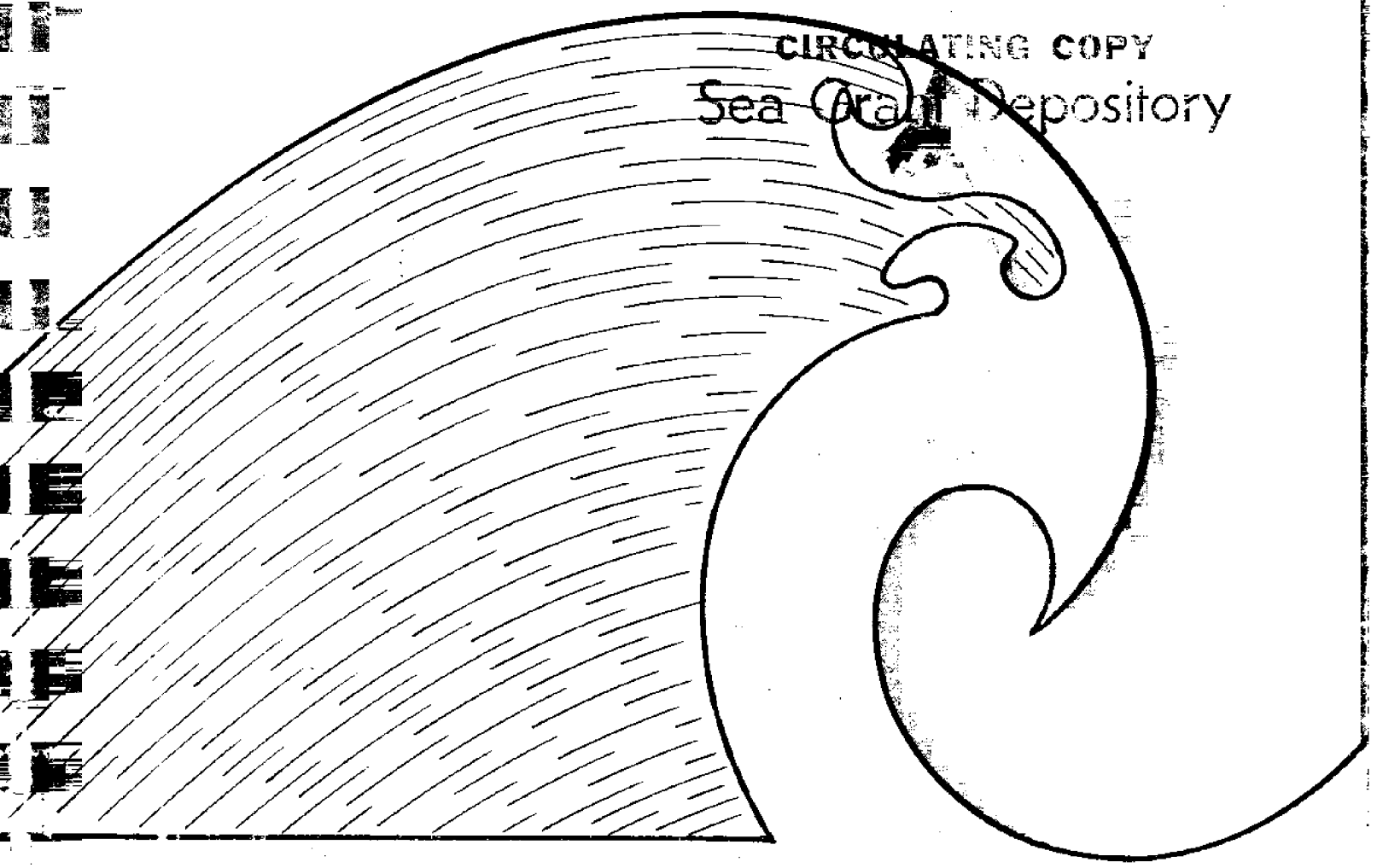


DEPARTMENT OF OCEAN ENGINEERING

SEA GRANT PUBLICATIONS

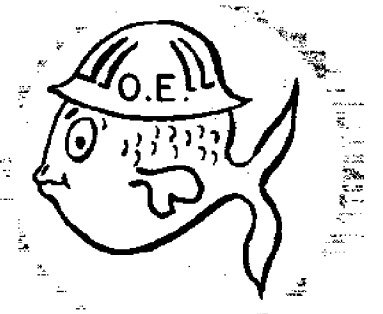
COLLEGE OF ENGINEERING UNIVERSITY OF RHODE ISLAND

Memorandum Number 5M

POLLUTION IN NARRAGANSETT BAY

BY
KURT W. HESS

16 JULY 1970



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Kurt W. Hess

Prepared for

National Science Foundation

Under

Sea Grant Contract Number GH-99

by

Department of Ocean Engineering

University of Rhode Island

16 July 1970

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1.0 INTRODUCTION

This paper serves to document the history and sources of pollution in Narragansett Bay. An attempt has been made to define pollution, making use of the State of Rhode Island water quality categories. The problem of specifying the unpolluted state of the water is briefly examined.

The major sources are municipal and industrial waste, which has continually been diverted into the bay, the state laws notwithstanding (1). As a result, the area of the bay officially designated as polluted has increased constantly from the earliest record.

2.0 POLLUTION

The first step to be taken is to define pollution itself. It should then become clear what the reduction of pollution involves.

Clarence Tarzwell of the National Marine Water Quality Laboratory in West Kingston, Rhode Island has offered a very suitable definition of pollution (2):

> the addition of any material or any change in the quality or character of a water that interferes with, lessens, or destroys a desired use.

Note the emphasis on the concept of water use. The Rhode Island Department of Health, Division of Water Supply and Pollution Control (D.W.S.P.C.) has defined water quality in terms of use. For seawater, there are four categories; they are:

1. SA Suitable for all seawater uses including shellfish harvesting for direct human consumption (approved shellfish areas,) bathing, and other water contact sports

2. SB Suitable for bathing, other recreational purposes, industrial cooling and shellfish harvesting for human consumption after depuration (restricted shellfish area;) excellent fish and wildlife habitat; good aesthetic value

3. SC Suitable fish, shellfish and wildlife habitat; suitable for recreational boating and industrial cooling; good aesthetic value

4. SD Suitable for navigation, industrial cooling and migration of fish; good aesthetic value

The most important criterion is the number of coliform bacteria per 100 milleliters of seawater. For an SA rating, the most

probable number (MPN) must be less than 70; for the SB, the MPN must be less than 700. All criteria for the SA appear in Table 1.

It may be useful to further identify pollution in terms of its sources. The two major sources are municipal sewage and industrial waste.

Sanitary, or municipal sewage is the product of cities and pollution occurs when the sewage receives inferior or no treatment before it enters the waterway. Common substances usually include chemicals which are produced by biological processes and bacteria.

Industrial wastes are of several types. Toxic chemicals and dying agents may render the receiving water unsuitable as wildlife habitats. Other chemicals may act as nutriants. Heated water from industrial cooling may attract some species, but repel others. Radioactivity is only one of many other possible pollutants.

A survey of polluters in the Narragansett Bay basin (3) taken in 1950 lists the sources of both types of pollution on the major tributaries. Any water-supply textbook (4) can be used to determine the constituants of the waste. A more recent survey undertaken by the Rhode Island Department of Health includes both direct and indirect polluters of the bay. Table 2 lists sources of direct pollution (fig. 1), and Table 3 lists indirect sources. Stations refer to the Department of Health water quality map.

Another point of interest is the "original state" of any polluted water. Although its present condition may be known, what would be a river's composition in the absence of industrial and municipal wastes? The answer may never be known unless adequate records of chemical composition exist for reasonably early (i.e., unpolluted) times. Indeed, under the "use" definition, a knowledge of the original state may be superflous. A chemical composition survey exists for several Rhode Island rivers, with data taken in 1925 and

1951 (5). While 1925 is probably not early enough, comparisons with later information give some idea of the changes occuring. Results of the survey appear in Table 4.

