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PWA-SPENGLER REPORT

FINAL PROJECT REPORT

Feasibility of Exposure Assessment For The Pilgrim Nuclear Power Plant

Prepared for
The Massachusetts Department of Public Health

by

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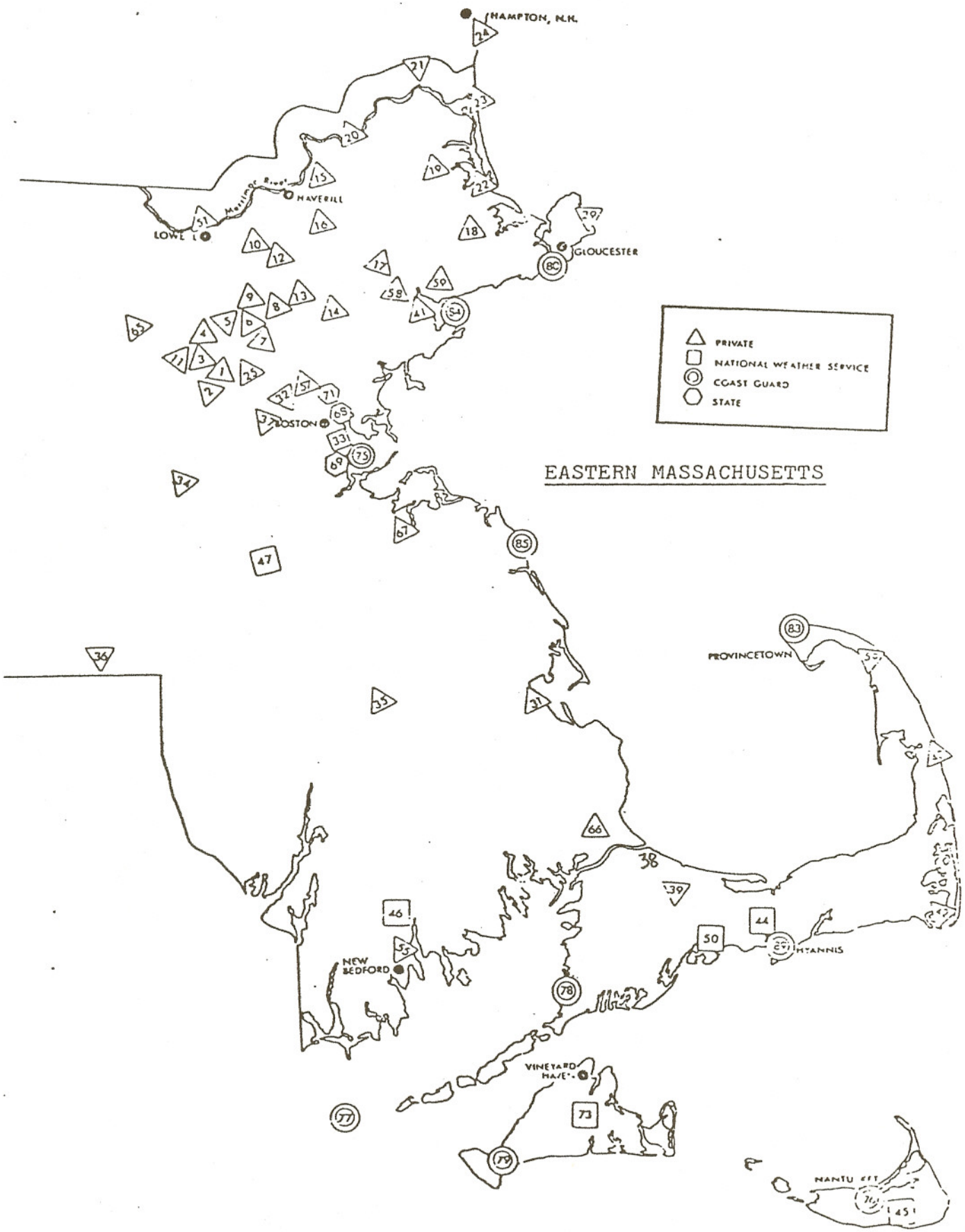
METEOROLOGICAL STATIONS IN NEW ENGLAND



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 not 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.

Table 4. Percent of days with onshore winds at 1500 LST - 1985				
Site	Spring		Summer	
	Sea Breeze	Gradient Flow	Sea Breeze	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

hours that each area would be downwind is given: for the entire year; for the spring or 2nd quarter; and for the summer or 3rd quarter. Looking at this table in a simplistic way, one can see that the communities located to the south of the Pilgrim site are downwind about 10% of the total hours of the year, and that about 41% of those hours occur in spring and summer. The spring and summer periods represent from 27-58% of the total hours annually downwind in each of the areas.

