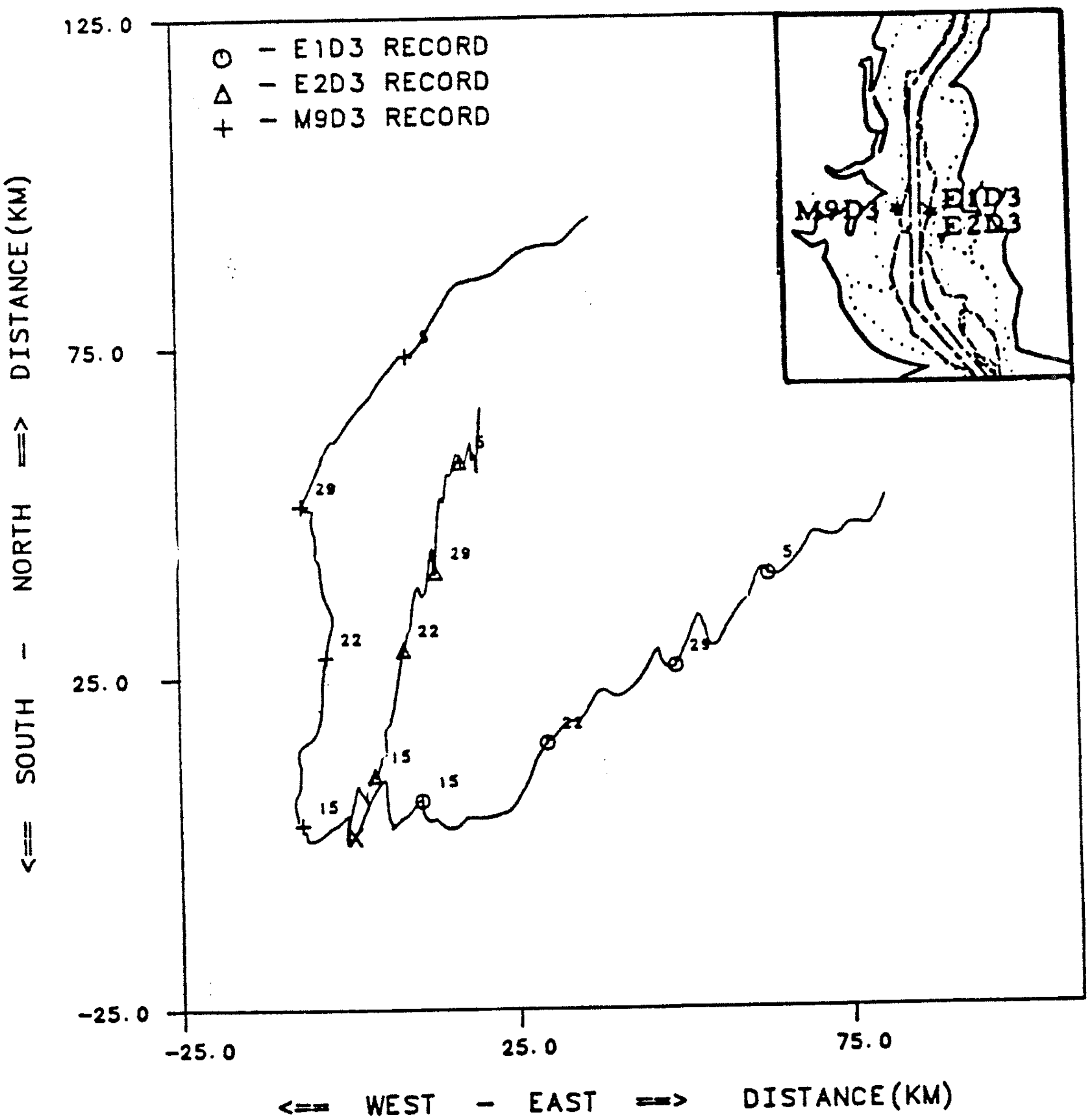


Figure 35

PROGRESSIVE VECTOR PLOT OF THE LOW PASSED NONTIDAL COMPONENT OF THE CURRENT RECORDS (MEAN INCLUDED) FOR DEPLOYMENT 3. MARKERS ARE MADE AT WEEKLY INTERVALS.

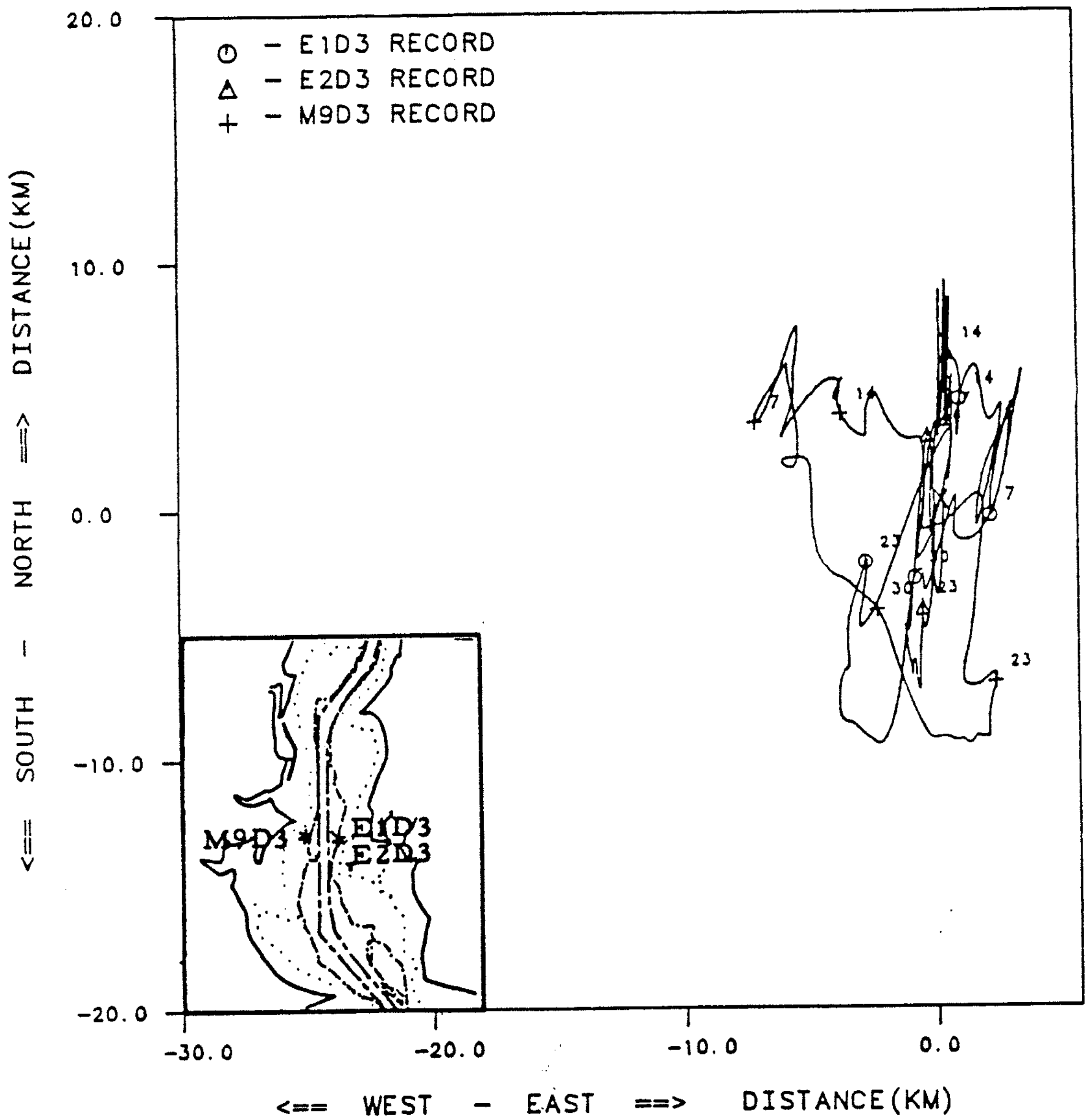


Figure 36

PROGRESSIVE VECTOR PLOT OF THE LOW PASSED NONTIDAL COMPONENT OF THE CURRENT RECORDS (MEAN EXTRACTED) FOR DEPLOYMENT 3. MARKERS ARE MADE AT DAILY INTERVALS.

