FINAL PROJECT REPORT

Feasibility of Exposure Assessment For The Pilgrim Nuclear Power Plant

Prepared for
The Massachusetts Department of Public Health

by

Dr. J.D. Spengler and Dr. G.J. Keeler
Spengler Environmental Consultants Inc.

May 12, 1988

Table of Contents

1 Summary of Findings

1. The sea breeze phenomena is observed at the Pilgrim site. While a sea breeze can occur throughout the year it occurs most frequently during the spring and summer months. On average, Pilgrim I. experiences about 45 sea breeze days during these two seasons. Typically, the onshore component commences about 10 AM and can persist to about 4 PM. The wind direction changes during the day veering from the north around through the southeast quadrant by late afternoon. The intensity of a sea breeze can be measured by the wind speed and distance of inland penetration. The intensity of a sea breeze circulation depends upon solar radiation (which is influenced by cloud cover), sea water temperature, and strength of the gradient wind flow. The intensity and effective inland penetration of the sea breeze front in the near environment of the Pilgrim site are not well characterized.

2. Coast line orientation and topography strongly influence wind patterns (the frequency, direction, and strength of onshore winds). Predominantly, in the summer and spring, a sea breeze on-shore component is observed along the Massachusetts coast. The dominant sea breeze components are east and east-southeast for Boston-Logan, easterly for Plymouth, northeast and east-northeast for the Canal site, and east and east-southeast for the Pilgrim Plant. This finding suggests that the wind speed and direction at one coastal site should not be used as a surrogate for other coastal sites.

3. The meteorological sites available provide limited ability to fully characterize or model the sea breeze circulation in the vicinity of the Pilgrim I Nuclear Power Plant.

Existing sites have limited value because the length of record is insufficient to fully characterize the extent of sea breeze occurrence in the 1974/1975 time period.

Physical modeling of coastal sea breeze circulation patterns is limited by both the number of meteorological monitoring sites in the vicinity of the Pilgrim Plant and the number of parameters monitored.

2 Comments on the Cobb Wind Theory

There are three observations that appear consistent with Dr. Cobb's theory. First, leukemia rates are elevated in towns to the west and north of the Pilgrim I Plant. Second, recorded emissions were higher during the 1974 to 1976 time period. Third, sea breeze and gradient winds would advect emissions over populated areas. In addition, the sea breeze circulation would limit inland penetration to a few miles.

Countering these observations are the following facts. First, the sea breeze circulation is <u>not</u> a closed loop in which emissions would be trapped and recirculated. Second, the direction of a sea breeze is not constant but rotates in a clockwise direction during the day. The winds start off normal to the shore and eventually blows parallel to the shore. However, this might preferentially expose populations to the west and north.

Thus a modified "Cobb hypothesis" is probable.

3 Recommendations

1. Installation of continuous recording meteorological instruments at additional inland sites in the Plymouth area should be considered. The parameters measured should include wind speed and direction, temperature, dew point, and solar insolation. The Plymouth airport would be a good candidate site for this purpose. Inland sites would help characterize the sea breeze intensity as well as provide improved network for dispersion modeling.

2. Exposure patterns for emissions from the Pilgrim I Power Plant can be determined using a first order approach. A probabilistic model could incorporate the properties of both a plume dispersion model and available wind frequencies. Area averaged exposures would be calculated on a relative basis for different distances and sectors around the Pilgrim Plant. Sensitivity analysis should be performed to determine how exposure scaling is influenced by assumptions about input conditions. The critical parameters to be tested are emissions, dispersion coefficients, and mesoscale circulation patterns. Exposure patterns are likely to be influenced by the height of the release location (stack vs. building vents) and assumptions about the averaging time over which the releases occurred. Based on sensitivity analysis the requirement to reconstruct release data by location of release and time of day (hourly average) would be considered.

3.1 Comments on a Retrospective Study

A retrospective study would be limited by:

1. Time resolution of the emission data from Pilgrim;
2. Inland meteorological observations;
3. Anticipated spread in concentrations may not provide sufficient spatial resolution.

It is difficult to assess the likelihood of success of a retrospective study not knowing the exact retrospective study design. However, if the study needs spatial and temporal resolutions beyond the capabilities of the models and input data, the study should not be done. While it may be difficult to establish clear differences in exposure to people living within 5 miles of the coast line, there should be differences in exposure between populations living beyond the typical sea breeze penetration distance.

An alternative approach would be to fund Phase 1 - Exposure Assessment for about $30,000. This would involve developing the model and decision scheme for sea breeze and gradient flow conditions. One to two years of meteorological records would be examinedand exposures to inland populations would be estimated. Critical to Phase 1 activities would be analysis of assumptions and uncertainties.

4 Introduction

4.1 Scope of Problem

The Pilgrim I Nuclear Powered electrical generating Plant is located in a coastal environment in Plymouth, MA. This coastal environment frequently experiences sea breeze circulation patterns. A sea breeze is a coastal localized wind that blows from the sea to land. It is caused by the temperature difference when the sea surface is colder than the adjacent land. Therefore, it usually occurs on relatively calm, sunny, spring and summer days. Depending on topography, intensity of solar heating and pressure gradients, a sea breeze front can penetrate inland from 1 to 15 km.

The observation of increased adult male leukemia diagnosed in 1982-1984 in five coastal communities including Plymouth generated the hypothesis that emissions from Pilgrim I increased radiation exposures above background. In October of 1987, the Environmental Epidemiology and Toxicology Division of the Mass. Department of Public Health established a contract with Prof. John D. Spengler and Associates to investigate the coastal circulation and feasibility of estimating exposure patterns in the vicinity of Pilgrim I Power Plant. This report presents the analysis and findings of our initial investigation.

The contract had two objectives: 1) to document and characterize the coastal circulation patterns; and 2) consider the efficacy of retrospectively modeling emissions and atmospheric dispersion to calculate exposure patterns in the coastal community. To respond to these objectives a series of tasks were devised. The following is an abbreviated listing of those tasks.

4.2 General Tasks

Task 1. Identify relevant meteorological monitoring sites in eastern Massachusetts.

Task 2. Obtain meteorological records from Boston Edison, New England Electric System, the National Weather Service, and observations from the Plymouth County Airport. Ancillary data were also collected from two Coast Guard Stations.

Task 3. Prepare comparable data sets of wind speed and direction for the time periods and sites of interest.

Task 4. Analyze meteorological record for the occurrence of on-shore circulation patterns. Compare frequencies of wind direction among sites. Examine occurrence of sea breeze over time period of interest.

Task 5. Examine specific sea breeze cases that occurred at the Pilgrim site to a) determine the occurrence at other coastal sites for predictability, and b) determine the occurrence inland for a measure of intensity.

Task 6. Review numerical sea breeze circulation models to determine a) suitability to Plymouth coastline and b) input requirements for retrospective applications.

Task 7. Organize a one-day workshop to review Task 1-6 with experts in the fields of meteorology and dispersion modeling as well as representatives of the Department of Public Health.

Task 8. Prepare a draft final report on Tasks 1-7 and make recommendations concerning the feasibility of developing a methodology to estimate exposures to radioactive releases from the Pilgrim I Nuclear Power Plant.