3.0 HISTORY OF POLLUTION

In general, the area of Narragansett Bay considered to be polluted is growing. Small areas of contamination may have appeared and disappeared, the overall trend has been the same.

Figures 2a-f show how this polluted area has grown. Each chart has been drawn using information of varying quality from many sources. The most recent data is the best; it comes directly from water quality surveys taken by the D.W.S.P.C. Legal descriptions are used whenever possible. Older records include fishery surveys and word-of-mouth reports.

A brief explanation of each figure follows:

Fig. 2a (1880) The oldest polluted area is probably the Providence River around Providence, possible due to municipal sewage. Reports said that once-common oysters had disappeared, possibly because of turbidity. Apponaug Cove was said to be devoid of fish because of chemicals discharged by a printing business. These observations appear in a fishery survey (6)

Fig. 2b (1904) A greater portion of the Providence River, and all of Greenwich Bay (the author does not believe that the Greenwich Bay restrictions accurately reflect conditions there) are restricted by law to shellfish harvesting (7). The Warren River and Newport Harbor are said to be polluted (8). The Taunton River is probably contaminated around Fall River (6), (9)

Fig. 2c (1940) All of the Providence River, and Quonset Point (due to Naval construction) are polluted according to a fish-and-game report (10). An unpublished D.W.S.P.C. map shows Greenwich Cove and Bristol Harbor as restricted areas.

Fig. 2d (1947) The oldest published D.W.S.P.C. map was the source of this figure. Naval installations now account for a large area in the East Passage. Note the inclusion of the entire Warren River - Barrington River confluent area, and the growing Mt. Hope Bay pollution.

Fig. 2e (1961) Another Rhode Island map and the Hurricane Barrier Study (11) are the sources for this figure. All of Mt. Hope Bay is now included.

Fig. 2f (1969) The latest map from D.W.S.P.C. shows the extent of pollution today.

Today the total polluted area of Narragansett is about 35 square miles, or nearly one-third of the total area. Figure 3 shows how this area has grown since the oldest records (1880). Alongside are charts of the state population growth and that for the two southern counties, Newport and Washington (12). Although there seems to be some correlation between population growth and pollution, any refined analysis should also include industrial growth and military population.

It has been seen that the upper bay has been polluted for a long period of time, and any clean-up project there would have to be monumental. However, the lower bay is still relatively "clean" and efforts should be made to protect it. Southern Rhode Island will see the next population boom, and the accompanying municipal sewage poses a great threat. This type of pollution can be studied by Bay Watch program, in accordance with the "evidence of danger" clause in the state law quoted in the introduction.

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TABLE 1

WATER QUALITY STANDARDS

SEA WATER

CLASS SA: Suitable for all sea water uses including shellfish harvesting for direct human consumption (approved shellfish areas), bathing, and other water contact sports.

Standards of Quality

Item	Water Quality Criteria
1. Dissolved oxygen	Not less than 6.0 mg/l at any time
2. Sludge deposits--solid refuse--floating solids--oil--grease--scum	None allowable
3. Color and turbidity	None in such concentrations that will impair any usages specifically assigned to this Class
4. Coliform bacteria per 100 ml	Not to exceed a median MPN of 70 and not more than 10% of the samples shall ordinarily exceed an MPN of 230 for a 5-tube decimal dilution or 330 for a 3-tube decimal dilution (See Note S.6)
5. Odor	None allowable
6. pH	6. 8 - 8.5
7. Allowable temperature increase	None except where the increase will not exceed the recommended limits for the most sensitive water use
8. Chemical constituents	None in concentrations or combinations which would be harmful to human, animal, or aquatic life or which would make the waters unsafe or unsuitable for fish or shellfish or their propagation, impair the palatability of same, or impair the waters for any othe uses
9. Radioactivity	(See Note S. 8)

TABLE 2

POLLUTION SOURCES

NARRAGANSETT BAY

N	Name	Location	BOD RAW	lb/day to River
1	Blackstone Valley Sewer District	E. Providence	52,200	42,300
2	Providence Sewerage Work	Providence	54,400	14,000
3	E. Prov. Sewerage Works	E. Prov. (Riverside)	5,000	1,000
4	Narragansett Village	Warwick	80	15
5	Warren Sewerage System	Warren	1,900	1,300
6	E. Greenwich Sewerage Works	Greenwich Cove (E.G.)	420	40
7	Bristol Sewerage Works	Bristol Harbor	3,900	2,000
8	Boat Manufacturing	Portsmouth	40	4
9	U.S. Navy	Melville	28	26
10	Electronic Products	Portsmouth	70	30
11	U.S. Navy	Quonset Point	2,700	1,100
12	U.S. Navy	Wickford Cove	140	10
13	Elmhurst Academy	Portsmouth	40	1
14	Newport S.W.	Newport	6,700	6,200
15	Jamestown Sewers	Jamestown (E. Passage)	260	260
16	Jamestown Sewers	Jamestown (CW. Passage)	30	30
17	URI-Narragansett	Narragansett	40	2
18	U.S. Navy-Ft. Adams	Newport	170	130
19	Narragansett Pier Sewerage Works	Narragansett	170	150
20	So. Kingstown Sewerage Works	Narragansett	0	0
21	Narragansett Sewerage Works	Scarborough	60	11

TABLE 2 (cont'd)

22	Middletown Sewerage Works	Easton Beach (Middletown)	30	30
23	Metal Finishing Plant	Warwick	N.A.	N.A.
24	Kent County Hospital	Warwick	90	4
25	Rubber Extrusion Plant	Warren	340	340
26	Metal Finishing Plant	E. Greenwich	45	2
27	Dairy	E. Greenwich	170	10
28	Tiverton High School	Tiverton	50	1
29	Metal Finishing Plant	E. Greenwich	87	2
30	Wool Finishing Plant	Belleville (No. Kingstown)	290	290

