NBP-90-47

Pathogens in Narragansett Bay: Issues, Inputs,

and Improvement Options 65 pp

Roman, C. T. (Narragansett Bay Project)

Narragansett Bay Estuary Program

PATHOGENS IN NARRAGANSETT BAY

- Issues, Inputs and Improvement Options -

A Narragansett Bay Project Technical Report

CHARLES T. ROMAN
Narragansett Bay Project
291 Promenade Street
Providence, Rhode Island 02908

#NBP-90-47

September, 1990

FOREWORD

The United States Congress created the National Estuary Program in 1984, citing its concern for the "health and ecological integrity" of the nation's estuaries and estuarine resources. Narragansett Bay was selected for inclusion in the National Estuary Program in 1984 and designated an "estuary of national significance" in 1988. The Narragansett Bay Project (NBP) was established in 1985. Under the joint sponsorship of the U.S. Environmental Protection Agency and the Rhode Island Department of Environmental Management, the NBP's mandate is to direct a five-year program of research and planning focussed on managing Narragansett Bay and its resources for future generations. The NBP will develop a comprehensive management plan by December, 1990, which will recommend actions to improve and protect the Bay and its natural resources.

The NBP has established the following seven priority issues for Narragansett Bay:

- management of fisheries
- nutrients and potential for eutrophication
- impacts of toxic contaminants
- health and abundance of living resources
- health risk to consumers of contaminated seafood
- land-based impacts on water quality
- recreational uses

The NBP is taking an ecosystem approach to address these problems and has funded research that will help to improve our understanding of various aspects of these priority problems. The Project is also working to expand and coordinate existing programs among state agencies, governmental institutions, and academic researchers in order to apply research findings to the practical needs of managing the Bay and improving the environmental quality of its watershed.

This report represents the technical results of an investigation performed for the Narragansett Bay Project. The information in this document has been funded wholly or in part by the United States Environmental Protection Agency under assistance agreement #CX812680 to the Rhode Island Department of Environmental Management. It has been subject to the Agency's and the Narragansett Bay Project's peer and administrative review and has been accepted for publication by the Management Committee of the Narragansett Bay Project. The results and conclusions contained herein are those of the author(s), and do not necessarily represent the views or recommendations of the NBP. Final recommendations for management actions will be based upon the results of this and other investigations.

PREFACE

The Narragansett Bay Project is charged with preparing a "Comprehensive Conservation and Management Plan" (CCMP) for protecting and enhancing Bay water quality and living resources. Potential corrective actions will be presented and implementation strategies suggested. Further, the CCMP will include a long-term environmental monitoring program to evaluate the effectiveness of implemented actions.

This draft Technical Report on "Pathogens in Narragansett Bay" is presented to the Project's Management and Policy Committees as a first step toward identifying preferred corrective actions for reducing the input of pathogens to the Bay. The draft report presents alternative corrective actions in brief. Based on Committee discussions and input from technical reviewers, the Project staff will pursue particular corrective options in detail. This detailed analysis will include identification of environmental benefits, technical-engineering feasibility, economic costs and institutional-regulatory-enforcement considerations.

Several corrective options are presented in this draft report. The Narragansett Bay Project and it's governing committees will ultimately recommend preferred options. However, <u>at this time, the Narragansett Bay Project is merely presenting options for discussion purposes and is not prepared to take a formal position</u>.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

ISSUES

In 1988, 25,743 acres (25%) of Narragansett Bay were permanently closed to shellfishing. Another 10,568 acres (10%) were closed for approximately 50% of the year as a direct result of storm-induced combined sewer overflows and wastewater treatment facility bypasses. In 1989, this area was closed for 74% of the year. The regulatory closure of shellfishing grounds in Narragansett Bay is intended to protect the public from consumption of shellfish that may be contaminated by human-sewage and associated disease-causing bacteria and viruses -- also known as pathogens. Similarly, beaches in the Providence River are closed to swimming, and other beaches throughout the Bay are routinely monitored for the presence of contamination.

Gastroenteritis (fever, vomiting, diarrhea), and to a lesser extent, hepatitis - both caused by viral pathogens - are the contemporary diseases of concern relative to consumption of shellfish and swimming in sewage-contaminated waters. Over 4,700 cases of gastroenteritis have been reported from consumption of sewage-contaminated shellfish in the northeast since the 1930s, with almost 80% of these occurring in the last decade.

This technical report evaluates the sources and relative loadings of pathogens to Narragansett Bay and then describes alternative source control or input reduction options.

PATHOGEN INDICATORS

Total and fecal coliform bacteria are used to indicate the possible presence of human fecal waste and thereby evaluate the suitability of Bay waters for shellfish harvesting and swimming. Use of the coliform indicator has contributed, among other factors, to the dramatic reduction in the incidence of diseases attributed to pathogenic organisms (e.g., typhoid fever, hepatitis). However, reported episodes of gastroenteritis related to viral agents have increased, suggesting the inadequacy of coliform bacteria in indicating the presence of viral pathogens. Narragansett Bay Project - sponsored research has found that;

- Viruses are more resistant to the process of chlorine disinfection than are bacteria. Since all Rhode Island wastewater treatment facilities (WWTFs) rely exclusively on chlorine disinfection, viral pathogens may be entering the estuary at greater densities than indicated by the coliform standard.

- Bacterial indicators die more rapidly in the water column in winter than viral indicators (phage). Therefore, regulators may underestimate the magnitude of health risk, particularly in winter.

Indicator Options

Recognizing the potential risks associated with consumption of shellfish, research at the national level is ongoing to evaluate relationships between various indicator levels in water and shellfish tissue and the actual incidence of shellfish-borne disease. The Narragansett Bay Project, and the EPA National Estuary Program, should assist wherever possible to ensure that this national research effort is completed in a scientifically sound and timely manner in order to resolve the indicator controversy.

POINT SOURCE PATHOGEN INPUTS

It is estimated that Narragansett Bay has over 120 combined sewer overflow (CSO) inputs. Research shows that CSOs represent the major source of pathogen contamination, as simulated by either the fecal coliform or Clostridium indicator. For instance, during a wet weather event in Mt. Hope Bay, 96% of the fecal coliform entering the Bay was from CSOs, 3% from the Taunton River and only 1% from WWTFs. In the Providence River, WWTF bypasses (at Field's Point and BVDC), and perhaps CSOs, appear to be major sources of fecal coliform during wet weather events. WWTFs are also considered as significant input sources of pathogens when evaluated based on the Clostridium indicator.

Point Source Control Options

A Bay and watershed-wide CSO abatement/mitigation plan must be adopted. Upon additional data synthesis (preparation of a CSO Technical Report by the NBP, initiation of Narragansett Bay Commission systemwide study, and Bay Project modeling efforts) related to pathogens and other parameters (metals, organics, nutrients), the Project will recommend a preliminary abatement plan, evaluate environmental benefits and estimate abatement costs.

Chlorination appears to be less effective at controlling viruses than other disinfection techniques. Further, there are instream toxicity effects associated with chlorination. Ozone or UV disinfection, although more expensive, are more efficient at viral control and have no well known toxicity effects. Alternative disinfection at WWTFs should be considered in conjunction with an effective CSO abatement program.

NONPOINT SOURCE PATHOGEN INPUTS

ISDS

Pathogenic organisms from individual sewage disposal systems (ISDS) can enter the estuary and tributaries by overland flow from failed systems or by groundwater. Evidence suggests that human viruses remain viable in groundwater up to 60 m (approx. 200 ft) downgradient from a septic system source. With almost 40% of the Rhode Island population dependent on ISDS technology, it is obvious that the potential for viral contamination from ISDS may be significant.

ISDS Options

Areas of high density development (perhaps >3 units/acre) that are unsewered and have multiple ISDS failures should be connected to existing or expanded WWTFs. The RI Sewer and Water Supply Failure Fund (a $5mil bond), a mechanism for financing critical sewer extensions and replacement of failed septic systems, is near complete obligation. Re-authorization should be considered or alternative funding sources evaluated.

To minimize the input of pathogenic viruses to the Bay, the density of septic systems within a critical zone (perhaps 1,000 ft) of estuarine and tributary waters should controlled. Within this critical zone, and especially adjacent to high quality areas (i.e., RIDEM Class A and SA waters; CRMC Type 1 and 2 waters), restrictive site criteria (i.e., minimum 150 ft setback and minimum 4 ft separation distance) and lot size controls (to be determined) should be instituted.

Further, it is recommended that local municipalities create Wastewater Management Districts (per 1987 RI enabling legislation) to promote adequate maintenance of septic systems and treatment/disposal of septage. Implementation of this option must be coupled with a regional plan to accept and treat septage.

BOATING ACTIVITY

It is estimated that approximately 34,000 boats annually using RI waters are, or should be, equipped with a head/toilet. If just 10% of these boats discharged their raw sewage to the Bay each day, the fecal coliform input would range from 51 to 51,000 x 10^{10} fecal coliforms/day. This upper limit is the same order-of-magnitude input as measured from some Providence CSO areas.

Boating Options

As of summer 1989 there were only 2 operational pump-out facilities in Narragansett Bay. Additional facilities are needed. The RIDEM currently requires (as a consent agreement) pump-out facilities in association with new or up-graded marina projects. CRMC's Harbor Management planning process represents another mechanism for insuring that an adequate number of facilities are located throughout the Bay.

The US Coast Guard (USCG) has enforcement authority over discharges to coastal waters. To enhance the enforcement presence, the RI Division of Boating Safety, in conjunction with local harbormasters, should assume responsibility for enforcing discharge prohibitions and enforcing use of available pump-out facilities. A Memorandum of Understanding with the USCG empowering enforcement responsibility to the State should be adopted.

A RI Sea Grant Marine Advisory Service working group on boat sewage is addressing the issue of pumpout facilities, including siting, education, enforcement, and waste transfer. Recommendations are forthcoming. Other options under consideration by the working group include designation of the Bay as a "no discharge zone", and restriction of live-a-boards to marinas with sewer hook-ups or pump-out facilities.

STORMWATER RUNOFF

Stormwater runoff is a significant source of fecal coliforms to estuarine waters. However, it is difficult to determine the actual input of human-derived pathogens from stormwater. Typical sources of fecal coliform in stormwater could include, wildlife and domestic animals. A human source could be from illegal sewage hook-ups to storm drains.

Stormwater Runoff Control Options

The RIDEM (Water Resources) currently evaluates sources of pathogen indicators to the Bay in conjunction with the shellfish growing area certification process. This activity of locating and mitigating inputs of human-derived sewage to stormwater drainage systems must be continued, and perhaps enhanced.

To further reduce stormwater runoff, and associated inputs of pathogens, best management practices recommended by the RIDEM must be pursued (i.e., Stormwater Management Technical Guidelines).

SOME GENERAL OPTIONS

Marine Outfalls and Regionalization

To enhance dilution of pathogen-contaminated effluent, consideration should be given to relocating WWTF outfalls that discharge into shallow, poorly flushed and/or isolated embayments. It is recommended that WWTF discharge locations be evaluated with respect to the hydrodynamic characteristics of receiving waters and proximity of outfalls to critical resource areas. If considered appropriate, the cost and engineering feasibility of outfall relocation should be further investigated.

There are over 30 WWTFs discharging into Narragansett Bay and tributary waters of the watershed. The objective of regionalization is to a) reduce the number of individual point source discharges throughout the Bay, and b) as presented above, promote discharge to well-flushed areas. Several options should be considered, ranging from regionalization of all WWTFs with an outfall to Rhode Island Sound to smaller regional efforts (e.g., focus on Providence area WWTFs).

Innovative/Alternative Wastewater Treatment

Numerous innovative technologies are available or being developed for wastewater effluent treatment. Some of these include, constructed wetlands, solar aquatics, and land-based spray irrigation. Implementation of these and other technologies, could reduce the direct input of treated wastewater to Narragansett Bay, and thus, reduce contaminant inputs (pathogens, metals, organics, nutrients). These technologies must be evaluated in more detail, taking into consideration the removal efficiency benefits, negative environmental consequences (e.g., viral contamination of groundwater), engineering feasibility and costs.

Shellfish Depuration and Enhanced Transplant Program

Decreasing the area of permanently and conditionally closed shellfish areas represents a primary objective of controlling pathogen inputs. Depuration and/or enhancing the existing transplant program are alternative options to enhancing the shellfish harvest potential of the Bay, while maintaining protection of public health. It is recommended that these options be carefully evaluated. The following must be considered; contaminant removal efficiency of depuration/transplanting (e.g., viruses, toxics), economic and market structure effects, and biological factors (potential depletion of spawning stock).

INTRODUCTION

SYNOPSIS OF THE ISSUE

Human sewage and associated disease-causing bacteria and viruses (or pathogens) enter Narragansett Bay by several pathways, including both point (combined sewer overflows - CSOs, wastewater treatment facilities - WWTFs, and WWTF bypasses) and nonpoint sources (septic leachate, boat discharges, runoff). By swimming in sewage-contaminated waters or consuming shellfish harvested from such waters, the potential exists for humans to contract diseases. The classic bacterial pathogen associated with consumption of contaminated shellfish is Salmonella typhosa, the agent for typhoid fever. Shellfish-borne typhoid outbreaks have not been reported in the United States since 1954 (Rippey, 1988), due in part to a bacterial coliform-based standard for management of shellfish harvest areas, widespread use of chlorine compounds as the active disinfectant in the wastewater treatment process, and dramatic reduction in the infected human population (Haas, 1986; Cabelli, 1990a).

Today, concern has shifted toward the increasing number of shellfish-associated disease outbreaks that are linked to viral agents (Richards, 1985; Goyal, 1986). Outbreaks of shellfish-borne infectious hepatitis were first documented in the United States in the early 1960's. Based on a survey conducted by the U.S. Food and Drug Administration (FDA; Rippey, 1988; Table 1), over 850 reported cases (from 1961-1988) have been attributed to consumption of quahogs (Mercenaria mercenaria) that were harvested from northeast coastal waters (NJ, NY, CT, RI, MA). The most recent hepatitis case in which Rhode Island was cited as a possible source of the infected shellfish occurred in 1983 (Rippey, 1988). A less severe disease, gastroenteritis, has also been linked to the consumption of shellfish (Table 1). In the northeast, there have been over 4,700 gastroenteritis cases reported since the 1930's, with almost 80% of these occurring in the last decade. The causative agent in these gastroenteritis attacks was mostly uncertain, but viruses were the most likely cause (Richards, 1985). The Norwalk virus, first associated with shellfish-transmitted gastroenteritis in 1980, is now well-documented as the agent for frequent and widespread illness in the northeast (Morse et al., 1986). This dramatic increase in reported gastroenteritis cases may reflect a real trend or be, in part, related to increased public awareness and increased disease reporting, or increased illegal harvesting and marketing of contaminated shellfish. Obviously, the gastroenteritis statistics presented in Table 1 do not reflect many of the mild cases that go unreported. Further, the increased trend in gastroenteritis over the last decade may, or may not, reflect the actual situation relative to consumption of Narragansett Bay harvested shellfish. Existing records at the FDA (Rippey, 1988) or Rhode Island Department of Health (RIDOH) are not sufficient to conduct a Narragansett Bay, or even Rhode Island specific, analysis.

The evidence (Table 1) clearly suggests a risk associated with consumption of shellfish harvested from northeast estuarine waters. To protect the public from consumption of pathogen-contaminated shellfish, 25,743 acres of Narragansett Bay were permanently closed to harvesting in 1988 (Fig. 1), representing 25% of the Bay. Another 10,568 acres were classified as conditionally closed (i.e., minimum 7-day closure after 1/2 inch of rainfall in a 24 hr period). During 1989, a particularly wet year, the conditional area was closed for 74% of the year (263 days). During years of near average annual rainfall, such as 1988, the Bay is generally closed about 50% of the year. An additional 497 acres in the vicinity of marinas and developed harbors (potential pathogen sources) were seasonally closed in 1988 (May 28 to September 30).

Aside from the shellfish consumption issue, gastroenteritis and other illnesses (swimmer's itch, ear infection) have been linked to swimming in pathogen contaminated waters (Cabelli, 1977; Cabelli et al., 1983). In Narragansett Bay, some bathing beaches are permanently closed (e.g., Riverside, East Providence), while others are monitored by the Rhode Island Department of Environmental Management (RIDEM) because of the potential for pathogen contamination (e.g., Barrington Town Beach).

Table 1. Disease outbreaks related to consumption of northeast (NJ, NY, CT, RI, MA) shellfish. Source: Rippey, 1988.

Disease	Agent	Year	State(s)	# of Cases
Typhoid	S. typhosa	1954	NY	1 (last)
Hepatitis	Hepatitis A virus	1961-88	Northeast	850
Gastroenteritis	Norwalk virus	1930-88	Northeast	4,742
		1980-88	Northeast	3,882

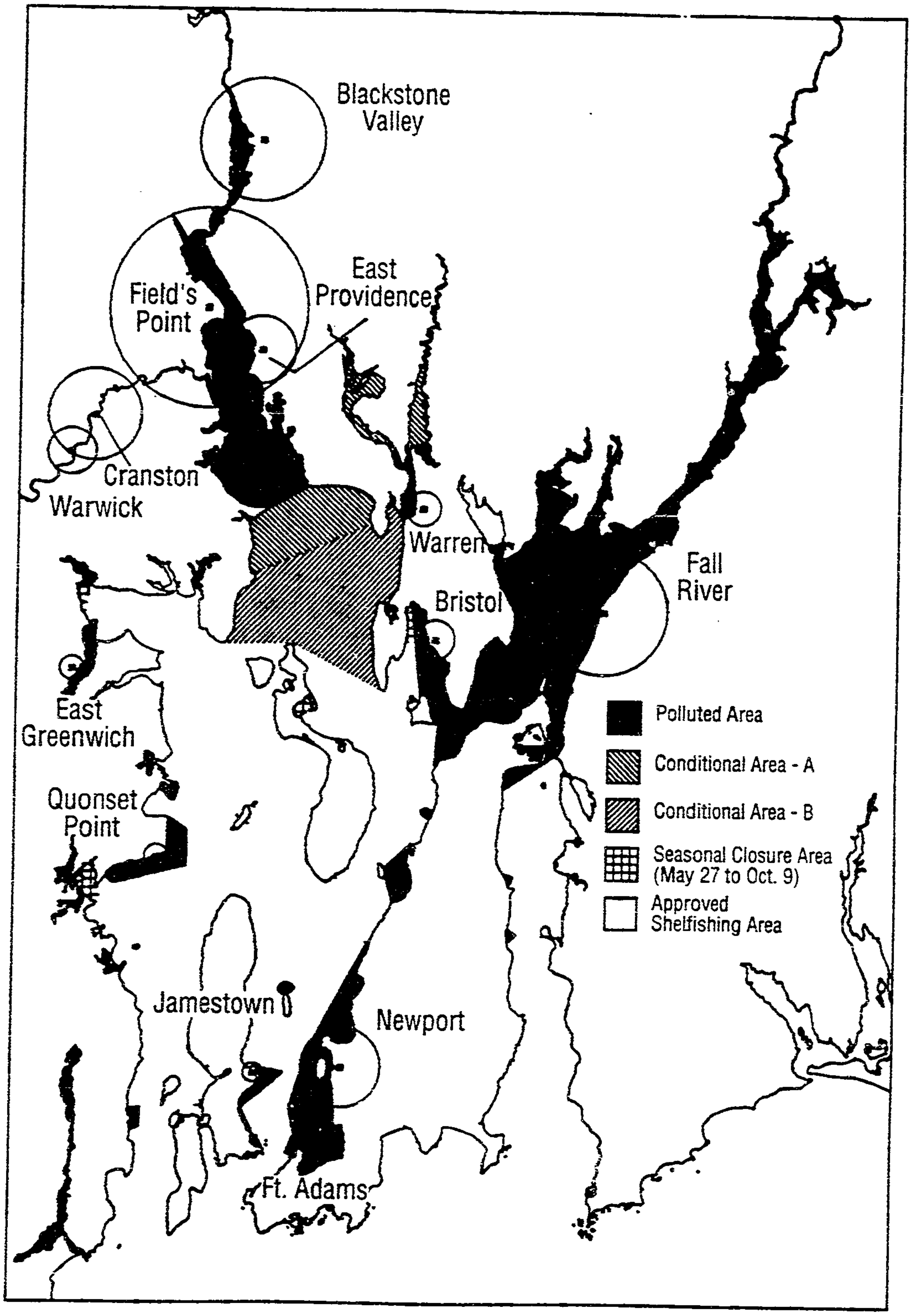


Fig. 1. Shellfish closure map for Narragansett Bay (1989). Closed and conditional areas in relation to WWTFs are shown.