4.3 General Description of a Sea Breeze

The uneven heating rates of land and water is responsible for the well known mesoscale coastal winds known as sea and land breezes. During the day, the land heats more quickly than the adjacent water, and the intensive heating of the air above the land produces a shallow thermal low. The air over the water remains cooler than the air over the the land and hence a shallow thermal high exists above the water. The overall effect of this pressure distribution is a surface breeze that blows from the sea. Since the strongest gradients of temperature and pressure occur near the land-water boundary, the strongest winds typically occur right near the beach and lesson inland. Since the greatest temperature difference between land and water usually occurs in the afternoon, sea breezes are strongest at this time.

At night, the land cools more quickly than the water. Air above the land becomes cooler than the air above the water producing a pressure differential. With the higher pressure now over the land the wind reverses itself and becomes a land breeze, flow from the land to the sea. Temperature gradients between land and water at night are usually much smaller than during the day, and hence the land breeze tends to be weaker.

Since sea breezes best develop when large temperature differences exist between land and water, their importance would be greatest in spring and summer in the mid-latitudes. During the summer, a sea breeze usually occurs in the midmorning after the land has been heated by the sun. By early afternoon the breeze has increased in strength and depth. In the late afternoon the cooler ocean air may extend inland for more than 10 miles and extend vertically up to 1000 ft. The leading edge of the sea breeze is referred to as the sea breeze front. As this front moves inland, a rapid drop in temperature occurs directly behind. Temperature drops of 5 degrees C or more can occur during the onset of the sea breeze. Along the Atlantic Coast, the passage of a sea breeze front is accompanied by a rapid wind shift, usually from west to east. If there is a sharp temperature gradient across the frontal boundary, the warmer air will converge and rise, typically marked by line of cumulus clouds. Along the sea breeze frontal boundary air can rise to elevations where it becomes part of the return flow. This return flow can rapidly mix the air down to the surface far behind the front.

The topography of the coastal environment also plays an important role in the sea breeze circulation. When cool, dense, stable marine air encounters a hill or mountain, the heavy air tends to flow around them rather than over them. This can alter the typical flow pattern expected from a typical sea breeze along a flat coastline.

These considerations are of great importance in estimating area-wide contaminant exposures in the coastal environment.

5 Meteorological Data Bases

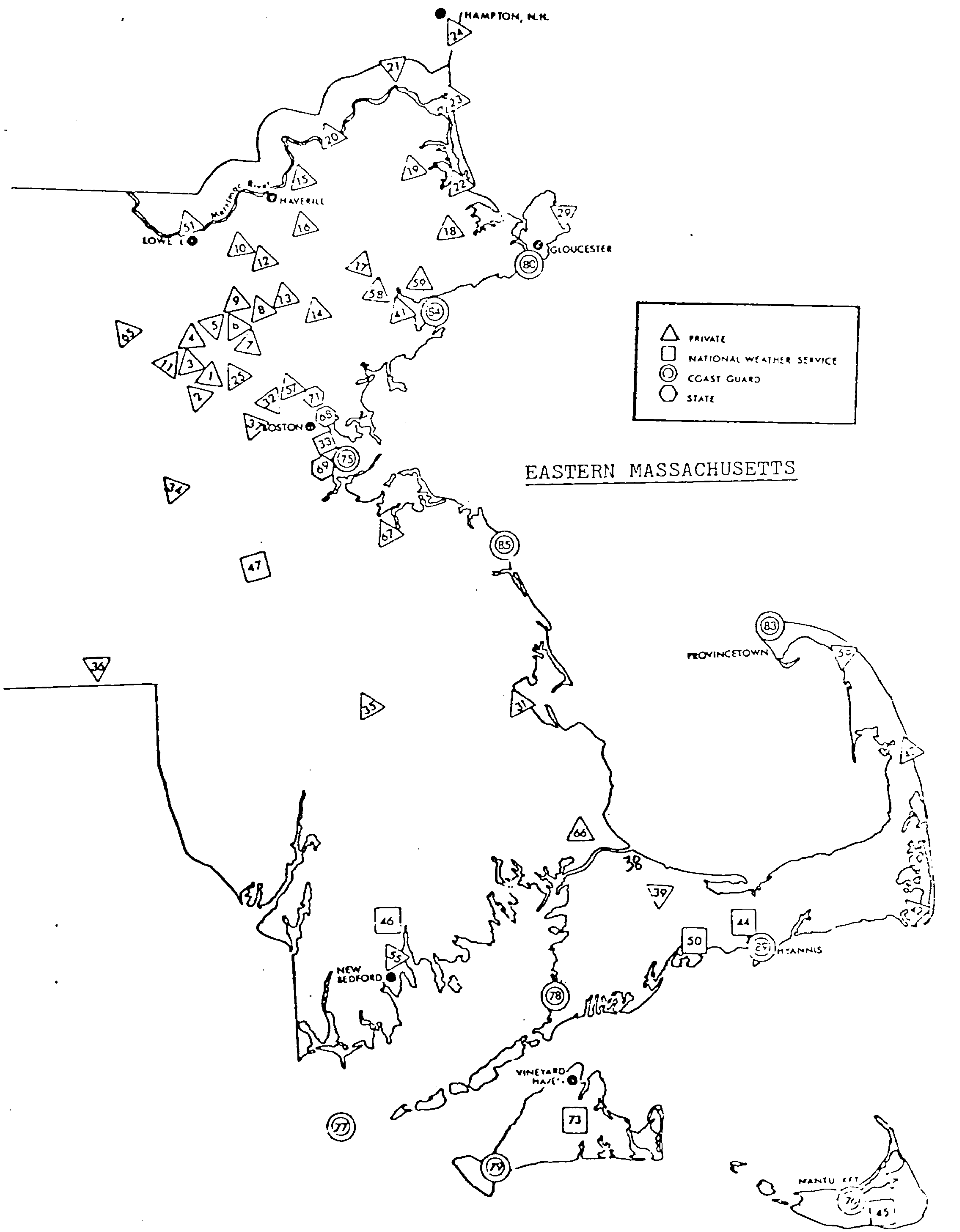
5.1 Meteorological Measurement Sites in Eastern Massachusetts

The location of all known private and public meteorological monitoring sites in eastern Massachusetts are shown in Figure 1. The exact location, dates of operation, and parameters measured for these sites are given in Table 1.

5.2 Meteorological Date Utilized in this study

The meteorological monitoring data bases used in this study are given in Table 2. The primary data base was from the on-site meteorological tower at the Pilgrim Plant; the National Weather Service (NWS) site at Logan Airport in Boston; NWS coast guard sites at Scituate Harbor and Cape Cod Canal; and observations recorded at the Plymouth Airport. These sites are displayed in Figure 2. The parameters obtained from each of these sites are given in Table 3. Those parameters shown in boldface type are the meteorological measurements analyzed.