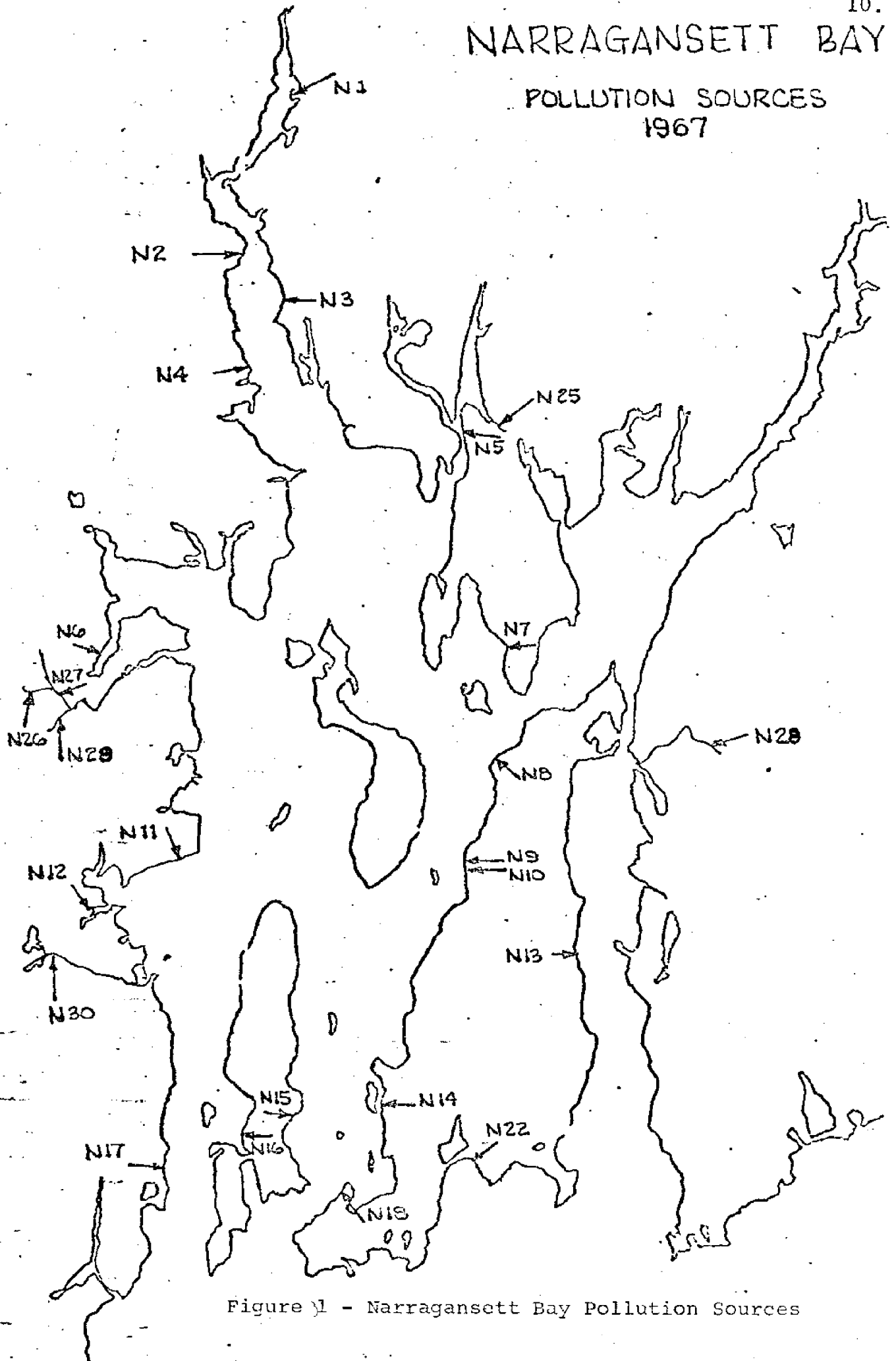


Figure 1 - Narragansett Bay Pollution Sources

TABLE 3

POLLUTION SOURCES (Feb. 1967)

BLACKSTONE RIVER

Station	Name	Location	BOD RAW	lb/day to river
B-1	R.I. State Sanitarium	Wallum Lake	60	10
B-2	Textile Industry	Bridgeton	200	200
B-3	Private Sewer	Harrisville	3,400	3,400
B-4	Wool Scouring & Finishing Plant	Harrisville	10	8
B-5	Burrilliville Sewerage Works	Oakland	0	0
B-6	Private Sewer	Glendale	10	8
B-7	Industrial Park	Slatersville	25	2
B-8	Wool Finishing Plant	Forestdale	1,100	1,100
B-9	Wool Scouring Plant	Branch Village	4,500	870
B-10	10 Textile Industries	Woonsocket	3,700	3,700
B-11	Woonsocket Sewerage Works	Woonsocket	11,100	5,400
B-12	Private Sewers	Manville	50	50
B-13	Wool Finishing Plant	Manville	250	70
B-14	Private Sewers	Albion	20	20
B-15	Private Sewers	Lonsdale	30	30
B-16	Glass Mfg.	Central Falls	N.A.	N.A.
B-17	Textile Industry	Pascoag	360	360
B-18	Cumberland Sewerage	Cumberland	0	0
TEN MILE RIVER				
T-1	Synthetic Yarn	E. Providence	60+	60+
MOSHASSUCK RIVER				
M-1	Copper Processing Plant	Lincoln	N.A.	N.A.
M-2	Saylesville Sewer System		1,250	1,250

TABLE 3 (cont'd)

			RAW	to River
WOONASQUATUCKET RIVER				
W-1	Textile Finishing Plant	Greenville	10,200	4,100
W-2	Laundry	"	6	1
W-3	Smithfield Sewerage Works	Georgiaville	20	15
W-4	Granite Cutting Plant	Providence	N.A.	N.A.
PAWTUXET RIVER				
PT-4	Laundry	Hope	260	260
PT-3	Dairy	"	50	50
PT-5	Textile Finishing Plant	Arkwright	12,800	980
PT-6	" " "	Hains	210	210
PT-1	Chemical Pt.	Quidnick	N.A.	N.A.
PT-16	Coventry Sewerage System	Coventry	0	0
PT-2	Textile Finishing Pt.	Crompton	300	300
PT-12	W.Warwick S.S.	Natick	3,310	1,270
PT-10	Dairy	Cranston	80	5
PT-7	Textile Finishing Pt.	Pontiac	6,000	520
PT-13	R.I. State Institutions	Cranston	2,640	280
PT-14	Warwick S.S.	Warwick	5,600	420
PT-15	Cranston S.S.	Cranston	7,450	640
PT-9	Textile Finishing Pt.	"	5,600	5,600
PT-8	Chemical Pt.	"	20,000	20,000
PT-11	Shopping Center	Warwick	20	1

R.I. Development Council
1953
Ground-Water Resources of Rhode Island
Geological Bulletin #6

Table 10.—Chemical analyses of surface water from selected rivers and ponds

(Dissolved constituents in parts per million)

Analyst: Jerome Deluty, Rhode Island Dept. of Health; M. D. Foster, U. S. Geological Survey

