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Analysis of the Bethlehem Steel Complex at Sparrows Point, Maryland

Final Report and Annotated Bibliography

ANALYSIS OF THE BETHLEHEM STEEL COMPLEX AT SPARROWS POINT, MARYLAND AND ITS IMPACT ON MODEL VALIDATION EFFORTS

Final Report

Part I: Technical Report

Part II: Annotated Bibliography

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FOREWORD

Numerous attempts at modeling air pollutants in the Baltimore area have shown that problems exist in the vicinity of the Bethlehem Steel complex southeast of Baltimore at Sparrows Point. In general, previous studies have shown modeled concentrations of air pollutants to be higher than those observed in the vicinity of the steel plant for both short and long periods. In this report, only long-term observations are assessed.

Urban areas are known to develop an area called a heat island where the atmosphere is warmer than the surrounding rural area. The basic causes are both changes in surface characteristics and heat released during combustion. Over the years, numerous studies have been undertaken to explain the lack of success in modeling the complex by hypothesizing the heat island typical of urban areas as a factor.

The main objective of the project was to incorporate a heat island algorithm in the Maryland Air Management Administration (MAMA) multiple-source dispersion model. A literature search was undertaken of the effects of urban characteristics on the environment and on dispersion. An annotated bibliography is included as part II of this document.

ABSTRACT

Numerous attempts to model the ambient particulate matter concentrations produced by the Bethlehem steel complex at Sparrows Point, Maryland have met with limited success. One hypothesis is the presence of a heat island at the plant site. The plant emits heat at a rate nearly equal to one quarter of the solar constant.

As part of this project, the Maryland Multiple-Source Dispersion Model has been modified to include an algorithm applicable to the heat island at the Bethlehem Steel plant. The heat island algorithm modifications include changes in the vertical wind speed profile; changes in mixing heights; the incorporation of a multiple-source plume rise enhancement factor; adjustments to the atmospheric stability classification at the plant site and further adjustments at the plant boundary. The inclusion of these modifications reduced the modeled concentrations and previous discrepancies between observed and predicted concentrations at monitors near the plant.

A bibliography of observational and numerical studies was assembled based on applicability to industrial complexes. Annotations were prepared for 41 references dealing with observations, 34 references on numerical modeling of the urban heat island, and 9 references relating to land/ocean thermal differences.

PART I: TECHNICAL REPORT

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1.0 BACKGROUND

1.1 Previous Studies

A study of air pollutant modeling at the Bethlehem Steel plant at Sparrows Point was done by Cimorelli et al. (1977) and for the 1978 Maryland State Implementation Plan (SIP) and a 1980 proposed revision.

Cimorelli assessed 24-hour total suspended particulate matter (TSP) concentration impacts using various screening modeling techniques and calculated emissions for 37 point sources and 5 line sources based on 1973 production rate data. One of the major conclusions was that the inclusion of a heat island algorithm would probably improve the modeled results. Particulate matter concentrations were expected to be accurate within a factor of 3.2.

For the 1978 Maryland SIP, annual TSP concentrations were assessed using the Multiple-Source Dispersion Model (MSDM), a version of the Air Quality Display Model (AQDM) revised to include the Briggs plume rise equations, vertical wind speed adjustments, morning and afternoon mixing heights, initial σ_z values calculated for low stacks and urban areas, receptor heights, and algorithms for particle settling. These model revisions have made MSDM more applicable to urban areas than AQDM. Source emission data for 1977 were used in the 1978 Maryland SIP modeling analysis. These source data differ considerably from data used by Cimorelli.

Model predictions were compared with measured TSP concentrations at 23 monitoring sites in the 1978 Maryland SIP. The modeling analysis produced a regression equation between observed (C_o) and modeled (C_m) concentrations: $C_o = 43.8 + 0.3668\ C_m$ and a correlation coefficient of 0.894. The high correlation coefficient indicates that measured and modeled concentrations correlated well in terms of relative magnitude; that is, the model predicted relatively high concentrations when the measured concentrations were

relatively high and relatively low concentrations when the measured concentrations were relatively low. However, the 0.3668 slope of the regression equation shows that the higher ambient particulate concentrations were overpredicted. The 1978 Maryland SIP indicated this result was probably due to inaccurate source data, especially for area and fugitive dust sources.

A proposed 1980 SIP (subsequently withdrawn) reported that annual TSP concentrations were assessed using MSDM and 1979 source data. While source data were not shown in the revised 1980 SIP, the modeled and measured TSP correlations are identical to those shown in the 1978 SIP. Thus the results of the 1980 SIP modeling analyses are unclear.

1.2 MSDM MODEL

The modifications to AQDM model which produced MSDM made the model more appropriate for application to urban areas. For example, during the computation of plume rise and vertical dispersion coefficients, σ_z, all periods of the stable atmospheric stability class E are shifted to the neutral stability class D. The elimination of E stability conditions for these computations makes the model more suitable for use in urban rather than rural areas.

Changes were also made to the mixing height used in the model which make it more appropriate in urban applications. In the original AQDM, the annual average maximum (afternoon) mixing height was the only mixing height value input to the model. For nighttime periods of D stability the mixing height used in the model was an average of the afternoon value and a value of 100 meters. For nighttime periods of E stability, the mixing height was set at a value of 100 meters. In MSDM, the annual average minimum mixing height replaces the 100-meter value. A mixing height of 100 meters is considerably less than typical annual average morning mixing heights and is much less than

the 439-meter value used for the Washington/Baltimore area as given by Holzworth (1972). The use of a larger mixing height, which provides a correspondingly larger dispersion volume, is another factor that makes MSDM more applicable to urban areas than AQDM.