Since a large percentage of the spring and summer days experience sea breeze circulations, it would be best to determine the sea breeze and gradient flow hours separately, as these days would potentially have much different dispersion conditions.

Table 6. Frequency of Potential Exposure during 1985.

TOWNS	*Plymouth*	*Plymouth*	*North Plymouth*	*Kingston Duxbury*	*Marshfield Scituate*
WIND DIRECTION Compass Head. Census Track	NNW-N 150-195 5308-5309	NNE-NE 195-240 5306,5307	ENE-E 285-330 5091,5071, 5306,5307	ESE-SE 285-330 5091,5071	SSE-S 330-015 5071,5052, 5062.* 5061.* 5051.*
Description	COASTAL SOUTH OF PLANT	INLAND AREAS TO SOUTH	COASTAL & INLAND TO NORTHWEST	COASTAL & INLAND TO NORTH	COASTAL AREAS TO NORTH
Hours Downwind					
Annual	876	772	478	576	778
Spring	217	128	101	172	155
Summer	146	84	84	164	124

8.5 Workshop Recommendations On Modeling

The hypothesis to be tested was: Do emissions from the Pilgrim Plant impact the communities where an elevated number of leukemia cases have been reported as the result of the recirculation of air masses in the seabreeze circulation?

It was suggested that the empirical calibration curve from Burda et al. (1987) be used to back calculate the intensity of the seabreeze phenomena. This in addition to quantifying the duration of penetration was felt to be important.

It was suggested that a worst case scenario of exposure from a release at the Pilgrim Plant may not necessarily involve a sea breeze day. Sea breeze days are typically characterized by substantial dispersion, whereas a drizzly, foggy day with a low inversion layer and constant easterly winds could potentially have less dispersion.

Dose can be defined as a product of concentration and episode duration. The duration is a function of the relative sea breeze strength. Thus, it is necessary to gather information on the affected receptor location, vector speed and strength, wind speeds, mixing heights, and spread statistics.

By utilizing two years of data in a Gaussian model, dispersion profiles can be constructed which can be scaled using factor scores thus providing simplistic zoning schemes.

Before employing 3-D models such as the one developed by Pielke, a number of issues need to be addressed. The cost of the model may be prohibitive. A single run of the model to simulate one day is ~$600. Initialization is both difficult and costly (setup costs comprise 75% of the total cost). Similar use of this model for an Everglades Study in FL cost $20,000 for analysis of 2 days. The time dependent component of the seabreeze condition may not be adequately handled. There are problems with validating results from this model. It is possible to calibrate and validate for flow (intensity of flow) using wind vector data from Plymouth Airport and Pilgrim data, however it is not clear if the dispersion/turbulence calculations can be calibrated. It is questionable whether the front passage can be predicted with sufficient resolution and whether the model can be fine tuned. It cannot use measured wind fields. Grid scales can vary from 10 X 20 km. to 100 X 100 km.

9 Dispersion Models

The transport, diffusion, and deposition of airborne species emitted along a shoreline can be influenced by mesoscale atmospheric motions (scale of 10-200 km). These atmospheric motions can not be adequately simulated using Gaussian plume or long-range transport type models. Lake and Sea Breeze circulations are an example of the intermediate or mesoscale type of atmospheric motions which are more difficult to model. A summary of some of the modeling studies attempting to simulate the dispersion and deposition of atmospheric pollutants in the coastal environment are given in Table 7.

Caiazza (1985) and Gotham et al. (1985) developed and tested a puff advection model (Dose Assessment Model) to study the deposition of airborne species emitted from the Nine Mile Nuclear Generation Plant in New York. There interest was in dispersion estimates during simulated emergency conditions. The shortcoming of their model is that it fails to give accurate results during conditions of light variable winds and when a land/sea breeze circulation existed.

Hydrodynamical models have been used to study land/lake breezes (Estoque (1963); Moroz (1967); Sheih and Moroz (1974)). Moroz (1967) and Sheih and Moroz (1974) studied the lake-breeze characteristics of Lake Michigan with their 2-D hydrostatic model. This model employed finite difference numerical methods and a constant planetary boundary layer height. The boundary layer parameterizations employed in their model are not adequate in describing the vertical structure of the planetary boundary layer in the lakeshore environment.