The Narragansett Bay Project has funded several studies to address the issue of pathogens in the Bay. This technical document will review and synthesize that research, along with other relevant literature, with the objective of evaluating the sources and relative loadings of pathogens to the Bay and then recommending alternative management options for source control/input reduction. Presentation of the pathogen issue in Narragansett Bay begins with an evaluation of the present system used to indicate the suitability of shellfish areas for harvest and bathing beach recreation.

INDICATORS

COLIFORM STANDARDS

Frequent shellfish-borne outbreaks of typhoid fever led to creation of the National Shellfish Sanitation Program (NSSP) in 1925. The NSSP, a cooperative program of the FDA and shellfish producing states, established a coliform-based indicator for evaluating the suitability of shellfish areas for harvest. Coliform indicator criteria, adopted by Rhode Island and approved by the NSSP, for the classification of shellfish harvest areas are listed in Table 2. Total and fecal coliforms are generally not considered pathogenic and do not have an exclusive human source (fecal coliforms are found in all warm-blooded animals); however, they are assumed to indicate the presence (or potential presence) of human fecal waste and human pathogens. It should be noted that several states have adopted a fecal coliform criterion of $\leq$ 14 MPN counts/100ml (MPN = most probable number based on a multiple tube fermentation technique). The Rhode Island criterion is 15 counts/100ml.

There are several reasons why the indicator concept is used as opposed to testing for specific pathogenic organisms. First, the occurrence of pathogens in the general population is low. Further, there exist too many pathogen types to monitor for, and the presence of one does not indicate the presence of others. Pathogens, if present are in relatively low concentrations and difficult to directly assay in the environment. The technology to isolate and culture specific organisms (especially viruses) in a routine, cost effective, and time efficient manner is not yet available. Consequently, indicators of fecal contamination are employed as sentinal organisms to show when the risk of disease is present.

The suitability of Rhode Island saltwater beaches for full- body contact recreation is also regulated based on total and fecal coliform indicator levels (Table 2). Gastroenteritis is probably the most common illness associated with swimming in sewage contaminated waters. Swimmer's ear, caused by a bacterial agent (Pseudomonas) and swimmer's itch (protozoa, shistosomes) may also be common. The U.S. Environmental Protection Agency (1986) has recommended that states adopt an enterococcus indicator in favor of the coliform indicators. Deacutis (1988), in a study conducted for the Narragansett Bay Project, suggested that the enterococcus group of bacteria are highly sensitive to chlorination (also see section of this report titled "response of indicators to chlorination"), and thus, when evaluating potential pathogen inputs in areas receiving chlorinated wastewater discharges (i.e., Narragansett Bay), enterococcus should not be used as the preferred indicator. In Rhode Island, total and fecal coliform remain as the regulatory indicators for saltwater beaches (Table 2).

SOME TRENDS IN COLIFORM INDICATOR LEVELS IN THE BAY

The State of Rhode Island (RI Dept. of Health and RI Dept. of Environmental Management) has been collecting coliform data from stations throughout Narragansett Bay since the 1940s. The early data records are fairly incomplete, with respect to limited sampling frequency (e.g., missing and/or lost data) and poor documentation (e.g., tide stage at collection, antecedent weather conditions). However, beginning in the 1960s, the data record is more complete and amenable to analysis.

Table 2. Rhode Island seawater quality criteria for fecal indicators.

	Indicator (MPN counts/100 ml)		
	Fecal Colif.	Total Colif.	Entero
Shellfish Harvest			
Approved areas			
median	15	70	-
maximum[a]	50	330	-
Bathing Beaches			
median	50	700	35[b]
maximum	500	2300	104

a Only 10% of samples may exceed this level.

b Enterococci criterion is a geometric mean (not median). RI has not adopted this EPA recommended indicator for recreational waters.

Four sampling stations in Upper Narragansett Bay were selected for analysis (Fig. 2), with the objective of evaluating temporal trends in total and fecal coliform levels. Stations 8A and 11A are located near Conimicut and Nyatt Points, respectively. Two downstream stations, 2 and 3C, are further from the immediate influence of Providence area sewage inputs. The data analyzed from stations 8A and 11A begin in 1960, while stations 2 and 3C are from 1979 to 1988.

During analysis the data for each station were sorted according to tidal stage at sample collection (flood or ebb) and antecedent weather conditions (wet = data collection within 7 days after a 0.5 inch or greater rainfall in a 24 hr period; dry = other times). As noted from Table 3, the downstream stations (2 and 3C) show no differences between coliform (total or fecal) data collected on a flood or ebb tide; however, stations 8A and 11A do show some significant differences, with ebb concentrations greater than flood, as expected. For downstream stations (2 and 3C) the influence of dilution/mixing is probably masking the tidal effect. With respect to rainfall effects, the data for all stations strongly indicate that under wet conditions, coliform levels are significantly elevated (Table 4). This justifies, in part, designation of the conditional shellfish harvest area in the Upper Bay. It is interesting to note that under wet conditions the mean of the coliform values collected over the period of analysis (1979-1988) at the downstream stations did not exceed the RI water quality criteria. However, on individual sample dates levels did exceed the criteria, thus justifying the "conditional" classification.

Long-term trends in the coliform data are difficult to discern. For example, at station 11A, under wet and ebb tide conditions, the nearly 30-yr record of total coliform levels is quite variable (Fig. 3). Plots (not shown) are similar for the other stations and conditions. However, it is interesting to note that over the past several years (1983-1988) there appears to be a statistically significant (Kendall's tau-b correlation) declining trend at some stations for total coliform (station 11A wet/ebb, $p < 0.01$, Fig. 4; station 11A, dry/flood, $p < 0.05$; station 8A, dry/flood, $p < 0.01$). Although many explanations can be considered, this recent trend may reflect efforts by the Narragansett Bay Commission to eliminate dry weather combined sewer overflows (CSOs), reduce wet weather CSO inputs, and improve disinfection practices. No such recent trends were noted for the fecal coliform data and no plausible explanations are offered for this apparent discrepancy between total and fecal coliform data.

ALTERNATIVE PATHOGEN INDICATORS

Use of coliform indicators has apparently contributed to the dramatic reduction in the incidence of waterborne diseases attributed to pathogenic bacteria (e.g., Salmonella typhosa) [Note: other factors include wastewater disinfection and reduction in infected population]. However, with the hepatitis and gastroenteritis outbreaks of the past several decades, much discussion has been generated concerning the adequacy of the bacterial indicator in safeguarding the public from viral illnesses. The Narragansett Bay Project funded several field surveys (Rippey and Watkins, 1988; Cabelli, 1990 a & b; Watkins and Rippey, 1990) aimed at comparing a variety of pathogen indicators (fecal coliform, Escherichia coli, Clostridium perfringens, enterococci, and bacteriophage). Results of these studies, along with other relevant literature, will assist in addressing some of the concern associated with the present use of fecal coliform as an indicator of pathogen input to the estuarine environment. Issues to be discussed include, 1) differential response of indicators to chlorination, 2) seasonal behavior of indicators, and 3) relationships between indicator levels in the water, sediments and shellfish tissue.

RESPONSE OF INDICATORS TO CHLORINATION

Research suggests that viruses are more resistant to the process of wastewater chlorination than are the bacterial indicators (see reviews by Haas, 1986; Water Pollution Control Federation 'Disinfection Committee,' 1987). This is demonstrated by indicator levels in pre- and post-chlorinated effluent at the Narragansett Bay Commission's Field's Point wastewater treatment facility (Table 5, Fig. 5). For fecal coliform and enterococcus there was a very efficient reduction in levels after

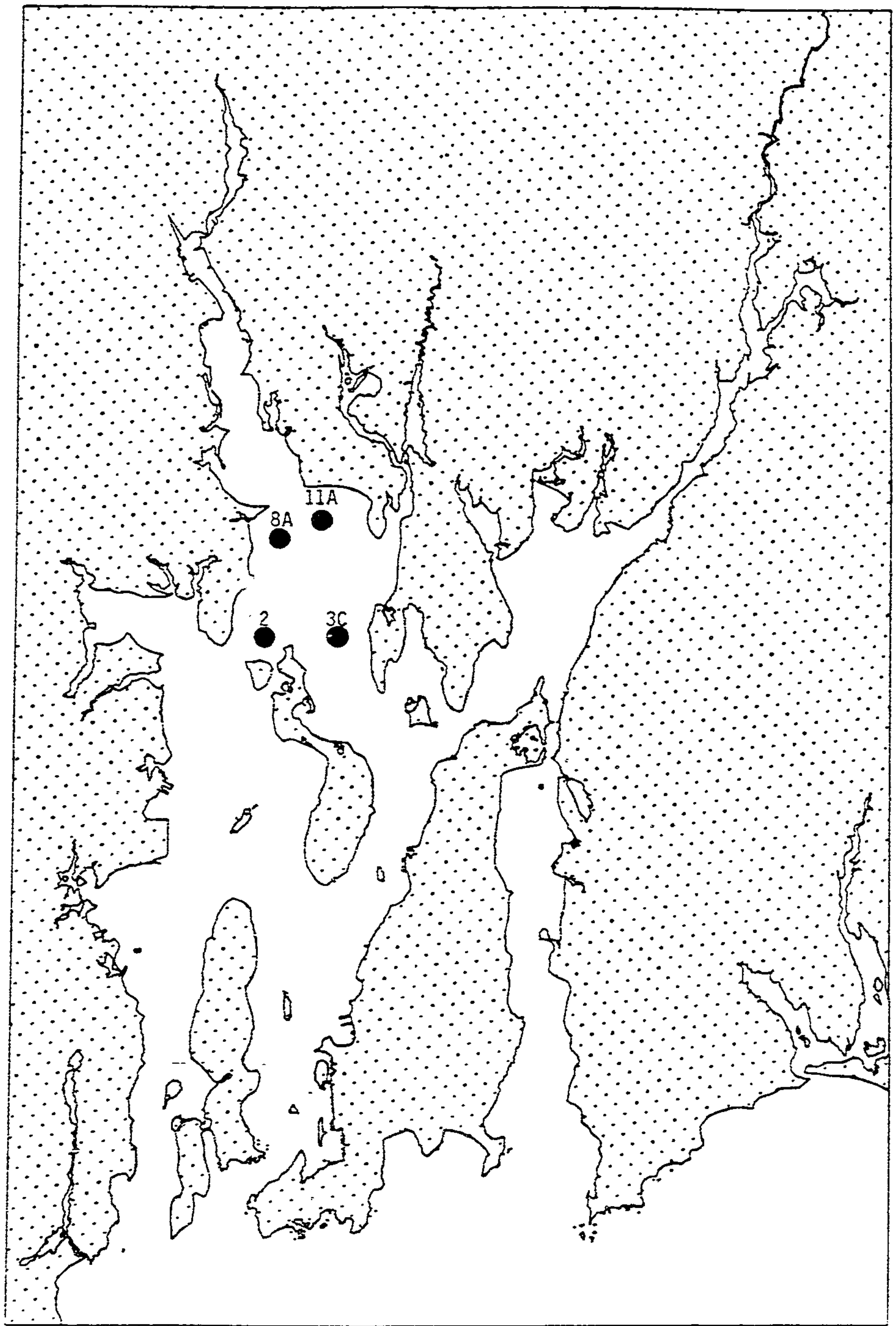


Fig. 2. Coliform sampling stations in Upper Narragansett Bay subjected to long-term trend analysis.

Table 3. Evaluation of tidal effects (F=flood, E=ebb) under both dry and wet weather conditions, on coliform levels in upper Narragansett Bay. Statistical significance is based on the Mann-Whitney U test (stations 2 and 3C, n=54-61; 8A and 11A, n=111-202).

Station	Dry			Wet		
	F		E	F		E
			TOTAL COLIFORM (MPN/100ml)			
2	6.0		7.4	38.0		38.0
3C	7.4		7.6	47.9		26.9
8A	45.7	**	74.1	151.4	+	218.8
11A	52.5	**	74.1	162.2		208.9
			FECAL COLIFORM (MPN/100ml)			
2	2.9		3.2	6.9		5.8
3C	2.8		3.2	7.8		6.0
8A	10.0		13.2	30.2		33.1
11A	10.7	*	16.6	31.6		38.0

+ $p < 0.10$
* $p < 0.05$
** $p < 0.01$

Table 4. Evaluation of rainfall effects (W=wet; D=dry), under both flood and ebb tide conditions, on coliform levels in upper Narragansett Bay. Statistical significance is based on the Mann-Whitney U test (stations 2 and 3C, n=54-61; 8A and 11A, n=111-202).

Station	Flood			Ebb		
	W		D	W		D
TOTAL COLIFORM (MPN/100ml)						
2	38.0	**	6.0	38.0	**	7.4
3C	47.9	**	7.4	26.9	**	7.6
8A	151.4	**	45.7	218.8	**	74.1
11A	162.2	**	52.5	208.9	**	74.1
FECAL COLIFORM (MPN/100ml)						
2	6.9	**	2.9	5.8	**	3.2
3C	7.8	**	2.8	6.0	**	3.2
8A	30.2	**	10.0	33.1	**	13.2
11A	31.6	**	10.7	38.0	**	16.6

** $p < 0.01$

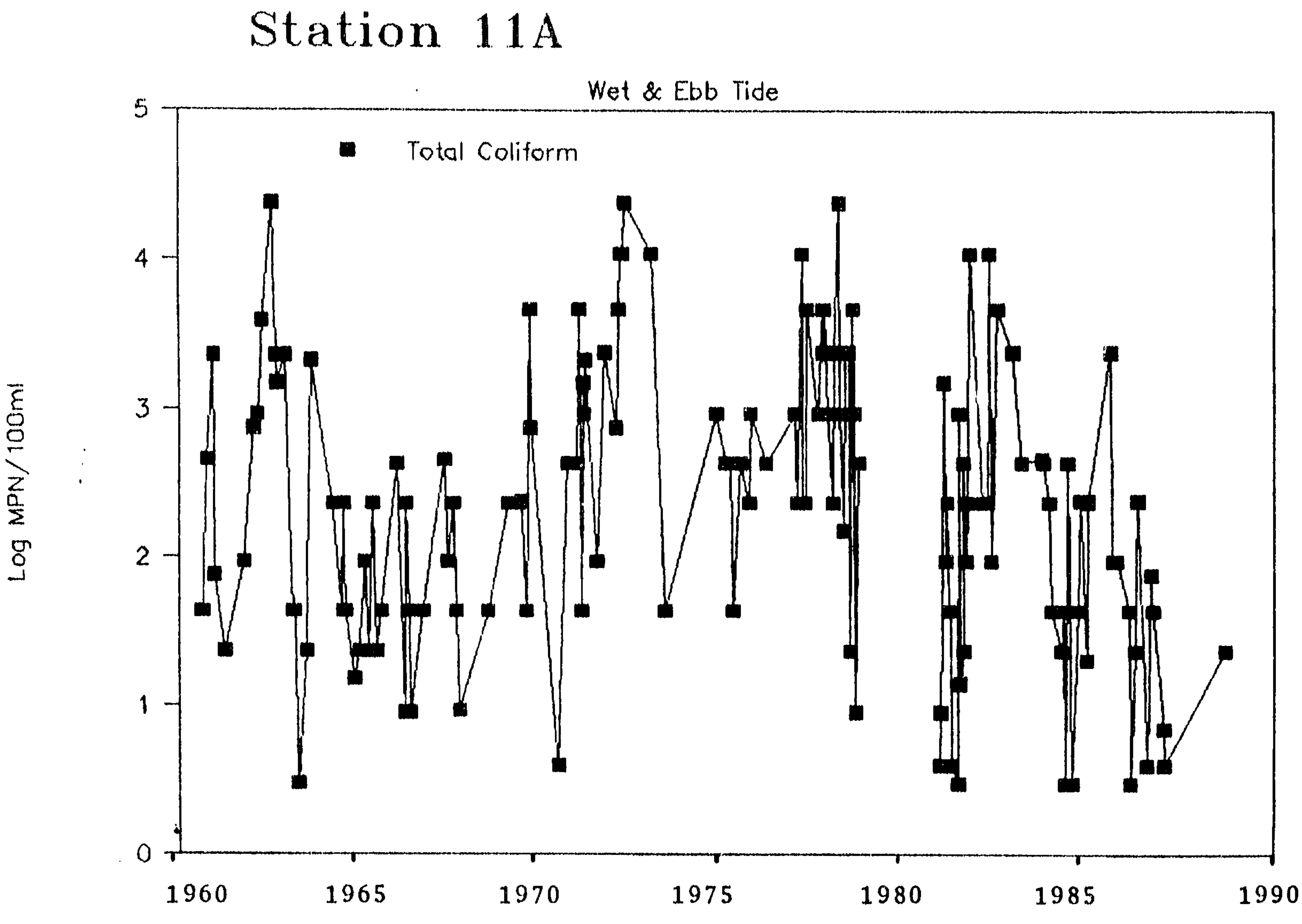


Fig. 3. Long-term trend in total coliform levels at Upper Narragansett Bay station 11A, under wet and ebb tide conditions.