2.0 SITE CHARACTERISTICS

2.1 Source and Receptor Locations

The Bethlehem steel plant is located at Sparrows Point, which extends into the Patapsco River on Chesapeake Bay. Five receptors were selected to test the results of the revised algorithm. The locations of sources and receptors used in the current study are shown in Figure 1. Additional receptors north of Sparrows Point not used in the current study (for example, Middle River Martins, Essex, Southeast Police) contained discrepancies between the reported UTM coordinates and the Maryland coordinates and should be rechecked for actual location coordinates.

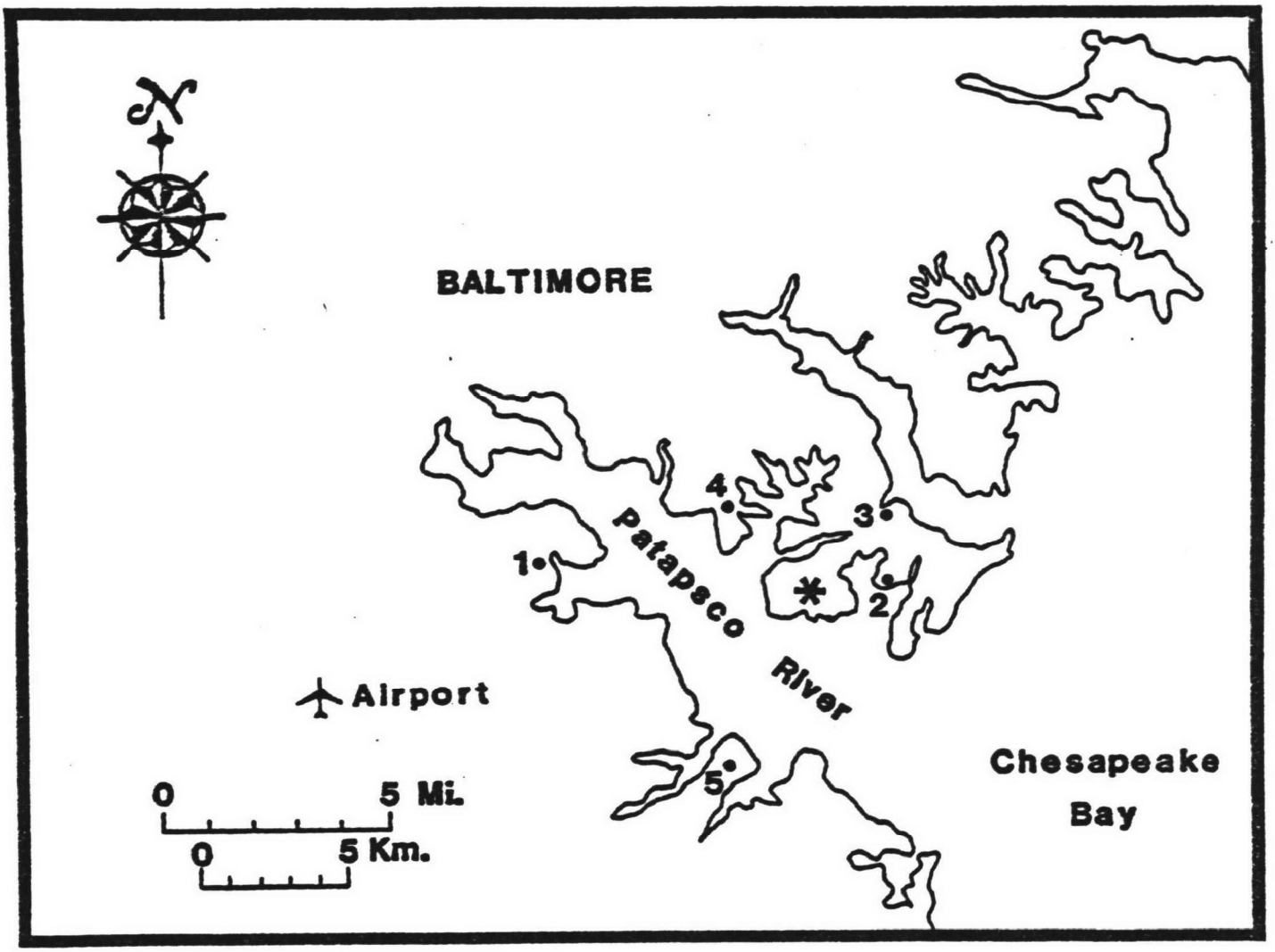
The city of Baltimore is approximately 10-12 kilometers northwest of the plant. The Patapsco River joins Chesapeake Bay southeast of the site.

The receptors having the highest impact from the plant are located just east of the plant. A much reduced influence is reflected in the remaining receptors.

2.2 Meteorological and Oceanographic Data

The meteorological data used consisted of STAR format wind and stability frequency distributions from Baltimore Airport about 15 kilometers west of the plant. Card decks were obtained for 1977 in five stability categories (A to E) and for 1979 in seven categories (A to C, D-day, D-night, E and F). During algorithm development, MSDM was modified to accept either STAR deck.

The proximity of water to the steel plant tends to have a moderating influence on the plant. A review of the reported water temperatures showed summer water temperatures to be considerably higher than corresponding ocean temperatures. The monthly average land and water temperatures indicate that the water is warmer than the air in all months except in early spring, as seen in Table 1 (U.S. Coast Pilot 3, 1976).