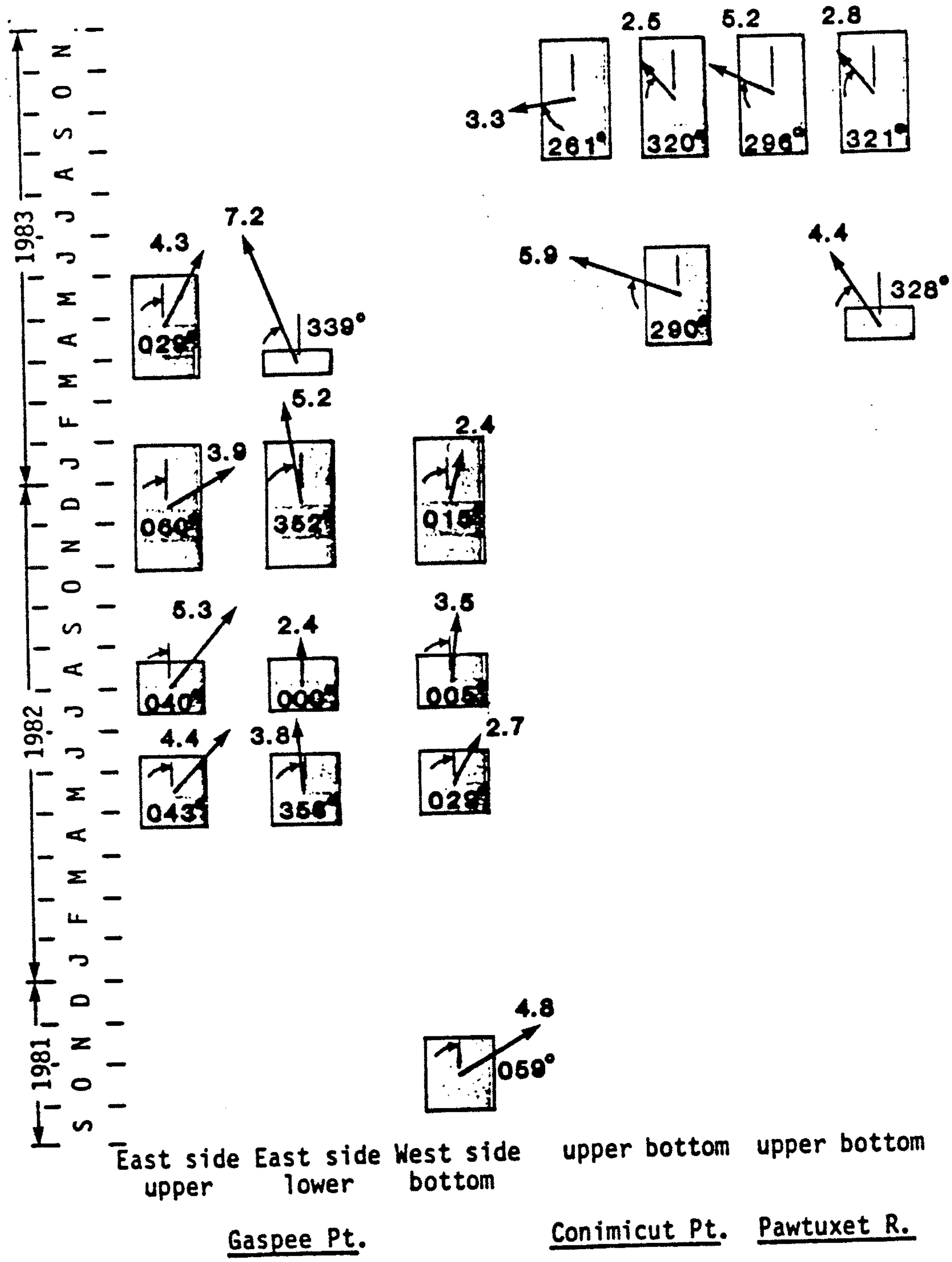


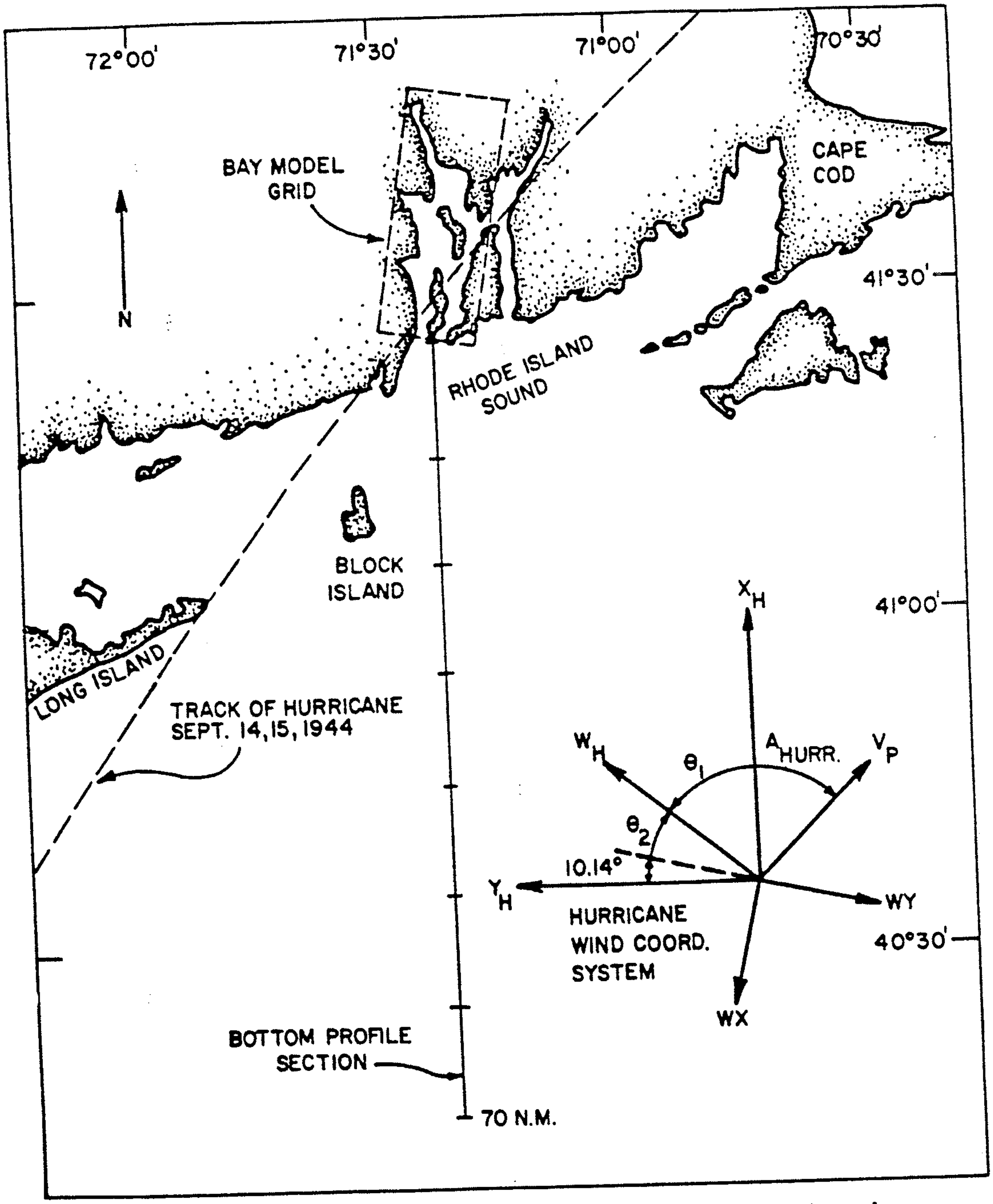
Figure 37

MEAN CURRENT VECTORS FROM THE CURRENT METER DATA. DIRECTIONS ARE IN DEGREES TRUE. VELOCITIES ARE IN CM/SEC.

Figure 38

MAJOR HURRICANES IMPACTING NARRAGANSETT BAY (HARRIS, 1963)

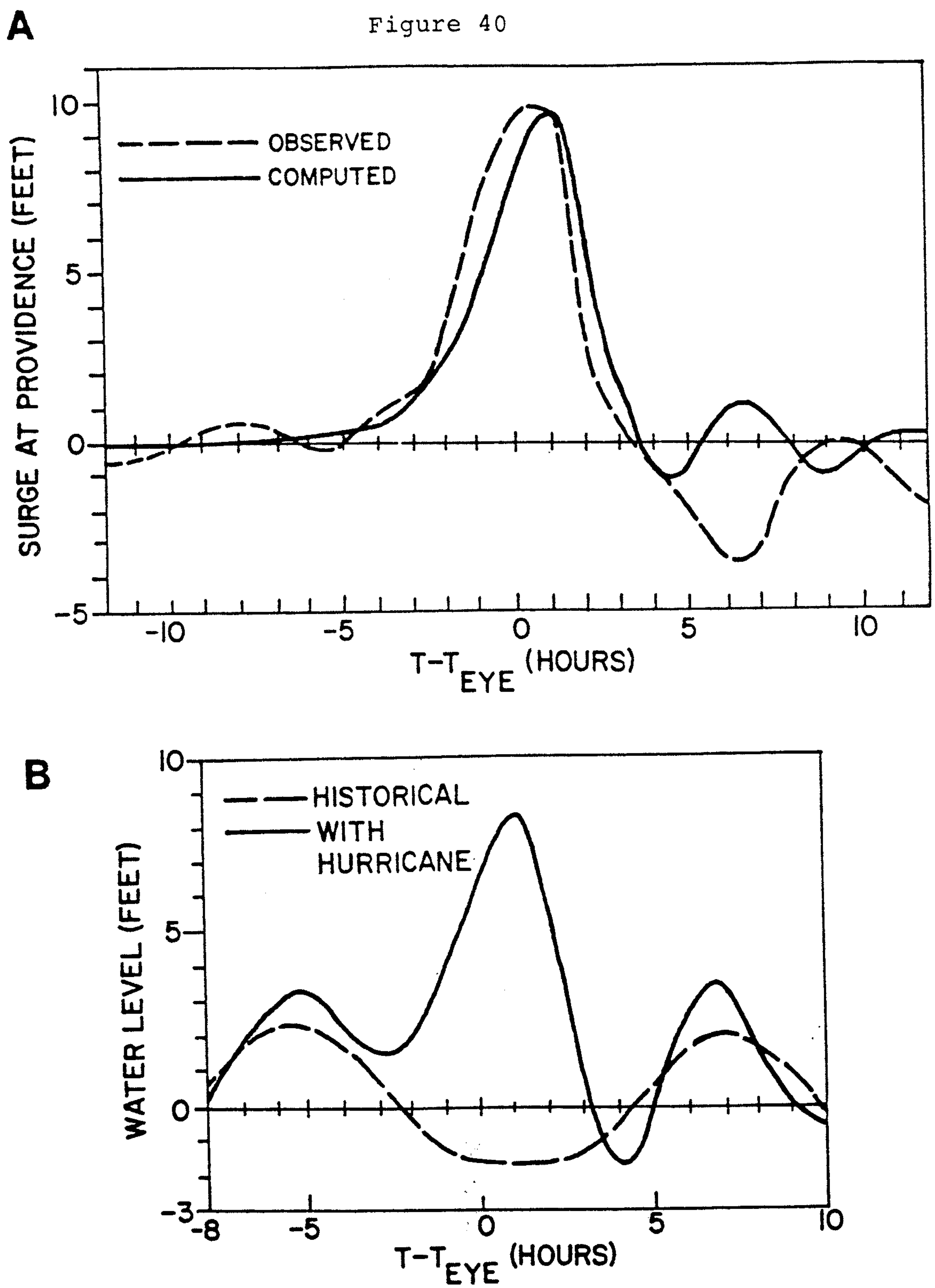
STORM	DATES	HIGH WATER HEIGHT (FT.) AT PROVIDENCE, R.I.
1938	21 - 22 SEP 1938	15.8
1944	13 - 15 SEP 1944	9.9
CAROL	30 - 31 AUG 1954	14.8
DONNA	9 - 13 SEP 1960	7.9



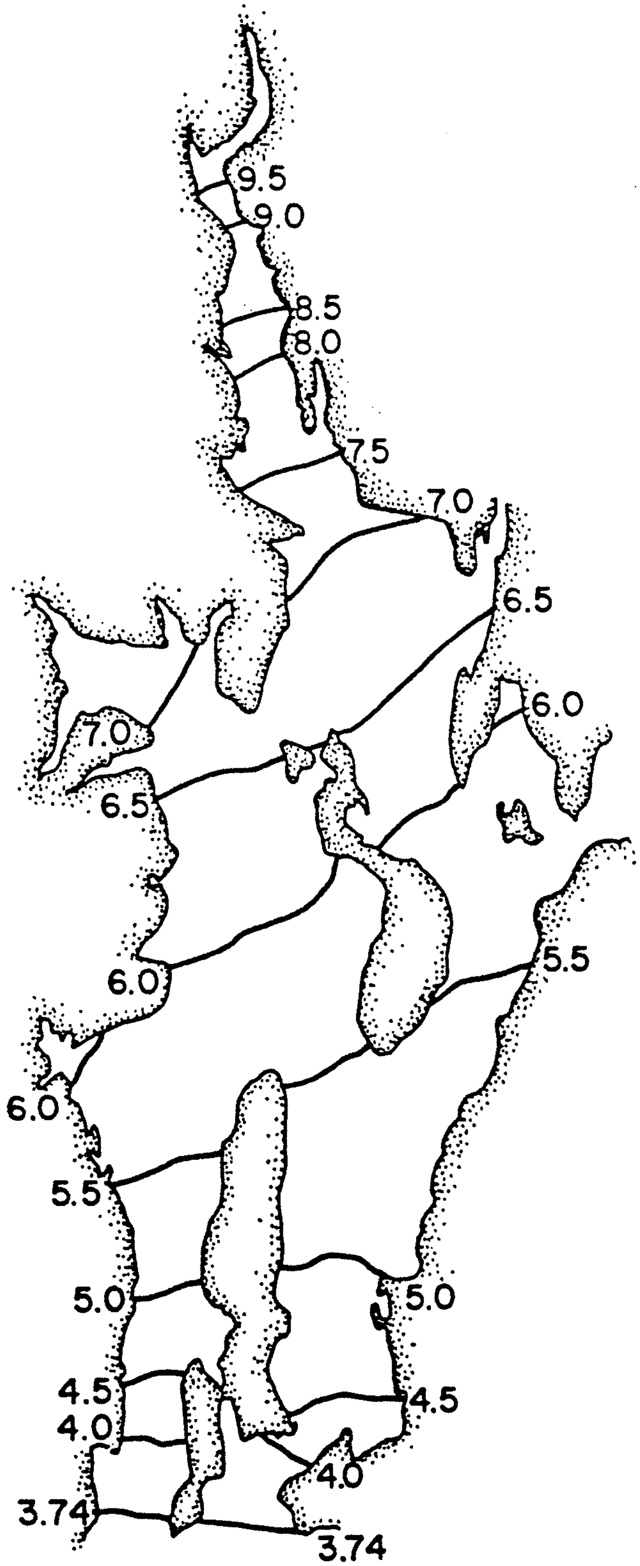
Geography of offshore region used in hurricane study and coordinate system for approaching storm.

Figure 39

Figure 40



Comparison of predicted and observed hurricane surge at Providence (A), and comparison of historical (without hurricane) and computed (with hurricane) water level at Providence Harbor (B).



Water-level isometry (in feet) in Narragansett Bay for simulated hurricane at the time of maximum surge at Providence Harbor.

Figure 41

I want to talk very briefly about density forcing in the river and the river's response to density-induced circulation. One of the classic pictures are these data taken by Hicks in April 1957 (Figure 42). It shows the vertical salinity structure from lower to the upper Bay. The lower Bay, in general, is well mixed. As we go toward the upper Bay region the stratification increases.

Some recent data taken by Oviatt (Figure 43) shows the surface salinity, with darkened circles, and the bottom salinity, with the open circles, going from the lower Bay to the upper Bay. The surface and bottom variation is less than a half a part per thousand in the lower Bay. The variation is from twenty-two to twenty-nine, or seven parts per thousand, in the upper Bay region. This is in direct response to the input from the Blackstone rivers.

However, if one looks at the seasonal variation at Station Three (Figure 44), from the previous plot, you can see a distinct response to the salinity from the increased freshwater runoff in the spring. In general the salinity is relatively constant. The temperature cycles are as you would expect based on a standard seasonal variation from heat input and losses. Models have been performed on the long-term salinity variation in the system. Hess did extensive work in his Ph.D. thesis on that topic.

I would like to show some data taken in the Providence River. Figure 45 shows low-frequency or low-pass time series of wind, atmospheric pressure, the residual sea level (after the tide has been removed), freshwater inputs, and salinity.

Figure 45 shows two salinity plots: one is a thin line representing the bottom, while the wider line indicates the surface salinity. You see that the bottom salinity remains relatively constant while the surface salinity responds quite markedly. It's not quite clear however what the source is of all those variations in the salinity. If one looks at just the freshwater input, one can see some correlation in the response. An interesting feature is that when the freshwater input increases, by almost a factor of three, (July 22) the stratification should also increase because there's more fresh-water coming down the river near the surface. That's not the case for these observations. Some of these other higher-frequency fluctuations are due to the wind forcing for a particular time period.