Source and location	Analyst	Date of Collection	Color	pH	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Dissolved solids	Hardness (as $CaCO_3$)		
																Total	Carbonate	Non-carbonate
Blackstone River at Blackstone, Mass.	U.S.G.S.	Aug. 12, 1925	15	6.2	3.9	.64	16	3.2	20	3.2	2.4	47	30	6.0	140	53	2.0	51
do.	R.I.D.H.	Feb. 19, 1951	40	6.4	7	.75	6.4	1.7	....	....	8.5	15	10	.89	65	23	7.0	16
Blackstone River at Manville	U.S.G.S.	Aug. 12, 1925	30	6.4	5.3	.81	9.3	2.0	17	2.0	17	28	17	4.8	109	31	14	17
do.	R.I.D.H.	Feb. 19, 1951	45	6.4	7	.80	6.4	1.7	....	..	8.5	17	11	.89	69	23	7.0	16
Blackstone River at Exchange St., Pawtucket	U.S.G.S.	Aug. 12, 1925	23	6.2	5.0	7.3	12	2.3	22	2.1	13	37	24	5.6	130	39	11	28
do.	R.I.D.H.	Feb. 19, 1951	45	6.4	10	.80	7.2	1.7	....	..	10	21	12	.89	81	25	9.0	16
Branch River (upper and lower reservoirs), Pascoag	U.S.G.S.	Aug. 12, 1925	25	6.6	3.5	.54	2.2	.7	2.9	.4	3.2	6.2	2.8	.05	30	8.4	2.6	5.8
Branch River (upper reservoir), Pascoag	R.I.D.H.	Mar. 15, 1951	25	6.4	8	.10	3.2	1.0	....	....	9.8	7.1	7	0.0	44	12	8.0	4.0
Branch River (lower reservoir), Pascoag	R.I.D.H.	Mar. 15, 1951	20	6.4	8	.20	3.2	1.7	....	....	10	7.2	7	0.0	57	15	8.5	6.5
Branch River above dam at Andrew's Mill	U.S.G.S.	Aug. 12, 1925	55	6.6	5.9	.97	3.8	1.0	11	.9	27	8.0	4.0	1.1	63	14	14	....
do.	R.I.D.H.	Mar. 15, 1951	25	6.8	8	.15	3.2	1.2	....	....	13	9.0	15	0.0	49	13	11	2.0
Chepachet Reservoir, Chepachet (source of Chepachet River)	U.S.G.S.	Aug. 3, 1924	25	6.2	1.0	.17	2.1	.9	2.1	.6	4.9	6.5	1.8	.94	25	8.9	4.0	4.9
do.	R.I.D.H.	Mar. 15, 1951	35	5.8	8	.0	2.0	1.5	....	....	2.4	5.6	6	0.0	32	11	2.0	9.0
Chepachet River above dam, Chepachet	U.S.G.S.	Aug. 12, 1925	120	6.0	6.6	.71	2.5	.6	3.2	.8	5.9	4.6	4.0	.05	51	8.7	4.8	3.9
do.	R.I.D.H.	Mar. 15, 1951	30	6.0	8	.0	3.6	.7	....	....	4.9	6.6	7	0.0	34	12	4.0	8.0
Chipuxet River on State highway between Kingston station and village	U.S.G.S.	July 28, 1924	18	6.3	5.4	.16	3.2	1.3	4.6	.9	11	7.5	5.0	1.0	36	13	9.0	4.0
do.	R.I.D.H.	Mar. 5, 1951	35	6.5	10	.1	5.2	4.1	....	....	4.3	12	11	0.0	63	30	4.0	26
Hunt River at U. S. Highway 1, East Greenwich	U.S.G.S.	Feb. 26, 1924	25	6.3	8.2	.18	2.3	1.2	3.5	.8	7.3	6.5	3.4	.30	33	11	6.0	5.0
do.	R.I.D.H.	Mar. 5, 1951	35	6.4	15	.75	3.6	.2	....	....	4.3	7.2	10	0.0	47	10	3.5	6.5
Sayles (Bleachery) Pond, Saylesville (source of Moshassuck River)	U.S.G.S.	July 15, 1925	18	7.0	6.0	.34	14	2.3	5.0	1.3	46	12	5.5	.50	79	44	3.8	6
do.	R.I.D.H.	Mar. 28, 1951	15	5.5	8	.10	10	2.9	....	....	22	12	12	1.3	70	38	18	20
Moshassuck River at Randall St., Providence	U.S.G.S.	July 15, 1925	35	....	12	2.5	37	6.5	71	7.2	163	67	67	.08	359	119	119	....
do.	R.I.D.H.	Mar. 28, 1951	....	2.6	30	1.50	24	8.5	....	....	0.0	193	24	0.0	644	95	0.0	95
Pascoag Reservoir, Pascoag	U.S.G.S.	Aug. 3, 1924	13	6.2	1.9	.16	1.7	.9	1.7	.6	3.4	6.3	1.7	.60	21	7.9	2.8	5.1
do.	R.I.D.H.	Mar. 15, 1951	20	6.0	8	.0	2.8	.7	....	....	5.5	6.1	8	0.0	34	10	4.5	5.5
Pawcatuck River at Shannock	U.S.G.S.	.....	45	6.5	5.0	.28	2.6	1.3	4.0	.8	9.8	5.1	4.4	.67	36	12	8.0	4.0
do.	R.I.D.H.	Mar. 21, 1951	55	5.7	13	.15	3.6	1.5	....	....	6.7	6.1	8	0.0	50	15	5.5	9.5

Table 4 - Chemical Analysis of Surface Water

Table 19.—Chemical analyses of surface water from selected rivers and ponds—Continued

Source and location	Analyst	Date of Collection	Color	pH	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Dissolved solids	Hardness (as $CaCO_3$) Total	Carbonate	Noncarbonate
Pawcatuck River at Kenyon	U.S.G.S.	Aug. 28, 1925	30	6.5	6.0	.65	2.8	.9	4.6	.9	7.3	5.3	5.6	1.1	42	11	6.0	5.0
do.	R.I.D.H.	Mar. 22, 1951	55	5.2	10	.20	3.6	1.7	....	....	6.7	6.7	8	0.0	47	16	6	10
Pawcatuck River at Westerly	U.S.G.S.	Aug. 28, 1925	43	6.7	6.5	.52	3.0	1.0	8.7	.6	18	6.0	5.6	.62	53	12	12	....
do.	R.I.D.H.	Mar. 21, 1951	55	5.7	10	.15	11	.2	....	....	21	7.4	7	0.0	55	29	18	11
North Branch Pawtuxet River at Hope	U.S.G.S.	July 16, 1925	30	6.8	5.4	.86	3.6	1.0	2.8	.7	11	4.8	3.2	.05	36	13	9	4.0
do.	R.I.D.H.	Feb. 28, 1951	10	5.7	6	.1	2.8	1.9	....	....	4.3	5.3	6	0.0	32	15	4	11
South Branch Pawtuxet River at Washington	U.S.G.S.	July 16, 1925	45	6.6	5.2	.39	1.9	.8	7.1	.6	17	5.0	2.2	.05	42	8.0	8	....
do.	R.I.D.H.	Feb. 28, 1951	35	5.6	8	.15	2.8	.7	....	....	4.9	.98	8	0.0	28	10	4.0	6.0
Pawtuxet River at Natick	U.S.G.S.	July 16, 1925	32	6.8	4.9	.65	4.7	1.2	6.9	.7	19	8.0	5.5	.53	51	17	16	1.0
do.	R.I.D.H.	Feb. 28, 1951	20	6.4	10	.1	3.6	1.2	....	....	9.2	6.4	9	0.0	47	14	7.5	6.5
Pawtuxet River at Warwick Ave., Cranston	U.S.G.S.	July 16, 1925	....	6.4	5.5	.70	6.8	1.7	15	1.8	36	14	8.4	.05	90	24	24	....
do.	R.I.D.H.	Feb. 28, 1951	25	6.5	8	.15	5.2	1.2	....	....	13	20	11	.89	86	18	11	7.0
Pawtuxet River at Old Pettaconsett Pumping Station, Providence	U.S.G.S.	Feb. 13-28, 1924	18	6.3	7.3	.15	3.4	1.3	4.2	.9	9.0	9.4	4.2	1.5	41	14	7.4	6.6
do.	R.I.D.H.	Feb. 28, 1951	25	6.6	10	.1	4.4	1.5	....	....	14	11	11	0.44	58	17	12	5.0
Queens River at Usquepaug	U.S.G.S.	July 28, 1924	18	6.6	7.2	.20	2.2	1.1	3.9	1.0	9.8	6.8	3.5	.55	32	10	8	2.0
do.	R.I.D.H.	Mar. 21, 1951	70	5.3	15	.15	2.8	.7	....	....	6.1	4.8	8	0.0	46	10	5.0	5.0
Saugatucket River above dam at Wakefield	U.S.G.S.	Aug. 5, 1925	25	6.8	6.5	.71	7.3	2.1	16	3.4	41	13	9.3	.10	95	27	27	....
do.	R.I.D.H.	Mar. 15, 1951	40	6.5	.10	.20	4.0	1.9	....	....	4.9	9.9	14	.89	73	18	4.0	14
Saugatucket River above Peacedale	U.S.G.S.	Aug. 5, 1925	28	6.9	3.4	.42	3.0	1.1	5.0	.2	9.8	5.2	5.6	.29	35	12	8	4
do.	R.I.D.H.	Mar. 15, 1951	40	6.5	10	.1	3.6	1.9	....	....	4.3	8.2	12	0.0	59	17	4	13
Wakefield Pond, Burrillville	U.S.G.S.	May 7, 1925	25	7.0	.6	.16	2.5	.6	2.5	.3	4.6	6.3	2.0	.30	24	8.7	3.8	4.9
do.	R.I.D.H.	Mar. 15, 1951	30	6.0	10	.0	2.4	.7		....	3.1	5.8	6	0.0	31	9	2.5	6.5
Waterman Reservoir, Glocester	U.S.G.S.	Aug. 3, 1924	18	6.7	1.4	.11	3.2	.9	2.6	.9	8.1	7.3	2.6	.75	28	12	6.7	5.3
do.	R.I.D.H.	Feb. 23, 1951	30	6.2	8	.10	4.8	1.2		....	8.5	9.9	12	0.0	48	17	7.0	10
Wood River above Arcadia	U.S.G.S.	Oct. 13, 1924	40	6.6	9.0	.14	1.9	.8	3.0	.7	7.6	3.9	2.9	.15	33	8.0	6.2	1.8
do.	R.I.D.H.	Mar. 21, 1951	35	6.2	12	.10	2.8	1.5	....	....	7.9	3.1	9	0.0	41	13	6.5	6.5
Woonasquatucket River above Stillwater	U.S.G.S.	Aug. 3, 1925	45	7.2	4.7	.49	3.9	.9	12	.8	32	5.1	5.6	.13	65	13	13	....
do.	R.I.D.H.	Feb. 25, 1951	30	6.2	10	.15	4.4	1.9	....	....	12	14	10	0.0	55	19	10	9.0
Woonasquatucket River, Manton Ave. at Atlantic Mills, Providence	U.S.G.S.	Aug. 3, 1925	38	6.6	3.1	.65	6.1	1.9	19	2.4	36	18	13	.73	93	23	23	....
do.	R.I.D.H.	Feb. 25, 1951	25	6.5	7	.20	6.4	2.2	....	....	12	13	12	.89	76	25	10	15
Woonasquatucket River at Eagle St., Providence	U.S.G.S.	Aug. 3, 1925	125	6.6	5.6	.70	14	3.3	9.5	7.8	156	42	70	.10	365	49	49	....
do.	R.I.D.H.	Feb. 25, 1951	25	6.5	7	.20	6.0	2.2	....	....	12	16	12	.89	76	24	10	14