* BETHLEHAM STEEL
SPARROWS POINT
PLANT

Figure 1. Bethleham Steel Sparrows Point plant and receptor locations used in developing an MSDM heat island algorithm.

TABLE 1

WATER AND AIR TEMPERATURE AT BALTIMORE (°C)

Month	Water	Land
January	3.0	1.5
February	2.8	2.1
March	5.9	6.1
April	11.7	12.3
May	17.9	17.9
June	23.4	22.5
July	26.4	24.9
August	26.4	23.9
September	23.9	20.1
October	18.6	13.9
November	12.2	7.5
December	6.1	2.1

Thus the maritime influence at the plant is minimal during the day with few periods of sea breezes expected. During the night the air over the water does not cool as much as it does over rural areas. The influence of the water on wind changes was not considered in this study.

2.3 Energy Output of the Bethlehem Steel Plant

The magnitude of the heat island effect at the Bethlehem Steel plant is dependent mainly on the heat released from the plant and other influences from surface roughness. The Sparrows Point plant's total energy output was calculated using the fuel use data supplied by the State of Maryland, shown in Table 2. Fuel combustion produces a total of 9.41×10^{13} Btu's at the plant which, spread over the entire area of the plant, yields an average of 335 W/m^2. This energy output is approximately equal to one-fourth of the solar constant and also is comparable with the energy output of central New York City. Most of this heat is to be released to the atmosphere and nearby waters.

TABLE 2

FUEL USED AT PLANT AND ESTIMATED Btu
1979

Fuel	BTU x 10^{11}
Coke-Oven Gas	257
Natural Gas	108
Blast Furnace Gas	294
No. 2 Oil	3
No. 4 Oil	1
No. 6 Oil	251
Waste Oil	3
Coal Tar	24
TOTAL	941

2.4 Source Emission Data

Changes have occurred in the Bethlehem Steel source emission data over the years. These changes have not been limited to emissions, but include changes in physical parameters such as stack height, diameter and exhaust gas flow rates. The total emissions from the Bethlehem Steel plant are now less than 40 percent of the amount used for the 1978 SIP. These differences were discussed with MAMA which indicated confidence in the current source data.

The emission data for the Bethlehem Steel plant are shown in Table 3 for 20 point and 49 area sources. The largest point source is source No. 5 (Coke-Oven Battery) which emits more than 7 times the amount of the next largest source (No. 4, the A to K blast furnace). Paved and unpaved roads (sources 30 through 69) constitute the largest area sources; coal handling, blast furnaces and the sinter plant comprise the remainder. The tilted plume portions of the model are used to estimate particle settling for the area sources.

TABLE 3
SPARROWS POINT SOURCE DATA

SOURCE NUMBER	SOURCE LOCATION (MD GRID) HORIZONTAL	VERTICAL	SOURCE AREA 10**8 SQ FT	ANNUAL SOURCE EMISSION RATE (LBS/DAY) SO2	PART	STACK DATA HT (FT)	DIAM (FT)	VEL (FT/SEC)	TEMP (DEG.F)
1	947.5	504.0	0.0	2736.00	0.0	100.0	6.5	66.7	500.
2	945.5	504.0	0.0	1974.00	0.0	150.0	5.0	3.3	300.
3	949.0	504.5	0.0	1040.00	0.0	100.0	6.0	2.0	300.
4	948.5	503.5	0.0	3160.00	0.0	70.0	1.3	25.0	400.
5	945.0	502.5	0.0	23280.00	0.0	100.0	6.0	2.0	600.
6	949.0	503.5	0.0	4112.00	0.0	100.0	6.0	2.0	400.
7	945.5	506.5	0.0	556.00	0.0	158.0	3.0	11.7	800.
8	949.5	507.0	0.0	570.00	0.0	125.0	6.7	28.0	1000.
9	946.5	508.0	0.0	34.00	0.0	50.0	1.7	11.8	1000.
10	946.0	504.0	0.0	2.00	0.0	50.0	6.0	2.0	100.
11	944.0	502.0	0.0	12.00	0.0	175.0	3.5	8.3	800.
12	945.5	508.0	0.0	126.00	0.0	100.0	6.0	2.0	100.
13	945.0	507.0	0.0	148.00	0.0	100.0	6.0	2.0	100.
14	944.0	507.0	0.0	76.00	0.0	130.0	9.0	14.4	580.
15	944.5	506.5	0.0	634.00	0.0	100.0	4.0	13.3	600.
16	949.0	504.0	0.0	2324.00	0.0	175.0	11.5	50.0	480.
17	949.0	509.0	0.0	64.00	0.0	40.0	3.8	47.3	375.
18	948.0	503.5	0.0	584.00	0.0	175.0	10.0	50.0	350.
19	947.5	506.0	0.0	296.00	0.0	110.0	5.0	35.0	375.
20	947.0	505.2	0.0	38.00	0.0	100.0	3.0	25.0	450.
21	942.0	503.0	0.03	0.0	3500.00	10.0	0.0	0.0	-0.
22	942.0	501.0	0.03	0.0	3500.00	10.0	0.0	0.0	-0.
23	944.0	501.0	0.03	0.0	3500.00	10.0	0.0	0.0	-0.
24	946.0	501.0	0.03	0.0	2922.00	10.0	0.0	0.0	-0.
25	946.0	503.0	0.03	0.0	2500.00	10.0	0.0	0.0	-0.
26	946.0	503.0	0.03	0.0	2500.00	10.0	0.0	0.0	-0.
27	948.0	503.0	0.03	0.0	2500.00	10.0	0.0	0.0	-0.
28	949.0	501.0	0.03	0.0	1619.00	10.0	0.0	0.0	-0.
29	942.2	500.8	0.03	0.0	720.00	10.0	0.0	0.0	-0.
30	942.2	502.8	0.03	0.0	1013.00	10.0	0.0	0.0	-0.
31	942.2	504.8	0.03	0.0	62.00	10.0	0.0	0.0	-0.
32	942.2	506.8	0.03	0.0	36.00	10.0	0.0	0.0	-0.
33	942.2	508.8	0.03	0.0	2.00	10.0	0.0	0.0	-0.
34	944.0	500.8	0.03	0.0	3878.00	10.0	0.0	0.0	-0.
35	944.0	502.8	0.03	0.0	2646.00	10.0	0.0	0.0	-0.