METEOROLOGICAL STATIONS IN NEW ENGLAND



Table

Massachusetts

No	Address	Coord	Elev	S	P	F	Period	R	Other
	AFCRL Mesonetwork Air Force Cambridge Research Laboratories L. G. Hanscom Field Attn. Dr. Leo Jacobs (The following are the Mesonetwork stations)								
1	E Runway	42 28 71 10	38	14	2	R	1972-P	P	T D P V
2	NE Runway	42 28 71 17	38	14	2	R	1972-P	P	T D P V
3	W Runway	42 28 71 18	38	14	2	R	1972-P	P	T D P V
4	Nike Site (Bedford)	42 29 71 15	49	14	2	R	1972-P	P	T D P V
5	VA Hospital	42 30 71 10	38	14	2	R	1972-P	P	T D P V
6	MITRE	42 30 71 14	38	14	2	R	1972-P	P	T D P V
7	WRKO	42 29 71 13	41	14	2	R	1972-P	P	T D P V
8	Chestnut St. Pumping Station	42 32 71 10	26	14	2	R	1972-P	P	T D P V
9	Region Tech High (Billerica)	42 33 71 13	32	14	2	R	1972-P	P	T D P V
10	Tewksbury St. Hospital	42 37 71 13	35	14	2	R	1972-P	P	T D P V
11	AF Dump	42 28 71 18	41	14	2	R	1972-P	P	T D P V
12	AVCO Towers	42 36 71 10	49	14	2	R	1972-P	P	T D P V
13	100 Acre Pumping Station	42 33 71 08	23	14	2	R	1972-P	P	T D P V
14	Camp Curtis Guild	42 32 71 05	29	14	2	R	1972-P	P	T D P V
15	Lawrence Airport	42 43 71 07	49	14	2	R	1972-P	P	T D P V
16	MITRE (Boston Hill)	42 39 71 06	113	14	2	R	1972-P	P	T D P V
17	County Farm (Middleton)	42 36 70 59	61	14	2	R	1972-P	P	T D P V
18	Sagamore Hill	42 38 70 49	56	14	2	R	1972-P	P	T D P V

KEY

System (S)

1 Taylor
2 Cape Cod
3 P420C
4 Don Kent
5 Bendix
6 Danford White
7 Rain
8 White
9 Maximum Inc.
10 Science Associates
11 Texas Instruments
12 (homemade)
13 Stewart
14 Climatronics
O (other)
U (unknown)

Parameters (P)

1 Wind speed
2 wind speed & wind direction
3 Wind direction

Frequency (F)

A Daily
B 2 times daily
C 3 times daily
D 4 times daily
E 6 times daily
F 7 times daily
G Every 3 hours
H 9 times daily
I 10 times daily
J 12 times daily
K 13 times daily
L 14 times daily
M 16 times daily
N 17 times daily
O 19 times daily
P Hourly
Q Every half hour
R Continuous
S Other
T No schedule
U Unknown

Data Reduced (R)

N Not reduced
U Unknown
M Monthly
D Daily
C Reduced for certain years
T Every 2 hours
S Seasonal
A Annually
W Monthly wind rose
B 3 times daily
E 2 times daily
P 1, 5, 15 min.
G 15 minutes
H Hourly

Other

BP Barometric Pressure
D Dewpoint
F Precipitation
RH Relative Humidity
V Visibility
T Temperature
SC Sky Condition
SR Solar [illegible]
N No other parameters measured

Massachusetts

No	Address	Coord	Elev	S	P	F	Period	R	Other
19	DPW (Rowley)	42 43 70 54	24	14	2	R	1972-P	P	T D P V
20	Haverhill	42 46 71 03	70	14	2	R	1972-P	P	T D P V
21	Po Hill (Amesbury)	42 52 70 56	93	14	2	R	1972-P	P	T D P V
22	Ipswich	42 42 70 48	37	14	2	R	1972-P	P	T D P V
23	Plum Island Coast Guard	42 49 70 49	3	14	2	R	1972-P	F	T D P V
24	Hampton	42 55 70 49	2	14	2	R	1972-P	P	T D P V
25	DPW (Rt. 128)	42 26 71 16	58	14	2	R	1972-P	P	T D P V
26	Attleboro Pumping Station Mr. Burton Blanchard West St. Attleboro, Mass.	41 56 71 20	31	1	2	P	1966-P	N	T P BP
27	Mr. Gerald Auge 17 Kittredge Rd. Pittsfield, Mass. 01201 443-0430	42 26 73 15	316	U	2	U	Unknown	M	Unknown
28	Mr. & Mrs. Bernard Auge Jr. 79 Central Ave. Dalton, Mass. 01226 684-3624	42 30 73 10	317	1	2	A	10/62-P	N	T RH BP P V SC
29	Rev. Ralph M. Barker 32½ South St. Rockport, Mass.	42 39 70 36	24	U	1	U	3/60-P	U	Unknown
30	Mr. Curits Barret 35 Elmwood Rd. Wellesley, Mass.	U	U	U	2	U	1961-P	U	Unknown

KEY

System (S)

1 Taylor
2 Cape Cod
3 P420C
4 Don Kent
5 Bendix
6 Danford White
7 RAL
8 White
9 Maximum Inc.
10 Science Associates
11 Texas Instruments
12 (homemade)
13 Stewart
14 Climatronics
O (other)
U (unknown)

Parameters (P)

1 Wind speed
2 wind speed & wind direction
3 Wind direction

Frequency (F)

A Daily
B 2 times daily
C 3 times daily
D 4 times daily
E 6 times daily
F 7 times daily
G Every 3 hours
H 9 times daily
I 10 times daily
J 12 times daily
K 13 times daily
L 14 times daily
M 16 times daily
N 17 times daily
O 19 times daily
P Hourly
Q Every half hour
R Continuous
S Other
T No schedule
U Unknown

Data Reduced (R)

N Not reduced
U Unknown
M Monthly
D Daily
C Reduced for certain years
T Every 2 hours
S Seasonal
A Annually
W Monthly wind rose
B 3 times daily
E 2 times daily
F 1, 5, 15 min.
G 15 minutes
H Hourly

Other

BP Barometric Pressure
D Dewpoint
P Precipitation
RH Relative Humidity
V Visibility
T Temperature
SC Sky Condition
SR Solar Radiation
N No other parameters measured

No	Address	Coord	Elev	S	P	F	Period	R	Other
31	Boston Edison Co. Pilgrim Station Plymouth, Mass. 424-2534	41 59 70 42	7 24	14	2	R	4/69-P	H	T P
32	Boston University Dr. Batchelder Department of Geography 111 Cummington St. Boston, Mass. 02215 353-2525	42 22 71 07	12	5	2	R	1/62-P	N	SC T RH D BP T SR
33	Boston WSFO Logan International Airport Boston, Mass.	42 22 71 02	9	U	2	P	Unknown	U	T D BP SC
34	Mr. Roland Boucher 3 Draper St. Natick, Mass. OL-2-2972	42 17 71 22	49	U	2	U	1956-P	U	BP T P
35	Bridgewater College Attn. Prof. Robert Dillman Instructor of Earth Sciences Bridgewater, Mass. 02324 617-697-6161	41 59 70 59	U	U	2	U	Unknown	U	Unknown
36	Mr. Roger Brisson 41 Brisson St. South Bellingham, Mass.	42 02 71 29	61	4	3	U	Unknown	U	Unknown
37	Cambridge Electric Co. Kendall Square Station Cambridge, Mass.	42 22 71 10	U	5	2	R	Unknown	U	Unknown
38	Canal Electric Co. Cape Cod Canal Station P.O. Box 527 Sandwich, Mass. 617-888-1301	41 25 70 29	46	5	2	R	2/71-P	H	N
39	Canal Electric Co. Otis Radio Towers	40 46 70 28	U	5	2	R	Unknown	U	Unknown
40	Cape Cod National Seashore Marconi Station South Wellfleet, Mass. 02663 617-349-3785	41 54 69 58	15	4	2	A	1/66-P	S	T RH BP P
41	Mr. Paul Carlin 26 Lee St. Salem, Mass. 01970 744-9270	42 32 70 54	9	U	2	U	Unknown	U	T BP P