A summary of the long-term residual flow from all the meter observations showed that at two-and-a-half and at five-and-a-half meters below the surface at the Providence River observation sites, the transport is always up-Bay; in eight meters of water. That means that all of the return flow of water coming down the Bay has to be above two-and-a-half meters below the surface. A very thin layer of fresh water coming down by the surface is

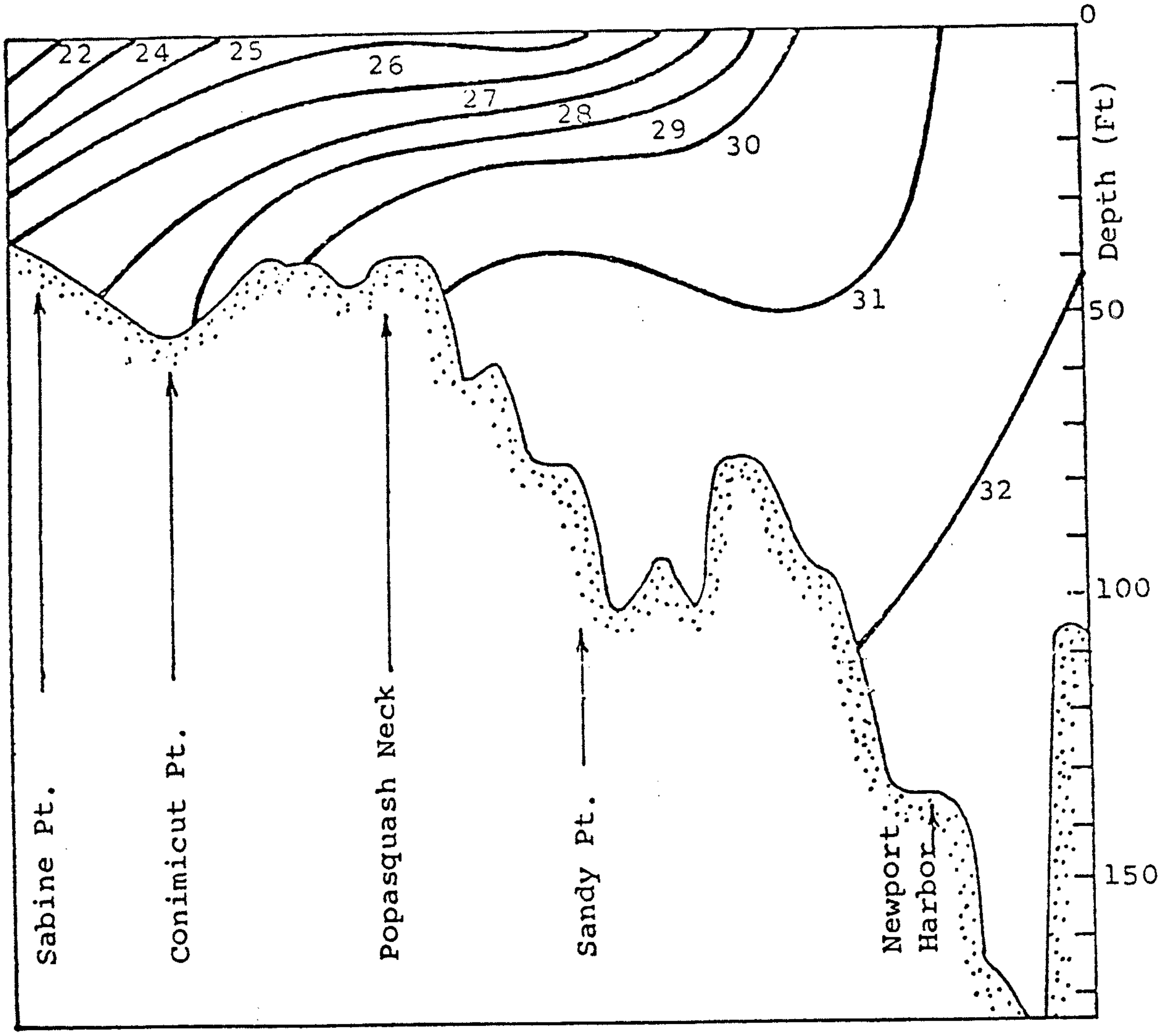
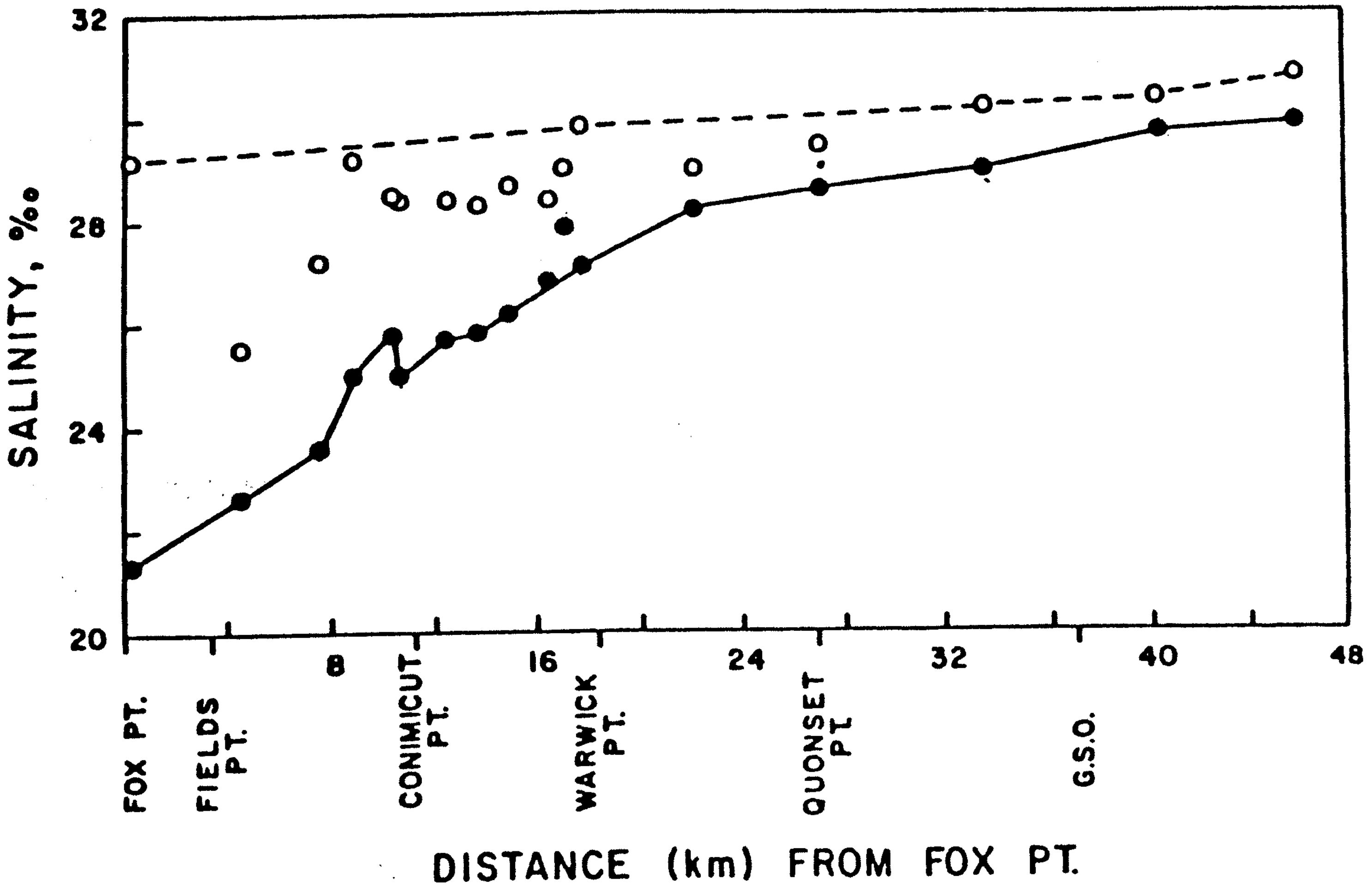


Figure 42

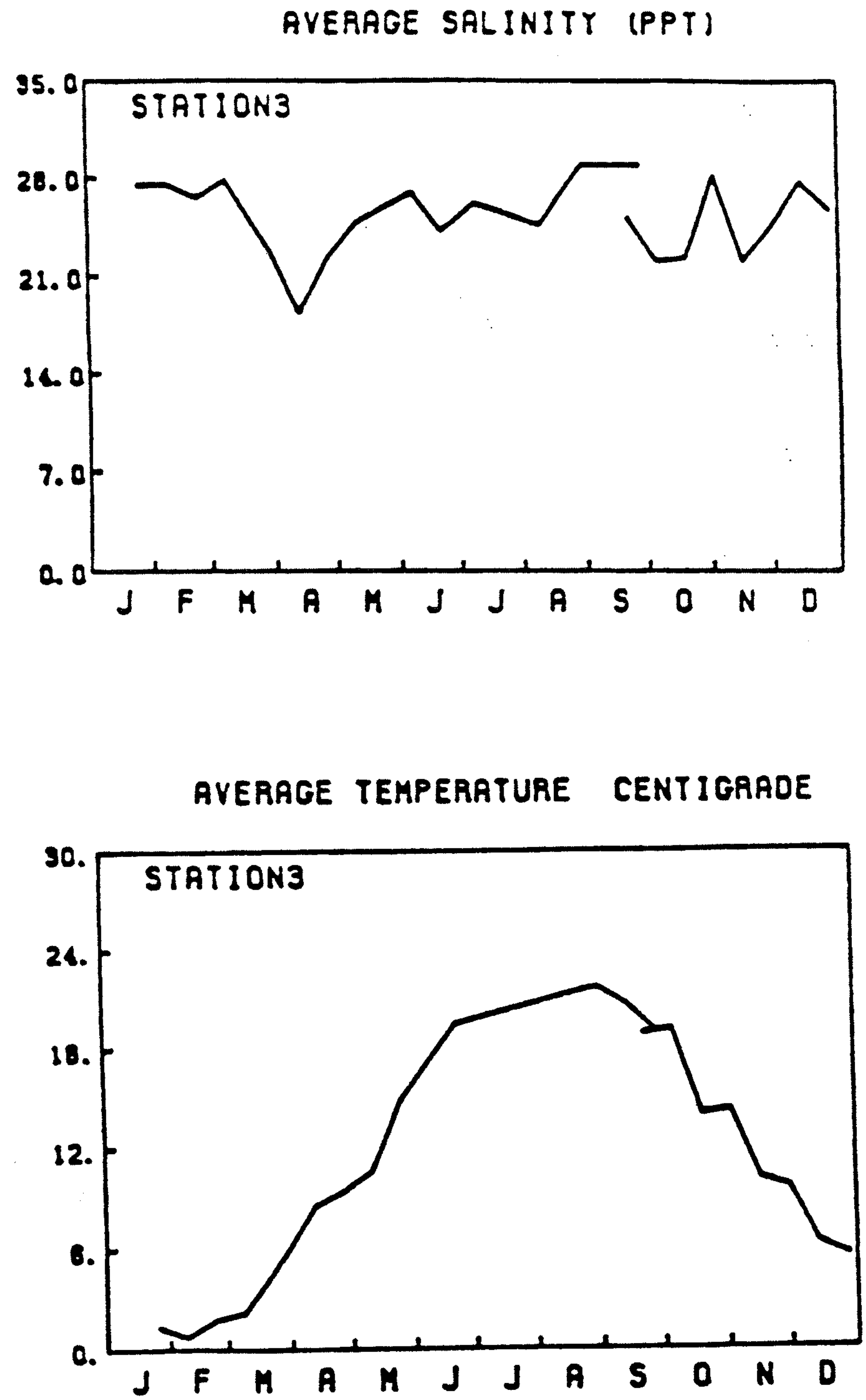
Ischalines along an axial section of Narragansett Bay at slack before ebb, April 1957

Figure 43



Averaged surface and bottom salinity in Narragansett Bay versus distance from the head of the Providence River (from Oviatt, 1980)

Figure 44



Variations in the vertically averaged salinity and temperature at a point in the river near Gaspee Point during 1979 and 1980 (from Oviatt, 1980).

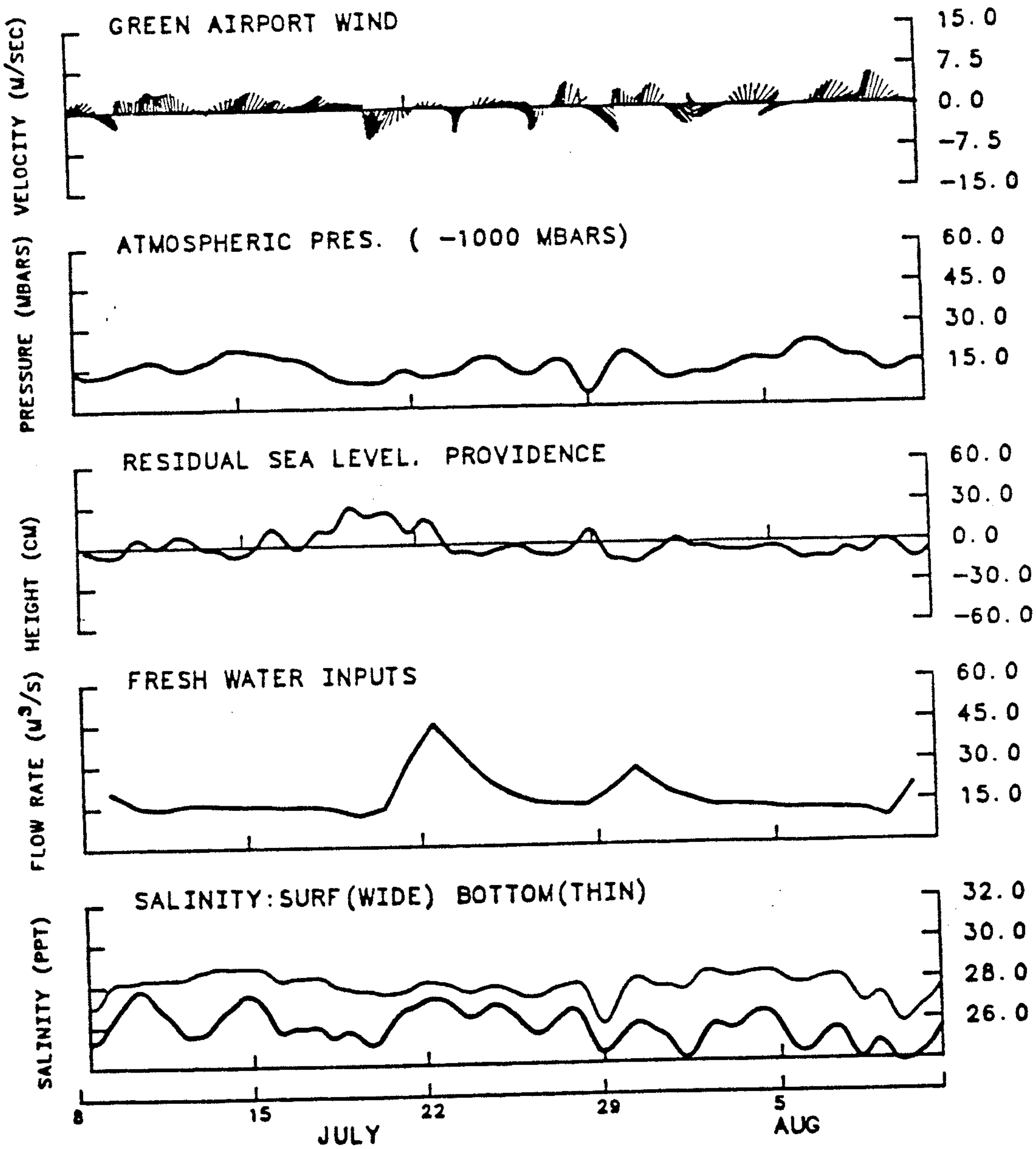


Figure 45

LOWPASSED TIME SERIES: WIND, ATMOSPHERIC PRESSURE, RIVER FLOW, RESIDUAL SEA LEVEL AND SALINITY RECORDS FOR DEPLOYMENT 3 IN THE GASPEE POINT TRANSECT.

balanced by a deep saline, long-term transport going up the Bay, focused in the dredged channel. The dredged channel has an important influence on the circulation in the Providence River in that it acts as the conduit for salt water to get to the upper Bay.