McPherson (1970) utilized a 3-D hydrostatic model to simulate sea-breeze occurrence on irregular coastlines. His model lacks of realistic and detailed boundary layer parameterizations for adequately simulating the complex flow patterns inherent in the land/sea breeze circulations. Pielke (1974) and Anthes and Warner (1978) developed a more sophisticated 3-D mesoscale model that simulates the features of a land/sea breeze circulation. Their model did not include parameterizations of the dispersion and deposition of pollutants.

Lyons (1975) studied the meteorological aspects of the lake breeze phenomena on Lake Michigan during the winter and summer seasons. This analysis pointed out the importance of the lake/land breeze circulation in the transport and deposition of pollutants emitted near the lakeshore environment. More recently, Christidis (1986) developed a 3-D mesoscale model to specifically study the dispersion and deposition of atmospheric pollutants

emitted in a coastal environment. This model employed sophisticated numerical techniques and a variable vertical grid to simulate the land/lake circulations.

Table 7. Summary of dispersion models applied to coastal environment.

MODEL	TYPE	APPLICATION	REFERENCES
----	2-D Hydrostatic	Lake Michigan	Estoque(1963) Moroz(1967) Sheigh & Moroz(1974)
----	Puff Advection Dose Assessment	Study of deposition near Nine Mile Nuclear Plant, N.Y.	Caiazza(1985) Gotham et al.(1985)
----	3-D Hydrostatic	Simulations of sea breeze on irregular coastlines	Mcpherson(1974)
----	3-D Mesoscale	Simulations of meteorological features of land/sea breeze	Pielke (1974) Anthes & Warner (1978)
MESOADM	3-D Mesoscale	Theoretical study of Lake Breeze.	Christidis(1986)

10 Future Tasks And Approaches

10.1 Development of a Probabilistic Exposure Model

Exposure estimates for the population living near to the Pilgrim Nuclear Power Plant requires knowledge of the following factors:

SOURCE FACTORS

Release rate by isotope- Since meteorology is changing continuously modifying direction of transport and the amount of dispersion, emission rates should be known on an averaging time of about one hour or less.

Unfortunately, time resolution of the emission rates are generally reported on a quarterly basis, and potentially available on a weekly basis. As a result our ability to model exposures is limited to the following options:

i. Assume quarterly averaged emissions occur equally for each hour.

ii. Examine generating load factor for Pilgrim I site to develop an emission factor on a quarterly basis. Apply these factors to the quarterly emissions to obtain an hourly emission factor.

iii. Utilize hourly integrated noble gas emission rates and appropriate empirically derived conversion factors to estimate particulate and Iodine emission rates for Pilgrim I.

iv. Intermediate approaches can be utilized to determine the sensitivity of our modeled exposure estimates to variations in emissions rates.

Point of Release. The location of emission release is important to estimating downwind concentrations. Release height differences are less important the further downwind one is from the source. For low level releases, it is more likely that emissions would be influenced by wake flow around the main building. It has been suggested that at Pilgrim I, emissions may have occurred at points not monitored. Without knowing how much, if any, radioactive emissions were released at non-monitored locations a critical limitation is imposed upon our ability to quantify exposures. As a possible response to this important issue a review of operation data should be conducted. Without specific knowledge, one approach would be to assume that non-monitored releases were proportional to the monitored releases.

Resolution of this issue is critical to the DPH's retrospective epidemiological investigation. At least the following quantitative information would be useful: 1) Estimate the ratio of monitored to non-monitored emissions; 2) Evaluate non-monitored release times by crude categories (i.e., season, year, day vs. night); and 3) Identify location of releases to determine if it would be influenced by structure wake air flow.

With this information, sensitivity analysis could be performed to determine if this type of emissions would result in exposure misclassification.

Isotope. Emission data should be specified by isotope. Assuming a wind speed of 2 m/sec (typical sea breeze wind speeds) the travel time to a point 10 km inland is 80 minutes. If an emitted isotope is short-lived (half-life on the order of 1 hour/day or less) correction factors will be necessary. Radiation exposure can result from isotope decay as air passes over a location or from injestion/inhalation of a biologically active isotope. Exposures to radioactive iodine would have to be considered using multiple pathways.

TRANSPORT FACTORS

Wind Speed - Accurately characterizing wind speed is critical to estimating concentrations. Wind speed is measured at the coastal site from a meteorological tower at 33ft. and 160ft. levels. The data obtained at the Pilgrim I. location may not accurately represent the plume transport wind speed. There are several reasons for this; 1) air flow over land is modified by topography and is retarded by surface friction 2) convective overturn or stratification of air can modify vertical wind speed profiles and 3) sea breeze winds will decrease in wind speed as they move inland. Since there are no appropriately located inland meteorological monitoring sites around the Pilgrim I location, there is no way to precisely adjust wind speed information for off-site transport conditions.