KEY

System (S)

1 Taylor
2 Cape Cod
3 P4200
4 Dan Kent
5 Bendix
6 Balford White
7 [illegible]
8 White
9 Maximum Inc.
10 Science Associates
11 Texas Instruments
12 (homemade)
13 Stewart
14 Climatronics
O (other)
U (unknown)

Parameters (P)

1 Wind speed
2 Wind speed & wind direction
3 Wind direction

Frequency (F)

A Daily
B 2 times daily
C 3 times daily
D 4 times daily
E 6 times daily
F 7 times daily
G Every 3 hours
H 9 times daily
I 10 times daily
J 12 times daily
K 13 times daily
L 14 times daily
M 16 times daily
N 17 times daily
O 19 times daily
P Hourly
Q Every half hour
R Continuous
S Other
T No schedule
U Unknown

Data Reduced (R)

N Not reduced
U Unknown
M Monthly
D Daily
C Reduced for certain years
T Every 2 hours
S Seasonal
A Annually
W Monthly wind rose
B 3 times daily
E 2 times daily
F 1, 5, 15 min.
G 15 minutes
H Hourly

Other

BP Barometric Pressure
D Dewpoint
P Precipitation
RH Relative Humidity
V Visibility
T Temperature
SC Sky Condition
SR Solar Radiation
N No other parameters measured

Massachusetts

No	Address	Coord	Elev	S	P	F	Period	R	Other
42	Chatham WSO Chatham, Mass.	41 40 69 58	16	U	2	G	Unknown	U	Unknown
43	Mr. William Chicoine Oxbow Rd. Charlton, Mass. 248-5068	42 00 71 59	U	U	2	U	Unknown	U	T BP
44	FAA Control Tower Barnstable Municipal Airport Hyannis, Mass.	41 40 70 17	16	U	2	N	Unknown	U	Unknown
45	FAA Control Tower Memorial Airport Nantucket, Mass.	41 15 70 04	4	U	2	P	Unknown	U	Unknown
46	FAA Control Tower New Bedford Municipal Airport New Bedford, Mass.	41 41 70 57	24	U	2	N	Unknown	U	Unknown
47	FAA Control Tower Norwood Municipal Airport Norwood, Mass.	42 11 71 11	15	U	2	K	Unknown	U	Unknown
48	FAA Control Tower Barnes Municipal Airport Westfield, Mass.	42 10 72 43	83	U	2	P	Unknown	U	Unknown
49	Mr. Charles Holz Lovell Rd. Holden, Mass.	42 22 71 55	251	U	2	U	1962-P	U	BP T SR SC
50	Mr. Frank W. Horn P.O. Box 495 Centerville, Mass. 775-1113	41 38 70 21	11	5	2	R	Unknown	U	Unknown
51	Lowell Technological Institute Meteorology Department Lowell, Mass. 01854	42 39 71 19	U	5	2	R	2/71-P	N	T P RH

KEY

System (S)

1 Taylor
2 Cape Cod
3 F420C
4 Don Kent
5 Bendix
6 Danford White
7 RAI[illegible]
8 White
9 Maximum Inc.
10 Science Associates
11 Texas Instruments
12 (homemade)
13 Stewart
14 Climatronics
O (other)
U (unknown)

Parameters (P)

1 Wind speed
2 wind speed & wind direction
3 wind direction

Frequency (F)

A Daily
B 2 times daily
C 3 times daily
D 4 times daily
E 6 times daily
F 7 times daily
G Every 3 hours
H 9 times daily
I 10 times daily
J 12 times daily
K 13 times daily
L 14 times daily
M 16 times daily
N 17 times daily
O 19 times daily
P Hourly
Q Every half hour
R Continuous
S Other
T No schedule
U Unknown

Data Reduced (R)

N Not reduced
U Unknown
M Monthly
D Daily
C Reduced for certain years
T Every 2 hours
S Seasonal
A Annually
W Monthly wind rose
B 3 times daily
E 2 times daily
P 1, 5, 15 min.
G 15 minutes
H Hourly

Other

BP Barometric Pressure
D Dewpoint
P Precipitation
RH Relative Humidity
V Visibility
T Temperature
SC Sky Condition
SR Solar Radiation
N No other parameters measured

Massachusetts

No	Address	Coord	Elev	S	P	F	Period	R	Other
52	Mr. Gerald W. McBride 87 Great Rd. Littleton, Mass. 01460 486-3454	U	U	6	2	U	Unknown	U	Unknown
53	Mr. Kevin McNicolas 567 North Ave. Wakefield, Mass. 245-6152	U	37	U	2	U	1962-P	U	T BP P
54	Mr. Victor Morris P.O. Box 215 North Truro, Mass. 02652	42 02 70 05	U	U	2	U	1960-P	U	T BP SC
55	New Bedford Light and Gas Canon St. New Bedford, Mass.	41 38 70 56	U	5	2	R	Unknown	U	Unknown
56	New England Power Co. Brayton Point Road East Somerset, Mass.	U	U	5	2	R	Unknown	U	Unknown
57	New England Power Co. Brighton Station East Brighton, Mass.	42 25 71 06	U	5	2	R	Unknown	U	Unknown
58	New England Power Co. Salem Station Salem, Mass.	42 34 70 55	U	5	2	R	Unknown	U	Unknown
59	New England Power Co. 24 Fort Ave. Salem, Mass.	42 34 70 53	U	5	2	R	Unknown	U	Unknown
60	Holyoke Water & Power Co. 1 Canal St. Holyoke, Mass.	42 12 72 37	U	0	2	R	Unknown	U	Unknown
61	Holden 1N 3 Scenic Drive Holden, Mass. 01520 617-829-6834	42 21 71 51	252	12	2	A	1/60-P	M	T BP P Y SC

KEY

System (S)

1 Taylor
2 Cape Cod
3 P420C
4 Don Kent
5 Bendix
6 Danford White
7 RAI
8 White
9 Maximum Inc.
10 Science Associates
11 Texas Instruments
12 (homemade)
13 Stewart
14 Climatronics
O (other)
U (unknown)

Parameters (P)

1 Wind speed
2 Wind speed & wind direction
3 Wind direction

Frequency (F)