Table 4 (Cont'd) Chemical Analysis of Surface Water

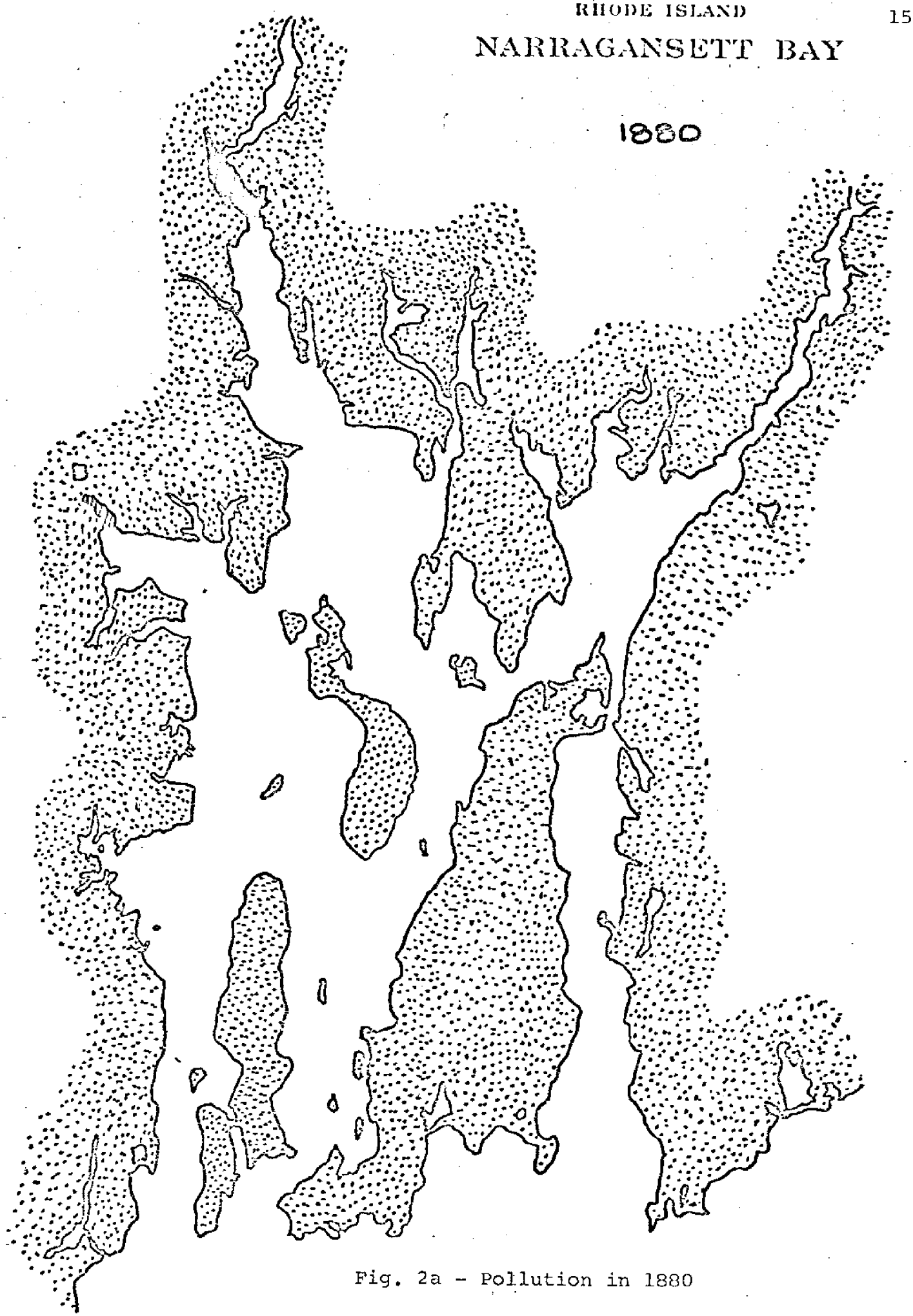


Fig. 2a - Pollution in 1880

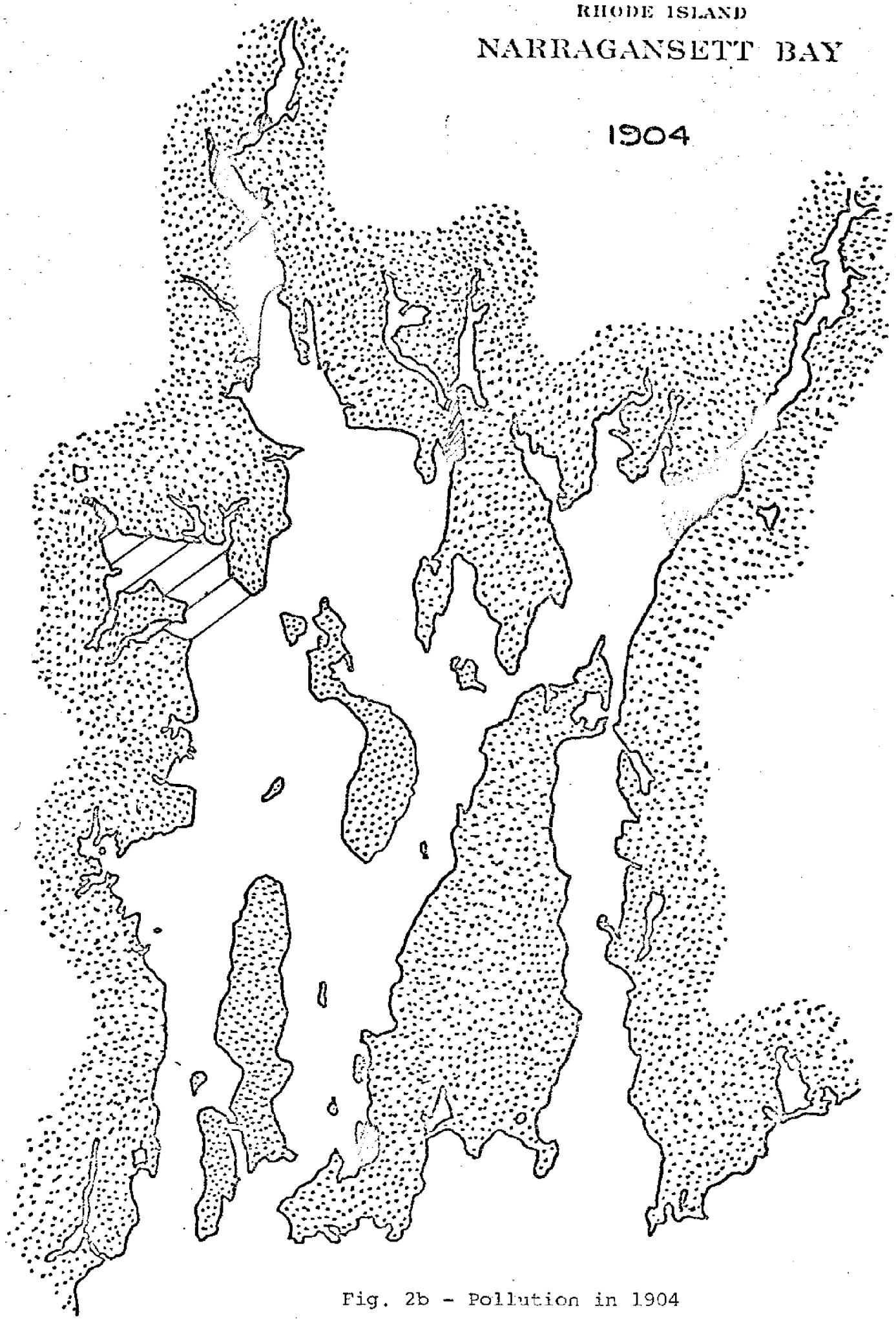