We've had several major water quality models for the upper Bay area as shown in Figure 46. In general, the model efforts have been two-dimensional, vertically averaged. We've been looking at the Bay as a whole and then the upper Bay specifically.

The estimates of flushing for the Bay range from sixty-five to thirty days based on previous work (Figure 47). These are based on salinity observations; the Corps of Engineers' physical model for the Bay; numerical modeling work that Kremer & Nixon did with input from the Hess & White hydrodynamic model; and on Pilson's recent analysis in which he looks at salinity and fresh-water inputs to the system.

In general, the Bay's has a response time, in terms of flushing, of about thirty days. When the river flow rates are higher, it drops to lower values of about ten days. When the river rates are lower, it increases to the order of forty days. Some very detailed hydrodynamic pollutant transport models have been developed. I showed you the hydrodynamic portion of that for this upper Bay area. We've attempted to look at the water quality impacts for a sewer of point-sources in the upper bay.

Figure 48 shows the fecal coliform bacteria trend along the river. This is a distance down the Bay starting at the head of the Providence River. The observations for the geometric means for the fecal coliforms are given. Model predictions using different source strengths are also shown. We've done sensitivity to source strength, point loads, decay rates, dispersion coefficients, and different discharges. We've looked at perhaps twenty or thirty different runoff simulations, three or four in some detail.

The idea of this work is to look at the water quality response to various pollutant treatment strategies for the combined sewer overflows and other point discharges (Figure 49).

I'd like to quickly summarize. Narragansett Bay is primarily a standing wave system with the surface elevation and tidal currents out of phase by about eighty degrees.

M2 forcing predominates. We have a 1.1 meter tidal amplitude at the Bay mouth and amplification of 1.3 at the head, primarily due to geometry with a twenty-minute phase lag. The interaction between the M2, M4 and M6 tides are important in terms of the double flood, single ebb response. The substantial differential

Figure 46

NUMERICAL WATER QUALITY MODELS
NARRAGANSETT BAY

REFERENCE	FEATURES
SPAULDING (1974) SPAULDING ET AL (1975)	2-D LATERALLY AVERAGED NARRAGANSETT BAY D.O.-B.O.D. VERIFIED WITH FIELD DATA 926 M GRID SIZE
HESS AND WHITE (1975)	2-D VERTICALLY AVERAGED NARRAGANSETT BAY (EXCLUDING MT. HOPE BAY), MARKED FLUID, NO VERIFICATION 926 M GRID SIZE
HUNTER AND SPAULDING (1975)	3-D PROVIDENCE RIVER, COLIFORM, VERIFIED WITH FIELD DATA 228 M GRID SIZE
SWANSON AND SPAULDING (1980, 1984)	2-D VERTICALLY AVERAGED UPPER NARRAGANSETT BAY, COLIFORM, VERIFIED WITH FIELD DATA 300 M GRID SIZE

Figure 47

FLUSHING RATE ESTIMATES FOR NARRAGANSETT BAY

AUTHOR	FLUSHING TIME (DAYS)
HICKS ET AL (1953)	65
RIDLEY AND OSTERICHER (1960)	45
KREMER AND NIXON (1978) BASED ON HESS AND WHITE (1974) MODEL	30
PILSON (1985)	$T = 41.8E^{-0.00437\ FW}$ WHERE T - FLUSHING TIME, FW - FRESHWATER INPUT

FLOW (M^3/S)	FLUSHING
LOW - 20	40
MEAN - 105	26
HIGH - 325	10

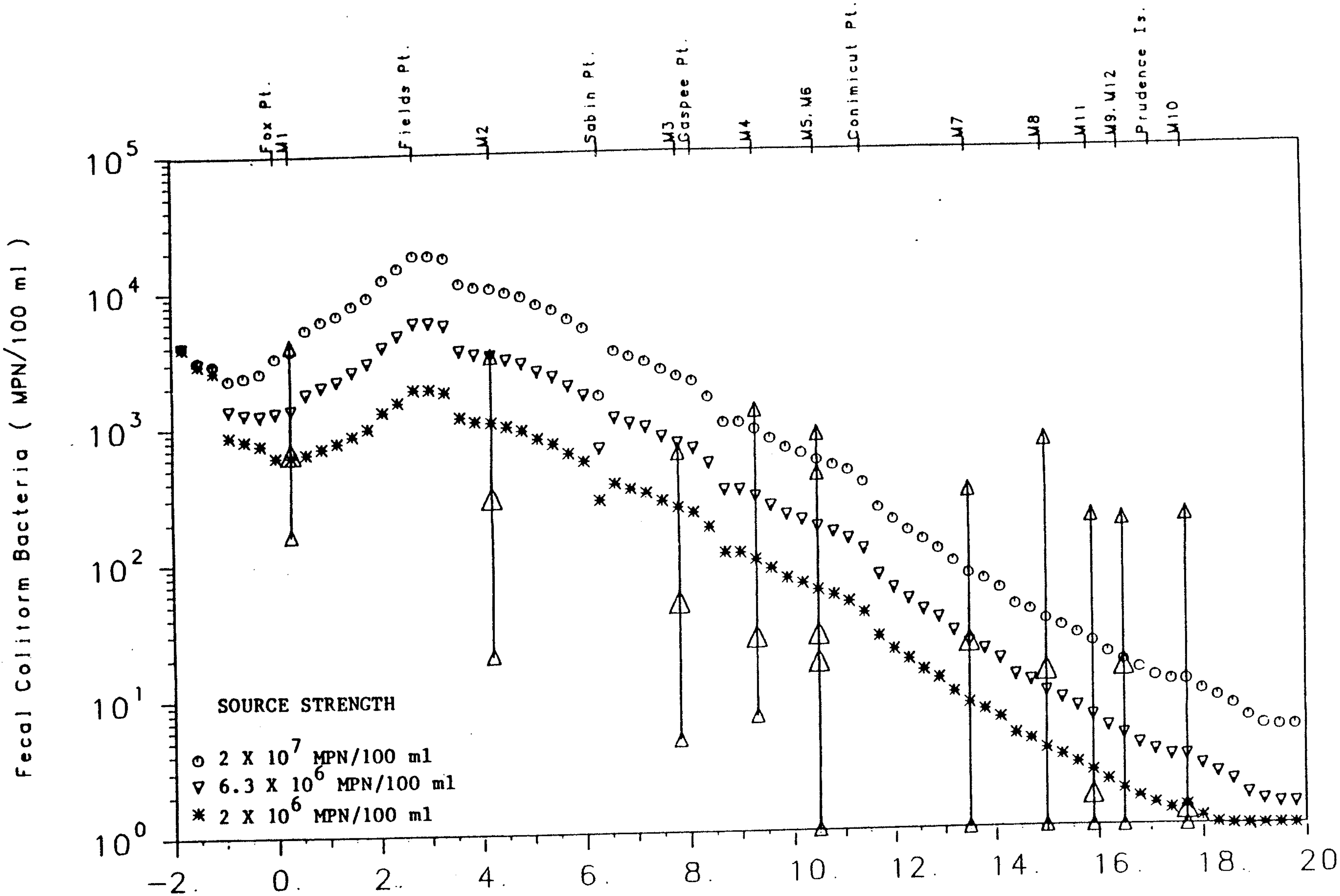


Figure 48

Distance from Fox Point (kilometers)

Sensitivity of model results to source strength.

Figure 49a

SUMMARY OF UNDERSTANDING

A. CIRCULATION DYNAMICS

1. LONG PERIOD WAVE (TIDE AND SEICHING) FORCING

- PRIMARILY STANDING WAVE SYSTEM WITH SURFACE ELEVATION AND TIDAL CURRENT OUT OF PHASE BY - 80°.
- M2 FORCING PREDOMINATES WITH A MEAN TIDAL RANGE OF 1.1 M AT THE BAY MOUTH AND AMPLIFIES A FACTOR OF 1.3 AT THE HEAD DUE TO BAY GEOMETRY. PHASE LAG OF 20 MINUTES.
- INTERACTION OF M2, M4 AND M6 TIDAL CONSTITUENTS AND 5 HR LONGITUDINAL SEICHING FREQUENCY OF BAY LEADS TO DISTINCT DOUBLE PEAK FLOOD CURRENTS
- FACTOR OF TWO DIFFERENTIAL IN DEPTH BETWEEN THE WEST (SHALLOW) AND EAST (DEEP) PASSAGE LEADS TO STRONGER TIDAL CURRENTS AND LARGER TRANSPORT IN THE EAST PASSAGE.

2. WIND FORCING

- SINCE THE BAY TIME RESPONSE OF 10 HRS IS SHORT COMPARED TO THE PREDOMINATE 4-10 DAY METEROLOGICAL FORCING THE BAY IS IN QUASI-STEADY STATE.
- WIND INDUCED FLOWS ARE STRONGLY IMPACTED BY THE PRESENCE OF THE TIDE AND THE RESULTING ENHANCED BOTTOM FRICTION
- THE DIRECTIONALITY OF WIND FORCING COMBINED WITH THE DIFFERENTIAL DEPTHS IN THE EAST AND WEST PASSAGE RESULTS IN SUBSTANTIAL INTER-PASSAGE TRANSPORT WITH MAGNITUDES 15-30% OF TIDAL TRANSPORT FOR TYPICAL WIND STRESS LEVELS.
- NON LOCAL WIND FORCING AT 2-10 DAY PERIODS MAY BE SIGNIFICANT IN LOWER BAY
- WIND INDUCED RESPONSE IS A STRONG FUNCTION OF LOCATION. EXTENDING FROM WEAK CORRELATION IN THE UPPER BAY TO STRONGLY CORRELATED IN THE LOWER BAY.

Figure 49b

3. DENSITY/RIVER RUNOFF FORCING

- BAY IS WELL MIXED IN THE LOWER REACHES, PARTIALLY MIXED IN THE MID SECTION AND STRATIFIED IN THE PROVIDENCE AND SEEKONK RIVERS

- DREDGED CHANNEL IN THE UPPER BAY STRONGLY IMPACTS RESIDUAL FLOW FIELD. SALTY WATER IS TRANSPORTED UP ESTUARY IN THE BOTTOM OF THE CHANNEL AND FRESHER WATER DOWN ESTUARY ACROSS THE ENTIRE RIVER IN A THIN (~3 M) SURFACE LAYER.

- IMPORTANT TERMS IN THE SALT BALANCE
  PROVIDENCE RIVER - HORIZONTAL ADVECTION AND DIFFUSION
  UPPER BAY - HORIZONTAL ADVECTION
  LOWER BAY - HORIZONTAL AND VERTICAL ADVECTION

B. POLLUTANT TRANSPORT DYNAMICS

- NARRAGANSETT BAY HAS A FLUSHING TIME OF 10 - 40 DAYS (MEAN VALUE - 26 DAYS) DEPENDING ON THE FRESHWATER RUNOFF. PROVIDENCE RIVER - 3-10 DAYS.

- THE PRINCIPAL TRANSPORT MECHANISMS IN PROVIDENCE RIVER ARE HORIZONTAL ADVECTION AND DIFFUSION. LATERAL DIFFUSION IS MOST IMPORTANT WHERE THE DREDGED CHANNEL REPRESENTS ONLY A SMALL PORTION OF THE CROSS SECTIONAL AREA.

- ALL POLLUTANTS SHOW HIGH VALUES IN PROVIDENCE RIVER IN THE VICINITY OF WASTES DISCHARGES AND DECREASE TO NEAR BACKGROUND AT MID-BAY. DILUTION RATES OF 0.5/DAY ARE TYPICAL. STORM INDUCED POLLUTANT LOADS MODIFY THIS CHARACTER FOR PERIODS - 5-7 DAYS.

between the two passages markedly influences the tidal dynamics in that larger transports occur in the East Passage than in the West Passage.

For wind forcing, the primary response time of the Bay is ten hours. Since the meteorological forcing has primarily a three or four to ten-day time scale, the Bay is normally in quasi-steady state.

The directionality of the wind forcing is particularly critical in terms of intra-Bay, inter-passage transport. Those intra-Bay and inter-passage transports can be as large as fifteen to thirty percent of the tidal transport. They are insignificant, even though they only last for short periods of time.

Non-local forcing, can be extremely important in circulation in the lower Bay. We need to monitor the tide height at the Bay mouth in order to be able to better understand this system.

The wind-induced response in the Bay is a strong function of location. In the upper Bay, Providence River specifically, the wind looks like a simple mixing agent. In the mid to lower Bay a significant inter-channel, inter-passage transport takes place, and the magnitude can be substantial relative to the tide.