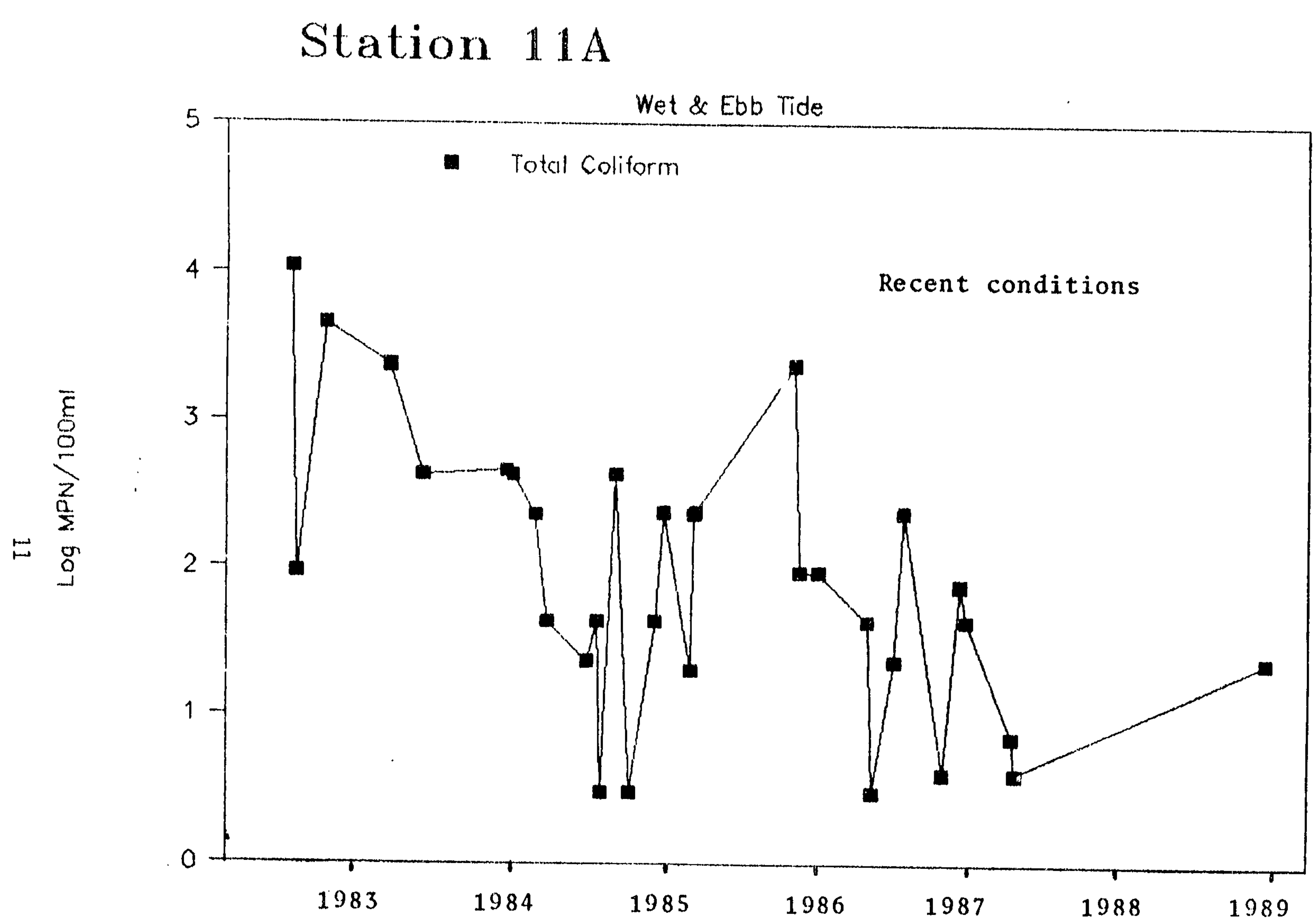


Fig. 4. Short-term trend in total coliform levels at Upper Narragansett Bay station 11A, under wet and ebb tide conditions.

Table 5. Comparison of pre- and post-chlorination levels of indicators at the Field's Point wastewater treatment facility. Data from Cabelli (1990[a])

Date	Treatment	Number organisms/100 ml			
		C. perfringens	F. phage	Enterococci	Fecal col
Dec. 1985 (n=5)[a]	Prechlorination	41,976[b]	18,923	59,566	330,370
	Postchlorination	12,503	6,887	27	206
	% reduction	70%	64%	99.9%	99.9%
July 1986 (n=4)	Prechlorination	22,542	16,293	8,892	77,983
	Postchlorination	10,046	9,057	177	173
	% reduction	55%	44%	98%	99.8%
July 1987 (n=3)	Prechlorination	2,891	4,027	6,412	17,865
	Postchlorination	4,898	4,256	1.2	16
	% reduction	Inc	Inc	99.9%	99.9%
Nov. 1985 (n=2)	Prechlorination	33,923	84,236	-	-
	Postchlorination	16,963	39,811	-	-
	% reduction	50%	53%	-	-

a n = number of corresponding pre- and post-chlorination data values collected over several consecutive days during the identified sample month.

b Values presented are the mean of n observations. % reduction is the mean of n pre vs. post calculations.

FECAL COLIFORM

CLOSTRIDIUM

PHAGE

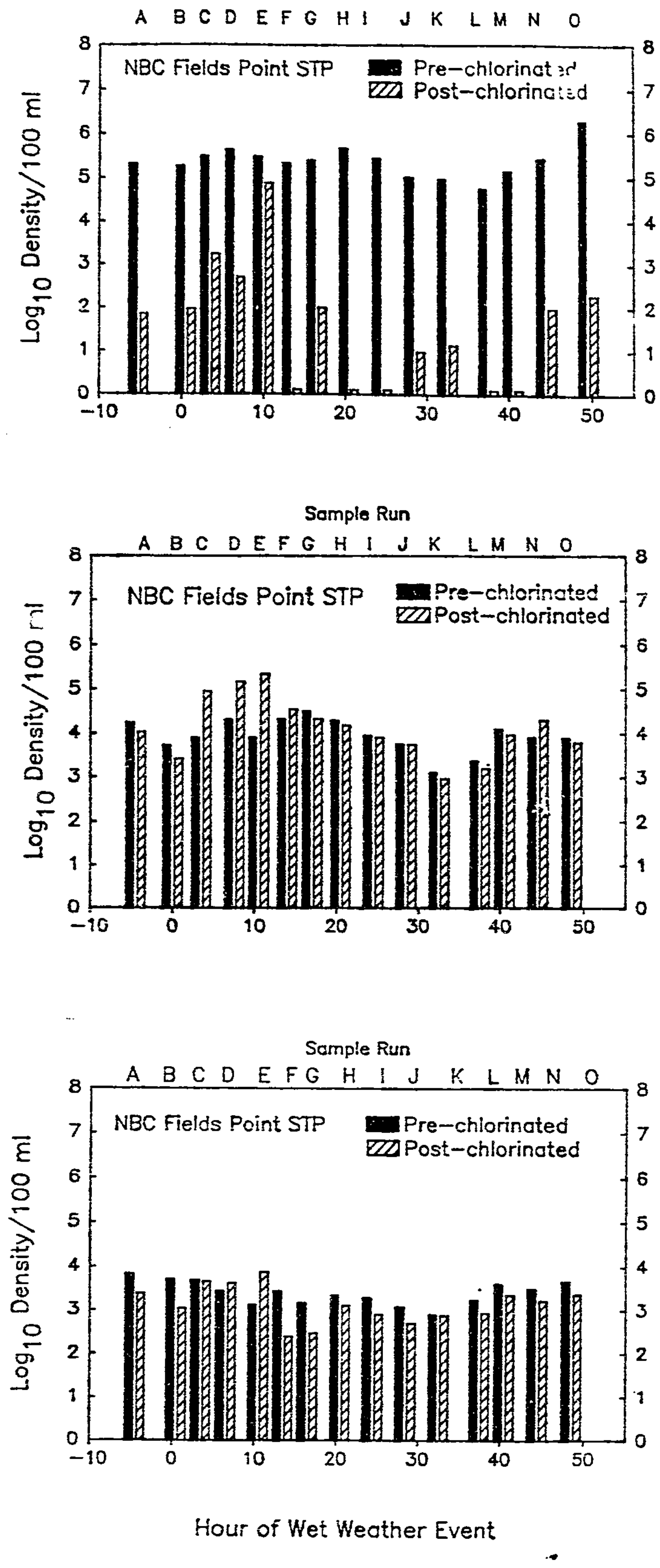


Fig. 5. Indicator densities in pre- and post-chlorinated effluent from the Field's Point WWTF during an October 1988 wet weather sampling event. Plots redrawn from Watkins and Rippey (1990)

chlorination (often greater than 99%). In contrast, Clostridium, a spore-forming bacterium, and the f-phage (a virus) appeared more resistant to chlorination as demonstrated by less dramatic reductions. In fact, on occasion, levels were higher in the post-chlorinated effluent for these latter two indicators. It should be noted that this data presentation (Table 5, Fig. 5) shows relative responses of the various indicators to chlorination. Each discrete pre- and post-chlorination sample pair was taken almost simultaneously, thus the same parcel of water was not tracked and sampled from pre- to post-chlorinated condition (i.e., there is about a 30-min contact time in the chlorination chamber). The fact that different parcels of water were sampled may explain, in part, the observed increase in indicator levels from pre- to post conditions.

This trend in indicator response to chlorination is interesting, especially with respect to the phage. Bacteriophages are a major class of viruses that attach to 'host' bacteria (Duckworth, 1987). It has been suggested that this viral indicator may serve as an effective simulant of human enteric viruses, such as the Norwalk virus (Gerba, 1987; Cabelli, 1990a). In a recent study, Keswick et al. (1985) found that the Norwalk virus was the most chlorine resistant when compared to other animal viruses (poliovirus, rotavirus), and further, similar to the Norwalk virus, the f-2 phage showed resistance to chlorination. As noted by Watkins and Rippey (1990), it is probable, therefore, that viral pathogens that are similar to the f-2 phage in their resistance to chlorination are surviving the treatment process and being discharged into receiving waters. These findings clearly identify the need for an indicator that is chlorine resistant or implementation of disinfection practices that are more efficient at viral control (to be discussed later in this report).

SEASONAL TRENDS

The studies conducted by Cabelli (1990 a&b) suggest that the various indicators respond differently with respect to season. For example, in winter the fecal coliform indicator levels in the water column had a greater biological decay rate than the phage indicator (Table 6). This implies that during cold weather periods viruses survive better than bacteria, suggesting that (at least in winter) fecal coliform may not be an appropriate indicator of virus-generated diseases. In summer, decay rates of the phage and bacterial indicator are similar, suggesting that the fecal indicator may be adequate. Although the decay rates between summer and winter conditions are statistically significant, Cabelli's (1990a) biological decay data must be viewed with caution because of a limited number of data points used to calculate decay coefficients.

Watkins and Rippey (1990) evaluated indicator decay rates in the Providence River in summer only, so a seasonal comparison as done by Cabelli (1990a) is not possible. However, it is interesting to note that based on tracking of indicator densities in a discrete dye patch originating from the Field's Point WWTF discharge, it took from 2.4 to 5.9 hours for fecal coliform to decay (i.e., biological decay or die-off, as opposed to decay related to sedimentation and dilution) one order of magnitude (i.e., one log/100 ml unit). No decay of the phage indicator was noted. Cabelli's (1990a) results, suggesting that decay rates for fecal coliform and phage are similar in summer, do not agree with those of Watkins and Rippey (1990). Although the results from these two independent studies provide some insight to the relative sensitivity of pathogen indicators in the estuarine environment, no definitive conclusions can be made at this time. Additional research evaluating the seasonal response of indicators in the water column is clearly needed.

Dramatic differences in levels of fecal coliform and phage indicator levels were noted, however, when quahog (Mercenaria mercenaria) tissue were examined. Figure 6 shows that in shellfish harvested from Mount Hope Bay (Rippey and Watkins, 1988), levels of the bacterial indicators were dramatically reduced in winter months. This suggests that the phage, and perhaps Clostridium, may be better indices of the pathogen-contaminated status of shellfish harvested from cold, temperate waters (Rippey and Watkins, 1988). This seasonal trend of indicator levels in shellfish harvested from Upper Narragansett Bay was not as apparent (Figure 7; Cabelli, 1990b). It is not

Table 6. Indicator decay for surface waters of the Providence River and Upper Bay. (source: Cabelli, 1990a).

Parameter	Sample Period	Indicator	
		F. Colif.	Phage
Biological Decay Coefficient	Dec 85	-0.230	-0.059[a]
	July 87	-0.167	-0.130
Distance Decay (km)[b]	Dec 85	4.4	16.9
	July 87	6.0	7.7
Time Decay (hr)[c]	Dec 85	35	134
	July 87	48	61

a significant at p <= 0.05, phage survived longer than the fecal coliform indicator in Dec. 1985.

b Distance for 90% reduction in indicator level.

c Time for 90% reduction in indicator level.

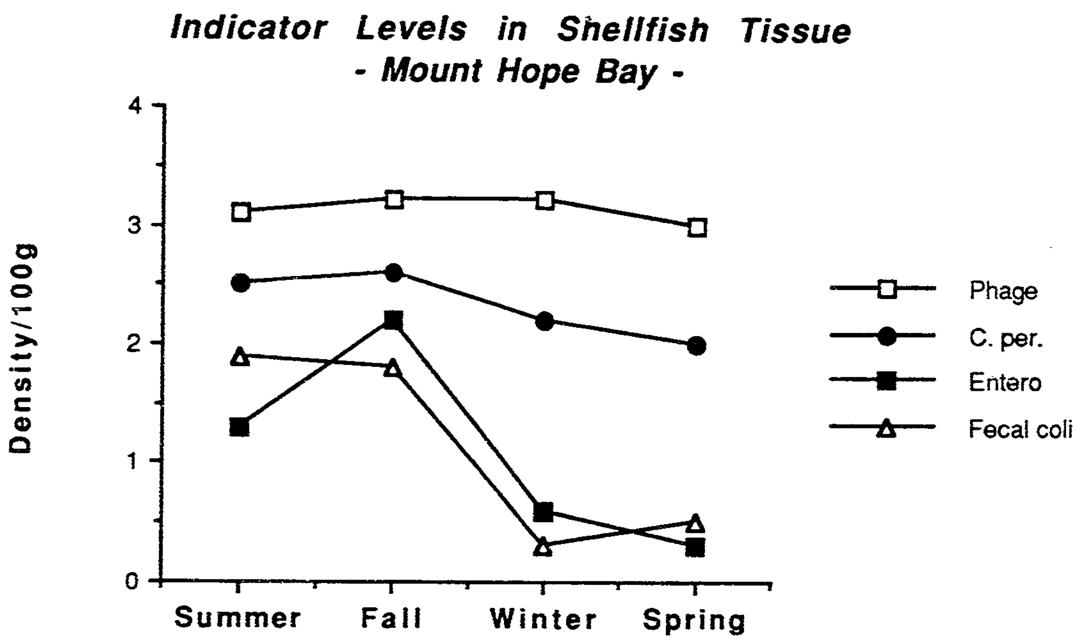


Fig. 6. Seasonal trends in various indicator levels from shellfish tissue. (Data source: Mt. Hope Bay, station 11; Rippey and Watkins, 1988)

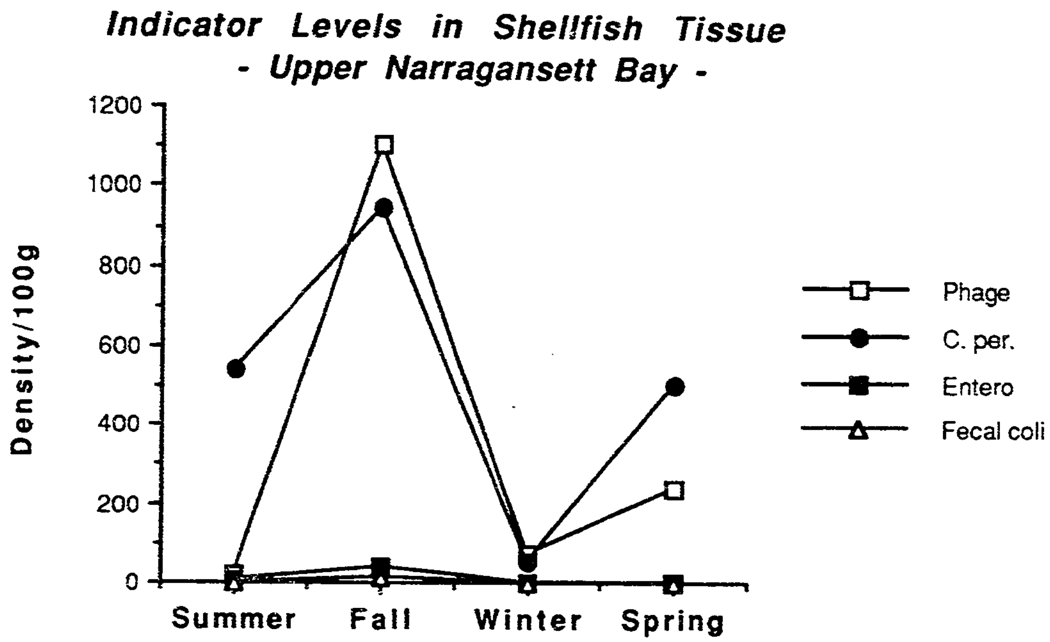


Fig. 7. Seasonal trends in various indicator levels from shellfish tissue. (Data source: Upper Narragansett Bay, station B; Cabelli, 1990b)

clearly evident why the seasonal trends from Upper Narragansett Bay and Mount Hope Bay (Figs. 6 and 7) are not more similar, however, it is noted that phage levels are always greater than the fecal coliform levels in the shellfish tissue. Laboratory studies (Cabelli, 1990b) conducted at 2.5°C (winter conditions) confirm that fecal indicator levels in the shellfish tissue are reduced more rapidly than the phage indicator (Fig. 8; i.e., phage survive longer in shellfish under winter conditions).