Fig. 2b - Pollution in 1904

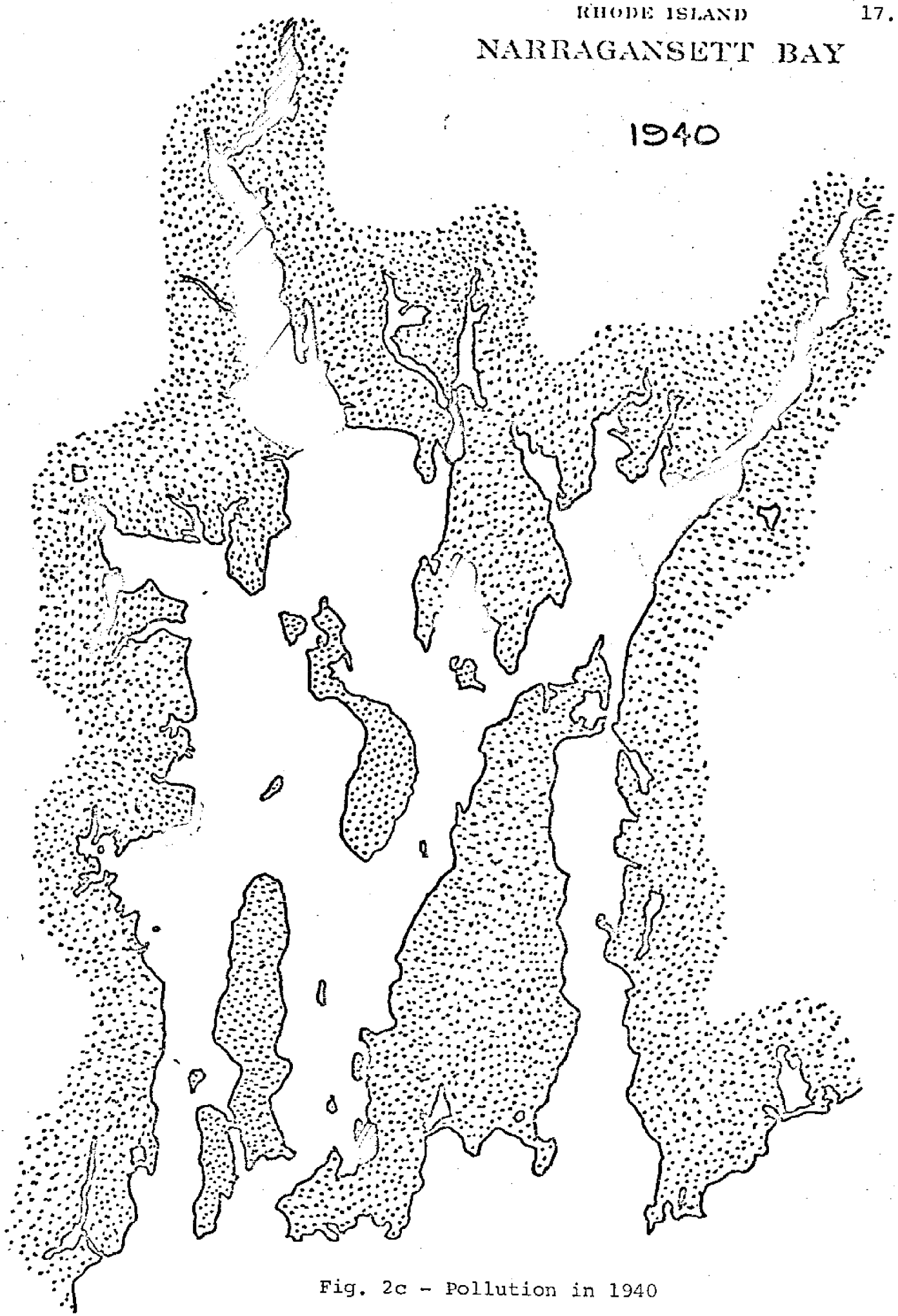


Fig. 2c - Pollution in 1940

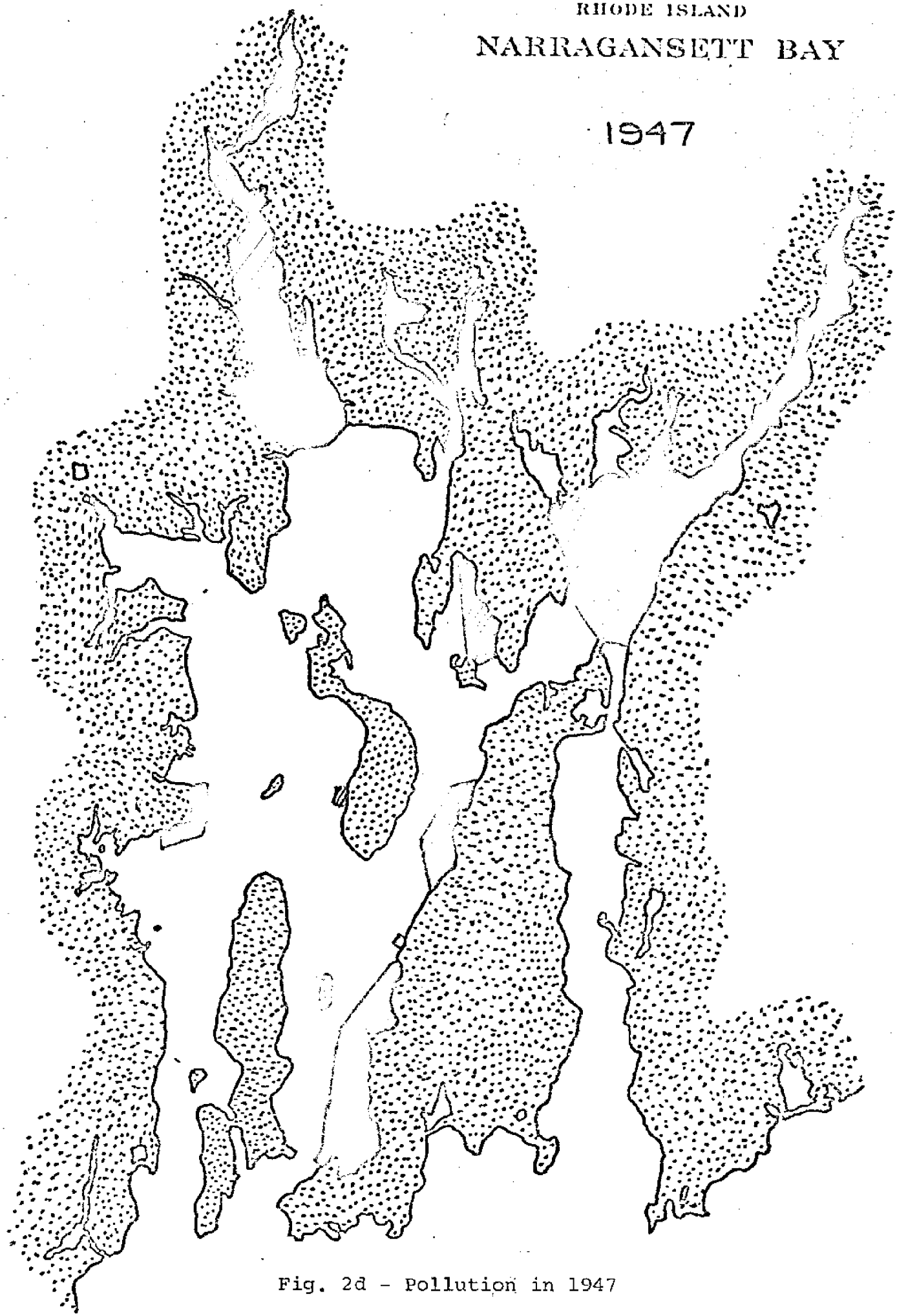