A Daily
B 2 times daily
C 3 times daily
D 4 times daily
E 6 times daily
F 7 times daily
G Every 3 hours
H 9 times daily
I 10 times daily
J 12 times daily
K 13 times daily
L 14 times daily
M 16 times daily
N 17 times daily
O 19 times daily
P Hourly
Q Every half hour
R Continuous
S Other
T No schedule
U Unknown

Data Reduced (R)

N Not reduced
U Unknown
M Monthly
D Daily
C Reduced for certain years
T Every 2 hours
S Seasonal
A Annually
W Monthly wind rose
B 3 times daily
E 2 times daily
F 1, 5, 15 min.
G 15 minutes
H Hourly

Other

BP Barometric Pressure
D Dewpoint
P Precipitation
RH Relative Humidity
V Visibility
T Temperature
SC Sky Condition
SR Solar Radiation
N No other parameters measured

No	Address	Coord	Elev	S	P	F	Period	R	Other
62	New England Power Co. Mr. Wayne Shippee Shelboune Falls, Mass. 01370	42 37 72 44	U	U	2	U	Unknown	U	T P
63	Northeast Utilities Denning Powell P.O. Box 270 Hartford, Conn. 06101 203-666-6911 (Station located in Northfield, Mass.)	42 38 72 25	348	14	2	R	12/73-P	G	T D V SR
64	Northeast Utilities Denning Powell P.O. Box 270 Hartford, Conn. 06101 203-666-6911 (Station located in Montague, Mass.)	42 33 72 32	95	14	2	R	9/73-P	G	T D V SR
65	Mr. Plourde P.O. Box 191 Westford, Mass. 692-2623	43 30 71 26	70	U	2	A	1961-P	U	T P
66	Quittacas Pumping Station New Bedford Water Dept. RFD 1 East Freetown, Mass. 02717 617-763-2231	41 47 70 35	18	U	3	C	1895-P	U	T P RH SC BP
67	Mr. P. Robert Skilling 10 Clifford Court Hingham, Mass. 02043 617-749-1117	42 15 70 55	9	2 14	2	U	11/54-P	N	T RH BP D P
68	State Bureau of Air Quality Attn. Mr. Ken Haigg 600 Washington St. Boston, Mass. 02111 617-727-2658 (Pittsfield Station)	42 28 73 15	U	14	2	F	1973-P	N	N
69	State Bureau of Air Quality Attn. Mr. Ken Haigg 600 Washington St. Boston, Mass. 02111 617-727-2658 (Quincy Station)	42 19 71 03	U	14	2	P	1972-P	N	Unknown

KEY

System (S)

1 Taylor
2 Cape Cod
3 P420C
4 Don Kent
5 Bendix
6 Danford White
7 RAL
8 White
9 Maximum Inc.
10 Science Associates
11 Texas Instruments
12 (homemade)
13 Stewart
14 Climatronics
O (other)
U (unknown)

Parameters (P)

1 Wind speed
2 Wind speed & wind direction
3 Wind direction

Frequency (F)

A Daily
B 2 times daily
C 3 times daily
D 4 times daily
E 6 times daily
F 7 times daily
G Every 3 hours
H 9 times daily
I 10 times daily
J 12 times daily
K 13 times daily
L 14 times daily
M 16 times daily
N 17 times daily
O 19 times daily
P Hourly
Q Every half hour
R Continuous
S Other
T No schedule
U Unknown

Data Reduced (R)

N Not reduced
U Unknown
M Monthly
D Daily
C Reduced for certain years
T Every 2 hours
S Seasonal
A Annually
W Monthly wind rose
B 3 times daily
E 2 times daily
F 1, 5, 15 min.
G 15 minutes
H Hourly

Other

BP Barometric Pressure
D Dewpoint
P Precipitation
RH Relative Humidity
V Visibility
T Temperature
SC Sky Condition
SR Solar Radiation
N No other parameters measured

Massachusetts

No	Address	Coord	Elev	S	P	F	Period	R	Other
70	State Bureau of Air Quality Attn. Mr. Ken Haigg 600 Washington St. Boston, Mass. 02111 617-727-2658 (Springfield Station)	42 08 72 32	U	14	2	P	1972-P	N	Unknown
71	State Bureau of Air Quality Attn. Mr. Ken Haigg 600 Washington St. Boston, Mass. 02111 617-727-2658 (Wellington Station)	42 25 71 04	U	14	2	P	1972-P	N	Unknown
72	State Bureau of Air Quality Attn. Mr. Ken Haigg 600 Washington St. Boston, Mass. 02111 617-727-2658 (Worcester Station)	42 15 71 49	U	14	2	P	1972-P	N	Unknown
73	Martha's Vineyard SAWRS Martha's Vineyard Airport	41 24 70 36	24	U	2	J	Unknown	U	Unknown
74	University of Massachusetts Dr. James Halitsky Dept. of Civil Engineering Amherst, Mass. 01002 413-545-5685	42 22 72 31	86	7	2	R	1972-P	H	T RH BP P
75	USCG Boston Lightship	42 21 71 03	0	5	2	G	Unknown	U	Unknown
76	USCG Brant Point, Mass.	41 17 70 05	0	8	2	G	Unknown	U	SC V T BP
77	USCG Buzzards Bay, Mass.	41 24 71 02	10	3	2	G	Unknown	U	Unknown
78	USCG Cape Cod Canal Station	41 35 70 37	3	3	2	G	Unknown	U	SC V T BP
79	USCG Gay Head, Mass.	41 21 70 46	0	0	2	G	Unknown	U	SC V T BP

KEY

System (S)

1 Taylor
2 Cape Cod
3 P420C
4 Don Kent
5 Bendix
6 Danford White
7 Rain
8 White
9 Maximum Inc.
10 Science Associates
11 Texas Instruments
12 (homemade)
13 Stewart
14 Climatronics
O (other)
U (unknown)

Parameters (P)

1 Wind speed
2 Wind speed & wind direction
3 Wind direction

Frequency (F)

A Daily
B 2 times daily
C 3 times daily
D 4 times daily
E 6 times daily
F 7 times daily
G Every 3 hours
H 9 times daily
I 10 times daily
J 12 times daily
K 13 times daily
L 14 times daily
M 16 times daily
N 17 times daily
O 19 times daily
P Hourly
Q Every half hour
R Continuous
S Other
T No schedule
U Unknown

Data Reduced (R)

N Not reduced
U Unknown
M Monthly
D Daily
C Reduced for certain years
T Every 2 hours
S Seasonal
A Annually
W Monthly wind rose
B 3 times daily
E 2 times daily
F 1, 5, 15 min.
G 15 minutes
H Hourly

Other

BP Barometric Pressure
D Dewpoint
P Precipitation
RH Relative Humidity
V Visibility
T Temperature
SC Sky Condition
SR Solar Radiation
N No other parameters measured