INDICATOR LEVELS IN WATER COLUMN VS. SHELLFISH TISSUE

The status of shellfish harvest areas in Narragansett Bay, as dictated by the NSSP, is evaluated by monitoring indicator levels in surface waters. It is assumed that these levels reflect the sanitary quality of the shellfish. However, data from both Upper Narragansett Bay and Mt. Hope Bay reveal extremely poor ($r=< 0.5$) and non-significant relationships between indicator levels in shellfish tissue versus overlying surface waters (Table 7). In Upper Narragansett Bay there was a significant, albeit poor, relationship in Fall for the fecal coliform indicator. In Mt. Hope Bay a positive relationship was noted only during periods when water temperatures were greater than 10°C; periods when the shellfish are metabolically active. For the phage indicator, in the Upper Bay there were no significant relationships when the data were analyzed by season, while in Mt. Hope Bay there was a significant relationship during the warm water periods. These generally poor, inconsistent relationships, and at times negative relationships, led both Cabelli (1990b) and Rippey and Watkins (1988) to conclude that the sanitary quality of shellfish areas should be evaluated by monitoring the indicator levels in the shellfish tissue, as opposed to overlying waters. However, it is noted that by sampling surface waters, worst case conditions are theoretically evaluated. Pathogen inputs are predominantly from freshwater sources (e.g., WWTFs, CSOs, rivers) and this less dense freshwater tends to overlie the more dense seawater (at least until mixing occurs).

INDICATOR OPTIONS

There is national debate over the adequacy of the fecal coliform indicator in protecting the public from consumption of pathogen-contaminated shellfish. The issue has been recently addressed by the U.S. House of Representatives Subcommittee on Commerce, Consumers and Monetary Affairs, Committee on Government Operations (General Accounting Office, 1988), NOAA's National Estuarine Inventory has highlighted the issue in an evaluation of shellfish harvest areas along the eastern U.S. coast (Leonard et al., 1989), and most recently, three federal agencies (NOAA, FDA, and EPA) have initiated a National Collaborative Shellfish Pollution Indicator Study. As identified by Narragansett Bay Project supported research, and other literature, this concern over the fecal coliform indicator is based on the following;

- Viruses are more resistant to the process of wastewater disinfection by chlorination than are bacteria, and thus, viral pathogens may be entering the estuarine environment (via WWTFs) at greater densities than indicated by the fecal coliform standard.

- Fecal indicators die more rapidly in the water column at winter temperatures than a viral indicator (phage). Regulators may underestimate the magnitude of health risk, particularly in winter.

- There is no strong relationship between indicator densities in shellfish tissue versus overlying waters. However, the sanitary status of shellfish growing areas is evaluated by monitoring surface waters, not the shellfish tissue.

To summarize, use of a viral indicator (i.e., phage) may be particularly effective at indicating the sanitary quality of effluent from wastewater treatment facilities. Fecal coliform remains,

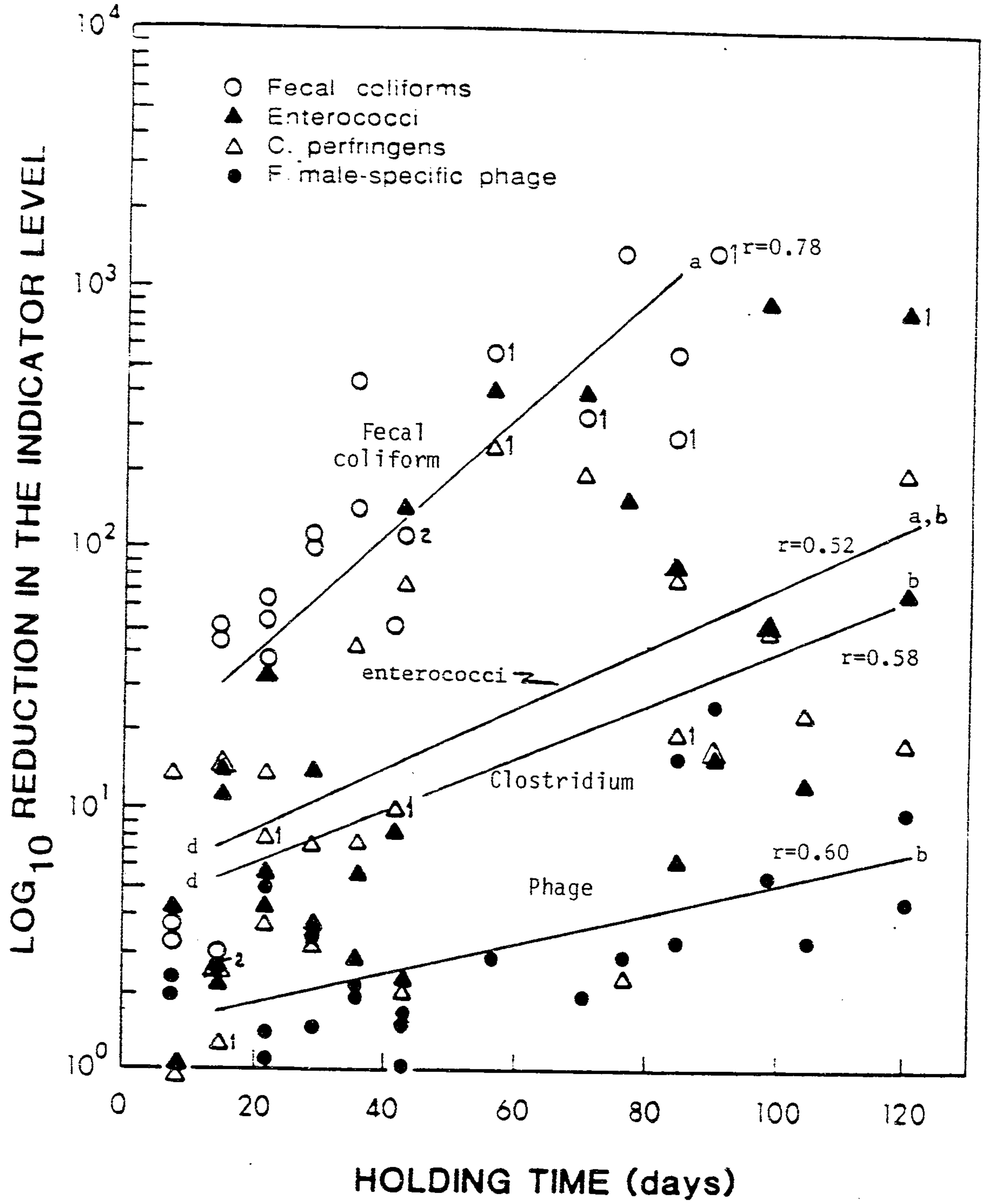


Fig. 8. Log reduction in indicator levels in shellfish tissue. Shellfish were maintained in laboratory tanks with flowing seawater at 2.5°C (winter conditions). Source: Cabelli, 1990b.

Table 7. Relationship between indicator levels in shellfish tissue versus overlying surface water. Correlation coefficients are shown and significance at $p <= 0.05$ indicated (*).

Location / Season	F. Colif	E. Coli	Clost.	Entero	Phage
Upper Narragansett Bay[a]					
Summer	-0.34	nd[c]	0.52	-0.59	0.16
Fall	0.63*	nd	0.40	0.17	0.51
Winter	0.01	nd	0.59*	-0.05	0.16
All	0.30	nd	-0.13	0.06	0.41*
Mt. Hope Bay[b]					
Warm water	0.48*	0.26	-0.31	0.39	0.53*
All	0.26	0.19	-0.44*	-0.01	0.52*

a From Cabelli, 1990b

b From Rippey and Watkins, 1988. Warm water is defined as greater than 10°C.

c no data

however, as a useful companion indicator, as high densities could suggest a source of untreated or inadequately treated sewage. There is clear concern over exclusive use of the fecal indicator; however, prior to recommending use of a new indictor, or suite of indicators, studies must be conducted to evaluate relationships between indicator levels and the actual incidence of shellfish-borne disease. An epidemiological feeding study, conducted jointly by EPA and NOAA, is currently underway using quahogs collected from Narragansett Bay. In this carefully controlled study, raw clams are fed to human volunteers and disease symptoms are closely evaluated. The shellfish are being collected from the conditionally approved shellfish harvest area of Upper Narragansett Bay and a relatively pristine "control" area of the Bay. At each harvest, indicator levels in the water column (surface, middle, bottom), sediments and shellfish tissue are determined and relationships to disease outbreaks evaluated statistically. In addition, three federal agencies (EPA, FDA, NOAA) have recently initiated the National Collaborative Shellfish Indicator Pollution Study. In this large-scale epidemiological study, numerous sites differentiating among point and nonpoint inputs and human or non-human sources are being established nationwide to validate relationships between indicators and disease.

These epidemiological studies will provide a scientific basis for evaluating the current indicator system and for establishing new numerical standards (if appropriate). Results from the NOAA/EPA epidemiological study using shellfish from Narragansett Bay are scheduled for completion in summer 1990. The National Collaborative Shellfish Indicator Pollution Study will not be completed until 1993-1994. Without the results of these studies it would be premature to recommend an alternative indicator. The controversy over pathogen indicators is clearly of national significance given the potential public health risks and alarming areal extent of shellfish closures along the nation's coastal zone (Leonard et al., 1989). The federal government must continue to take a lead role in identifying and implementing an effective program for monitoring the pathogenic status of shellfish harvest and recreational waters.

POINT SOURCE PATHOGEN INPUTS

SOURCE DESCRIPTION

The major point source inputs of human-derived pathogens to Narragansett Bay include CSOs, WWTFs, and WWTF bypasses. Rivers, such as the Blackstone, Taunton and Pawtuxet can also be considered as point sources, but in actuality, rivers represent the cumulative total of numerous point and nonpoint source inputs from their respective watersheds.

CSOs are a predominant source of pathogen indicators (and presumably actual pathogens) to Narragansett Bay. Combined sewer systems collect both domestic wastewater flow and stormwater (urban runoff). With sufficient precipitation, the capacity of wastewater treatment facilities and/or the combined sewer itself are exceeded and excess flows of untreated sewage and runoff are discharged or "overflow" directly into Bay waters (Fig. 9). The sewer systems of Providence, Pawtucket, Central Falls, Fall River and Newport are combined. Other urban areas, such as Cranston and Warwick, have separate systems with wastewater discharged to treatment plants and storm flow transported in separate lines for direct discharge to receiving waters.

It is estimated that Narragansett Bay has almost 120 CSO inputs (Providence - 65, Pawtucket/Central Falls - 30, Fall River - 19, Newport - 2). Many of these combined sewer overflow structures are designed with a slot-type regulator as shown in Fig. 10. During dry weather, the flow (predominantly wastewater) travels along the combined sewer pipe and is diverted by the slot to an interceptor line with ultimate transport to the treatment facility. During wet weather the capacity of the interceptor and slot/connector regulator are exceeded and untreated flow is transported to the receiving water.

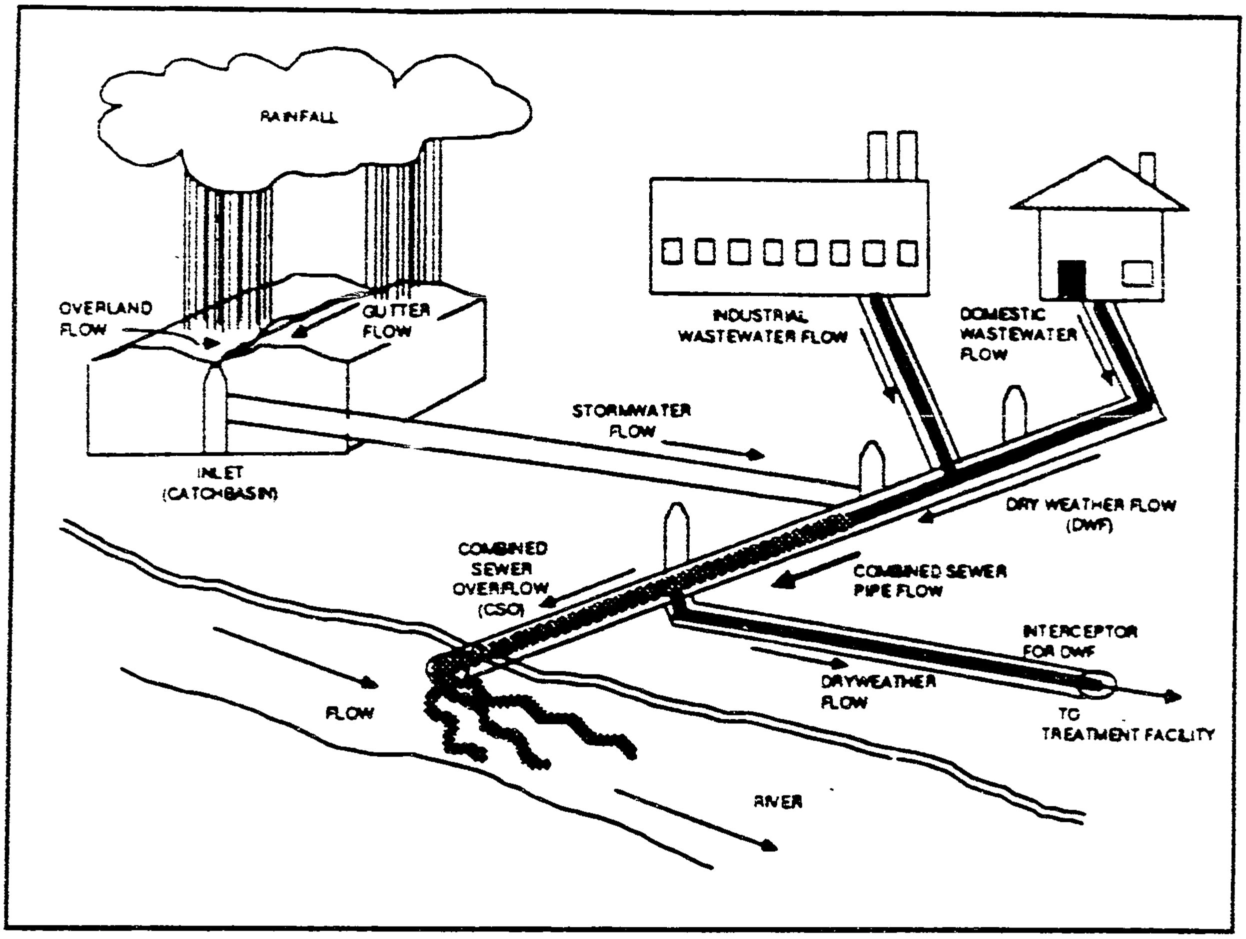


Fig. 9. Schematic representation of a combined sewer overflow system. (Source: Save-the-Bay, 1988).

Dry weather overflows can also be a problem. With obstructions of the slot and/or connector pipe (see Figure 10), flow will bypass the interceptor and discharge directly into receiving waters.

WWTF bypasses are another significant point source of pathogens. Often during rainfall events, WWTFs reach their maximum capacity and wastewater flow must be diverted around all or part of the treatment process. A secondary bypass essentially implies that the wastewater has undergone primary treatment and bypassed the secondary process. Chlorination of the primary treated effluent generally occurs (as at the Field's Point WWTF). When the wastewater is diverted at the WWTF headworks prior to treatment, it is called a primary bypass (e.g., BVDC).

RELATIVE LOADINGS

WET WEATHER INPUTS

The Narragansett Bay Project has sponsored two major research efforts to specifically quantify the relative loadings of pathogen indicators to the Bay during rainfall-related (wet weather) events -- the Mt. Hope Bay study (Rippey and Watkins, 1988) and the Providence River wet weather study (Watkins and Rippey, 1990).

For Mt. Hope Bay, pathogen indicator inputs from major sources were quantified, including the Fall River and Somerset WWTFs, several CSOs in the Fall River area, and several point-runoff discharges on the western shore of Mt. Hope Bay (Bristol area). The Taunton River, which drains over 560 sq. miles with numerous point and nonpoint inputs, was considered as a single point source. The data clearly show that CSOs represent the major source of pathogen contamination, as simulated by the fecal coliform indicator, to Mt. Hope Bay (Fig. 11, Appendix 1). During a wet weather event, 96% of the fecal coliform entering the Bay was from CSOs. Although the Taunton River dominates all the measured inputs with respect to volume, only 3% of the total fecal coliform was contributed by this source during wet weather. It is noted that this 3% may be an underestimate as it is probable that the Taunton River was not sampled coincident with the peak flow period. However, regardless of this potential flaw in the study design, CSO input clearly dominates. Based on post-chlorinated effluent, relative input from the two wastewater treatment facilities was negligible. Because fecal coliforms are highly sensitive to chlorination the concentration in post-chlorinated effluent is low, thus the insignificant loading.

During the dry sampling event, there was an even more impressive 98% input from CSOs. Dry weather CSO inputs from Fall River are being eliminated under order from the U.S. Environmental Protection Agency. Assuming this, the data then indicate that an industrial discharge (76%) dominates dry weather inputs (Taunton River - 23%, WWTFs - 2%). [Note: The principal investigators identified a source as "industrial discharge" because of location of a discharge pipe in close proximity to an industrial establishment. It is unknown whether the effluent from the discharge pipe was derived from the industry or another source, such as a CSO (personal communication, FDA field personnel)].

For the Mt. Hope Bay data set, estimating relative source loadings of pathogens can also be evaluated based on the Clostridium indicator -- a spore-forming bacterium. The spores are highly resistant to chlorination, and thus, this indicator may be particularly useful for assessing relative sewage loadings, especially when comparing treated (chlorine disinfected) effluents and untreated discharges (Watkins and Rippey, 1990; Cabelli, 1990a; Also see Table 5, Fig. 5). The fecal coliform indicator, although being the key regulatory parameter, may not be appropriate for comparing treated and untreated discharges because of its sensitivity to disinfection. As noted from Fig. 12, CSOs remain the dominant wet weather source of pathogen loading to Mt. Hope Bay (73%) when based on the Clostridium indicator. However, the relative significance of WWTF discharge (23%) becomes more evident.