Fig. 2d - Pollution in 1947

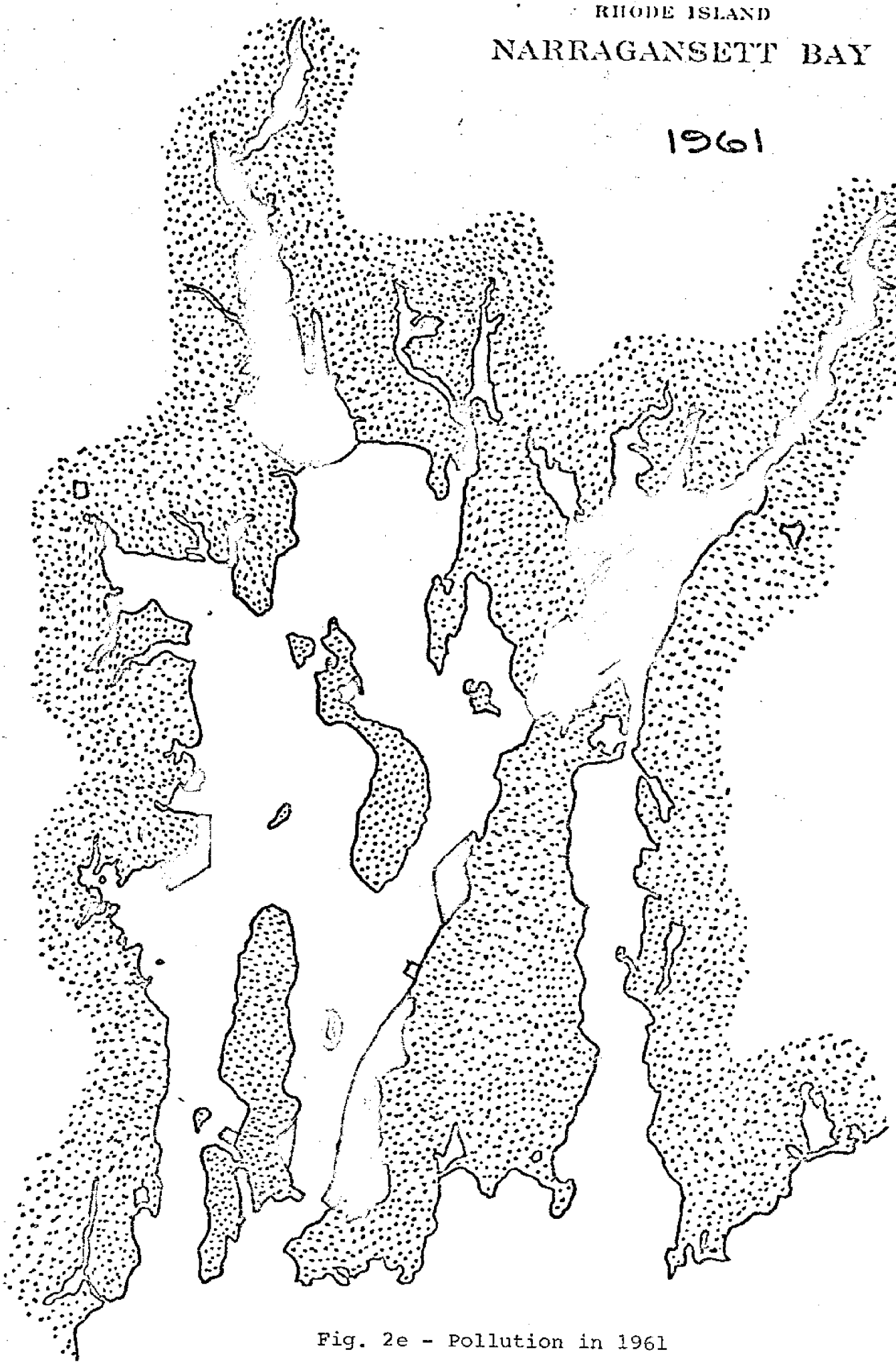


Fig. 2e - Pollution in 1961

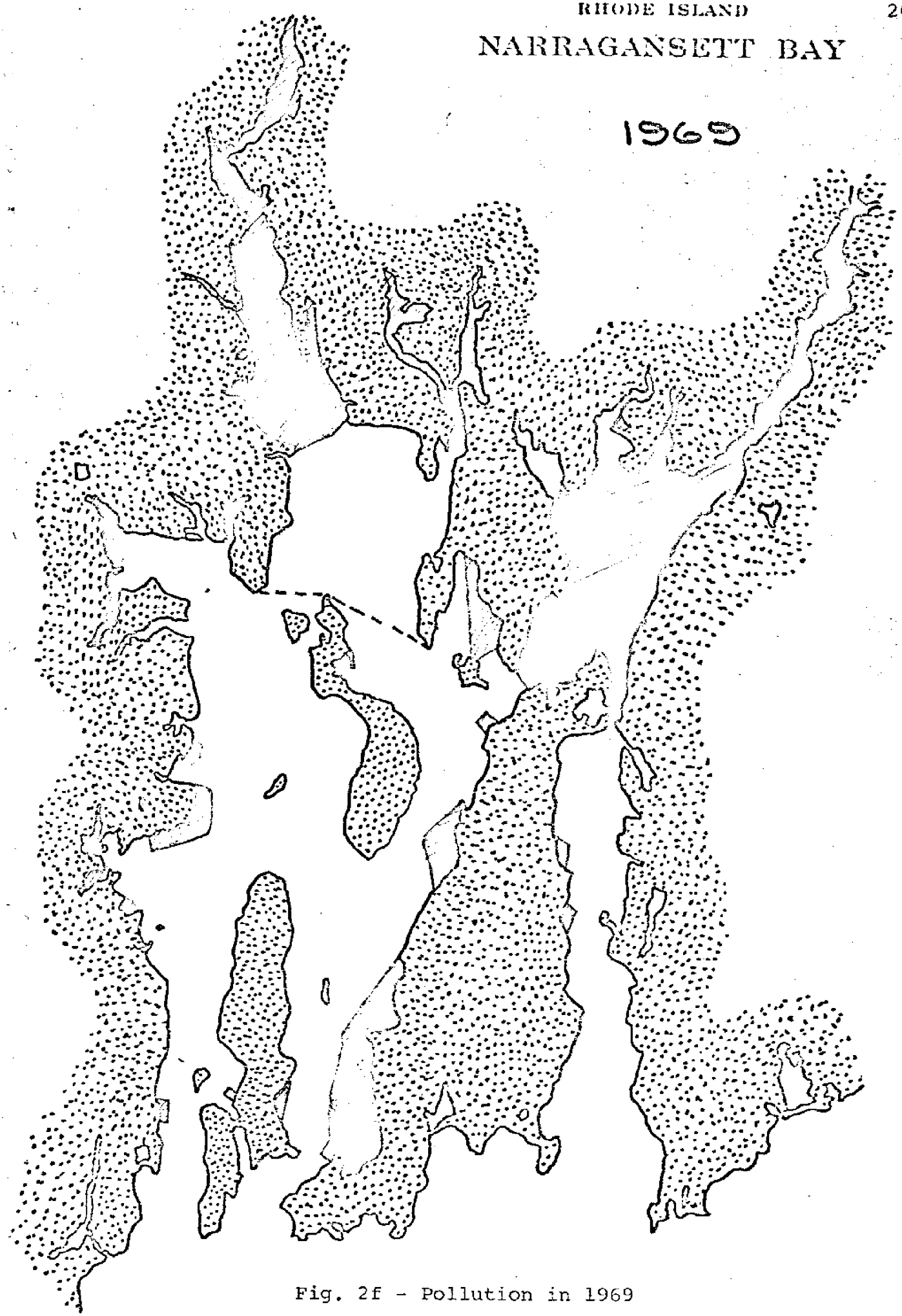
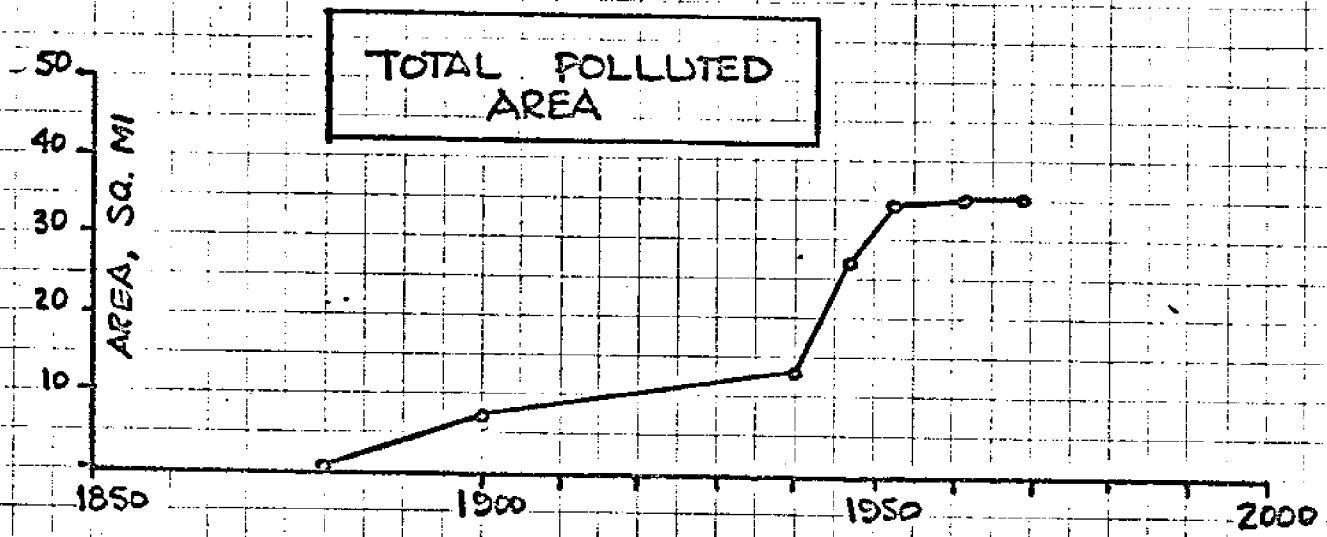