TABLE 3
SPARROWS POINT SOURCE DATA
(continued)

SOURCE NUMBER	SOURCE LOCATION (MD GRID) HORIZONTAL	VERTICAL	SOURCE AREA 10**8 SQ FT	ANNUAL SOURCE EMISSION RATE (LBS/DAY) SO2	PART	STACK DATA HT (FT)	DIAM (FT)	VEL (FT/SEC)	TEMP (DEG.F)
36	944.0	504.8	0.03	0.0	595.00	10.0	0.0	0.0	-0.
37	944.0	506.8	0.03	0.0	1032.00	10.0	0.0	0.0	-0.
38	944.0	508.8	0.03	0.0	55.00	10.0	0.0	0.0	-0.
39	944.0	510.8	0.03	0.0	2.00	10.0	0.0	0.0	-0.
40	945.7	500.8	0.03	0.0	679.00	10.0	0.0	0.0	-0.
41	945.7	502.8	0.03	0.0	3328.00	10.0	0.0	0.0	-0.
42	945.7	504.8	0.03	0.0	474.00	10.0	0.0	0.0	-0.
43	945.7	506.8	0.03	0.0	190.00	10.0	0.0	0.0	-0.
44	945.7	508.8	0.03	0.0	274.00	10.0	0.0	0.0	-0.
45	945.7	510.8	0.03	0.0	38.00	10.0	0.0	0.0	-0.
46	947.5	500.8	0.03	0.0	3171.00	10.0	0.0	0.0	-0.
47	947.5	502.8	0.03	0.0	7386.00	10.0	0.0	0.0	-0.
48	947.5	504.8	0.03	0.0	514.00	10.0	0.0	0.0	-0.
49	947.5	506.8	0.03	0.0	322.00	10.0	0.0	0.0	-0.
50	947.5	508.8	0.03	0.0	69.00	10.0	0.0	0.0	-0.
51	947.5	510.8	0.03	0.0	12.00	10.0	0.0	0.0	-0.
52	947.5	512.8	0.03	0.0	44.00	10.0	0.0	0.0	-0.
53	947.5	514.8	0.03	0.0	74.00	10.0	0.0	0.0	-0.
54	949.2	500.8	0.03	0.0	6866.00	10.0	0.0	0.0	-0.
55	949.2	502.0	0.03	0.0	5988.00	10.0	0.0	0.0	-0.
56	949.2	504.8	0.03	0.0	268.00	10.0	0.0	0.0	-0.
57	949.2	506.8	0.03	0.0	86.00	10.0	0.0	0.0	-0.
58	949.2	508.0	0.03	0.0	26.00	10.0	0.0	0.0	-0.
59	949.2	510.8	0.03	0.0	120.00	10.0	0.0	0.0	-0.
60	949.2	512.8	0.03	0.0	44.00	10.0	0.0	0.0	-0.
61	949.2	514.8	0.03	0.0	65.00	10.0	0.0	0.0	-0.
62	951.0	500.8	0.03	0.0	843.00	10.0	0.0	0.0	-0.
63	951.0	502.8	0.03	0.0	3849.00	10.0	0.0	0.0	-0.
64	951.0	504.8	0.03	0.0	560.00	10.0	0.0	0.0	-0.
65	951.0	506.8	0.03	0.0	5.00	10.0	0.0	0.0	-0.
66	951.0	508.8	0.03	0.0	10.00	10.0	0.0	0.0	-0.
67	951.0	510.8	0.03	0.0	21.00	10.0	0.0	0.0	-0.
68	951.0	514.8	0.03	0.0	61.00	10.0	0.0	0.0	-0.
69	947.0	506.0	0.03	0.0	904.00	10.0	0.0	0.0	-0.

3.0 MODEL AND PROGRAM REVISIONS

3.1 Revised Alogrithm for Urban Areas

A revised algorithm was developed for the Bethlehem Steel plant. The heat output of the plant has a density similar to mid-Manhattan with a total output equivalent to a medium-sized city. The revised algorithm was developed with the following constraints:

1. Applicability to Sparrows Point
2. Consistency with the MAMA dispersion model to simulate seasonal and annual concentrations

In addition, it was desired that the revised algorithm:

1. Be generally applicable to urban areas
2. Generate only minor input changes
3. Be economical

A review of the literature under Task 1 (Atwater and Anderson 1981) showed changes in the urban area when compared with the surrounding rural area in:

1. Wind speed profile
2. Mixing height
3. Plume rise
4. Stability

In addition, the nearness of the site to water suggested a fifth change: the possible formation of a thermal internal boundary layer resulting from advection over or from the water.

3.1.1 Wind Speed Profile

The roughness of the urban area is significantly higher than the surrounding rural area and generally results in a reduced wind speed at the same height. This effect is generally observed at high wind speeds (greater than 4 meters sec^{-1}). At lower wind speeds, some observations show increased urban wind speeds (Bornstein 1977).