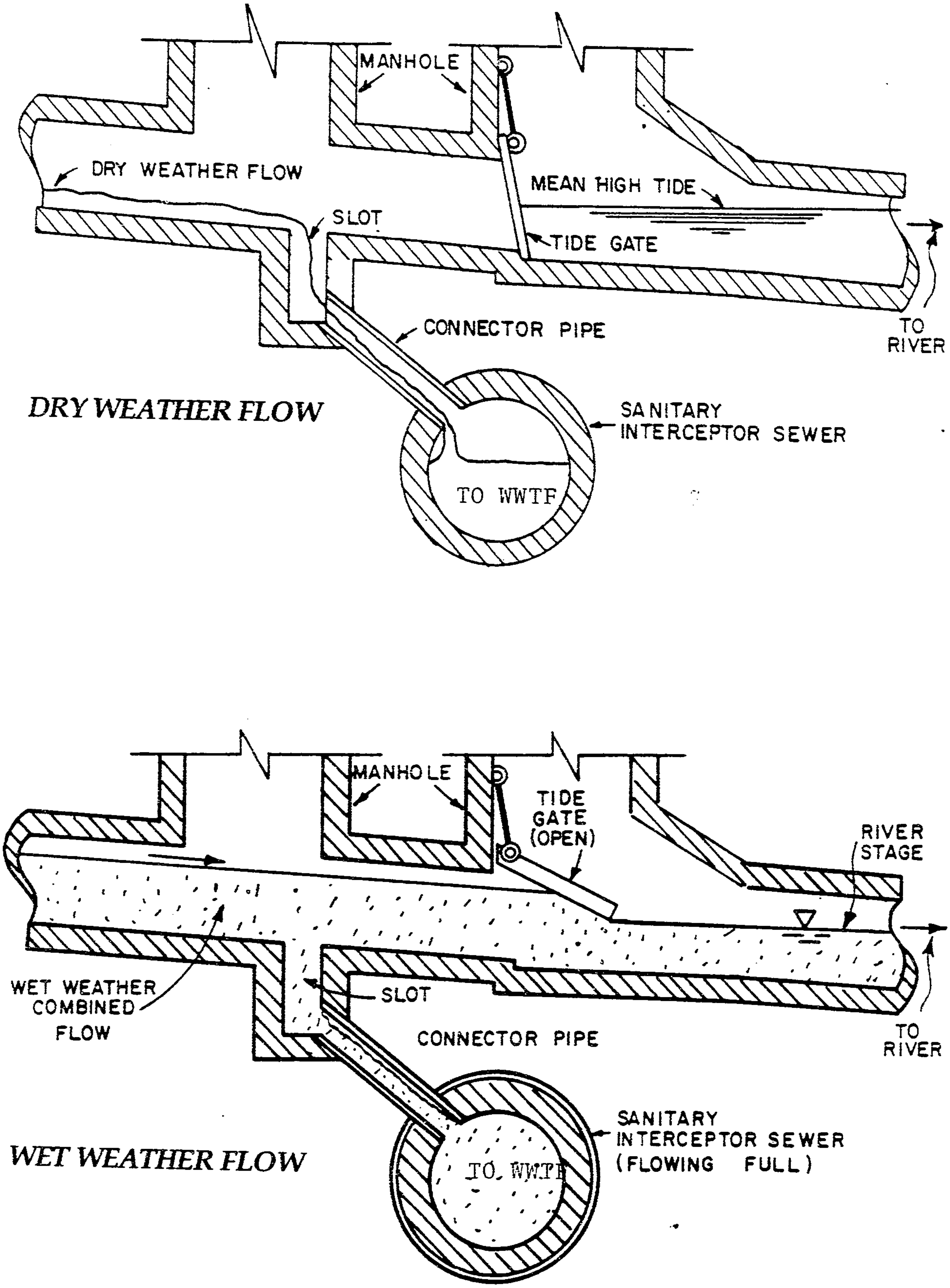


Fig. 10. Cross-sectional diagram of a CSO with a slot-type regulator. a) dry weather flow, b) wet weather flow. (Source: OBrien & Gere, 1988)

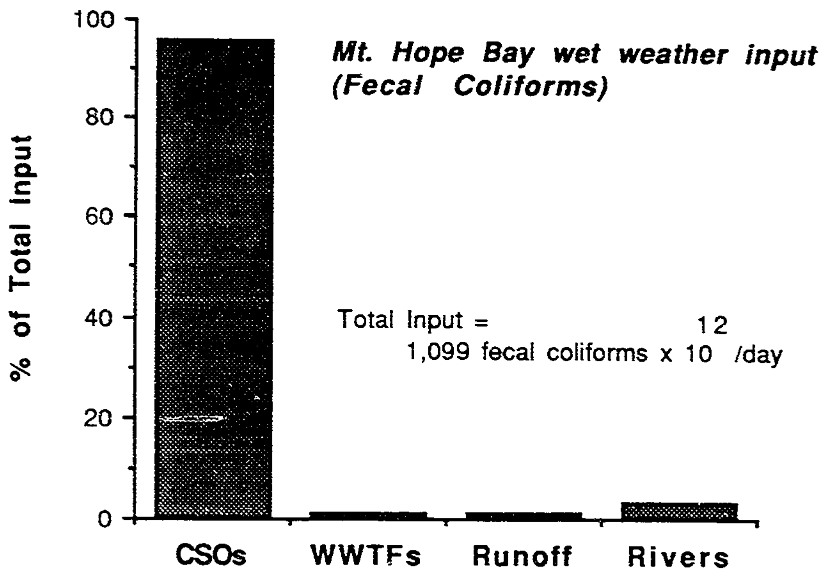


Fig. 11. Summary of fecal coliform source inputs to Mt. Hope Bay during a wet weather event. (Date source: Rippey and Watkins, 1988)

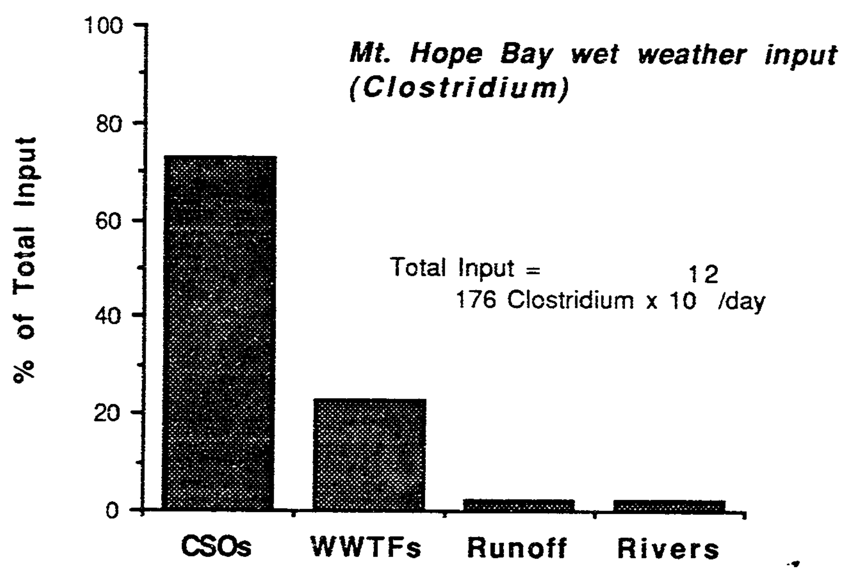


Fig. 12. Summary of Clostridium source inputs to Mt. Hope Bay during a wet weather event. (Data source: Rippey and Watkins, 1988).

Similar to the Mt. Hope Bay study, Watkins and Rippey (1990) estimated the relative loading of pathogen indicators to the Providence River and vicinity during three storm events. Measured inputs included point sources (WWTFs, WWTF bypasses, and CSOs) and rivers (Blackstone, Woonasquatucket, Moshassuck, Ten Mile, Pawtuxet). The river stations provide a collective representation of point and nonpoint source inputs from the drainage basin upstream of each sampling point. The three storm events were quite variable with respect to storm duration and rainfall amount (Oct. 22, 1988, 0.89 inches, 11 hr duration; May 10-12, 1989, 2.25 inches, 32 hr duration; June 13, 1989, 0.43 inches, 8 hr duration); however, the relative ranking of sources was similar among storms, with few exceptions (see Watkins and Rippey, 1990). When considering the three storm events collectively, it becomes evident that the untreated sources of pathogens (as determined by the fecal coliform indicator) predominate (Fig. 13, Appendix 2). The WWTF bypasses at BVDC (58%) and NBC Field's Point (16%) accounted for over 70% of the fecal coliform load to the Providence River. The two CSOs monitored (CSO 9, CSO Area D #010) contributed only 8%. The rivers combined contributed about 17% of all the fecal coliform input measured over the 3 storm events. Loadings from the WWTFs (excluding bypasses) were negligible. When relative wet weather pathogen loadings to the Providence River are evaluated based on the Clostridium indicator (Fig. 14, Appendix 2), input from WWTFs becomes more significant (48%), with a corresponding decrease in bypass loadings.

To summarize, Clostridium appears to be a good pathogen indicator to employ when comparing relative inputs from diverse sources, including treated/disinfected and untreated discharges. Based on this spore-forming indicator, CSOs appear to be the dominant source of pathogens to Mt. Hope Bay (73%) during rainfall events, with the Fall River and Somerset WWTFs also being quite significant (23%). In the Providence River and vicinity, three WWTFs (NBC Field's Point, BVDC, East Providence) contributed 45% of the total loading, with CSO input being relatively minor (2%). WWTF bypasses and rivers contributed 23% and 25%, respectively. Because only 2 of the 95 CSO discharges located in the Providence-Pawtucket-Central Falls area were directly measured during the 3 storm events, the relative percent input from this source may have been dramatically underestimated. It is noted that the wet weather sampling program did indirectly account for most of the CSO discharges by sampling the river inputs. However, for each river input it was not possible to separate the CSO contribution from other potential sources (i.e., stormwater, WWTFs, etc.).

The relative contribution of CSOs to fecal coliform input in the Providence River and vicinity can be evaluated, at least in part, by comparing CSO input data generated by the Narragansett Bay Commission with data from other input sources (i.e, Watkins and Rippey, 1990). Untreated sources, CSOs and WWTF bypasses, clearly represent the dominant fecal coliform inputs during wet weather to the Providence River (Table 8). However, this comparison should be viewed with caution because, a) Watkins and Rippey (1990) presented loadings data on a per storm basis, while in Table 8 their data were converted to a per hour basis, thus assuming an even input over the storm duration, b) the CSO estimates are derived from model results (except CSO 9), and thus, are not generally comparable to the Watkins and Rippey (1990) data, and 3) fecal coliform is not the preferred pathogen indicator to use when comparing treated and untreated inputs (see previous discussion).

ANNUAL PATHOGEN LOADING (A PRELIMINARY ASSESSMENT)

Available information sources to estimate annual loadings of pathogens, or pathogen indictors, to Narragansett Bay are somewhat limited. Table 9 couples several data sources in an attempt to provide a crude estimate of annual loadings. Annual input from the 65 CSOs in Providence represents over 1.6 times the combined loading from the Blackstone River, Pawtuxet River and three WWTFs (excluding bypasses).

Modeling efforts currently underway by the Narragansett Bay Commission and assessments of all inputs to the Providence River by Wright (wet weather study) and Hoffman (NBP technical report), may provide additional estimates of both wet weather event and annual loadings.

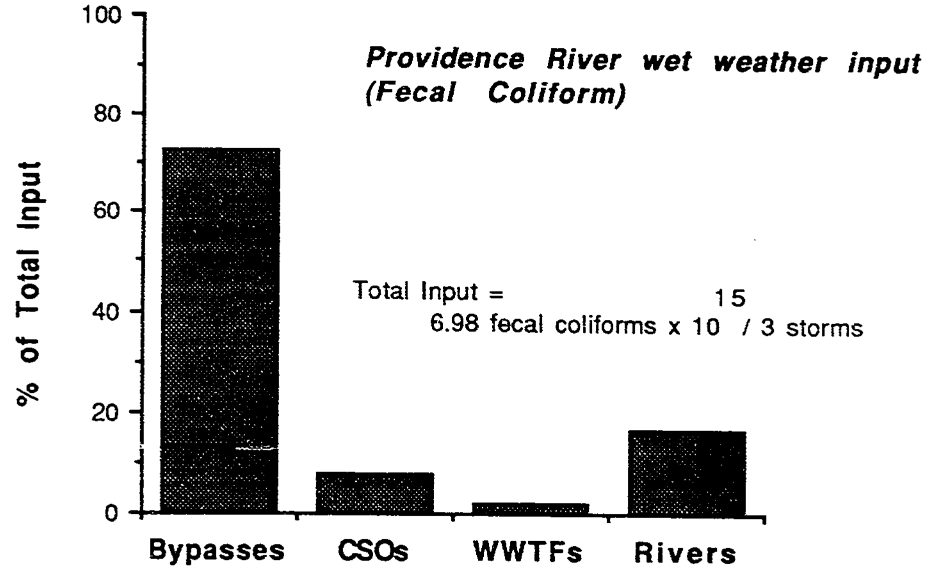


Fig. 13. Summary of fecal coliform source inputs to the Providence River and vicinity during 3 wet weather events (events combined). (Data source: Watkins and Rippey, 1990)

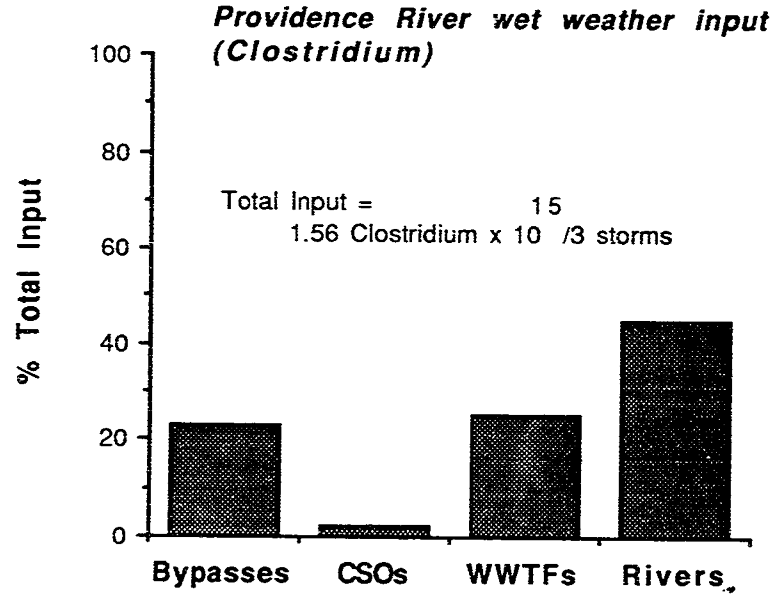


Fig. 14. Summary of Clostridium source inputs to the Providence River and vicinity during 3 wet weather events (events combined). (Data source: Watkins and Rippey, 1990).

Table 8. Relative magnitude of instantaneous (per day) fecal coliform inputs from major sources in the Providence River and vicinity.

SOURCE	INPUT (cells/day x 10^{10})	DATA SOURCE
Rivers		
Blackstone	9,900(yr. avg)[a]	Oviatt, 1981
	720(w)[b]	Cabelli, 1989a and Hoffman, 1988
Pawtuxet	490(yr. avg)	Oviatt, 1981
	46(w)	Cabelli, 1989a and Hoffman, 1988
	276(d)	IEC, 1985
Treatment Plants		
Field's Point	38(w)	Cabelli, 1989a
	3.9(yr avg)	RIPDES, 1988
BVDC	7.4(yr avg)	RIPDES, 1988
E.Providence	.03(yr avg)	RIPDES, 1988
CSOs[c,d]		
CSO Area B	720,000-1,238,500(w)	O'Brien & Gere, 1988
CSO Area C	31,000- 59,000	Camp,Dresser,McKee, 1989
CSO 9	42,819(w)	IEC, 1985
		IEC, 1985
Separate Storm Sewers		
CSO Area B	360-820(w)	O'Brien & Gere, 1988

a Oviatt (1981) presented an annual input of fecal coliform to the Providence River from the Blackstone River of 3.6×10^{16} cells, and 1.8×10^{15} cells from the Pawtuxet River. These annual estimates were converted to a per day basis.

b w = wet weather, d = dry weather

c The Narragansett Bay Commission has divided Providence into six discrete CSO study areas (CSO 2, 9, A, B, C, and D)

d Data from CSO Area B & C are a range of model results for the 3 month-6hr to 12 month-6hr reference storms. CSO 9 data represent a field sampling event.

Table 9. Estimated annual loading of fecal coliform to the Providence River and vicinity.

Input	INPUT (f.c./yr x 10^{13})	Data Source
Rivers		
Blackstone	3,600	Oviatt, 1981
Pawtuxet	180	Oviatt, 1981
Subtotal	**3,780**	
WWTFs		
Field's Point	1.4	RIPDES, 1988
BVDC	2.7	RIPDES, 1988
East Providence	0.01	RIPDES, 1988
Subtotal	**4.1**	
CSOs[a]		
CSO Area B	2,880	O'Brien & Gere, 1988
CSO Area C	467	Camp, Dresser, McKee, 1989
All 65 Prov. CSOs	**6,100**	Metcalf & Eddy, 1983

a For CSO Area B, it was assumed that the simulated loading from the 3 month-6hr storm (72,000 x 10^{11} fc) would occur 4 times annually. This represents and underestimated loading from CSO Area B, as less intense storms can also trigger CSO flows.

For CSO Area C, Camp, Dresser & McKee (1989) modeled annual fecal coliform input from the entire study area.

For all 65 CSOs, Metcalf & Eddy (1983) modeled annual wet weather fecal coliform input. Numerous assumptions, as noted by Metcalf & Eddy (1983), were used to derive this estimate.

POINT SOURCE CONTROL OPTIONS

ELIMINATE/MITIGATE CSO INPUTS AND WWTF BYPASSES

In 1989, 10,568 acres of the Upper Bay were closed for a total of 263 days (74% of the year) as the result of rain-induced CSO and bypass flows. An additional 5896 acres were permanently closed in the Providence River because of fecal coliform levels exceeding the state criteria. Predictive water quality models have indicated that with reduction of select wet weather CSO inputs to the Providence River (i.e., CSO Area 9 and 2), additional areas (up to 2,471 acres) of the Providence River and Upper Bay could be permanently opened to shellfishing (Metcalf and Eddy, 1983). [Note: This was an early modeling effort when data from the Providence CSO study areas were limited. Efforts are currently underway, by the Narragansett Bay Commission, to refine this receiving water modeling.] To conclude, CSO and bypass abatement will substantially reduce pathogen loading to Narragansett Bay.

In August 1989, the US EPA issued a "National Combined Sewer Overflow Strategy". In response, EPA Region 1 issued a policy stating that CSO abatement planning should provide for compliance with water quality standards at all times, or alternatively, the complete elimination of CSO discharges. If such compliance is technologically or economically not feasible, then water quality standards for particular receiving water segments may be changed in accordance with specified criteria. The RIDEM is currently developing a CSO policy, as required by the National Strategy and by EPA Region I.

Efforts in the Narragansett Bay watershed are currently underway to address the CSO issue. The Narragansett Bay Commission is engaged in a 5-yr $152 million effort to control the 65 CSOs in Providence (NBC Capital Improvement Program: FY88/89 - 92/93). Newport is now correcting their 2 CSO inputs. Pawtucket and Central Falls have not yet begun a study to quantify the problem and recommend alternatives. Fall River dry weather overflows are being corrected, yet a plan for wet weather abatement is needed. CSO abatement alternatives that are or should be considered in the abovementioned CSO control initiatives are;

-Best management practices (decrease stormwater runoff via land use planning, porous pavement, street cleaning etc.)