The choices for the Pilgrim site are limited to the on-site meteorological tower located within 500m of the shore line. Wind speed data are available at two levels (33ft. and 160ft.) on the 220 foot tower. One could utilize the data from either level or one could use an algorithm derived from one or both of the measurement levels.

Wind Direction - Wind direction will change with height above the ground and will be influenced by terrain features. The coriolis effect will cause a clockwise turning of wind direction as the sea breeze develops over the course of the day. This effect is reflected in the coastal wind sensor, but the effect of surface friction and surface features are not. As a result wind blowing inland will experience the frictional effects of the surface which decreases speed and changes direction.

It is difficult to account for this effect in sea breeze dispersion. The plume moves inland aloft before it disperses and is mixed to the surface. Given the uncertainties in other parameters adjusting wind direction for unquantifiable terrain and friction effects does not seem reasonable.

Dispersion - Turbulence in the atmosphere causes a plume to spread and hence dilute. Turbulence is generated by surface friction and thermal instabilities. The over-water turbulent conditions can be estimated from the meteorological measurements at the Pilgrim site. However, with onshore winds the tower measurements do not reflect the effects of the overland conditions. As the plume disperses inland the turbulent structure is modified. Gradient wind flow can be associated with high pressure systems migrating to the north, or low pressure systems passing to the southeast and east of Plymouth. Under these conditions turbulence would be characterized as slightly stable as wind approached the shore and modified to neutral as air moves inland.

For sea breeze situations, the wind is likely to be slightly stable as it approaches the land and meteorological tower. As air flows over a heated surface thermally generated turbulence is induced. Under sea breeze conditions the turbulence structure of the atmosphere will not be accurately determined by the meteorological sensors at the coastal site. There will be a transition between an onshore stable air mass to a convective layer within the heated lower boundary layer. If the plume remains aloft then the coastal meteorological tower may represent turbulent conditions. However if the plume intersects the internal boundary layer then enhanced mixing and downward mixing can occur. Emissions near the surface will mix more rapidly within the vertical extent of the internal boundary layer.

The Pilgrim I site does not have inland meteorological monitoring. Turbulence can not be objectively inferred from the vertical temperature lapse rate, vertical wind shear or from the fluctuations in wind direction. Turbulence within the IBL would be a function of wind speed, surface roughness and solar insolation. As a result, it would be expected to undergo transitions over the course of a sea breeze event. Yet, for estimating exposures using a dispersion model, simplified parameterizations can be used where complex formulations are not appropriate due to the lack of adequate input data. Within the IBL, turbulence typified by a Pasquill-Gifford condition C should be assumed. Inland above the IBL a P-G classification of E (slightly stable) is appropriate.

exist in the morning and turn through the southeast by afternoon. Although vertical mixing may occur with in the first km, there could be a factor of 5 difference in the IBL height inland.

Sea Breeze Circulation

A few relevant conditions of sea breeze circulations should be understood in order to appreciate the limitation of modeling exposures. Unlike onshore gradient flow sea breeze circulation have a shallow inflow layer of between 100m to 1000m. The outflow layer is typically twice as deep and hence has a lower velocity. The landward flow is usually has a maximum at heights less than 300 m. Under intense land-water contrast and weak synoptic flow, horizontal wind maximum velocities of 10 m/s are possible along the shore.

The inland extent of the sea breeze front varies during the day. It will depend upon several factors such as strength and direction of synoptic flow, clockwise turning of the wind in northern latitudes because of the coriolis effect and solar heating (plus sea temperature). The extent of sea breeze penetration can not be determined directly for the Plymouth area. There is only limited data from the one inland site, the Plymouth Airport. Examining the records of this site indicates that 67% of the sea breeze occurrences penetrated at least 8 km inland. The full extent of the landward movement of the sea breeze front could not be determined. It would be important to at least approximate the inland distance of sea breeze penetration. An empirical relationship might be derived from examining the combined meteorological record of Logan, Bedford, Plymouth, Pilgrim, and the Coast Guard Stations.

The Sea breeze circulation is quite complex and it is not the simplified closed circulation often depicted. Trajectories within the sea breeze cell are three-dimensional in nature. The along-shore wind components most often prevent pollutants from returning to the same point that they were released. Pollutants, therefore, will not be built-up within a closed cell but they will be spread over a wider area. If the sea breeze front is sufficiently far inland and fumigation does occur, then the coriolis force causes the fumigation spot to rotate. This reduces the time-integrated pollution concentration at any one point and pollutant exposure is distributed more widely.