The Bay is partially mixed, in general, in terms of its density-induced circulation. It's partially mixed in most of the Bay mid-section, well mixed in the lower Bay, and stratified in the upper Bay. The dredged channel in the Providence River plays a critical role in terms of the circulation dynamics in the Providence River area. Salty sea water is funneled by the channel up the Bay, and there's a very thin layer of return freshwater coming down the river. The important terms in the salt balance are horizontal advection in the upper Bay and horizontal and vertical advection in the lower Bay.

In terms of the pollutant transport dynamics, Narragansett Bay has about a ten to forty-day flushing time. Typically, the Providence River is three to ten days of that total. The principal mechanism of transport of pollutants in the upper Bay is advection. Diffusion plays only a minor role and only where the channel cross-section is small compared to the total cross-section.

All the pollutants that we've modeled show a decided decrease from upper Bay to lower Bay. This reflects the fact that the principal sources are in the upper Bay. The Bay gets wider toward the ocean; there is more dilution and a decrease in concentration.

Where does that leave us in terms of longer term implications? Well, I have three areas that I recommend for further study (Figure 50). First, we really don't have a good idea of the freshwater budget in the Bay. Considering we've been working on Narragansett Bay all these years, we have very poor salinity observations. We are unable to balance the freshwater in the system to within a factor of fifty percent. The recent observations for the freshwater input vary by a factor of almost two from the numbers we've been using as accepted values in many papers and analyses.

We've seen that from our modeling point of view we've done a very adequate job with our coarse grid models, but we're starting to look at areas, and size and time scales where finer resolution modeling is absolutely necessary. We're going to need good field observations to calibrate and compare these models. We have a lot of simulations, but no field data to back them up in terms of saying, "Yes, that's what's observed," or "No, that's not what's observed." So that's item number two.

Finally, in terms of Narragansett Bay as a whole, we still have no idea of what the exchange is between Narragansett Bay and Rhode Island Sound waters. We've had a lot of conjectures. We've tried to support the argument that there is a low exchange between the Bay and the offshore waters. We have little hard data.

So with that, I will conclude and answer your questions.

QUESTION: Why is the freshwater balance so bad?

DR. SPAULDING: Ungauged river basin drainage area. We did an analysis of the drainage areas versus the flow rates observed in the rivers, and the numbers didn't balance. That's because much of the area remains ungauged. There's a major source of freshwater coming in, the Taunton River, the second largest freshwater input to the Bay. It's clear that part of that freshwater comes through Mt. Hope Bay into Narragansett Bay directly. Part of that flow goes down through the narrow straits and into the Sakonnet River. We have some crude numbers for estimating that amount, but they're based on less than one cruise worth of salinity information. Even though salinity is such an easy variable to measure we still don't have good long-term measurements.

QUESTION: What's the minimum field program necessary to verify some of these models?

DR. SPAULDING: I guess the way I look at understanding the circulation dynamics in Narragansett Bay is as a matter of how we handle the studies we perform. What happens is that there is an evolution over time in terms of our understanding. We make little advances on it here, a little progress there.

Figure 50

RECOMMENDATIONS FOR FUTURE STUDY

- BUDGET FRESHWATER INPUTS AND OBSERVED MEAN SALINITY IN THE BAY - 8-10 SECTORS, IMPROVED FLUSHING ESTIMATES; BY SECTOR.
- COMPREHENSIVE BAY WIDE FINE RESOLUTION (350 M) NUMERICAL HYDRODYNAMIC MODEL AND CURRENT, SALINITY, AND TEMPERATURE MEASUREMENT PROGRAM TO DESCRIBE WIND, DENSITY, AND TIDALLY INDUCED TRANSPORT ACROSS SELECTED SECTIONS OF THE BAY - PASSAGES, PASSAGE INTERCONNECTIONS. MUST MONITOR NON LOCAL FORCING AT THE BAY MOUTH.
- FIELD PROGRAM TO ESTIMATE THE EXCHANGE RATE OF NARRAGANSETT BAY WITH RHODE ISLAND SOUND.

We made a major impact with Sea Grant funding in understanding the circulation in the upper Bay. I would like to see a program equivalent to that applied to some of the inter-channel transport in the lower Bay. I look at the thing as on the order of, say, three to five deployments per transect for, say, five transects.

What we found previously is that when we'd go out, we'd take some measurements, and we'd think we were very clever. We'd take measurements of the currents and we'd take measurements of the temperature. And then we'd go out and do one salinity survey during that time, and we'd get the freshwater input from someone else.

We'd go back to do the budget and we found that they didn't all fit. The reason they didn't fit is because the data were really not there. We often have collected the wrong information.

When we went to compare our model to observations of a really nice detailed vertical structure of the wind-induced flows, we found out that we didn't have surface elevation at the Bay mouth, which we needed to understand the non-local forcing. We could get the local, but we couldn't get the non-local. Because we couldn't get the two, we couldn't really say how well the model compared to the observations.

QUESTION: What is the freshwater input to the Bay?

DR. SPAULDING: The total is about a hundred cubic meters per second. The rivers account for about twenty, twenty-one at the highest. The Blackstone is a little larger than the Taunton. So in terms of what happens in the upper Bay, the Blackstone River discharges into the Seekonk, the water comes over the falls, and right there the salinity stratification is from about sixteen to seventeen parts per thousand on the bottom to zero on the surface.

QUESTION: What kind of procedures have you been using for the numerical hydrodynamics and water quality models for the Bay?

DR. SPAULDING: In general, we've used two-dimensional vertically averaged finite difference models. For the hydrodynamics we've used multi-operational schemes, for the water quality, alternating direct implicit. For the three-dimensional hydrodynamic modeling work Hess used a steady state finite difference approach, again, multi-operational.

For our most recent time-dependent work we've been using a three-dimensional model solved by Galerkin weighted residual finite element method in the vertical, and forward in time, centered in space finite difference in the horizontal.

QUESTION: Is the transport fairly proportional to wind velocity?

DR. SPAULDING: No. The transport scales non-linearly with the wind velocity. That's because we're essentially looking at the scaling of stress, not the wind directly. So it goes like the square of U2 + V2 which is the magnitude of the stress. So it doesn't scale linearly is the quick answer.

QUESTION: Why weren't current measurements made closer to the surface?

DR. SPAULDING: We were concerned about our ten thousand dollar current meter. It was necessary to get the meter out of the shipping traffic.

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MANAGEMENT ISSUES

Mr. Robert Bendick, Jr.

MR. BENDICK: What I'm going to try to do is briefly describe the framework of environmental management in Rhode Island; talk a little bit about some of the progress that's been made on Narragansett Bay; try to identify the problems that are left; and then discuss the future.

I want to review some of the things that have been previously mentioned: the historical framework of the development of the Bay. Roger Williams discovered Providence while paddling a canoe up the Bay, and that set the model of the Bay as being the central part of the State's life. It was first used for transportation among the rural communities, then as a fishing resource. It later became a place for the China trade to begin and where the Brown family and some of the other founding fathers of Rhode Island built their fortunes, which they soon invested in the textile industry to make Rhode Island one of the first industralized places in the country. With textiles came water power, and the Bay was used to transport the textiles out of the state and as a place to put textile wastes. Newport calls itself the country's first resort. There was also a great deal of recreation on the Bay, not only for the wealthy who stayed in Newport or Narragansett, but also for the millworker who used excursions on the Bay to get a day away from the mills. The military played a major role in the Bay from the beginning of World War II at the Quonset Point and Newport Naval Bases. Then, from 1955 to 1975 there were some very rapid changes. The textile industry declined quickly. The central cities--Woonsocket, Pawtucket, Providence, and West Warick--which were based around that textile industry, declined with the industry. That changed the waste discharge into the Bay.

In 1973, the Navy pulled most of its industrial operations out of the Bay. With the weakening of the central cities, the loss of the textile industry, and the development of transportation of highways after the War, the land-use pattern of Rhode Island in the area surrounding the Bay started to change quickly. Wnstead of the tight central city nodes surrounded by country, the Bay area and region began to be suburbanized.

The Bay today does not reflect the many problems of conflicting interests. There is its use for waste disposal. There's recreation, which I think can be divided into two categories--boating, and other high-cost recreation, such as condominiums, second-home developments, restaurants on the water, and development-oriented recreation. Then there is passive recreation. Those two interests, the people who look at the Bay as a place for nature and a place for natural beauty, and those who see it as a base for recreation don't have the same views.

There is industry located directly on the Bay; fishing and shellfishing are still strong. There's suburban development that surrounds the Bay and that uses the Bay as a different sort of resource. Suburbanites include the recreational experience in their everyday lives. There's still military use and talk of bringing a battleship to Narragansett Bay which would have some major impacts. There is transportation and shipping. And then I guess you could say there's sort of the Bay for its own sake; the Bay for its ecological value in the abstract, apart from the human uses.

Let me talk for a second about the institutional framework for resolving those kinds of conflicts. Most of the Bay is in Rhode Island; the upper Blackstone, the Taunton River, and Mt. Hope Bay are in Massachusetts. It's mostly in one state with a little bit of a second state involved. Within Rhode Island, the Department of Environmental Management, the department of which I'm the Director, has the responsibility for everything in the environment except for drinking water. Within our department, the Water Resources Division has the main function for managing water quality. We have recently taken permit delegation from the Federal Government. We do construction grants, planning, and enforcement of water quality regulations. The Fish and Wildlife Division deals with fish and wildlife. Working in conjunction with it is the Marine Fisheries Council that makes rules and regulations governing commercial fish and shellfish resources. The Land Resources Division regulates the on-site disposal of sewage, which may or may not relate to the Bay's problems. EPA looks over our shoulder, gives us money, and still participates in parts of that regulatory process. We also have a strong coastal resources management plan. There's a Coastal Resources Management Council that must grant permits to all development within the coastal region. That function is staffed by University of Rhode Island (URI) and by the Department of Environmental Management. Those permits require input from other agencies, including a water quality certification from our department.

The city and town governments still have control over land use in Rhode Island. There are a lot of problems with that. We are only the size of a county around here, Fairfax county, say, yet we have thirty-nine jurisdictions in the state dealing with zoning and land-use. It becomes very difficult to have a sensible and comprehensive land-use policy under these conditions. There is another factor involving the former Navy lands which include several thousand acres bordering the Bay. They are subject to a consent agreement that resulted from an environmental lawsuit at the time the Navy pulled out. Review procedures have to be taken into account before those Navy lands are disposed of or have anything built on them.

URI, a very large oceanographic school in a very small state, obviously plays a large role in the decision-making process on the Bay in Rhode Island. We have some strong environmental groups. Save the Bay is the largest environmental group in the state and exerts a lot of influence on Bay policy. There is a coalition of coastal communities that comes together on certain Bay issues. We have an unusual press situation in which we have one state-wide newspaper and a lot of local newspapers that compete with and try to out perform the State wide newspaper. This means that everything that anybody does having to do with the Bay is subject to instant, extensive press coverage. You can't do anything which doesn't result in something happening in the press a day later. Within all of those managers and management contexts there are certain documents that have laid out the objectives for the future of the Bay. Let me talk a little bit about what they are. There are, of course, the water quality classifications that everybody has, "A, B, C" or SA, SA, SB." We have a water quality classification for the Bay; some of the Bay is in compliance with its classification, while some is not. About two-thirds of Narragansett Bay is Class A water. We've heard a lot of about pollutant inputs today and it's not quite as bad as it might seem. We also have a construction grants priority list which, while a short list, has a lot of content in terms of where the worst water polllution problems that can be solved by construction grants might be.

The CRMC--the Coastal Council--has a state plan for all the coastal waters that sets out what ought to happen there. Their most recent revision of that plan is a zoning of the Bay's water limiting what uses are allowed in certain locations. Many years of study have gone into the coastal plan, and it reflects a good state consensus on what ought to happen.

The zoning aspect only deals with the water uses; the land-side is still up to the communities. We have a state guide plan, which is kind of a general state plan, and the coastal plan is supposed to be consistent with that and is, to a certain extent. There's no requirement that local zoning be consistent with the state guide plan or with the Coastal Resources Management ordinances for the Bay or the adjoining water. In an effort to try to achieve unity, the Coastal Council, working with URI, has begun to do something called Special Area Management Plans that are designed to work with the local communities to establish goals for a specific area. That's just getting off the ground. It remains to be seen how it's going to work. The state has a land acquisition policy for public land preservation around the Bay, and there's not much left to buy, but it's basically to buy as much Bay shore property as we can and to purchase the major landmarks around the state. The Estuarine Sanctuary Program has been very helpful toward that goal.

Let me talk about some of the things that have been done recently. Since I represent government, I'm only going to talk about the good things. Then I'll try to end up with some problems, and then discuss our options.

The Providence Sewage Treatment Plant was an unbelievable mess. Given the amount of construction grants that might be available, the state knew that it was never going to be able to solve that problem, the problems of the CSOs and related issues to it, without additional support. About three or four years ago the state voted an eighty-seven million dollar bond issue just for the Providence plant. This was a state-wide bond issue to solve the City of Providence's problem, reflecting the tremendous regard for the Bay that people in this state had. That bond issue resulted in the establishment of the Narragansett Bay Commission. They took the plant away from the City of Providence. The Commission is doing a vastly superior job in managing the plant, and in bringing other communities to establish pretreatment. Most major inputs to the pollution problem of the Bay have taken a step forward toward solution.

Now, the possible elimination of construction grants, is not going to help the effort. We're talking about a hundred-and fifty to two-hundred-million dollars. The eighty-seven-million dollars of state money goes a long way.