- System improvement and maintenance (sewer cleaning/flushing, infiltration/inflow reduction, flow diversion, sewer separation).

- Structural changes (new interceptors and pumping stations, in-line storage, off-line storage with primary treatment)

It is premature for the Narragansett Bay Project to recommend at this time a specific, or even general, plan for reduction of CSO inputs to Narragansett Bay. Additional data synthesis is currently underway (e.g., NBC systemwide CSO analysis by R. Wright; NBP water quality modeling) that will help to prioritize CSO problem areas, evaluate environmental benefits and estimate abatement costs. Further, parameters other than pathogens (i.e., metals, organics, nutrients), must be included in the problem assessment phase.

ALTERNATIVE DISINFECTION AT WWTFs

WWTFs represent a relatively minor point source of fecal coliforms to Narrgansett Bay. However, as previously noted, viruses are more resistant to chlorination than the fecal indicator, thus viral pathogens may be entering the estuary at greater densities than indicated by the bacterial-based standard. This is supported, in part, by the Narragansett Bay Project sponsored studies that evaluated both the phage and Clostridium pathogen indicators. Further, as documented by on-going Narragansett Bay Project research, and other studies (US E.P.A, 1987a), there are instream toxicity effects associated with chlorinated effluent.

Chlorination is the exclusive disinfection technique used by WWTFs discharging into Narragansett Bay. Other disinfection practices, such as ozone and ultraviolet disinfection are more efficient at viral control and have no known toxicity effects. Table 10 compares some of the key characteristics of disinfection alternatives. Annual capital and operating costs (in 1986 dollars) for ozone or UV disinfection are more than 50% the cost of chlorination. For both UV and ozone disinfection, the treated effluent must be relatively free of suspended materials. Extensive reviews of the merits and shortcomings of disinfection technologies are available (U.S. EPA, 1987a).

The RIDEM "Effluent Disinfection Policy" recognizes the potential toxic effects of chlorine compounds. The Policy calls for optimizing the efficiency of chlorine contact chambers, dechlorination of effluent and/or installation of an alternative disinfection facility.

NONPOINT SOURCE PATHOGEN INPUTS

Septic systems and direct discharges from boats represent the major nonpoint sources of human-derived pathogens to Narragansett Bay. Pathogens are also introduced to the Bay by waterfowl, wildlife, domestic animals, and by stormwater input.

INDIVIDUAL SEWAGE DISPOSAL SYSTEMS (ISDS)

Pathogenic organisms from septic systems can potentially enter Narragansett Bay in two ways. First, poorly maintained systems or improperly placed systems (i.e., water table or impervious formations near the ground surface, steep slopes) can fail and discharge effluent directly to the surface and be transported by overland flow to surface waters (i.e., estuary, streams, rivers, wetlands). Second, effluent and associated pathogens can be transported to the Bay's waters through groundwater.

Discharge from failed septic systems is most prevalent in areas that were developed prior to the adoption of state regulatory criteria for system design and siting (1969). Examples of unsewered, relatively high density development (>3 units/acre) are found in isolated sections of most of the communities surrounding the Bay. It is difficult to quantify the input of pathogens from failed septic systems, except to note that in fiscal year 1988-89, the RIDEM issued 103 Notices of Violation, statewide, for improperly functioning septic systems. This figure represents a minimum number because violations are first reported to the RIDOH (Division of Food Protection and Sanitation). If the failed system is not corrected upon request by the RIDOH, then the RIDEM issues a Notice of Violation. While estimates of the magnitude of pathogen input from failed septic systems is unattainable at this time, it is noteworthy to mention that when failures do occur, the potential for direct discharges of untreated human-derived sewage is greatly accelerated.

Pathogen inputs by the groundwater pathway are less obvious, but may be quite significant (see Table 11, and literature reviews by Cogger, 1988; Reneau et al., 1989). In a study conducted on Long Island (NY), human viruses from a large-scale septic system (serving 40 units) were detected at a down-gradient distance of 220 ft from the source and at a groundwater depth of 45 ft (Vaughn et al., 1983). The surficial geology and general soil characteristics of the Long Island site are similar to coastal Rhode Island, thus justifying a comparison. In three septic systems serving individual families in Wisconsin, poliovirus was introduced to the systems and recovered down-gradient at distances of 174 ft, 69 ft, and 30 ft (Stramer, 1984 as cited in USEPA, 1987b). In a review of numerous studies evaluating the fate of viruses from land application of sewage effluent, horizontal or down-gradient migration in

Table 10. Comparison of alternative WWTF disinfection techniques. Source: U.S. EPA, 1987a.

FACTOR	TECHNIQUE			
	Cl	Cl/ Decl	UV	Ozone
Bacterial Control	Good	Good	Good	Good
Viral Control	Poor	Poor	Good	Good
Toxicity Effects	Toxic	Non-toxic	Non-toxic	Non-toxic
Plant Size	All	All	Sm-Med	Med-Lg
Annual Cost (50 mgd)	$0.5 mil	$0.6	$1.2	$1.5

Table 11. Pathogen Travel Distances (ft) from Septic Systems. Bacterial transport was evaluated as fecal coliform and viral transport by introduction of polio virus at the source.

Location	Travel Distance (ft)	
	Bacteria	Virus
Long Island (NY) (Vaughn et al. 1983)	5	220 +
Long Island (NY) (Vaughn, 1988)	-	30-60+
Wisconsin (Stramer, 1984)	-	30-175
Buzzards' Bay (MA) (Weiskel & Heufelder, 1989)	7	-
Texas (Brown et al., 1979)	4	-
Oregon (Rahe et al, 1978)	50	-
Virginia (Reneau & Pettry, 1978)	20-40	-

groundwater as far as 1312 ft and penetration to depths of 220 ft have been reported (Keswick and Gerba, 1980).

For bacterial pathogens, persistence in groundwater appears to be much less significant (Table 11). Weiskel and Heufelder (1989) found that horizontal transport of fecal coliform from a cesspool along the shoreline of Buzzard's Bay (MA) was about 7 ft. Similarly, transport of fecal coliform was less than 6 ft from the previously mentioned septic system studied on Long Island (Vaughn et al., 1983). This latter study found no correlation between viral pathogens and fecal coliform, a commonly used indicator of pathogenic microorganisms in groundwater. However, some studies have noted significant travel distances for fecal coliform (up to 50 ft; Rahe et al., 1978).

Regulations for the placement of individual sewage disposal systems in Rhode Island, as well as Massachusetts, may not be adequate to protect the Bay and the associated watershed from viral inputs. As currently regulated in RI, new systems must be at least 3 ft above the seasonal high water table (or 5 ft above impervious formations). With respect to setbacks, the system must be at least 200 ft from surface drinking water supplies and a least 50 ft from other watercourses. (NOTE: a -- CRMC requires greater setbacks of up to 180 ft if an area is erosion prone; b --approval of ISDS located within 50 ft from a marsh, swamp, bog or pond, 100 ft from a river of < 10 ft in width, or 200 ft from a river of 10 ft or more in width, will not be issued until RIDEM issues an wetlands permit). The RI ISDS regulations have also established critical resource areas. For the coastal pond area the minimum setback distance is 150 ft and the groundwater separation distance should be at least 4 ft. The Scituate Reservoir critical area requires a minimum 200 ft setback.

Based on the available literature (see Table 11) these set- back distances and depth to seasonal high water separation distances may not be adequate to sufficiently attenuate viral input from septic leach fields to surface and groundwaters of the Narragansett Bay watershed. The U.S. Environmental Protection Agency (1987b) has developed a rating system to assist in siting of septic systems so that minimal potential for pathogen contamination is achieved. The system considers numerous factors including, water table depth, net recharge rate, hydraulic conductivity of the aquifer, groundwater temperature, soil texture, aquifer medium, application rate, and setback or buffer distance. Based on site specific information, each factor is assigned a rating from 0-10 (0 = least impact, 10 = most impact). These ratings are then multiplied by an assigned relative weight for each factor. The products are summed to derive a rating index.

The EPA rating system has been applied to several hypothetical sites in Rhode Island (see Appendix 3 for summary of all the input data). All sites were assumed to be in regions of the stratified drift aquifer -- the principal aquifer of Rhode Island. Various combinations of critical factors were evaluated, including vertical separation distance from the septic system to the water table (30 ft, 10 ft, and 3 ft) and buffer or setback distance from surface waters of Narragansett Bay or tributary waters (50 ft, 150 ft, and 500 ft). The rating system applies a maximum relative weight to these factors. Similarly, the system considers soil texture as an important controlling factor, with fine grained soils (i.e., clay-dominated) being most effective at viral control and coarse grained soils (i.e., gravel to sand and sandy loam) least effective. Soils in the Narragansett Bay watershed are generally clustered toward the least effective end of the relative rating spectrum, and thus, this parameter is not very sensitive or variable in our region.

As noted from Fig. 15, an index is derived from the rating system. The index provides a relative indication or probability of the potential for contamination by microorganisms.

0-75	not very probable
75-150	possible
150-225	probable
>225	very probable

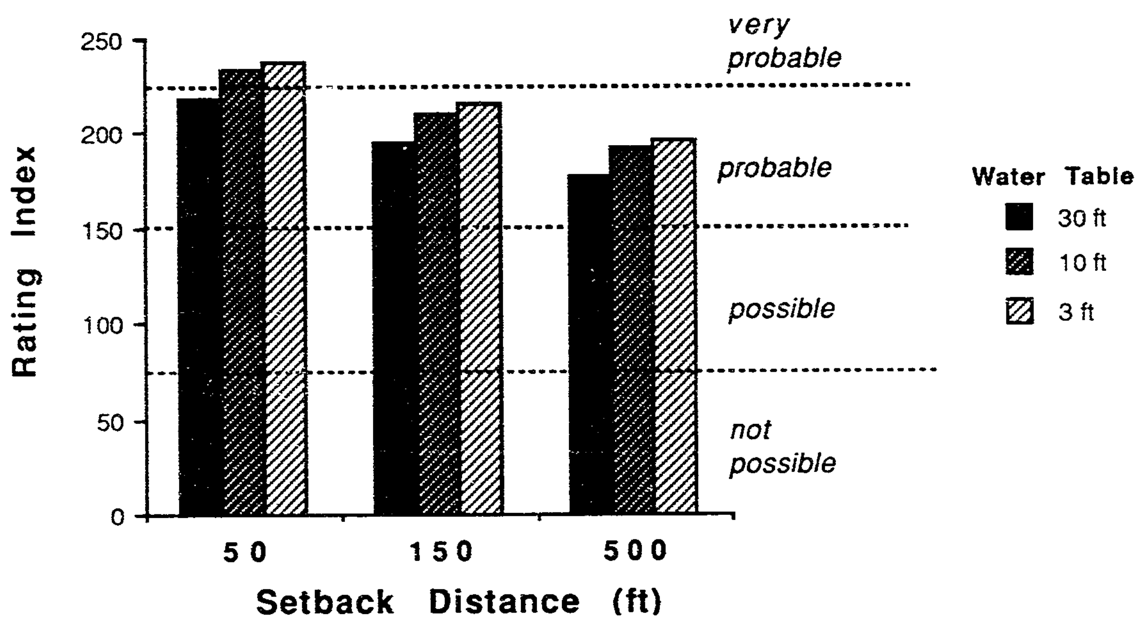


Fig. 15. Results of a USEPA (1987b) model to evaluate the probability of pathogen contamination (groundwater or surface water) from septic systems. The model was run after specifying various site-specific water table depths and setback distances between septic leach fields and watercourses. The probability of contamination is indicated. See Appendix 3 for details of input data.

It becomes obvious that the potential for pathogen contamination of groundwater or surface waters from septic systems located in the Narragansett Bay watershed is high. Even under most restrictive siting criteria (30 ft water table, 500 ft buffer), it is still predicted that pathogen contamination would be probable. Under conditions that may commonly exist along borders of the Bay or streams/wetlands (i.e., water table depths 3-8 ft and buffers of 50-100 ft), it is probable to very probable that contamination will occur.

The scientific evidence shows that human-derived viruses can travel greater distances, both horizontal and vertical, than accounted for in existing regulations. The potential for viral contamination of estuarine waters by septic systems becomes especially relevant when considering that of the 378 mi of shoreline directly bordering tidal portions of the Bay, over 280 mi (75%) are served by ISDS (Figure 16). The cumulative effect of this band of septic systems around the Bay is undoubtedly significant, yet difficult to quantify. On a population basis, almost 40% of Rhode Island depends on approximately 143,900 individual sewage treatment systems (RI Department of Environmental Management, 1988a; RI Department of Administration, 1989).

ISDS OPTIONS

Connect high density unsewered areas to municipal WWTFs. Areas of high density development (perhaps > 3 units/acre) that are unsewered should be considered for connection to existing or expanded WWTFs. Priority should be given to areas that are adjacent (within 1000 ft) to high quality waters of the Bay and Bay watershed (e.g., RIDEM Class A freshwater and SA marine water; CRMC Type 1 and 2 waters). The RI Nonpoint Source Management Plan calls for extension of sewer lines to areas of chronically failing septic systems (RI Department of Environmental Management, 1989). The RI Sewer and Water Supply Failure Fund provides matching grants (50%) to municipalities for connecting WWTFs to areas of documented multiple ISDS failure and provides loans to single family housing for replacement or rehabilitation of failing ISDS. This $5 million state bond fund is near complete obligation. The relative success of this fund, begun in 1984, must be evaluated and re-issuance considered.

It is expected that this recommendation, if implemented, will not promote development in undeveloped areas. The extention of sewer lines is proposed for areas of existing high density development with little opportunity for additional growth.

To assist in implementation of this recommendation and to highlight the potential magnitude of the problem, it would be appropriate to identify the specific areas within the Narragansett Bay watershed that have chronically failing septic systems. Upon identification, communities could consider restricting new development in unsewered areas with a history of failed systems.

Control density of septic systems in critical areas. Human viruses derived from septic systems have the potential to travel great distances in groundwater as stated above. One way to minimize the input of pathogenic viruses to the Bay is to adopt more restrictive standards for setback distance and vertical separation distance for septic systems. However, the U.S. EPA (1987b) methodology suggests that such new regulations (in excess of 500 ft setback and 30 ft separation distance) could not be reasonably implemented. Another, and perhaps more realistic approach toward minimizing pathogen input to the Bay from septic systems is to control the density of systems in critical resource areas surrounding the Bay and watershed. It is recommended that the critical resource area be defined as a (perhaps 1000 ft zone) adjacent to RIDEM Class A freshwater and SA marine waters and CRMC Type 1 and 2 waters. Within this critical zone, RIDEM ISDS regulations for the state's coastal ponds and the Scituate reservoir should be adopted (minimum 150 setback and minimum 4 ft separation distance), as well as initiating a minimum lot size requirement for development to be served by ISDS. By establishing more restrictive site criteria and lot size controls, the cumulative impact of septic systems throughout the coastal zone will hopefully by minimized.

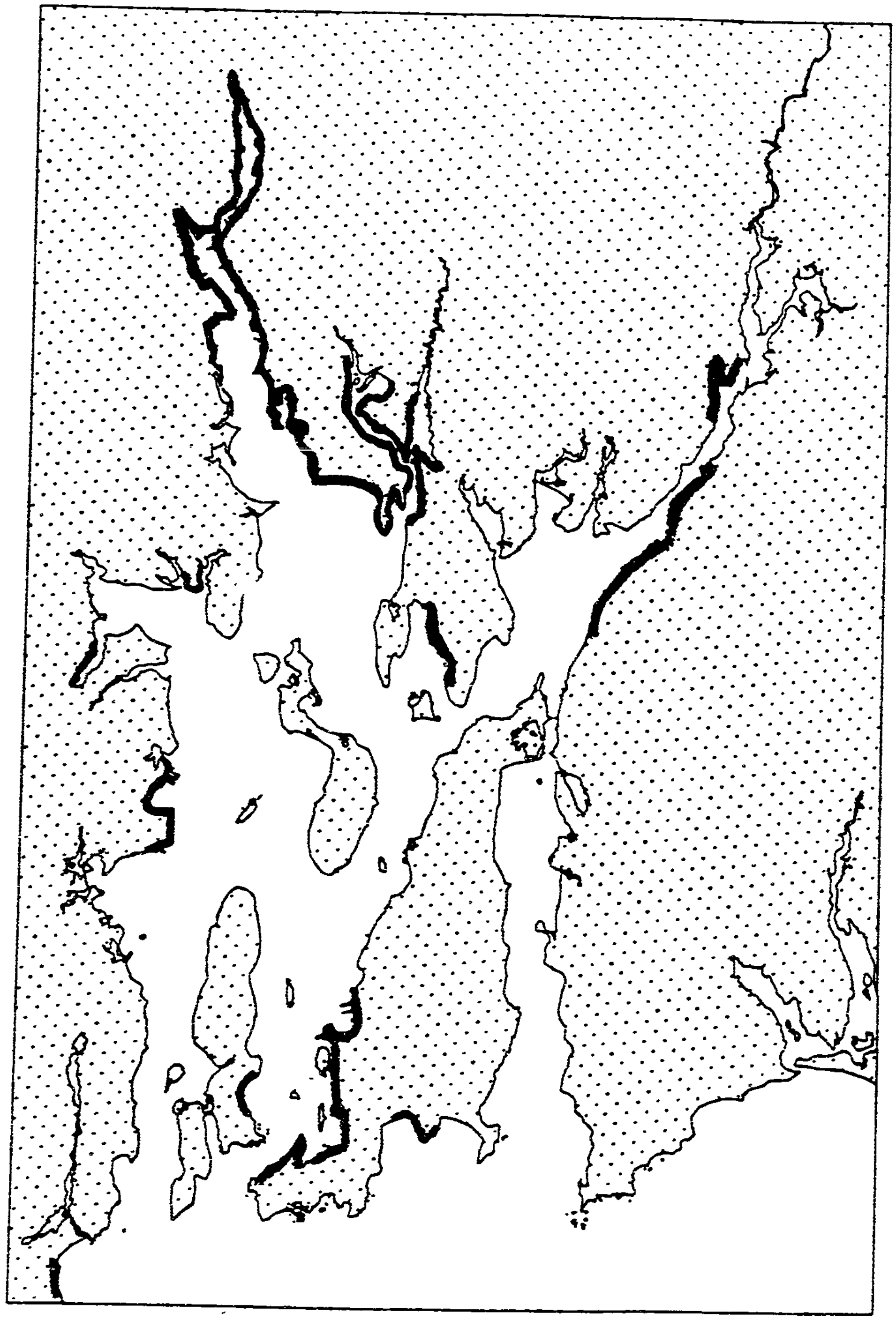


Fig. 16. Portions of the Narragansett Bay shoreline that are served by municipal WWTFs (indicated by heavy black line). Data compiled from county public works maps on file at RIDEM (Water Resources). Maps were last updated ranging from 1979-present.