Massachusetts

No	Address	Coord	Elev	S	P	F	Period	R	Other
80	USCG Gloucester, Mass.	42 35 70 40	6	3	2	G	Unknown	U	Unknown
81	USCG Merrimac River, Mass.	42 49 70 49	0	8	2	G	Unknown	U	SC V T BP
82	USCG Nantucket Lightship	40 33 69 28	0	5	2	G	Unknown	U	Unknown
83	USCG Racepoint Lifeboat Station Provincetown, Mass.	42 05 70 13	12	3	2	G	8/67-P	U	BP P SC
84	USCG Aerology Dept. Salem, Mass. 01970	42 32 70 52	U	U	2	G	1953-1967	U	Unknown
85	USCG Scituate, Mass.	42 12 70 43	0	8	2	G	Unknown	U	SC V T BP
86	Western Mass. Electric Co. 15 Agawan Ave. W. Springfield, Mass.	42 09 72 35	U	0	2	R	Unknown	U	Unknown
87	WHAI Radio 486 Main St. Box 32 Greenfield, Mass. 01301 413-774-4301	42 37 72 36	61	8	2	P	None	N	T BP P
88	WHMP Radio 78 Main St. Northampton, Mass. 01060 413-584-4275	42 19 72 39	46	1	2	Q	Unknown	U	T RH BP D SC
89	WOCB Radio 278 South Sea Ave. West Yarmouth, Mass.	41 38 70 14	2	2	2	P	Unknown	U	T RH BP D P SC
90	Woods Hole Oceanographic Institute Attn. Mr. Robert Alexander Woods Hole, Mass. 02543	42 05 70 13	U	U	2	U	Unknown	U	BP SR
91	Worcester WSO Worcester Municipal Airport Worcester, Mass.	42 16 71 52	310	U	2	P	Unknown	U	Unknown

KEY

System (S)

1 Taylor
2 Cape Cod
3 P420C
4 Don Kent
5 Bendix
6 Danford White
7 Rain
8 White
9 Maximum Inc.
10 Science Associates
11 Texas Instruments
12 (homemade)
13 Stewart
14 Climatronics
O (other)
U (unknown)

Parameters (P)

1 Wind speed
2 Wind speed & wind direction
3 Wind direction

Frequency (F)

A Daily
B 2 times daily
C 3 times daily
D 4 times daily
E 6 times daily
F 7 times daily
G Every 3 hours
H 9 times daily
I 10 times daily
J 12 times daily
K 13 times daily
L 14 times daily
M 16 times daily
N 17 times daily
O 19 times daily
P Hourly
Q Every half hour
R Continuous
S Other
T No schedule
U Unknown

Data Reduced (R)

N Not reduced
U Unknown
M Monthly
D Daily
C Reduced for certain years
T Every 2 hours
S Seasonal
A Annually
W Monthly wind rose
B 3 times daily
E 2 times daily
F 1, 5, 15 min.
G 15 minutes
H Hourly

Other

BP Barometric Pressure
D Dewpoint
P Precipitation
RH Relative Humidity
V Visibility
T Temperature
SC Sky Condition
SR Solar Radiation
N No other parameters measured

Table 2 Meteorological Monitoring Data Bases

SITE	LOCATION		SITE	STATION	MEASUREMENT	DATA ANALYZED	
	LAT.	LONG.	STARTUP	CODE	FREQUENCY	START	STOP
Boston Edison Pilgrim Plant	4157	7033	1969	01	24 obs/day	5/1974 1/1985	12/1975 12/1985
Logan Airport	4222	7102	1949	02	24 obs/day	1/1974 1/1984	12/1975 12/1985
Cape Cod Canal	4147	7030	1967	03	8 obs/day	9/1974 1/1985 3/1986	12/1975 12/1985 8/1986
Scituate Harbor*	4212	7043	1967	03	8 obs/day	1/1985 3/1986	12/1985 8/1986
Plymouth Airport	4154	7043	1982	04	4 obs/day	1/1985	12/1986