The roughness height was increased from 2 centimeters to 20 centimeters over the Bethlehem Steel plant. Due to the compactness of the plant, we further assumed the wind at a level of 500 meters above the plant not to be influenced by changes in roughness height. To account for changes in wind, it may be shown that:

$$u_u = u_r \left(\frac{z_c}{z_o}\right)^{P_r - P_u} \tag{1}$$

where u is wind velocity, z_c is the height of constant wind velocity over urban and rural areas, z_o is the height of observed wind, P is the power law coefficient, and the subscript u refers to urban areas and r to rural areas.

In general, P is a complicated function of roughness height and the Monin-Obukhov length. Panofsky et al. (1960) developed a nomograph relating these properties. Using the assumed roughness height, the urban exponent was about .05 greater than the rural values; urban and rural coefficients are shown in Table 4. Corresponding to these changes, the wind speed for each category was also changed following Equation 1. These wind speed values are also included in Table 4.

TABLE 4

RURAL AND URBAN POWER LAW COEFFICIENTS AND VALUES OF WIND SPEED (m/sec)

Power Law Coefficient Stability	A	B	C	D	E	
Rural	.10	.15	.20	.25	.30	
Urban	.15	.20	.25	.30	.35	
Wind Speed Category	1	2	3	4	5	6
Rural	1.5	2.5	4.5	6.9	9.6	12.5
Urban	1.2	2.0	3.7	5.7	7.9	10.3

3.1.2 Mixing Height

Changes are induced by the heat island in the mixing height. Landsberg (1981) showed that increases of 200 meters were to be expected. Previous estimates made by Holzworth (1972) were increased by 200 meters in both morning and afternoon to 728 meters and 1770 meters, respectively.

3.1.3 Plume Rise

Plume rise from an urban area with numerous sources will be higher due to 1) changes in the urban stability to a greater instability, and 2) enhancement from multiple plumes. Stability changes will be examined in the next section.

Plume rise, h, may be computed from:

$$h = h_s + E \Delta h \tag{2}$$

where h_s is the stack height and Δh is the plume rise computed by using Briggs (1969); E is an enhancement factor. Stern (1976) examined various factors and presented:

$$E = [(n+s)/(1+s)]^{1/3} \tag{3}$$

where n is the number of sources

s is $6\ (w/n^{1/3}\Delta h)^{3/2}$

w is the width of the source area

Various data were used to compute E. For the Sparrows Point plant, the computed enhancement factor ranged from 1 to 1.13. Therefore, 1.1 was used in the tests reported below.

3.1.4 Stability Changes

In view of the large amount of heat emitted by the plant to the atmosphere environment, the stability will be altered to some degree and will change not only the computations of the vertical standard deviation, σ_z, as in the current model, but also wind speed, plume rise and mixing heights. The diffusion of pollutants outside the urban area should not be altered by the urban stability changes. Thus, two changes are examined: 1) urban stability class changes, and 2) urban-rural stability changes.

The first change makes the stability over the urban area one class more unstable than the surrounding area for either: 1) nighttime only, or 2) at all times. The two modes, shown in Table 5, were used by the ISC model for σ_y and σ_z computations (Bowers et al. 1979) and are based on the Pasquill stability category. In the current model, only five stability classes are used and the D class is split into 60 percent for daytime and 40 percent for nighttime.

TABLE 5

STABILITY CLASS CHANGES FOR THE URBAN AREA

STAR Class	Rural Mode	Urban Mode 1	Urban Mode 2
A	A	A	A
B	B	B	A
C	C	C	B
D	D	D	C
E	E	D	D
F	E	D	D
G	E	D	D

Whenever a plume transverses a region of different stability such as from urban to rural, the standard deviation (σ_z) will change at a different rate. When the plume enters a more (less) stable region, the standard deviation will be less (more) than with the original stability. The procedure

outlined here follows from Lyons and Cole (1973) and Ball et al. (1980) and is based on a virtual source.

For this study, the plume is assumed to be emitted from a stack, S, in an urban, relatively unstable area and will be transported to a receptor, R, in a more stable rural area, as shown in Figure 2. The standard deviation for vertical diffusion in the model is given by:

$$\sigma = a\, x^{b} + c \tag{4}$$

where a, b, and c are coefficients dependent on the stability class and x is the distance from the source to the receptor given in the notation of the figure as R - S in absolute units. It is also assumed that:

$$\sigma_u\,(U - S) = \sigma_r\,(U - I) \tag{5}$$

where the subscripts denote the urban, u, and rural, r, coefficient used to compute σ. The term U - S is the absolute distance from the urban-rural boundary (U) to the source (S), and U - I is the absolute distance from the urban-rural boundary to the virtual source I. Substituting to find the urban-virtual source distance yields:

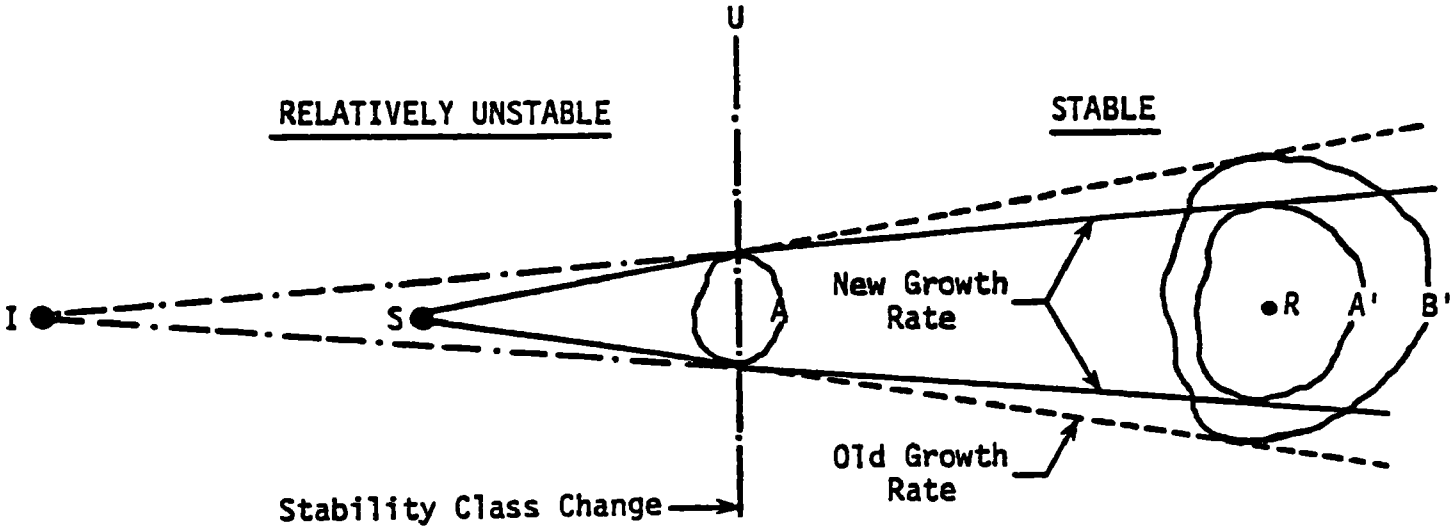
$$U - I = \left(\frac{1}{a_r} \quad [\sigma_u(U - S) - c_r] \right)^{1/b_r} \tag{6}$$

And the effective, σ_E, is defined as:

$$\sigma_E(R - S) = a_r[(R - U) + (U - I)]^{b_r} + c_r \tag{7}$$

In view of the program design, the σ_u at the boundary was computed from:

$$\sigma_u\,(U - S) = \sigma_u\,(R - S) \left[\frac{(U - S)}{(R - S)} \right]^{b_u} \tag{8}$$



LEGEND

——— Actual Growth Rate

- - - - Growth Rate if virtual distance not included

A, A' Actual Puff

B' Incorrect Puff

S Stack Location

I Virtual Source Location

R Receptor Location

Figure 2. Recalculation of virtual distance when stability class changes.

Thus σ_u partially incorporates the initial dispersion function for low-level sources.

The virtual source would be closer to the boundary, rather than farther, as shown in Figure 2, when the stability classes are reversed. Further, in the real atmosphere the stability change is more gradual than shown here.

The boundaries used for the urban area in this study (in Maryland grid feet) were 940,000, west; 953,000, east; 499,000, south; and 512,000, north.

3.1.5 Thermal Internal Boundary Layer

When air moves from one temperature to another temperature, as a sea breeze from the cold ocean to warm land, a thermal internal boundary layer (TIBL) develops in the cooler air where the air is more stable above a relatively unstable layer. This could cause higher concentrations due to fumigation at various distances downwind of the plant (Lyons and Cole 1973). The height of the TIBL, h, has been given by Venkatram (1977) as:

$$h = \frac{u_*}{u_m} \left[\frac{2\ (T_1 - T_w)}{T\ \ (1 - 2F)}\ x \right]^{1/2} \qquad (9)$$

where u_* is the friction velocity, u_m is the mean wind speed, T_1 and T_w are the land and water temperatures, T is a lapse rate and F is a constant often assumed to equal 0 and x is distance.

Using typical values, the height at 4 kilometers distance from the land-water boundary is about 200 meters for a $1^{\circ}C$ temperature difference and 440 meters for $4^{\circ}C$ difference. At 1 kilometer, heights are reduced by 1/2.

In view of the fact that most of the Bethlehem Steel stacks are less than 50 meters in height and that the plume rise would not be such that the effective height would be above the TIBL, no further consideration was given to its inclusion in the MSDM on an annual basis. The effect on short-term modeling may need to be considered in the future.

3.2 MSDM Computer Code

The MSDM computer code has been modified to a large extent over the past few years. When the program was received in its present form, it appeared to be inefficient and difficult to revise easily. For example, there are five lengthly subroutines to perform essentially the same computations.

The test data set supplied by Maryland was used to make the necessary program changes for our UNIVAC computer. In some cases, poor programming practices prevented the code from being run on other than the MAMA computer. The major change was the use of a named common area the same as a subroutine name. Other changes were six character words in data statements that were converted to four characters.

Another error that became apparent was that the wind speed was not initialized in subroutines POL3 and POLUT2.

Once these errors were corrected, the test data set was run and the results showed that possible minor errors remained. However, the results were identical to those of MAMA. Therefore a new test data set was developed. This data set used a different program logic.

The major error was a lack of consistency in the common between subroutines SORT, SEL12, REG, and SELECT and the remainder of the program. The dimension of XRECEP was 2,12 in the above subroutines and 3,12 for the remainder of the program. Another major error was the lack of initialization of CPOLUT in subroutine POL3. These errors cause unknown errors in the predicted concentrations.

Other errors discovered were the lack of any calls to subroutine REG and an incorrect number of calls to subroutine POL3 from subroutine DIFMOD. While numerous errors were found and corrected, the program was not subjected to rigorous line-by-line code inspections to determine whether additional errors

remained as this was beyond the scope of this project. However, the correction of these errors produced results from the data sets that seem correct.