This presentation represents an estimate. Detailed revisions/updates are underway (RI Statewide Planning).

Establish wastewater management districts (WWMD). State legislation was passed in 1987 enabling local municipalities to establish wastewater management districts, thereby giving power to raise funds, to enter private property to inspect septic systems, and to require periodic system maintenance (RI Depart. of Administration, 1987). Upon establishment of a WWMD, local communities will be able to insure that septic systems are well maintained (i.e., pumped) and that failed systems are identified and funds or loans provided to owners for replacement costs. Further, establishment of WWMDs will provide a procedure for local communities to dispose of septage. As of February 1990, only 1 community (Jamestown) had established a WWMD. The issue of septage disposal appears to be the major obstacle to the establishment of more WWMDs. Communities with no municipal treatment facilities and communities with small municipal facilities are being unsuccessful at establishing agreements with larger facilities to accept septage. The septage committee, a subcommittee of the State Planning Council, is presently addressing this issue (S. Millar, RI Div. of Planning, personal communication). Upon resolution of the obstacle, all communities within the Bay watershed must be encouraged to implement the WWMD program.

Alternative septic systems. As recommended in the RI Nonpoint Source Management Plan (RIDEM, 1989), alternatives must be found for replacement of failed systems where existing conditions prevent repairs/replacement in compliance with regulations. Some alternatives include the Wisconsin Mound System, on-site created wetlands, or small packaged treatment facilities.

BOATING ACTIVITY

In 1988 there were over 29,000 boats registered with the RI Division of Boating Safety (Table 12). It is estimated that an additional 28,000 boats, including vessels documented by the US Coast Guard, vessels not required to register, and visitors, also occupied Rhode Island waters. This intense boating activity represents a potential, and perhaps significant, source of pathogens to Narragansett Bay.

Under Section 312 of the Federal Water Pollution Control Act (see West et al., 1980), boats are required to use approved marine sanitation devices (MSD; heads/toilets) for treating and/or holding human wastes for proper release. If the wastes are treated on-board with a Type 1 or 2 MSD (approved by the Coast Guard), discharge in the Bay is permitted. However, most of the boats in Narragansett Bay (i.e., recreational boats) that have a head/toilet facility use a holding tank (Type 3 MSD) or portable device. This untreated sewage can only be discharged beyond the 3 mile limit or transferred to the land for proper treatment. Because of enforcement limitations by the Coast Guard, a paucity of pump-out facilities at marinas and few boater education programs, untreated sewage is discharged from boats directly into Narragansett Bay.

It is assumed that approximately 34,000 boats using Rhode Island waters in 1988 were equipped, or should have been equipped, with a head/toilet (Table 12). As a worst-case scenario, if all those boats had discharged their raw wastes into the Bay, it would have amounted to over 270,000 gal/day. If only 10% or 1% of the boats had discharged on a particular day, the input would have obviously been less. As noted in Table 13, the worst-case scenario represents a flow similar in order-of-magnitude to a small WWTF (e.g., Jamestown, East Greenwich). Flow from larger facilities and wet weather CSO events are substantially greater. However, it must be recognized that the discharge from boats is raw "untreated" human waste, as opposed to treated-disinfected wastewater effluent or diluted raw sewage from CSO's (as reflected in the fecal coliform concentration data, Table 13). When coupling the flow estimates with the concentration of each source, assumed inputs are derived.

Table 13 should not be viewed as a bay-wide inventory of fecal coliform inputs, but rather serves to illustrate the potential significance of pathogen inputs by boating relative to other sources. In actuality, the boat waste problem is most focussed in poorly flushed coves of the Narragansett Bay

Table 12. Facts and assumptions used to derive the number of boats utilizing Rhode Island waters that are equipped with a head/toilet. (MSD=Marine Sanitation Device).

Boats With MSD

Number boats registered with RI Division of Boating Safety (1988)	29,101
- Boats >20 feet (assume MSD)	10,128
Number of boats documented with the U.S. Coast Guard (assume MSD)	18,000
Number of visiting boats (assume MSD)	6,000
Total number of boats assumed to have MSD	34,128

POTENTIAL DISCHARGE TO WATER (boat/day)

Assume		1 gal./flush
Assume		2 persons on board
Assume		4 flushes/person/day
Total	=	8 gal/boat/day

Table 13. Boating inputs of fecal coliforms to Narragansett Bay compared to several wastewater treatment facilities and CSO areas.

Source	Flow (mgd)	Density[a] (fc/100ml)	Input ($fcx10^{10}$/day)
Boats[b]			
100%	0.27	$1x10^5$ - 10^8	102 - 102,000 (13,600)[c]
10%	0.03	$1x10^5$ - 10^8	51 - 51,000 (1,300)
1%	0.003	$1x10^5$ - 10^8	1 - 1,140 (136)
WWTF			
Jamestown	0.48[d]	5 - 200	0.001 to 0.36
E. Greenwich	0.77	5 - 200	0.015 to 0.58
NBC	51.44	5 - 200	0.97 to 38.94
CSO's[e]			
Quequechan R.	54.0	180,000	39,800
CSO Area B	15.9	----	719,800
CSO Area C	8.7	----	31,000

a Fecal coliform density for raw sewage discharge from boats is assumed to range from 1 x 10^5 (pre-treatment wastewater) to 1 x 10^8 (somewhat dilute from human feces). From WWTFs the range assumes variable effectiveness of disinfection by chlorination. See footnote 4 for explanation of CSO densities.

b Assumes 34,000 (100%), 3,400 (10%), and 340 boats (1%) simultaneously discharge to the Bay

c An alternative method to estimate fecal coliform input from boats is to assume an input of $2x10^9$ fecal coliform/person/day (from ISSC formula) multiplied by 2 persons per boat, multiplied by the total number of boats discharging. The results are comparable to the other calculation method.

d WWTF flows are annual averages for 1986 (from RIPDES files).

e Quequechan River CSO (Fall River) data are from Rippey & Watkins (1988). CSO Area B (O'Brien & Gere, 1988) and CSO Area C (Camp, Dresser & McKee, 1989) data refer to 3-mo 6-hr storm predicted values for the entire area. Predicted density data are not available.

estuary. Inventories of all pathogen sources from particular harbors/coves are needed to estimate, with some degree of certainty, the relative significance of boats versus WWTFs, stormwater runoff, CSOs or other sources. Such an evaluation is currently not available in Narragansett Bay, or elsewhere in the northeast.

Aside from the mass balance or inventory approach, the potential impact of boats on pathogen loading to Narragansett Bay harbors/coves can be evaluated by predictive modeling. The RI DEM requires use of the Interstate Shellfish Sanitation Conference (ISSC) formula (or model) as a method to determine the maximum number of boats that a harbor or cove can sustain while maintaining water quality status. There are many assumptions associated with the formula including; 100% occupancy rate, overboard discharge by all occupied boats, 2 persons/boat with a discharge of 2×10^9 fecal coliforms/person/day, wastes are completely mixed, no bacterial die-off or growth, and no other sources of fecal coliform to the area. The ISSC recognizes that many of these assumptions are generalized and that site-specific information can be incorporated. It should be noted that there has been much criticism of the ISSC formula, citing unrealistic assumptions and conceptual errors (Swanson and Spaulding, 1990).

Regardless of the abovementioned controversy, the ISSC formula is currently recognized as an approved (i.e., RIDEM, EPA, ISSC) approach. For several coves/harbors in Narragansett Bay, Table 14 compares the actual number of boats present in a particular harbor with the allowable number calculated from the ISSC formula. As noted, the formula has been run with varying occupancy rates. According to on-site surveys conducted during peak boating activity, Eldredge (1989) has found that a 100% occupancy rate is not realistic for Narragansett Bay harbors (e.g., Newport 51%, East Greenwich 27%, Portsmouth 28%, Average 38%). For some typical harbors in the West Bay area, the existing number of boats far exceeds the allowable number (even with low occupancy rates). For these shallow, relatively small, enclosed harbors, the potential for pathogen contamination is clearly demonstrated. For Newport, a deeper, larger and better flushed harbor, the predicted allowable capacity has not yet been achieved.

The ISSC formula has some obvious flaws, particularly with respect to calculating dilution volumes (M. Spaulding, personal communication; comments presented at the "Workshop on Boat Sewage Management in Rhode Island: Present and Future," 1 June 1989, RI Marine Advisory Service). A more refined and conceptually improved method for estimating harbor carrying capacity is needed. However, until a revised and tested technique is approved for use by the ISSC, USEPA and other agencies, the present formula remains as the standard practice for estimating carrying capacity.

OPTIONS FOR DECREASING PATHOGEN INPUTS FROM BOATING ACTIVITY

Pump-out Facilities

As of summer 1989, there were only 2 operational pump-out facilities in Narragansett Bay (Barrington Harbor, Newport Harbor). Several others (approximately 9) are proposed. Additional pump-out facilities must be established and strategically located throughout the Bay. The RIDEM currently requires (as a consent agreement) pump-out facilities in association with new or up-graded marina projects. However, additional mechanisms must be used to establish even more facilities to compensate for the Bay's existing deficit. It is expected that the process associated with creating Harbor Management Plans in accordance with guidelines set forth by the RI CRMC will provide the necessary framework (CRMC, 1988). As stated in Section 120.3, Harbor Management Plans may recommend the location of pump-out facilities, and further, Section 220.3 states that in response to increasing recreational opportunities, Harbor Management Plans should encourage the establishment of pump-out facilities. The RI DEM (Water Resources) has recently developed a policy to specifically address the assessment of water quality in harbor/coves.

Table 14. Select harbors in Narragansett Bay comparing the actual number of boats estimated (by survey) to occupy the area with the allowable number as predicted by the ISSC formula. The ISSC formula was run based on 100%, 50%, and 25% occupy rate[a].

Harbor/cove	Number of Boats	
	Actual	Allowable (ISSC)
Warwick Cove	2,143[b]	20 (100%) 40 (50%) 60 (25%)
Greenwich Cove	973	60 (100%) 120 (50%) 240 (25%)
Apponaug Cove	530	12 (100%) 24 (50%) 48 (25%)
Newport Harbor	1,592	1,921 (100%) 3,842 (50%) 7,684 (25%)

a Data for Warwick, Greenwich and Apponaug Coves provided by RIDEM (Water Resources); Newport Harbor data provided by Eldredge (personal communication)

b Actual number of boats includes all size classes, yet it is probable that a majority of the boats are >25 ft and have heads/toilets.

There appears to be a strong willingness by marina operators to install and maintain pump-out facilities. However, for a Bay-wide program to be effective there must be extensive boater education to promote use of the facilities. Enforcement mechanisms must also be considered. At present the U.S. Coast Guard (USCG) has enforcement authority over discharges to coastal waters. To enhance the enforcement presence, the RI Division of Boating Safety, in conjunction with local harbormasters, should assume some of this authority. The USCG should enter into a memorandum of understanding with the State that grants the State enforcement authority.

The issue of treating the boat wastes once transferred to land must be addressed. Options include, a) direct discharge to a municipal wastewater system, b) collection in a land-based holding tank, with periodic transfer to a WWTF, and c) construction of a large-scale on-site septic system. For options b and c to be effective, there must be close coordination among the permitting authorities (RIDEM - ISDS program and Underground storage; CRMC). Creation of the previously discussed Wastewater Management Districts (WWMD) may play a role in addressing the septage issue.

The issue of pump-out facilities, including siting, education, enforcement, and waste transfer is currently being addressed by a RI Sea Grant Marine Advisory Service working group. This working group is well-represented by all interests (e.g., regulatory agencies, academics, marina owners, marine trades). Recommendations are forthcoming. Other options to be considered by the RI Sea Grant Marine Advisory Service working group include, designation of Narragansett Bay as a "no discharge zone," and restriction of live-a-boards to marinas with sewer hook-ups or pumpout facilities.

STORMWATER RUNOFF

Stormwater runoff is a significant source of fecal coliforms to estuarine waters. Although the Narragansett Bay Project has not collected data specifically evaluating this source, the Buzzard's Bay Project has assembled a considerable data set documenting substantial elevations in fecal coliform densities during rainfall events. However, it is difficult to determine the actual input of human-derived pathogens from stormwater runoff. Typical sources of fecal coliform in stormwater could include, wildlife (birds, waterfowl) and domestic animals. A potential human pathogen source could be derived from sewage hook-ups to storm drains. Regardless of the actual source of stormwater pathogens, all stormwater pathogen inputs are assumed to pose a public health threat. Research is required to address the issue of disease transmission from other vertebrates to humans. [Note the related problem of "passive" transmission of pathogens by vertebrates that eat human waste and defecate near water supplies].

OPTIONS FOR CONTROLLING STORMWATER INPUT OF PATHOGENS

Survey Storm Drains for Sewage Hook-ups

In accordance with the NSSP shellfish certification process, the RIDEM (Water Resources) conducts sanitary shoreline surveys to evaluate sources of pathogens (as indicated by fecal coliform and total coliform) to the Bay. An attempt is made to sample all storm drains and other point inputs. When elevated fecal coliform concentrations are noted, the RIDEM (Water Resources) enforcement division is notified to investigate the actual source. This activity of locating and mitigating inputs of human-derived sewage to stormwater drainage systems must be continued, and perhaps, enhanced.

Implement Stormwater Control Best Management Practices

Runoff of stormwater, and associated pathogens, must be reduced. Technical guidelines for stormwater management in Rhode Island (RI Department of Environmental Management, 1988b) include implementation of on-site stormwater control (vegetated swales, dry and wet detention basins, infiltration systems). The Narragansett Bay Project supports prompt implementation of these best management practices, as an effort to reduce nonpoint source loading of pathogens to the Bay.

GENERAL CONTROL OPTIONS

MARINE OUTFALLS FOR WWTFs

To enhance dilution of pathogen-contaminated effluent, consideration should be given to relocating WWTF outfalls that discharge into shallow, poorly-flushed and/or isolated embayments. It is recommended that all WWTF discharge locations be evaluated, and if considered appropriate, the cost and engineering feasibility of outfall relocation should be determined. In addition to a preliminary evaluation of receiving water hydrodynamic characteristics, other factors, such as proximity of the existing outfalls to critical resource areas (e.g., shellfish harvest areas, beaches) should be considered.

REGIONALIZATION OF WWTFs

There are over 30 municipal WWTFs discharging into Narragansett Bay and tributary waters throughout the watershed (Fig. 17). The objective of regionalization is to a) reduce the number of individual point discharge points throughout the Bay and watershed (i.e., consolidate discharge) and b) as presented in the previous option, promote discharge to well-flushed areas (eliminate discharge to shallow, isolated embayments, such as Greenwich Cove).

Several options can be considered ranging, among others, from, a) regionalization of all the WWTFs with a single outfall in Rhode Island Sound, b) regionalization of the WWTFs of the Providence River basin (NBC, BVDC, Woonsocket, Warwick, West Warwick, Cranston, East Greenwich) under authority of the NBC, and c) regionalization of the East Providence, Woonsocket and BVDC WWTFs, under authority of the BVDC. The option of regionalization cannot be effectively considered based only on the pathogen reduction issue. Economic and engineering feasibility and a suite of potential environmental benefits/costs must be considered.

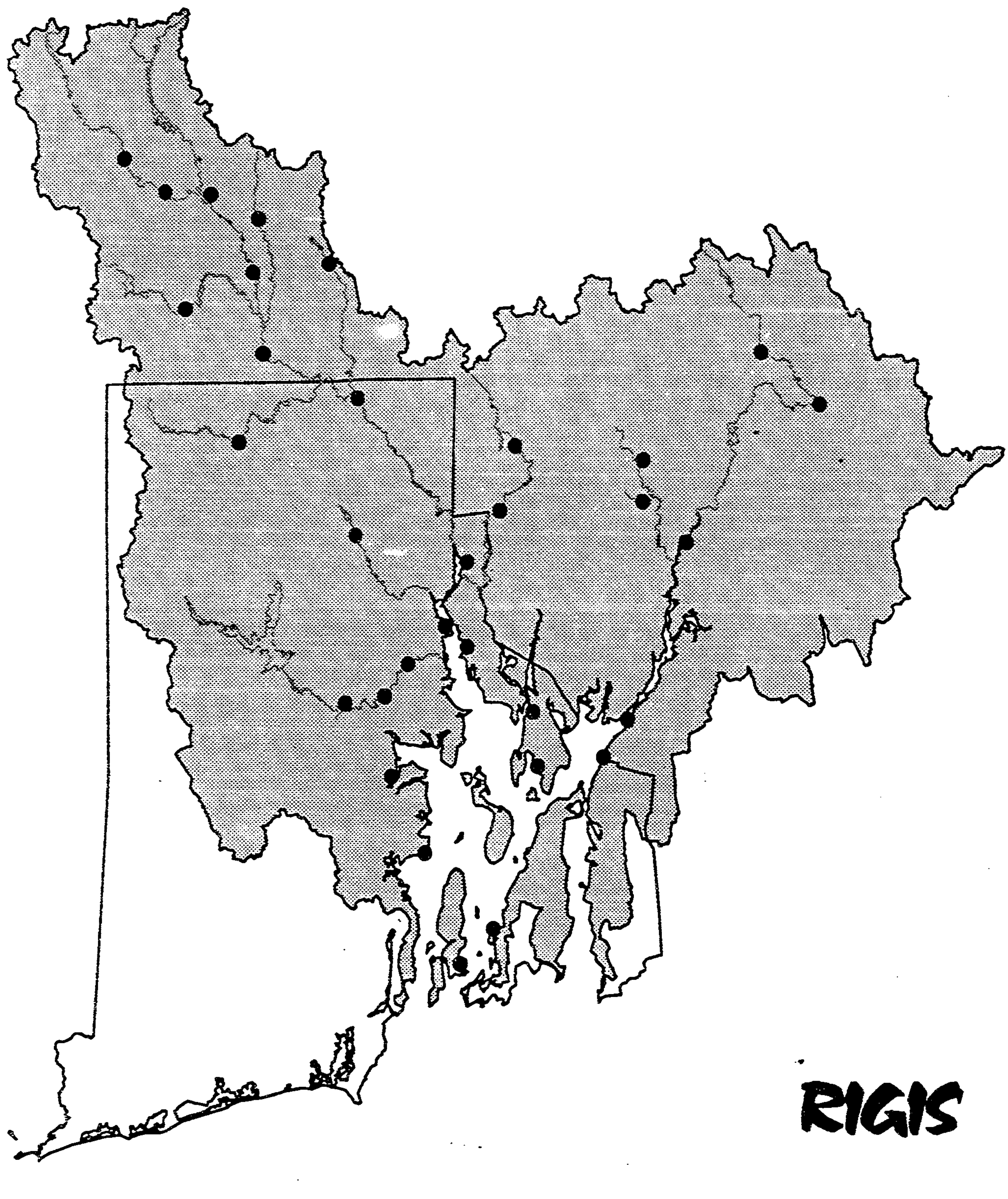
INNOVATIVE ALTERNATIVE WASTEWATER TREATMENT

Numerous innovative technologies are available or being developed for wastewater effluent treatment. Some of these include constructed wetlands, solar aquatics, and land-based spray irrigation. Implementation of these and other technologies, could reduce the direct input of treated wastewater to Narragansett Bay, and thus, reduce contaminant inputs (pathogens, metals, organics, nutrients). These technologies must be evaluated in more detail, taking into consideration the removal efficiency benefits, negative environmental consequences (e.g., viral contamination of groundwater), engineering feasibility and costs.