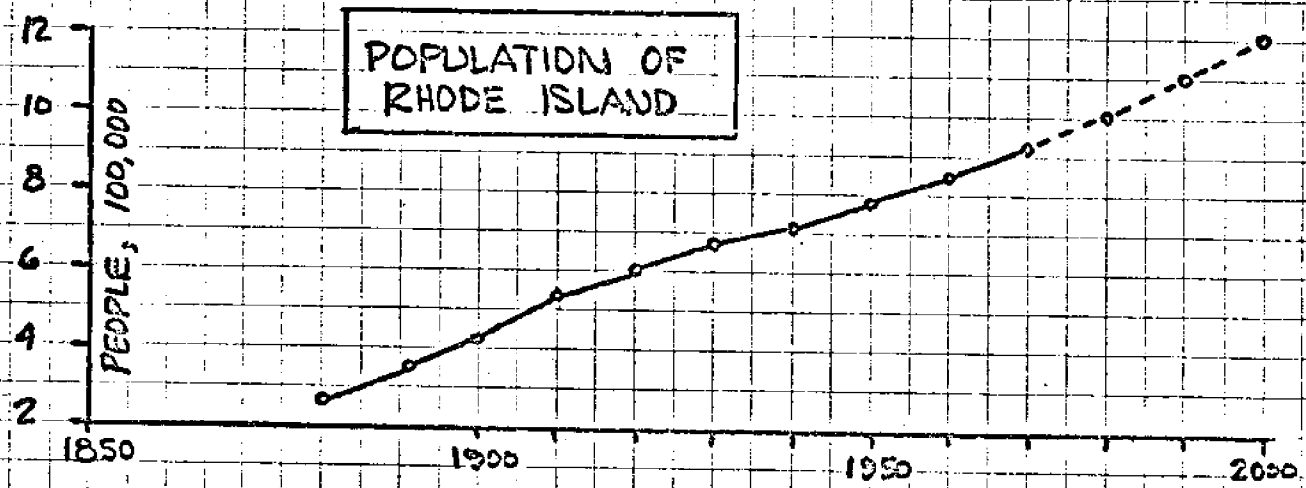


Fig. 2f - Pollution in 1969





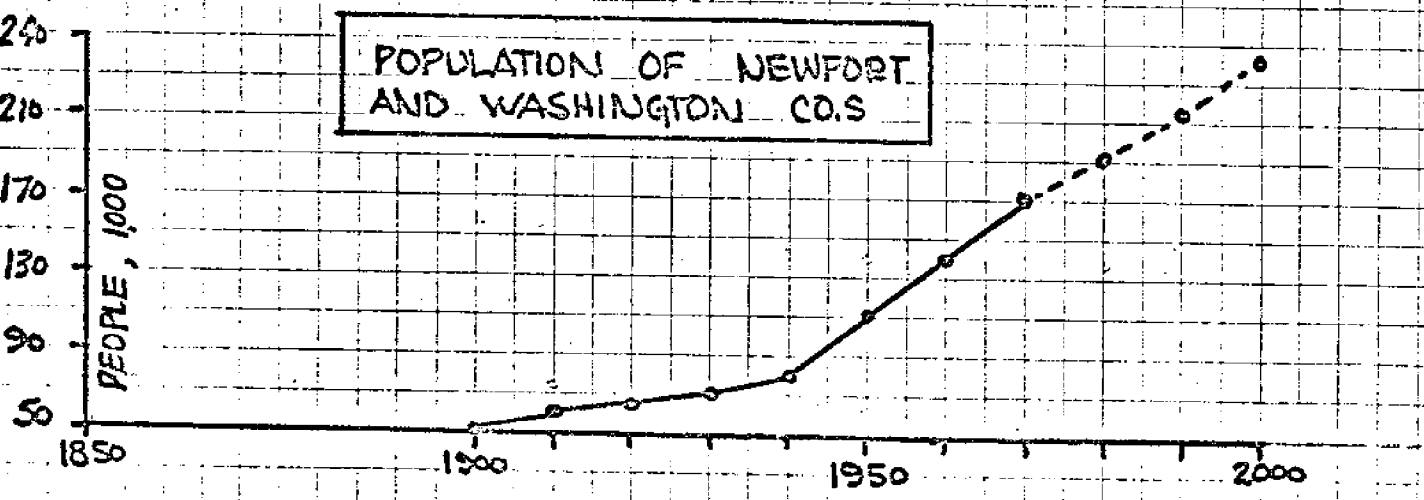


Fig. 3 - Pollution vs Population