The necessary program corrections were made and have been forwarded to MAMA to ensure that the corrections are incorporated into their version of MSDM.

3.3 Program and Input Modifications

The computer program was modified to incorporate the heat island algorithm described in Section 3.1. The goal was to make only minor input changes so that existing data sets would need only minor modifications. The modifications to input were generally minor using default values where no changes were to be made. The changes are described in detail in Table 6.

Mixing depth is currently specified in the input so that only new data are used. Additional items specified in the namelist include the wind speed categories and power law coefficients of Table 4, the plume rise enhancement factor and changes in stability classes. If wind speed categories, power law coefficients and a plume rise enhancement factor are not input, the rural power law and wind speed categories will be used and the plume rise enhancement factor will be 1.

The stability class changes are set up to accept a 5 or 7 stability class STAR deck and convert it to a 5 class using the relationships in Table 7. It should be noted that 32 blank cards must be added to the end of the input for 5 class stability decks. The format of the cards is the same as that supplied by National Climatic Center. The changes in use of the STAR deck are mandatory in the modified version of the program, regardless of whether other changes are planned.

TABLE 6
INPUT MODIFICATIONS

No Changes Except Actual Numbers

Mixing Depth
DPTHMX = XXX, XXX

Changes Added to Namelist
(If no change desired, no cards are needed, default used).

Wind Profile Changes

Wind Speed UU and Power Law Coefficient P.
UU = XXX, XXX, XXX, XXX, XXX, XXX, XXX
P = XXX, XXX, XXX, XXX, XXX

Plume Rise Enhancement Factor

AAMA = XXX

Stability Class Changes

INFQC = iii, iii, iii, iii, iii, iii, iii

Items Removed From Namelist

WNDFRQ

Data Added Immediately After Namelist Completion

WINDIN (6, 16, 7) array from STAR deck.
Seven-category STAR deck from NCC with no changes.
112 cards with format
bbbbbbb N N N N N N

Urban Boundary (After completion of WINDIN)

Column	Variable	Number
1-10	Western urban boundary X*	XXX
11-20	Eastern urban boundary X	XXX
21-30	Southern urban boundary Y	XXX
31-40	Northern urban boundary Y	XXX

* Maryland grid units. A blank card removes stability changes at the urban boundary.

Code

XXX any number including sign and decimal point
iii any integer number
bbb any punch is not read
N number and decimal of 7 columns

TABLE 7

DEFAULT CATEGORY FOR STABILITY CLASS

Reported	5 Class	A	B	C	D	E	Blank	Blank
	7 Class	A	B	C	D (day)	D (night)	E	F
Program		A	B	C	D	E	E	E

The boundaries of the urban area are read on a card immediately after the STAR deck using the Maryland grid coordinates. In this study, the boundaries used were 1 kilometer larger than the rectangular area containing the Bethlehem Steel Sparrows Point plant. If the urban-rural stability change is not to be used, one blank card will be needed.

If both settleable and nonsettleable particulate matter sources are going to be modeled in the same MSDM computer run, care must be taken to input the source data properly. The nonsettleable source emissions (either SO_2 or particulate matter) may be modeled by using the SO_2 emission rate input data field. However, for either SO_2 or particulate matter emissions, the model output will title the concentrations SO_2.

A more serious problem arises concerning the input cards for the particle settling parameters. The problem occurs when nonsettleable particulate matter (or SO_2) point sources are modeled in the same computer run with settleable particulate matter area sources. The (nonsettleable particulate matter or SO_2) point sources must be input first, followed by the (settleable particulate matter) area sources. In order for the particle settling computations to proceed correctly, two blank cards must be input for each of the (nonsettleable particulate matter or SO_2) point sources immediately ahead of the cards containing the particle settling parameters for the (settleable particulate matter) area sources. Otherwise, the particle settling parameters will be applied to the nonsettleable particulate matter (or SO_2) point sources.

The emissions labeled PART in the source emissions table are not used in the former MSDM program. Rather the total emissions as defined by particle size are used. In the modified version, both are being printed so that input errors may be readily identified.

4.0 RESULTS

Eight tests were developed to examine the various changes in model input and additional algorithms to simulate the effects of the heat island. These tests are summarized in Table 8. An initial test (test 0) was undertaken to show the original results.

TABLE 8
TESTS OF VARIOUS ALGORITHM MODIFICATIONS

Test Number	Modification
0	Base case
1	Urban wind speed categories and power law coefficients
2	Mixing height
3	Stability class - Urban Mode 1
4	Stability class - Urban Mode 2
5	Plume enhancement = 1.1
6	Urban-Rural Stability change
7	Combination of tests 4, 5 and 6
8	Test 7 with adjustment of D stability (night)

The modifications include a revised wind speed and height profile, (Test 1); higher mixing heights for the study area (test 2); two different scenarios for changing the atmospheric stability toward more unstable classes (tests 3 & 4); an increase in plume rise for point sources (test 5); and urban-rural stability class changes (test 6). The results of combined tests 4, 5 and 6 comprise test 7. In all the above tests the stability classes on the 1979 STAR deck were assumed to be A to G, as shown in Table 5. In reality, the STAR deck used D classes broken into day and night with no G class included. The revised data are used in test 8.

Each test used 69 Bethlehem Steel sources and five selected receptors. The 20 particulate matter point sources were input to the model as SO_2 sources since particle settling characteristics were not provided for these sources. The 49 particulate matter area sources were modeled as particulate matter sources using the particle settling characteristics provided by the State of Maryland. The results for TSP for each test are shown in Table 9.