SHELLFISH DEPURATION AND/OR ENHANCE TRANSPLANT PROGRAM

Decreasing the area of permanently and conditionally closed shellfish areas represents a primary objective of controlling pathogen inputs. Additional open areas will presumably enhance the economic value of the shellfishery in Narrgansett Bay. Depuration, or cleansing of contaminated shellfish, is an alternative option to enhancing shellfish harvest potential of the Bay while presumably maintaining protection of public health. Depuration plants can be state or privately owned

Fig. 17: **Wastewater Treatment Facilities in the Narragansett Bay Watershed**



RIGIS

and operated. A shellfish depuration facility designed to handle 162 bushels of quahogs per day (=12,960 pounds) would cost an estimated $196,000 in capital costs (1978 dollars) and an estimated $81,000 per year in operating costs (Zakaria, 1979).

Depuration has been discussed in Rhode Island for decades. In general, the shellfishers consider that depuration may, 1) negatively alter the existing market structure, 2) reduce efforts to improve water quality in the Upper Bay, and 3) lead to a negative public perception about the quality of RI shellfish (Pratt, 1988). Further, there is concern that depuration facilities may not effectively control viral pathogens. The validity of these items must be carefully evaluated.

The RIDEM (Division of Fish & Wildlife) currently coordinates a management program whereby shellfish are harvested from polluted waters and transplanted to approved waters for harvest after the organisms have been "naturally" purified. In the Greenwich Bay transplant program, shellfish are harvested from Greenwich Cove in May, transplanted to Greenwich Bay, and harvested for market approximately 6 months later. Similar to controlled depuration, an enhanced transplant program represents an option for increasing the shellfish harvest potential of the Bay, while protecting public health. According to Pratt (1988), enhancement of Rhode Island's transplant program seems feasible, but consideration should first be given to the economic advantages of a shore-based depuration facility, the persistence of pollutants and viruses in the transplanted shellfish, the public perception of transplant quality, and the role of closed areas as spawner sanctuaries.

If based solely on public health benefits, the depuration and/or transplant options seem highly appropriate. [This assumes that pathogenic organisms (particularly viruses) and other contaminants (metals) are adequately reduced in the respective programs.] However, other considerations, such as economic and market structure and biological factors (depletion of spawing stock) are equally important and must be evaluated prior to considering these as feasible options.

REFERENCES CITED

Brown, K.W., H.W. Wolf, K.C. Donnelly, and J.F. Slowey. 1979. The movement of fecal coliforms and coliphages below septic lines. J. Environ. Qual. 8:121-125.

Cabelli, V.J. 1977. Indicators of recreational water quality. pp. 222-238. In A.W. Hoadley and B.J. Dutka (eds.), Bacterial Indicators/Health Hazards Associated With Water, ASTM STP 635, American Society for Testing and Materials, Philadelphia, PA.

Cabelli, V.J., A.P. Dufour, L.J. McCabe, and M.A. Levin. 1983. A marine recreational water quality criterion consistent with indicator concepts and risk analysis. Journal WPCF 55 (10): 1306-1314.

Cabelli, V.J. 1990a. Microbial indicator levels in the Providence River and upper Narragansett Bay. Report to Narragansett Bay Project.

Cabelli, V.J. 1990b. Microbial indicator levels in shellfish, water and sediments from the upper Narragansett Bay conditional shellfish-growing area. Report to Narragansett Bay Project.

Camp Dresser & McKee, Inc. 1989. Combined sewer overflow mitigation study, CSO Area C: Upper Woonasquatucket River interceptor drainage Basin: Vol I and II. CDM Final report to the Narragansett Bay Commission. Camp Dresser & McKee, Inc., Providence, RI.

Coastal Resources Management Council. 1988. Guidelines for the development of municipal harbor management plans. Adopted Nov. 22, 1988. RI Coastal Resources Management Council, Wakefield, RI.

Cogger, C. 1988. On-site septic systems: the risk of groundwater contamination. Journal of Environmental Health 51(1): 12-16.

Deacutis, C. 1988. Bathing beach monitoring for new indicators. Report to the Narragansett Bay Project. #NBP-88-06. 36pp.

Duckworth, D.H. 1987. Ch. 1, pp.1-44. In S.A. Goyal, C.P. Gerba, and G. Bitton (eds.) Phage Ecology, John Wiley & Sons, New York.

Eldredge, M. 1989. The contribution of recreational boating to bacterial water pollution: a model for determining sewage loading rates. Draft paper for Proceedings of Workshop on Boat Sewage, May, 1989, Rhode Island Sea Grant Marine Advisory Service, Narragansett, RI.

Gerba, C.P. 1987. Phage as indicators of fecal pollution. Ch. 8, pp. 197-210. In S.A. Goyal, C.P. Gerba and G. Bitton (eds.), Phage Ecology, John Wiley & Sons, New York.

Goyal, S.A. 1986. Viral pollution of the marine environment. Critical Reviews in Environmental Control 14(1):1-32.

Haas, C.N. 1986. Wastewater disinfection and infectious disease risks. Critical Reviews in Environmental Control 17(1):1-20.

Hoffman, E.J. 1988. The First Year of the Narragansett Bay Project: Results and Recommendations. A report submitted to the Narragansett Bay Project Management Committee, May 1988. Revised draft.

Industrial Economics, Inc. 1985. Benefits of water quality improvements in the Providence River and upper Narragansett Bay. Final report prepared for Benefits Branch, Office of Policy Analysis, U.S. EPA. Industrial Economics, Inc., 2067 Massachusetts Ave., Cambridge, MA.

Keswick, B.H. and C.P. Gerba. 1980. Viruses in groundwater. Environmental Science and Technology 14(11):1290-1297.

Keswick, B.H., T. Satterwhite, P. Johnson, H. DuPont, S. Secor, J. Bitsura, G. Gary, and J. Hoff. 1985. Inactivation of Norwalk virus in drinking water by chlorine. Applied and Environmental Microbiology 50(2):261-264.

Leonard, D.L., M.A. Broutman and K.E. Harkness. 1989. The quality of shellfish growing waters on the east coast of the United States. National Estuarine Inventory. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Office of Oceanography and Marine Assessment, Ocean Assessments Division, Strategic Assessment Branch. Rockville, MD. 54pp.

Morse, D.L., J. Guzewich, J. Hanrahan, R. Stricof, M. Shayegani, R. Deibel. J. Grabau, N. Nowak, J. Herrmann, G. Cukor, and N. Blacklow. 1986. Widespread outbreaks of clam- and oyster-associated gastroenteritis: Role of Norwalk virus. The New England Journal of Medicine 314(11):678-681.

O'Brien and Gere. 1988. Combined Sewer Overflow Mitigation Study, CSO Area B: Moshassuck River Interceptor Drainage Basin. Final report to the Narragansett Bay Commission. O'Brien & Gere Engineers, Inc., Syracuse, NY.

Oviatt, C.A. 1981. Some Aspects of Water Quality in and Pollution Sources to the Providence River. Report for Region I, Environmental Protection Agency. Sept. 1979 - Sept. 1980. Contract #68-04-1002. The Marine Ecosystems Research Laboratory, Graduate School of Oceanography, University of Rhode Island, Kingston, RI. 236 pp.

Pratt, S.. 1988. Status of the hard clam fishery in Narragansett Bay. Report to the Narragansett Bay Project, #NBP-88-07. 89pp.

Rahe, T.M., C. Hagedorn, E.L. McCoy, and G.F. Kling. 1978. Transport of antibiotic-resistant Escherichia coli through western Oregon hillslope soils under conditions of saturated flow. Journal of Environmental Quality 7: 487-494.

Reneau, R.B. and D.E. Pettry. 1975. Movement of coliform bacteria from septic tank effluent through selected coastal plain soils of Virginia. Journal of Environmental Quality 4: 41-44.

Reneau, R.B., C. Hagedorn, and M.J. Degen. 1989. Fate and transport of biological and inorganic contaminants from on-site disposal of domestic wastewater. Journal of Environmental Quality 18: 135-144.

Rhode Island Department of Administration. 1987. Waste water management districts...a starting point. Report Number 62. Division of Planning, Providence, RI.

Rhode Island Department of Administration. 1989. State guide plan element 120: Land Use 2010: State land use policies and plan. Division of Planning, Providence, RI.

Rhode Island Department of Environmental Management. 1988a. An assessment of nonpoint sources of pollution to Rhode Island's waters. RI Department of Environmental Management, Providence, RI.

Rhode Island Department of Environmental Management. 1988b. Recommendations of the stormwater management and erosion control committee regarding the development and implementation of technical guidelines for stormwater management. RI Department of Environmental Management. Providence, RI. 108 pp.

Rhode Island Department of Environmental Management. 1989. Rhode Island's nonpoint source management plan. RI Department of Environmental Management, Office of Environmental Coordination. Providence, RI. 87pp. (plus Appendices).

Richards, G.P. 1985. Outbreaks of shellfish-associated enteric virus illness in the United States: Requisite for development of viral guidelines. Journal of Food Protection 48(9):815-823.

Rippey, S.R. 1988. Shellfish Borne Disease Outbreaks. Dept. of Health and Human Services, Public Health Service, Food and Drug Administration, Shellfish Sanitation Branch, Northeast Technical Services Unit, Davisville, RI. 43pp.

Rippey, S.R. and W.D. Watkins. 1988. Mt. Hope Bay Sanitary Survey - Microbiological, 1986-1987. Report to the Narragansett Bay Project. #NBP-88-11. 64pp. and appendices.

Save the Bay. 1988. A Raw Deal: Combined Sewer Overflow Pollution in Rhode Island. Save the Bay, Providence, RI. 16pp.

Stramer, S.L. 1984. Fates of poliovirus and enteric indicator bacteria during treatment in a septic tank system including septage disinfection. Ph.D. dissertation, University of Wisconsin, Madison, Wisconsin.

Swanson, J.C. and M.L. Spaulding. 1990. Marina boat carying capacity: an assessment and comparison of methodologies. Paper presented at, 2nd National Marina Research Conference, Clearwater Beach, FL. International Marina Institute, Wickford, R.I.

U.S. Environmental Protection Agency. 1986. Ambient Water Quality Criteria for Bacteria - 1986. EPA440/5-84-002. U.S. Dept. of Commerce, National Technical Information Service, Springfield, VA. PB86-158045. 18pp.

U.S. Environmental Protection Agency. 1987a. Municipal disinfection practices and risks to aquatic wildlife from residual chlorine. Office of Policy, Planning and Evaluation. Washington, D.C.

U.S. Environmental Protection Agency. 1987b. Septic tank siting to minimize the contamination of ground water by microorganisms. Office of Ground-Water Protection, Washington, D.C.

U.S. General Accounting Office. 1988. Seafood safety: seriousness of problems and efforts to protect consumers. Report to the Chairman, Subcommittee on Commerce, Consumer and Monetary Affairs, Committee on Government Operations, House of Representatives. GAO/RCED-88-135. US GAO, Gaithersburg, MD.

Vaughn, J.M. 1988. Human virus entrainment in a glacial aquifer. Funded by the Suffolk County Dept. of Health Services and the U.S. Environmental Protection Agency. Dept. Microbiology, Univ. of New England.

Vaughn, J.M., E. Landry and McH. Thomas. 1983. Entrainment of viruses from septic tank leach fields through a shallow, sandy soil aquifer. Applied and Environmental Microbiology 45(5):1474-1480.

Water Pollution Control Federation Disinfection Committee. 1987. Assessing the need for wastewater disinfection. Journal WPCF 59(10):856-864.

Watkins, W.D., and S.R. Rippey. 1990. Narragansett Bay Project wet weather study - Microbiology. **DRAFT** report submitted to the Narragansett Bay Project, Providence, RI. 198 pp (plus Appendices).

Weiskel, P. and G. Heufelder. 1989. The impact of septic effluent on groundwater quality, Buttermilk Bay drainage basin, Massachusetts. Part I: Indicator bacteria. Report submitted to The Buzzard's Bay Project, US Environmental Protection Agency, Region I and Massachusetts Executive Office of Environmental Affairs.

West, N., C. Heatwole, and L. Smith. 1982. Environmental improvement on Narragansett Bay as a result of Section 312 implementation of the Federal Water Pollution Control Act. Coastal Zone Management Journal 10(1/2):125-140.

Yates, M.V., S.R. Yates, A.W. Warrick, and C.P. Gerba. 1986. Use of geostatistics to predict virus decay rates for determination of septic tank setback distances. Applied and Environmental Microbiology 52(3): 479-483.

Zakaria, S. 1979. Depuration--as it relates to the hard shell clam of Narragansett Bay, Rhode Island. In: Proceedings of Northeast Clam Industries: Management for the Future. Sponsored by: Cooperative Extension Service University of Massachusetts, Massachusetts Institute of Technology Sea Grant Program, Department of Food and Resource Economics University of Massachusetts, Massachusetts Department of Marine Fisheries, New England Marine Advisory Service, Shellfish Institute of North America. April 27-28, 1978. Hyannis, MA. pgs. 109-119.

Appendix 1. Input of fecal coliform and Clostridium to Mt. Hope Bay during wet weather from major sources. Data derived from Rippey & Watkins, (1988).

Input	INPUT/DAY f.c. x 10^{12}	Clost x 10^{12}	% Total Input f.c.	Clost
Taunton R.	31.7	3.9	3	2
WWTFs				
Fall River	0.01	20.9		
Somerset	0.63	18.7		
Subtotal	0.64	39.6	<1	23
CSOs				
Quequechan	398	35		
Birch St.	398	86		
Middle St.	200	4		
Other CSOs	60	4		
Subtotal	1,056	129	96	73
Stormwater Runoff				
Site W2	10	3		
Site W3-W6	0.6	0.4		
Subtotal	10.6	3.4	1	2
TOTAL INPUT	1,099	176		

Appendix 2a. Fecal coliform source strengths for the three storm events, combined. Data from Watkins and Rippey (1990).

Rank	Point Source	Total Input	%
1	BVDC Bypass	3.95×10^{15}	57
2	NBC FP Bypass	1.11×10^{15}	16
3	Moshassuck River	5.67×10^{14}	8
4	Blackstone River	4.17×10^{14}	6
5	CSO 9	3.71×10^{14}	5
6	CSO D #010	1.84×10^{14}	3
7	Woonasquatucket R.	1.72×10^{14}	2
8	Pawtuxet River	7.80×10^{13}	1
9	NBC FP STP	5.34×10^{13}	<1
10	Woonsocket STP	3.98×10^{13}	<1
11	BVDC STP	2.20×10^{13}	<1
12	Ten Mile River	1.29×10^{13}	<1
13	EP STP	1.52×10^{11}	<1
Total Fecal Coliform Input		6.98×10^{15}	(100%)

Appendix 2b. Clostridium source strengths for the three storm events, combined. Data from Watkins and Rippey (1990).

Rank	Point Source	Total Input	%
1	NBC FP STP	3.51×10^{14}	23
2	BVDC STP	3.29×10^{14}	21
3	Blackstone River	2.33×10^{14}	15
4	BVDC Bypass	1.94×10^{14}	12
5	NBC FP Bypass	1.77×10^{14}	11
6	Pawtuxet River	1.14×10^{14}	7
7	Woonsocket STP	5.45×10^{13}	3
8	Woonasquatucket R.	2.28×10^{13}	1
9	Moshassuck River	2.14×10^{13}	1
10	CSO 9	1.95×10^{13}	1
11	EP STP	1.67×10^{13}	1
12	CSO D #010	1.51×10^{13}	1
13	Ten Mile River	8.56×10^{12}	<1
Total *C. perfringens* Input		1.56×10^{15}	(100%)

Appendix 3 . Input data for U.S. EPA (1987b) septic tank siting rating system.

Factor	Rating x	Weight	=	Score
Water Table Depth = 30 ft	6	5	=	30
10 ft	9	5	=	45
3 ft	10	5	=	50
Net recharge = 10-17in/yr	9	2	=	18
Hydraulic Cond. = 1500gpd/ft^2	8	3	=	24
GW temperature = 14^{o}C	6	2	=	12
Soil texture = sandy loam	10	5	=	50
Aquifer medium = sand				
50 ft from watercourse	10	3	=	30
150 ft from watercourse	9	3	=	27
500 ft from watercourse	8	3	=	24
Application rate = assume <5 cm/day	1	4	=	4
Setback Distance = 50 ft	10	5	=	50
150 ft	6	5	=	30
500 ft	3	5	=	15

Variables	Rating Index
50 ft setback	
3 ft water table	238
10 ft	233
30 ft	218
150 ft setback	
3 ft	215
10 ft	210
30 ft	195
500 ft setback	
3 ft	197
10 ft	192
30 ft	177

Appendix 3 (continued)

Information on soil characteristics for input to the methodology were derived from;

Rector, D.D. 1981. Soil survey of Rhode Island. US Dept. of Agriculture, Soil Conservation Service and RI Agricultural Experiment Station. 200 p. (and maps).

Information on groundwater and aquifer characteristics were derived from;

Rosenshein, J.S., J.B. Gonthier, and W.B. Allen. 1968. Hydrologic characteristics and sustained yield of principal ground-water units, Potowomut-Wickford area Rhode Island. US Dept. of Interior, Geological Survey, Water-Supply Paper 1775, in cooperation with RI Water Resources Coordinating Board. 38 p. (and maps).

Allen, W.B. 1956. Ground-water resources of the East Greenwich Quadrangle, Rhode Island. US Geological Survey and RI Development Council. Geological Bulletin No. 8. 56 p (and maps).