* *Long periods of void data*

METEOROLOGICAL MONITORING SITES

Fig 2

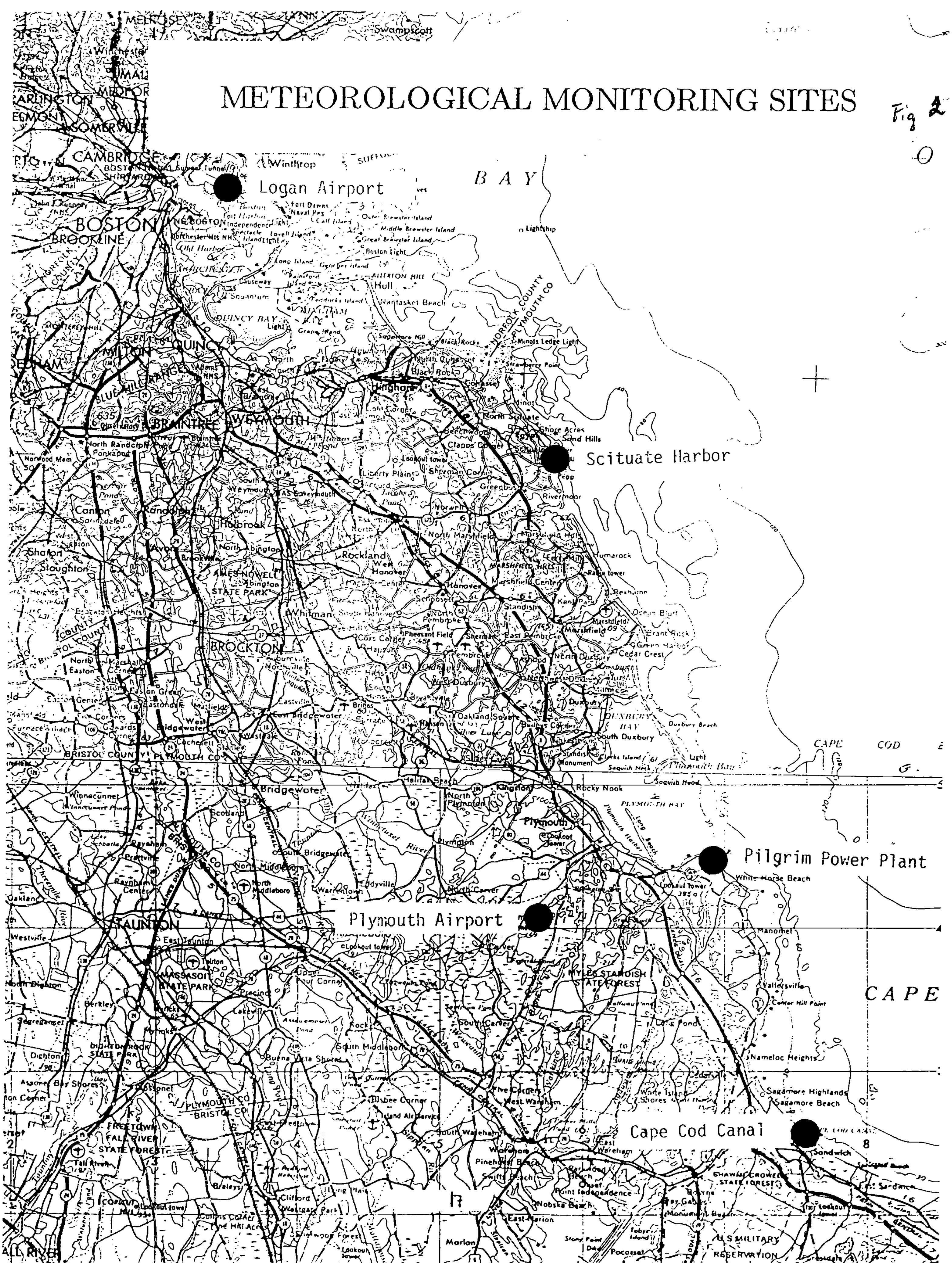


Table: METEOROLOGICAL MONITORING KEY

Station Code 01	Station Code 02	Station Code 03	Station Code 04
Wind Speed*	**Wind Speed**	**Wind Speed**	**Wind Speed**
Wind Direction*	**Wind Direction**	**Wind Direction**	**Wind Direction**
Air Temp.**	**Air Temp.**	**Air Temp.**	**Air Temp.**
delta Temp.***	**Sky Condition**	**Sky Condition**	**Sky Condition**
	Sky Cover	**Sea Temp.**	**Sky Cover**
	Visibility	Visibility	Visibility
	Precipitation	Precipitation	Precipitation
	Barometric Pressure	Barometric Pressure	
	Vision Obstruction		
	Dewpoint Temp.		
	Relative Humidity		

** measured at 33′ and 160′*
*** measured at 5′ and 160′*
****(160 - 5)*
NOTE: boldface indicates data analyzed; non-boldface indicates data available.

6 Methods

6.1 Approach

Once the existing data bases were identified and obtained from the appropriate agency, a cross-sectional analysis was performed. Meteorological data from the calendar year 1985 was utilized from four sites: Logan Airport, Plymouth Airport, Cape Cod Canal Coast Guard Station, and the Pilgrim I. Nuclear Power Plant. The year 1985 was chosen as a complete meteorological record was available from all four sites. Hourly calculations of the joint frequency of wind speed and wind direction were performed for the Logan and Pilgrim sites only. Wind directional frequency was also calculated using the 1500 LST observations available from all four sites. The results from each site were then compared to determine the variability in the wind patterns along the south coast.

A longitudinal analysis was also performed on the hourly data taken at the Pilgrim Plant and Logan Airport sites. Several years of meteorological data for each site were examined in a similar way as for the cross-sectional analysis to determine the year-to-year variability in the wind flow patterns. Wind directional frequency was also calculated using the 1500 LST observations from all four sites for 1985 and for three of the four sites for the years 1974-1975. The distributions calculated in this analysis will provide some insight into the area-wide wind directional variability, and hence in an estimate of the area wide dispersion.

The results of the wind frequency analysis suggested that the occurrence of onshore winds was substantial. Since not all of the onshore winds are associated with the sea breeze circulation, it was necessary to perform further analyses to differentiate the onshore gradient winds from the sea breeze winds. This analysis required the availability of additional meteorological and sea water temperature data. Indepth case studies were then performed to determine a sea breeze climatology at each of the three coastal sites and the Plymouth Airport.

6.2 Analysis Procedures

1. Joint Wind Speed-Wind Direction Frequency

Hourly averaged wind speed and wind direction data were obtained from the NWS site at Logan Airport and from the on-site meteorological tower at the Pilgrim Nuclear Facility. Measurements at the Pilgrim site were made at two heights on the tower, 33 ft. and 160 ft. Joint wind frequencies were calculated from the hourly data for each season and for the entire calendar year.

Wind frequency was also calculated using the wind data recorded at 1500 LST at each of the sites given in Table 2. The 1500 LST record was chosen as representative of the afternoon period when sea breeze occurrence is most prevalent.

2. Sea Breeze Determination by Case Study

There have been several studies looking at the occurrence of land-sea breezes along the coastal environment. These studies have provided some general criteria for determining when a sea breeze circulation pattern may occur. In this study we defined the minimum criteria for sea breeze occurrence at the Pilgrim site as follows:

A. Winds must be onshore, specifically from N - SSE, and a well defined wind shift must be observed during the daylight hours.

B. The difference between the air temperature recorded at the Pilgrim site and the sea water temperature recorded at the closest coast guard station must be greater than zero.

C. The total sky cover must be less than 100%, i.e. no overcast conditions and no wide-spread precipitation. Clear skies are more favorable for the development of a sea breeze circulation.

D. There must be a weak synoptic scale pressure gradient.

These four criteria were used to identify the subset of days in which a sea breeze could develop. These days were then scrutinized to determine if non-sea breeze days could be eliminated from the group. This was accomplished by detailed analysis of surface and upper air meteorological maps, and upper air observations obtained from the National Weather Service.

7 Results

7.1 Wind Frequency Analysis

Wind roses were constructed from the frequency tabulations to facilitate the site-to-site comparisons. The wind roses consist of a circle from which 16 lines emanate, one for each compass point. The length of each line is proportional to the frequency of the wind from that direction.

The data utilized for each wind rose are the 1500 LST wind observations only. There is one wind rose for each site for each of the Spring and Summer seasons. As mentioned earlier, these two seasons are most favorable for the development of a sea breeze circulation.

It should be noted that the lines on the wind roses are often longer for those corresponding to the directions N, NE, E, SE, S, etc., than for those corresponding to NNE, ENE, ESE, etc. This often attributable to "observers' bias" caused by the tendency of the observer to read the wind direction to eight compass points instead of sixteen.

The wind roses constructed from the 1985 frequencies are shown in Figures 3 and 4, for the spring and summer seasons, respectively. The wind roses for the four sites display considerable inter-site variability. The influence of the coastal configuration is quite obvious, with the most prominent 1500 LST wind directions being onshore. The inter-site differences in the longest bars is due largely to the directions which can be considered "onshore" at the various sites. The Boston Logan site, for example, is situated in Boston Harbor and therefore has onshore flow from ENE to SE directions. The Pilgrim Power Plant is situated on a small peninsula, and has onshore flow from NNW around to SE. Differences in the surface wind frequencies could also be influenced by differences in topography in the local vicinity of each site.

The occurrence of onshore winds during the spring (March, April, May) and summer (June, July, August) months in 1985 are summarized in Table 4. The onshore winds at each site were further identified as being associated with a sea breeze circulation (SB) or from onshore gradient flow (GF). Gradient flow included all non-sea breeze onshore flow. The frequency of onshore flow was greater during the summer than spring at each of the sites. The coastal sites showed a larger difference than the inland site at the Plymouth airport. The difference in onshore flow between seasons is attributable to the increased frequency of sea breeze days during the summer period.

Table 4. Percent of days with onshore winds at 1500 LST - 1985

Site	Spring Sea Breeze	Spring Gradient Flow	Summer Sea Breeze	Summer Gradient Flow
Pilgrim I.	20	19	32	13
Plymouth Airport	14	14	26	14
Logan Airport	25	21	30	15
Cape Cod Canal	20	22	30	12

The seasonal variations in the wind flow patterns are also obvious from Figures 3 and 4. Onshore flow is much more frequent at the Pilgrim Plant and Cape Cod Canal sites during the summer months than in the spring. This is also true at the Boston-Logan and Plymouth Airport sites, but to a much smaller degree. Winds from the SW-SSW were observed more frequently during the summer months.