We have managed to solve a number of the other priority point-source municipal discharge problems around the state. Newport remains a problem. There are three or four that are still on the list. We are concerned that the list is much longer than the amount of construction grants that are going to last for the next two to three years. Having made this tremendous commitment to Providence, whether the state can actually fund the rest of the communities around the state when construction grants go, remains to be seen.

In the area of permitting, we received a delegation last October from EPA along with a blacklog of permits. We issued our first permit last week. All of our permits are now going from the four or five pollutant type permits to the seventy to a hundred pollutant type permits. The trial balloon on this, which we worked on with EPA, was a Ceiba-Geigy Chemical Corporation permit that was issued about a year-and-a-half ago. This was a very complex effort, and our staff is trying to get up to speed to deal with these permits. We are restructuring our staff so that there are fewer engineers and more chemists and biologists. We have established a computerized permit tracking system that's been an incredible help. Basically, all the permit data, which involves ninety to a hundred permits and monitoring data on almost that many from any one of a number of point sources is managed by a computer system. The monitoring data is entered, and the computer produces all of the violations each month on a turn-around document for the engineers to work with and provides the whole history of violations for each pollutant if required. This may be a small step but it is a big step for us.

We are using the tool of water quality certification, which is built into the legislation for the coastal resources permit, as a way of beginning to attack non-point source pollution around the state. Any project of any magnitude which requires a coastal permit, which is any project that adjoins the water, requires a certification. In that way a marina, for example, or parking lot or anything which might be construed as producing non-point sources of pollution, can be evaluated and the coastal council can be advised on whether they ought to issue a permit or not. The process has really caused a lot of anger on the part of the development community because it's a new card that they have to deal with. We recently had a big fight over a marina where they wanted to put in two hundred and twenty boats and we said that fifty-five boats was all that could be there or we wouldn't give a water quality certification. We won that battle, but I'm not sure what's going to happen in the future. We are also beginning to look at more non-point source in some detail, the focus is more on the urban runoff problem. We don't believe agricultural runoff is a major problem in Rhode Island, because of our diminishing agricultural resource.

In terms of state policy for land adjoining the Bay, we recently established the Bay Islands Park, which consists of about twenty-five hundred acres of undeveloped land running right down the center of the Bay. Much of the land came from the Navy. They had ammunition dumps and depots and other facilities up and down the Bay. At the central site at the south end of Prudence Island, which is right in the middle of the Bay, some people very much wanted to put in a LNG terminal. There was a big crisis about the future of the Bay. If this LNG terminal was right in the middle of the eight hundred acres of vacant land on the Bay then it would be industrialized, and if it remained vacant, it would not. It did become part of the Bay Islands Park through some peculiar maneuvering in Washington and some lucky accidents. That was the core of the Bay Islands Park. The Narragansett Bay National Estuarine Sanctuary is at the other end of Prudence Island and Patience and Hope Island within the sight of the Providence skyline. It is an absolutely unspoiled area with deer herds and other wildlife. It's a legitimate wilderness right in the middle of the metropolitan area. We are still trying to buy other major landmarks down the Bay and, as I will explain in a minute, link them with water transportation to do something a little different.

We've had to fight with the Federal Government on some of these a couple of years ago. There was a policy to sell much of this Federal surplus land to the highest bidder, which seems to have been abandoned. It was difficult to accumulate all the landmarks that we wanted.

In the area of local land use we've been not nearly so successful. Rhode Island has archaic zoning enabling legislation which hasn't changed much since 1924. All kinds of things that are normal everywhere else cannot really be done under Rhode Island's enabling legislation. We, in the department, have published a Developers' Guide to the Rhode Island Coast to try to explain to people that if you have to develop on the shore how to do it with the fewest possible impacts. Providence has taken the initiative, along with the state, to come up with a waterfront plan for the city that fits into an overall scheme of preserving the character of the Bay. I think that's the first step, positive land use planning on the Bay shore. Maybe other communities are going to follow that lead.

Despite all of this, there are a bunch of problems that remain. One is the question of toxics. What are their impacts on the Bay? Are they important? Are traditional pollutants still more important or are those limiting factors? We're not sure what the impacts on the biology of the Bay are, e.g., the traditional limiting factors of BOD. We need to find out more about that.

We have a long way to go with pretreatment. Rhode Island has big electroplating jewelry industries. Therefore, being really successful with pretreatment is going to be some what contingent on how effectively we can understand the impacts on the Bay of the metals, and the other toxics that they put out, so we can work backwards from that point.

We have, through some of the work Eva's done, discovered, like everybody else, the major impacts of non-point source pollution, particularly from highways. The change of the Rhode Island landscape, the suburbanization that I talked about, is converting what was an essentially rural Bay shore a few years ago into a suburban area much more like Long Island than Rhode Island.

There are not too many barriers in the way of continuing, urbanization, as tragic as some people might think that is. An attempt to control growth and to try to keep it from wrecking water quality and wrecking the character of the Bay is one of the biggest problems that we face.

There are many competing recreational uses, as previously described. Like everywhere else, there is a vcicious competition between commercial and recreational fishermen over the use of the Bay's resources.

To get to the heart of some of these things, how do we solve them? There is this Narragansett Bay Study, which is supposed to solve all the problems. It won't, but we hope will go a long way toward answering some of the questions that I've just raised. The Narragansett Bay Study is associated with a couple of other studies already under way. One of the basin plans, the first of which we're doing differently from the basin plans that have been done in the past, and the back-up research for the first basin plan, which is on the Pawtuxet River, our most polluted river, has been completed by Dr. Quionn and a team from URI. They have looked at the origins and fates of pollutants, including toxics, in that river and built a mathematical model. We can now see from the point-source and from the major non-point source discharges what happens to the pollutants as they move down the river. We expect to be able to use that model as a major tool for writing the permits and balancing the permits on the river. We're going on to the Pawcatuck River in the southern part of the state and then the upper Bay with that style of basin planning. There were sixteen thousand separate sample analyses done for that one basin plan on that one river.

Using the fines from Providence we managed to recapture a quarter of a million dollars to fund an upper Bay toxics project. The upper Bay toxics project is designed to examine the origins and fates of toxics in that area with specific attention to the input of toxics into sewage treatment plants and what happens to them then. Do they go up into the air as toxic air pollution? What component ends up in the sludge? How much goes out the other end? The prcject will then assess risks to human health in the environment from the different paths that the toxics take.

The third item I want to mention, after the basin plan and the upper Bay toxic study is what we call the Sherlock Monitoring Program. A bill was passed in the state to charge industries to allow us to monitor their effluent and to monitor the dispersion of their effluent in the river from industries and municipal plants. We're now collecting data on all the major point-source discharges--and this is, again, data for a wide suite of materials.

Combining all of these projects with the Narragansett Bay Study, we expected, first, to establish some baselines for how bad or good the condition of the Bay is. We don't really have very good baselines right now. Secondly, we wanted to define more clearly what the pollutant inputs to the Bay are. More importantly, we wished to try to assess what the impacts of those inputs are. Impact assessment is a tremendous weak point in what we're doing. What is the actual biological or ecological input of the different constituents that are going into the Bay? Finally, we will develop management strategies and establish a state-wide environmental computerized data collection system, which is a combination of a very sophisticated data base management system and a geographic mapping system. We feel that this is the only way we're going to be able to make all these studies make some sense. Using this approach for Narragansett Bay is going to be very complicated. We're going to start out with ground water but we're going to design all of the Bay Study so the input will be put in the system and we'll be able to use it for the open Bay too.

QUESTION: What are the programs you're considering?

MR. BENDICK: It's called ARC Info.

We hired a consultant to do nation-wide search for the best geographic mapping and data management system for this purpose, and that's what he selected.

There's a big problem between all the people who spoke before and somebody like me which is: I couldn't really understand everything that was said. Yet, the elected officials unfortunately understand even less than I do because they don't spend as much time on it. Trying to digest all this data and put it into a format that non-scientists can use to make decisions is the purpose of the system. We think that being able to convert data into and into geographic format will allow non-technical people to make some intelligent decisions about where the Bay is going and what ought to happen. The nature of the system we're hoping to set up will be that we will be able to track events from day to day or month to month, and we will be able to see what's happening out there. I know that's ambitious and I'm not sure it will work but we think it's worth the gamble. This system will, we think, give us the basis for writing these very complex permits in the future and then understanding, at least to some extent, what the impacts of the new permits are on the system we're managing. By dealing with integrated toxics; that is, not only just looking at the inputs into the Bay, but also examining the question of whether it ends up in the sludge or it ends up in the air, we think we can regulate waste disposal in the state in a more intelligent way. I think it's no surprise to anybody here that regulating water pollution without understanding where else the toxics are going isn't very functional. What we're trying to do, by this combination of studies, is at least having the material to make some intelligent judgements as to whether it's better for these materials to go up in the air, into the Bay, or into a land fill.

We also, I think, have to grapple with non-point sources and we're beginning to do that. The system isn't going to be able to help us with that. The problem is just too complicated.

I now want to talk about land-use. Unless we get a better handle on Bay-related land-use, we're still not going to solve the problem because the general impact of urbanization on the Bay shore is still going to undermine everything, no matter how good a job we do elsewhere. There is now a hot issue in the state as to whether the Coastal Resources Management Council is too pro-development. In this Legislature there are four different bills to reorganize the Management Council, to give it a legal staff and technical staff that's more under the control of the Governor, and to try to make its decisions more protective of the Bay. A lot of pieces of that system are now in place. The idea is to try to restore the Providence waterfront and therefore restore the desireability of Providence as a place to live. Providence used to have a population of two-hundred-and-twenty thousand. It now has a population of a hundred and fifty thousand. The Providence waterfront, and the water around it which is less sensitive to development, could be a potentially wonderful magnet for the growth that otherwise might take place somewhere else. There are other nodes of development around the Bay which could accommodate more development if they were planned properly.

The Bay Islands Park is an open space spine down the center of the Bay. Major State parks on both sides of the Bay and down the center, if you include the State parks in the Bay Islands Park, add up to maybe five thousand acres of undeveloped shore-front land. My hope is to get people to accept the idea of linear open space system, which preserves the open character of the Bay down the center, and nodes of development, which can limit suburban impact around the Bay and attract growth from what otherwise would be suburban development. A water transportation system linking all of these sites would lessen the dependence on the automobile. There are people planning that right now. All of that requires a lot of balancing of social goals and what's important to whom. I think there is a gut feeling in Rhode Island that the Bay is our most important resource and that a fairly radical departure from the way people think about things is warranted in order to preserve that resource for the people of the state. We have a long way to go, but I have a lot of hope that it's going to happen.

(Applause.)

DR. PEARCE: In just one moment Dr. Nixon will commence leading the panel, and I hope that people will stay because this is one of the more important aspects of this kind of meeting.

Part of what we're going to talk about this afternoon will be ways in which we can resolve some of the problems that have been identified. I want to take an opportunity to thank the speakers that were here today, and I also want to thank Congressman Schneider for coming and addressing the group, I hope that the discussions for the next fifteen or twenty minutes will lead us toward some ideal of where the gaps are in the information.

During the lunch break some people suggested, "There's so much information there; what more research needs to be done?" I think that's a testament to drawing all of this information together. But there are gaps so how can the various agencies--EPA, NOAA, etc.--help these regional estuarine problems?

With that, I'll turn the program back to Scott Nixon and see if we can get an effective discussion going.

DR. NIXON: I think what we ought to do is give you a chance to ask Bob questions on his talk before we go any further.

MR. BENDICK: I wanted to just add one quick thing. I don't think I quite tied the two parts together, the land-use business and the pollutant business. Somewhere, if you clean up the Bay--if cleaning up the Bay is not an abstraction and has some human benefit--and you don't have adequate access, whether it's visual access, physical access, or adequate use of the resource, you've spent all this money on one thing and haven't been able to take advantage of it. I think that's why the land-use has to be so tightly connected to the other items.

QUESTION: Did I hear you say that in your state that your new permits required continuous monitoring?

MR. BENDICK: It's not continuous. It depends on the plant and on the discharge. The frequency depends on the permittee and the components of his discharge. We do require weekly monitoring in some places.

QUESTION: How about municipalities?

MR. BENDICK: We've only issued one permit for a municipality so far. And I would guess it's about monthly. Most things are monthly to bi-weekly.

QUESTION: What would you estimate the additional cost for monitoring to be?

MR. BENDICK: I don't know.

QUESTION: What kind of relation do you have with Massachusetts to deal with that one part of Narragansett Bay that you do not control, Mt. Hope Bay?

MR. BENDICK: Well, there's the Blackstone River, the source of which is the Worcester sewage treatment plant. That's an important component for Massachusetts, too. There hasn't really been that much cooperation yet. On both the Blackstone and on Mt. Hope Bay there's a lot that needs to be done. We have not really addressed that problem.

QUESTION: As I understand it, Rhode Island has a system of town conservationist commissions.

MR. BENDICK: Yes

QUESTION: What significance are they in developing some of these concepts of unified approach toward solving some of these problems?

MR. BENDICK: In general, the conservation commissions are very weak and don't play a major role in this kind of thing.

QUESTION: Did you say what the state role would be in administering the Narraganset Bay Study money grant?

MR. BENDICK: We are partners with EPA on this project. The regional administrator, and I are co-chairs of the project. We have hired Eva as the Director of the Narragansett Bay Study, and EPA is going to assign a full-time person; we're going to work hand-in-hand on this.

QUESTION: What have you done with the 404 Program?

MR. BENDICK: I believe we are still on a trial basis with the 404 Program. We have a temporary delegation but not full delegation. Our Coastal Council Coastal Resources Division handles the salt water problems. The freshwater items are addressed by our so-called Land Resources Division. We're not sure whether we want full delegation or not at this point.