Seasonal wind distributions can vary greatly from one year to the next. In order to determine how climatologically representative the 1985 distributions are we compared them to the wind distributions displayed in Figures 5 and 6. These wind roses were constructed from data recorded from the five-year period 1954-1958. Comparing the 1500 LST distributions for the Boston-Logan site shown in Figures 3 and 4 to those in Figures 5 and 6 suggests that the 1985 observations were representative. The onshore flow components differed by only a few percent. Figures 5 and 6 also reveal the influence of the coastal orientation on the 1500 LST wind roses. The dramatic differences between the Rockport and Squantum distributions indicate the difficulties in determining dispersion patterns in the coastal environment.

Wind roses were also constructed from the summer 1974, spring and summer 1975 wind frequency distributions. This period was of special significance as this was the period that radioactive releases occurred at the Pilgrim I. Plant. The wind roses for the Pilgrim and Boston-Logan sites are shown in Figures 7 to 9. Comparing the summer 1974 distributions with the distributions shown in Figure 4 for 1985 reveals a stronger onshore component in 1974 at the Boston-Logan site. The wind roses shown for the Pilgrim site are also quite different. There was a strong southeasterly component during the summer of 1974 and a fairly weak southwesterly component. This is opposite to what was observed in 1985, in which the southwesterly component was quite strong and the southeasterly component was negligible. The wind frequencies for the 160 foot level on the tower at the Pilgrim Plant are also shown in Figure 7. The wind frequencies for the two levels during the summer period in 1974 are not significantly different.

The wind roses constructed for the spring and summer of 1975 are shown in Figures 8 and 9. Onshore flow is slightly more prevalent in the spring of 1975 than in the spring of 1985. There also appears to be more of an easterly component in the wind directional frequencies calculated for the spring of 1975. Onshore flow is also more prevalent, approximately 14% more, at the Pilgrim Plant during the summer of 1975 than during the summer of 1985. There was also a stronger northerly component to the onshore flow during the summer months in 1975. This was also true for the wind distributions calculated for the Cape Cod Canal site. It should be emphasized that this analysis utilized only the 1500 LST wind data in calculating the frequency distributions. Therefore, *care should be taken not to over analyze* the results presented. If several daytime hours of data were utilized instead of just one hour, the frequencies presented above could change by as much as 5 to 10%.

7.2 Case Studies

The occurrence of a sea breeze circulation was investigated by detailed analysis of the available meteorological data. Those days which were identified as having onshore flow occurring during the daytime hours, roughly 8 AM to 8 PM, at each site were flagged as potential sea breeze days. This procedure eliminated approximately 50% of the possible days in the year. The remaining days were then studied in great detail to determine if the onshore flow was associated with a sea breeze circulation or if the flow was due to the larger scale gradient wind flow.

The results of this analysis are found in Table 5. The percent of all spring and summer days that a sea breeze occurred at each of the four sites is shown. The bold number shown beneath this percentage is the percent of time that a sea breeze was occurring at that site when a sea breeze occurred at the Pilgrim Site. For example, in 1974, a sea breeze was observed at the Boston-Logan site 73% of the time when a sea breeze occurred at the Pilgrim site.

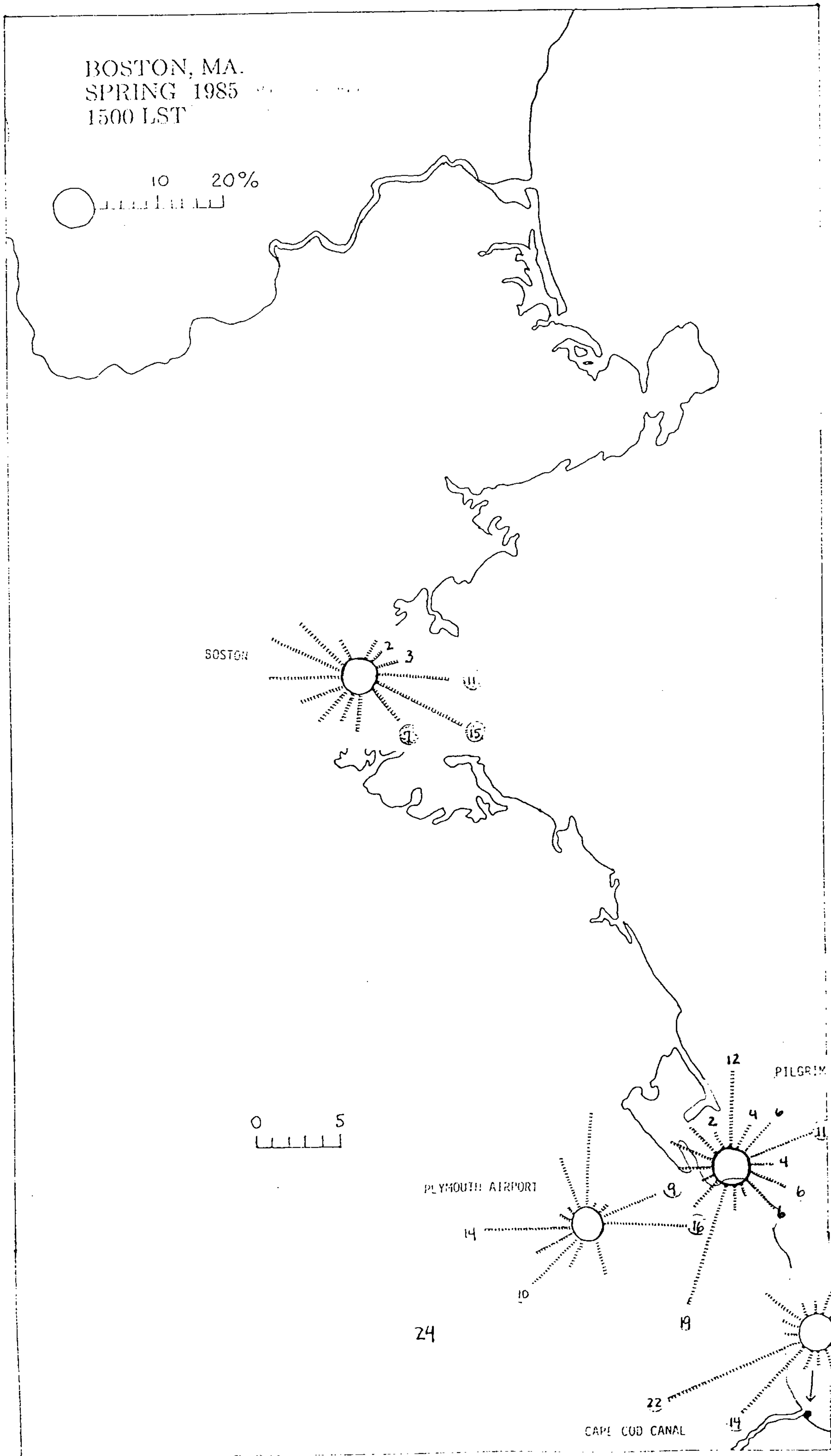

BOSTON, MA.
SPRING 1985
1500 LST
10 20%
BOSTON
PLYMOUTH AIRPORT
PILGRIM
CAPE COD CANAL
0 5

Fig. 5

24