QUESTION: Wouldn't that be yet another tool to use to control development in the coastal area?

MR. BENDICK: It might be. The Corps is fairly decent about it. Both are in Rhode Island anyway. They want to do some things with which we may not agree, but our Freshwater Wetlands Act is stronger than 404, so that takes care of the freshwater part of it.

QUESTION: Are there any health problems, bacterial or viral, associated with shellfishing?

MR. BENDICK: In the Bay?

QUESTION: Yes.

MR. BENDICK: Well, I'm not the best person to answer that question. There are of course, shellfish-related diseases--astroenteritis, from shellfish-polluted waters. We try very hard to keep people from digging shellfish in polluted waters. About two-thirds of the effort of our office's division is spent on that one task since it's a very large resource in the area that is not open to shellfishing. We have conditional areas that move back and forth in the case of rain. We do close beaches, conditionally, in the case of very high rainfall when the Providence plant is flooded out. But I don't know of any other source that documented. It would be a useful objective to open up more areas of the Bay for shellfishing. As somebody said earlier--I think it was Scott--there are seven miles of area that could potentially be opened to shellfishing, which represent a tremendous resource, assuming there's a market.

DR. THOMAS: Scott, I think we're particularly interested in the gaps. Where you see particular holes and where you see some positive things that NOAA and the other agencies might be able to do to help.

PANEL DISCUSSION

DR. NIXON: Well, I think one of the things that can't help but strike anybody when they get into this business is how little we know about Narragansett Bay even after forty-some years of study of the Bay with a marine laboratory sitting right next to it and government fisheries laboratories and an EPA laboratory, which at one time was a public health service laboratory, and all the various state efforts that are under way as well. When you ask the most basic questions that people want to know which are: What's going into the Bay? Where's it going once it gets in there? What happens to it once it gets into the Bay? and What biological effect does it have? We see that we have little to say that's very useful to any of the people in management positions when they come with these kinds of specific questions.

I think this lack of information is due to the entrepreneurial approach we've taken toward research. You write an National Science Foundation (NSF) proposal, you get funded, and you do the work. With the idea of trying to take a systematic look at the way any material behaves in the marine environment, we find that we can't answer a basic chain of questions concerning the biological effects.

Those questions probably increase in difficulty. The easiest thing to figure out is how much material comes in, and even that's hard to do. You witnessed Eva Hoffman computations this morning with the sewer system and everything else. When we deal with other substances that come in at the mouth of the Bay, then we immediately get into all the problems Malcolm Spaulding talked about concerning what's going on in that area, how little we know about those processes, and then, the final deposition of these materials within the Bay proper.

Well, most of these things are tied to sediments where they bind very tightly, at least for part of the time and under certain conditions. We know very little about where sediments go and how they behave in Narragansett Bay. Coupling the sediments to the transport models that Malcolm has, we have absolutely zero. We've only begun to get data on the absorption-desorption characteristics of a few compounds in metals and how they behave in the MERL tanks where we can use radioactive isotopes and do some controlled mass balance studies. There's a whole host of things we haven't studied and we don't often know the effect of temperature, salinity, particle size, physical mixing, or the binding of metals with dissolved organic matter. There's a whole other series that is going to change the behavior from what you observe if you used pure isotope additions.

Then we get to the harder things: What are the biological effects? If we do know the effects on polychaetes, bivalves, or zooplankton in the water, getting from there to the effects on bluefish, striped bass, or winter flounder represents another generation of difficulty. So the problem is that most of the constituency is out there wringing their hands and begging for information about the hardest link in the whole chain. If Save the Bay really wanted to know where the cadmium was going in Narragansett Bay, if that was their burning question, we might stand some chance of giving them a fairly rapid response. But when the question is: "What does the cadmium have to do with hard clam yield?" Then the problem increases.

P. CAHN: Just to change the scene a little bit. You don't want Rhode Island to become a Long Island. Since I am from Long Island, I want to ask the economist the question: How can one expand the economy of Rhode Island, increase the GNP, the CPI, and so on, without increasing marine industry, and land development?

DR. RORHOLM: Obviously, there's no single answer to that question. I think that Bob Bendick's land-use scheme has a lot of promise. In many cases, these conflicts need not occur and his proposal may open an important way in which to avoid having to accept a decrease in environmental quality in order to achieve economic growth.

P. CAHN: But now you're speaking of a theoretical not a practical economy, correct?

DR. RORHOLM: I think the point is that income producing activities do not necessarily mean that you have to ruin the Bay in the process. As a matter of fact, as I mentioned, I have the very strong feeling that the Bay environment itself is one of the strong economic forces in the state. That's a very indirect relationship and not one that I can prove. But it is one that I am left with after many years of researching impact. I think it is possible, given that we can quantify the environmental as well as the economic tradeoffs, to have both a flourishing economy and an environment that encourages use of our natural resources.

P. CAHN: But what I'm really getting at is, isn't the dollar what determines this multiple-use conflict? Isn't that really what pushes the whole thing along? When the final decisions are made, isn't it the economy that really determines what will happen?

DR. RORHOLM: Yes, but, consumer spending and industries that are associated with manufacturing are also an important driving force in the state. If we cannot keep the coastal estuarine environment the way people like it when they make a decision to go there, then we're going to fail. Income earning is not always in conflict with maintaining the environment. In fact, more often than not they go in the same direction. I think another answer to your question is not trying to put the economy up against an objective analysis of impacts on ecosystems. I've been to a lot of hearings on this subject, and if you get up and say--although I happen to believe it's true--that you shouldn't build something because it's going to be ugly, wreck the scenery that's been there for many years so people won't think it's nice any more, you lose. If you say that the project is going to change the water quality classification of the adjacent waters from A to B, you win. Part of the need for the Narragansett Bay Study is to better understand what the objective impacts of development are so that you can make decisions based on impacts on the ecosystem, on swimming, fishing, shellfish resources, and things like that and not on the Bay aesthetics or wilderness.

QUESTION: The Chesapeake Bay has a big distinction between fish that use the Bay as a breeding ground and those that come in for feeding. Do you see that distinction in your Bay? In other words, are the fish anadromous or breeders? Are there feeders that come in? What type of deterioration do you expect in the fishing industry?

DR. NIXON: We have all those kinds of fish. We have some that breed in the Bay and we have some that come in. We don't have the anadromous fishery that you have. We have alewives that come in and fill up the streams. We have some, like menhaden, which come in and feed in Narragansett Bay and which are caught there.

DR. NIXON: Do you know the Marine Fisheries Council's position on any of this?

MR. BENDICK: I don't think that question has ever been asked quite in the same way. The idea is that Narragansett Bay is a good place for fish breeding. In fact, the upper Bay, where the water isn't as clean has more larval fish than the lower Bay. The migratory species, such as blue fish, swim all the way up to Providence past the sewage treatment plant. So I'm not sure that's a perceived distinction.

QUESTION: What about winter flounder? That wouldn't be true?

MR. BENDICK: No. They breed in the Bay. One of the ideas of cleaning up the Bay is to preserve that resource. I don't think anybody has made the distinction between migratory fish and breeding fish in the Bay.

QUESTION: Well, it was thought that breeders, even those that are not fish, are declining in coastal systems all over the U.S.

DR. NIXON: I have to go back to the clam question. Rhode Islanders talk more these days about clams than they do about finfish, in terms of Narragansett Bay, simply because it's a bigger commercial fishery.

As Bob Bendick said, on the one hand you say, "Let's open up more ground to go get more clams." At first glance that seems like there's a clear-cut objective. We can latch on to that as a management goal.

Some of the fishermen who are there now would not like to see the grounds opened up because that will increase the harvest, which will drive down the price. They say, "Hey, wait a minute, don't clean up the upper Bay because we don't want to drive the price down." You also have some of the fisheries biologists running around saying, "We better not open up the upper Bay because all those big old clams up there above the pollution line are brood stock for the area down below. The only reason we've maintained the clam population, in spite of this heavy fishing pressure, is because the pollution has saved this brood stock. If you open that up, that will destroy the fishery." So what's manager to do but wring his or her hands and go on to the next problem?

QUESTION: Scott, historically, is it fair to say that the anadromous fish runs were terminated with textile dams?

DR. NIXON: It sure made a start. DEM has had a program to open the anadromous fisheries up.

MR. BENDICK: That is true. They were eliminated a long time ago. The dam on the Blackstone, which did have salmon in it, was built around 1783. We are trying to restore anadromous fish to the Pawcatuck system. We have a small fairly successful salmon program there. That is by far a cleaner system which is right on the Connecticut-Rhode Island border, the so-called Little Narragansett Bay. We are getting some returns there, but on the two major rivers, the Blackstone and the Pawtuxet, that are the main rivers in the Bay, it's a hopeless case. We have no plans to restore anadromous fish, because there are too many dams. The component on the Pawtuxet half of the low-flow volume on that river is sewage. You are just not going to get salmon in there.

QUESTION: Well, what I think this means your perception of the problem that anadromous fish have been replaced by ocean-spawners has been colored for maybe a century. The Chesapeake has experienced successful anadromous runs and successful harvests. Yours were truncated by existing dams so that the perception of the public has been altered. They don't see the problem that in fact, may be there. In fact, I'd like to ask why you are trying to clean up Narragansett Bay, other than incidental fishery problems, human disease problems, and the closing of certain beaches from time to time. What is your goal?

MR. BENDICK: I think it's swimming and shellfishing that are the two main things.

QUESTION: We're hearing some social problems about whether we should open up the shellfish area or leave that as a sanctuary.

MR. BENDICK: I think that's a transitional market problem not a long-term problem. The market is used to accepting a certain amount of shellfish from Narragansett Bay and is built around doing that. Last summer, because the Providence plant was making a good deal of progress and because there wasn't very much rain last summer, we opened the Bay substantially farther north than it's been opened for four or five years. We could only allow shellfishing in that area for four hours a week one morning a week because the market could not absorb the resource that could be dug up there. But, eventually, the prevailing idea was to just open it when it's clean enough, not manage it for economic purposes. There will be a lot of dislocation to begin with, but eventually the market will work itself out.

QUESTION: Do you have great citizenry backing?

MR. BENDICK: Yes.

QUESTION: ---for cleaning Narragansett Bay?

MR. BENDICK: Eighty-seven million dollars. The eighty-seven million dollar bond issue is the largest bond issue in the history of Rhode Island. And it passed overwhelmingly because cleaning the Bay is, you know, a sacred task.

QUESTION: Scott, you raised an issue that I'd like to hear a little bit more about, which is that there are an awful lot of experts up there in many different areas and there's an awful lot of information that would be very useful. Who is going to put all of those scientists into a room, shut the door and lock it until they come up with a consensus plan on what is the most--advisable?

DR. HOFFMAN: Starting the second weekend in January of 1985 we had a series of meetings held at the University where we invited experts representing a number of different issue-oriented disciplines. We invited a group of modelers and said, "All right, what is the status of modelling in Narragansett Bay; where do we go from here; what are your problems?" That was a three-hour meeting. It was attended by about ten modelers.

The next day we had a meeting of chemists. It was attended by fifteen or sixteen chemists from the state, the Narragansett Bay Commission, and from the Field's Point Sewage Treatment Plant. Their chemists interacted with the oceanography chemists. We barely got through everybody's current level of activity in the three hours, so we had to have another three-hour meeting to decide where we should go from here. The chemists took about six hours.

Then we had a meeting of ecological biologists, fisheries biologists, and shoreline planners. Then we had meetings with Jack Pearce and people from NOAA and explored the coordination of potential areas of interest.

We've had meetings with Sea Grant and with Save the Bay for the same purpose. We had meetings with Save the Bay with regard to what issues they felt were most important from the public education and public information point of view. Along with the Save the Bay personnel we also had people from Ecology Action for Rhode Island.

QUESTION: And what's next?

DR. HOFFMAN: Well, we made a list of suggested projects that would be appropriate for Narragansett Bay. Made the list, looked at it, and I said, "I wish I had five million instead of one." The list is now under review by the EPA regional offices and by Bob Bendick's staff to prioritize the items on the basis of what their water quality management and resource management goals are. Those are due in my office tomorrow. We can always hope for a consensus. I have a feeling that this is not going to happen. We'll have to sit down and do some hard talking in the next week or two.

DR. BARBER: Speaking about the priorities, you all have represented a number of different viewpoints here. If we can take as given that the objectives for cleaning up the Bay are for swimming and shellfish, have I heard a bias toward industrial pollution being something that really should be given first attention?

DR. HOFFMAN: I don't think that decision has been made yet.

DR. BARBER: I'm asking you all today. I'm wondering if I've heard that bias from you all.

DR. HOFFMAN: I think that there are two major issues: the nutrient eutrophication-low oxygen problems that happen in the summertime, and the problem with industrial contamination. You have two possible attacks. Now, I'm not sure which one will come up with the highest priority at this point.

DR. BARBER: Well, if you add the economic point of view and the fact that you're trying to have nodes of development, industrial development or whatever, it would be nice, at the same time that you're trying to attack industry, to be able to give them some guidelines about how they might not affect the Bay or how they should interact with the Bay as they come in.

MR. BENDICK: I think that's why the studies have to relate so closely to the permit program, because those are the guidelines--the permit program and then the working back through the permit of the POTW to the pretreatment program. I think I have a slight bias toward toxics because it's an issue that would be nice to be dismissed or taken seriously. There's an overall public concern about toxics that is very pressing to them because people feel they're irreversible and that they may have some unknown impact that we have to address. If we can define the toxics problem a little better and then see if there really is a crisis, then we can go on to some of the other items. Now, in the Pawtuxet River study, which contains the highest concentration of toxic inputs, we all thought that toxics were the limiting factors in that river. The study that Dr. Quin and Eva did found that it was primarily the traditional pollutants, not the toxics, that were the overriding problem there. That was a revelation in terms of how you manage that river and some of the things you need to address in the future. But you wouldn't have known that unless you really had looked at the toxics problem first.

DR. HOFFMAN: I think that's right. Beforehand, the chemical plant already mentioned, discharged directly into the Pawtuxet River, and we evaluated that river before the tie-in occurred and you obtained a scenario of what the pollutants looked like in the river. Well, they tied into an upgraded Cranston municipal treatment facility and the municipal facility was designed with this chemical waste in mind. This plant was designed on a pilot-plant basis using this industrial input from the very beginning. When the tie-in occurred, they placed it in over a couple of months period so that everything got acclimated. The treatment plant worked very, very well on the chemical wastes. Concentrations of a number of the toxicants in the river decreased by a couple of orders of magnitude at the station that was formerly downstream of the discharge. So what we have here is a success. The success was not reported in the state-wide newspaper. Whenever there was trouble with this particular chemical company before, it always hit front page. But whenever we made some progress along that line, The Providence Journal sent a reporter to the meeting. He said, "What are all these chemicals? I don't understand it." And he left.

But what Bob Bendick says now, by and large, is true but only in the recent history, because this tie-in only occurred in 1983. Prior to that, it was a different situation altogether. This is one of DEM's inspirations and success stories. There was a great perception that it wouldn't work, that the Cranston plant wouldn't be able to handle it. However, because of the way the plant was designed, with this particular input in mind, it was a remarkably successful industrial tie-in. I'm afraid that the industrial tie-ins in the past were not so successful, but this one was.

MR. BENDICK: This particular plant produced some exotic chemicals that came only from this plant that showed up, far away, in the Bay. That raises questions in people's minds about the pathways of toxic chemicals. These chemicals don't happen to be particularly serious, but could be, if certain toxics ended up in lobsters in Rhode Island Sound. I think those are the kinds of things we'd like to begin to deal with as a high priority.

QUESTION: It is evident from the data that Scott presented and in some of Eva's data as well that you have a very nice plankton. In terms of plankton and water quality, you have a diatom-based system without the nuisance blooms we all have. In fact, in terms of water quality, it seems, again, that you don't have nitrogen and phosphorous problems yet.

You also have vertical mixing all the way to the bottom, which is a unique situation compared to Chesapeake Bay. What I'm asking is if you have increases in cholorophyll, which is a desirable food product for your plankton and probably a desirable food product for your menhaden, that perhaps it might be a good idea to look at that commercial fish catch of the menhaden and then look at the toxics for controlling absence of macrofauna right at the discharges. What I'm saying is that you have a nice system, and I don't see why you're trying to clean up Narragansett Bay.

QUESTION: The bloom in diatoms is later every year. There were no blooms of blue-greens nor of reds?

DR. NIXON: That's correct. There are a couple of things going on. One is that what you say is true. In lower Narragansett Bay, if we have an average maximum of ten micrograms per liter of cholorophyll now and if it were to go to twenty micrograms per liter in the lower Bay, all it would probably do is make some more fish food, and maybe it would even make more fish. Maybe it would all just get respired by the micro-flagellates and the benthos. It probably wouldn't create anything that would be called an adverse impact. The problem with eutrophication is in the upper Bay, in the whole structure of the Providence River, the Seekonk and possibly over in Mt. Hope Bay where we do have stratification and where we do have low oxygen conditions during the summertime over fairly large areas of the bottom. So that's where the major problem comes up.

In the lower Bay itself, Snada's record shows some interesting unexplained changes in the diatoms, and the flagellates, both in the timing, the magnitude, and in the species composition. The problem we have is that no one's been able to show in any clear way that that is an indication of a progressive eutrophication of the lower Bay. We don't know if that's the case or it's simply a response to longer term climatic changes.

Similarly, Perry Jeffries has a twenty-five year record of demersal fish from the West Passage of Narragansett Bay showing large cycles in the flounder and reciprocal cycles in scup. Perry thinks maybe it's interactions between scup and flounder, but he doesn't really know. Maybe it has something to do with the benthos.

Recently we've become aware that we have a ten-year or twelve-year record in Mt. Hope Bay. At a number of stations there we not only have phytoplankton, fish, and the invertebrates, but also nutrients, oxygen, salinity, and temperatures. So we're trying to work with that record to see if we can get anything out of it. I think we're at the point where we're still trying to unravel the long-term records that we have to find out what we can get out of them.

The other problem we continually have with the metals, the organics and everything else, is the extent of a fixed pollution gradient in the Bay, because there is the very large adsorptive capacity of the sediments, but to what extent is that wedge moving down the Bay. We haven't been able to sort that all out yet. That's going to take a good bit of coring and sediment transport examination and to determine behavior over time.

QUESTION: Malcolm, you showed us some flushing time data to try to get a sense of how pollutants are washed out of the Bay. I was wondering if there was some easy way you can talk about tidal pumping. It almost seems that the way materials get flushed out of the Bay is through a sort of tidal pumping. If so, would you be able to do that for other Bays? Could that explain why Narragansett Bay, even Long Island Sound, which both seem to have inputs comparable to the Chesapeake Bay but don't have the problems that Chesapeake Bay has?

DR. SPAULDING: All of those calculations--the tidal prism calculations, the mixing calculations, and the flushing calculations--rely on knowing the salinity balance. They don't really talk about how it all happens. They say, "I see so much freshwater come in here, I know that the observed salinity is this value, and that the observed salinity is this value here, and that it's another value at another location. I know in that order to get that measurement over the long-term, this is how much I have to mix salt water from out here to this much fresh water to get that observed salinity value." That's how all those calculations are done. The problem with the Narragansett Bay calculations is that there's not really any good long-term, reliable, consistent salinity measurements for the Bay. People go out and take salinity measurements for different reasons. Some people like to go down to the Bay and take transects and then collect salinity independent of the tide. They'll take data every day. They'll start at the same place in the Bay and go down and collect salinity; they forget to correct it for the tidal influence. The tidal influence in some places in the Bay is almost as large as the variation over many, many, kilometers. They take the weighted average of the salinity, then take the river flow, get it wrong by a factor of two, then calculate flushing time. So you've got a really nasty problem for something that ought to be relatively straight forward.

QUESTION: I wonder how close we have to be. You know, a factor of two is good for biology.

DR. SPAULDING: Oh, yes.

QUESTION: And to make the kind of permit decisions that biologists need to make, that value could be close enough, don't you think?

DR. SPAULDING: I guess the way I look at the problem is this! I'm interested in the physical side of transport business. I would like the errors not to influence the predictions at all. I would like to drive to the point where I can say, "This is how the system operates," and the controlling parameters are in someone else's ballpark. I'm also interested in the long-term understanding of why the circulation is that way. You can see the evolution of all these studies. In spite of all the programs that come along and the different driving forces, what we hope is over the next twenty years, we will start to understand more and more about the Bay. You can see how that's evolved since 1931. But my sense is in terms of the circulation. The flushing time is absolutely critical if we're going to understand these processes in the upper Bay, and it's important for us to narrow those things down so that when we see variability we can say, "That variability is due to a natural process," or "That variability is due to some biological process." It's when we can start to sort those things out to get natural variability, and be able to define that and the anthropogenic variability, and be able to define that, then we can understand the system well enough to manage it.

DR. PEARCE: It seems to me that one of the things that hasn't been addressed very well, or perhaps not at all here, is the matter of perception. A while back we were talking about how some advisors or managers wouldn't want to ameliorate the polluted conditions in the upper Bay for fear that would allow people to harvest clams that provided a source of larvae; I'm sure that people have seriously suggested this. Another side to this is that there is a perception in the public's mind that shellfish generally are not satisfactory to eat. Many people who would like to eat raw shellfish, or even cooked shellfish, hesitate to do so. Increasingly, as a matter of fact, many people hesitate to eat fish because they feel they have PCBs or some other contaminant in them. I therefore think, as we're looking to these kinds of meetings to direct our future research endeavors, we have to keep this sort of thing in mind. Perhaps one of the things we want to do, in a scientific manner, is to look at those variables which will improve, in the public's mind, the quality of seafood so that in fact more people will eat shellfish. Now, that might mean that we despoil all of the shellfish beds; that is, if people really felt that these animals were desirable to consume, they would go ahead and eat them and pretty soon we'd have an over-harvesting problem.

In the end the real reason that we're concerned with a lot of these issues is the quality of seafoods and ensuring that these resources can be productive through the coming decade. Those of you with the National Marine Fisheries Service know there are some ambitious goals to increase the yield of seafoods. A few years ago we were talking about a ninety percent increase, almost a doubling of the yield of seafoods. That cannot be done in the face of pollution and public perception. So it's one of the problems we have to deal with. Perceptions of the New York Bight, for instance, meant that in many people's eyes ocean dumping had something to do with that low DO event a few years ago. There are many scientists that believe that today; i.e., that ocean dumping of sewer sludge was somehow a causal agent in the hypoxia that extended over several hundred square kilometers. Again, that's the result of perceptions. So it seems to me as we are looking at what we're going to do in the future, we're going to want to produce information that will allow people to have a better attitude toward seafoods, and then to deal with some of the very real problems that we have.

It may be that Eva's parking lot with those oil stains is one of the more important pollution problems in the Northeast. Certainly in Denmark, where they recognized this problem some years ago, they now require that their cars be inspected; if there are no oil drips, there are substantive reductions in the amount of petroleum in Danish coastal waters. The Danish scientists that I know are accurate in their reporting of this matter.

DR. NIXON: I wonder how much tainted seafood eating and problems that people have are due to the environmental contamination versus how much is due to improper packaging and handling in the wholesale and retail end? The most direct impact on that might be through the technology and practices of handling of seafoods.

DR. PEARCE: I think that would have been a problem a few years ago, but American generally packs well nowadays--it was only a few years ago that McDonald's got all of its seafood sandwiches from Iceland or Poland, and today a good deal of that comes from U.S. packers. Certainly you can go to Steamboat Springs Colorado, and get beautiful fish on the west side of the Rocky Mountains, blue fish and so on; somebody has had to learn how to pack it, handle it, and ship it. This might still be an issue, but I don't know if it's of the same magnitude as before.

MR. BENDICK: I just want to make one comment: "Why clean it up?" I don't spend a lot of nights awake worrying that we're going to get Narragansett Bay too clean. Given the current trends, it's just not going to happen. We're not going to end up spending too much money to make it too clean. In terms of why we study these things, from a manager's point of view, we do so because the decision-making on permits or priorities for treatment plants are under such incredible pressure these days, from every side, and so much of the information that is being used in the public forum to bear on these decisions is so wrong. It is a benefit to economic development and to the functioning of the state's economy to go through these studies to find out what makes sense and what doesn't. Even now, in the distance we've come, it's easier to operate and to make decisions by having some information.

For example, in one case of the Ciba-Geigy Chemical permit, once these studies had come along, the hysteria was gone and the permit could be issued intelligently. Without the results of the Narragansett Bay Study, we can't make these decisions in a rational way. We can guess, but we don't have the information.

QUESTION: I wasn't at all questioning the appropriateness of cleaning up Narragansett Bay. I really want to learn how you're doing it, how you got the support of the people of Rhode Island.

And I find it's probably because you have one newspaper and three major institutions like URI and the National Marine Fisheries Services and EPA and not a very large state, and people are very much involved with Narragansett Bay. That doesn't seen to be the situation that pertains in any other areas like Chesapeake Bay and Long Island Sound and so on.

I was wondering how you went about selling the need to clean up Narragansett Bay when you really weren't using seafood or fisheries or end products as a main concern.

MR. BENDICK: Well, part of the environment for pushing it was in 1980 and 1981. The Providence sewage treatment plant failed. I mean, it just failed. Raw, undigested sewage was floating up on people's beaches, and that did it.

QUESTION: I think it's really because it's quite a small area. However, we may have that happening in the Chesapeake Bay, too.

DR. RORHOLM: I think part of it is that it's a small area. But we come back to the notion of value, and we don't really know what value people put on the Bay in various states. Because it's a fact that in many of the communities in the northern part of the state where I'd say probably ninety percent of the population will never effect the Bay, they voted for this. There's a willingness to pay because they don't think that it should be polluted. They think this ought to be clean. It's our resource.

QUESTION: I think it's wonderful. I was just trying to learn how you did it.

DR. RORHOLM: Yes. Well, I would like to learn something more about those kinds of value systems.

DR. NIXON: There's a sort of fantasy in Rhode Island, too. I mean, it calls itself The Ocean State, and it likes to revel in its privateers and Newport and whaling. Really, you know, this maritime thread runs deeply through the community, which in reality, of course, is and has been very heavily an industrial smokestack economy for two hundred years or so. But it's a very important thing.

MR. BENDICK: Those millworkers, for two hundred years they took those paddle wheel steamers. They took the trolley down the Blackstone Valley and got on the steamer in Providence, and that was summer vacation. That is ingrained in the culture of the state: that the Bay is a place to get away from the mill. I think that has never gone away.

QUESTION: I think you have an opportunity here to focus a lot of money in a small enough space to make some difference. I've always thought that we totally underestimated these problems by at least a factor of ten. But I think you're making a good point that sociological studies must go hand-in-hand with scientific studies.

We have an opportunity here to look at a small area, the impacts before and after this type of thing, and to obtain some very useful information.

MR. BENDICK: You should look at Scott Nixon and a team of people from URI in a smaller area. Look at the Rhode Island coastal ponds over time. They really got involved in the sociology of the use of the ponds, and it's really a good study, really interesting work.