TABLE 9
MODELED TSP ($\mu g/m^3$) AT FIVE RECEPTORS USING
BETHLEHEM STEEL PLANT SOURCES

Receptor	Observed	Test 0	1	2	3	4	5	6	7	8
1	77	7.0	7.9	7.0	7.2	5.6	6.9	7.5	6.8	6.5
2	57	54.8	62.7	54.8	55.8	49.4	54.5	55.9	51.1	48.7
3	48	20.0	22.5	20.0	20.4	17.0	19.9	20.3	17.8	16.1
4	76	21.7	24.5	21.7	22.1	17.9	21.6	22.0	18.4	15.5
5	50	8.7	9.8	8.7	9.0	7.1	8.7	9.5	8.6	8.4

The urban wind speed profile exponents caused increases in modeled particulate matter concentrations at all receptors (test 1). The higher mixing heights did not change any of the impacts at any of the receptors (test 2). Although the mixing height over the Bethlehem Steel heat island is surely greater than over other portions of the study area, the mixing height does not generally affect the ground level pollutant concentrations calculated with MSDM until the plume is quite distant from the source.

Shifting each of the stability classes obtained from the input meteorology to the next highest unstable class (that is, E to D, D to C, and so forth), decreased concentrations by 15 to 20 percent at all receptors (test 4). Shifting only the nighttime E stability periods to D stability (test 3) produced a slight increase in the particulate matter impacts at all the receptors. In this case the particulate matter impacts from the area sources decreased slightly at receptors nearest the plant and increased slightly at the more distant receptors.

In test 5, the plume rise of the point sources was increased by a factor of 1.1 to account for the increased buoyancy produced by adjacent plumes in the heat island. This change resulted in a slight decrease in particulate matter concentrations from the point sources at four of the five receptors and no change at the relatively distant fifth receptor.

In test 6, the input atmospheric stability classes A, B and C were made one stability class more stable (that is, B, C, D) at the plant (heat island) boundary to simulate the transition from urban to rural dispersion characteristics at the plant boundary. When used by itself, this change resulted in a slight increase in the modeled particulate matter concentrations from the point and area sources at all the receptors. The rural dispersion coefficients are smaller than the urban coefficients; thus, outside the plant boundary, the atmospheric dispersion is reduced and the particulate matter concentrations increase.

After reviewing the results of the model modifications that were tested, those modifications that together best simulate the heat island at the Bethlehem Steel, Sparrows Point plant were tests 4, 5 and 6. When operated together, these options simulate the increase in atmospheric instability over the heat island, the increase in plume rise associated with adjacent buoyant plumes in the heat island, and the return to a more stable atmosphere over the more rural areas surrounding the heat island. The results from this final test show reduced modeled concentrations at all receptors.

At all receptors, the modeled concentrations from the steel plant were reduced with the inclusion of the heat island modifications. The nearby receptors were reduced about 4 $\mu g/m^3$ to 6 $\mu g/m^3$. The largest point sources (5, the coke-oven battery) produced up to 9.5 $\mu g/m^3$ at the nearest receptor and more than 2 $\mu g/m^3$ at distant receptors. The roads (29-69) contributed 21.2 $\mu g/m^3$ to the nearest receptors and 2 $\mu g/m^3$ to 6 $\mu g/m^3$ at the remaining receptors. When the background concentration and the emissions from other areas are included, it appears that receptor 2 will still have modeled concentrations higher than observed.

5.0 RECOMMENDATIONS

During the course of this project, it became obvious that the MSDM had grown inefficient for programming and contained a number of errors. There are currently five lengthy subroutines that contain essentially the same computer codes for plume diffusion. Thus, changes need to be made consistently in all five places. Changes in the computer code might result in increased efficiency. Using our data set, the running time was reduced about 40 percent through program modifications with no change in the results. Thus, the first major recommendation is to revise completely the computer code if future use of the model is planned.

A second recommendation is to review the source emissions for accuracy for the coke oven and the roads. The road emissions, which cause particularly high impacts at the nearest receptor, may be modified further by removing the additional initial standard deviation or by allowing quicker particulate matter settling. Errors may occur in the settling algorithm, which was not examined in this project.

The third recommendation is to use a heat island algorithm similar to our test case 8 that includes 1) plume enhancement, 2) stability urban class mode-1, and 3) urban-rural stability changes. The urban mixing height should be considered for distances greater than those of the present tests. Consideration should also be given to extending the urban-rural stability class changes beyond those presently programmed to include receptors in urban areas with rural sources and stability changes between the source and receptors.

The fourth recommendation is the inclusion of these changes in a short-term model. TIBL should also be incorporated in sea breeze situations in the short-term model, particularly in cases where modeled concentrations are lower than observed.

6.0 REFERENCES

Ball, R.J., C.A. Jacobs and J.P. Pandolfo 1980. Development of A Combined Numerical Boundary Layer - Gaussian Puff Model. Final report to EPA. CEM 4226-668. Hartford: Connecticut Center for the Environment and Man, Inc., 88 pp.

Bornstein R.D. and D.S. Johnson 1977. Urban-Rural Wind Velocity Differences. Atmospheric Environment 11:597-604.

Bowers, J.F., J.R. Bjorklund and C.S. Cheney 1979. Industrial Source Complex (ISC) Dispersion Model User's Guide. EPA-450/4-79-030. Research Triangle Park, NC: Environmental Protection Agency.

Briggs, C.A. 1969. Plume Rise. AEC Critical Review Series, TID-25075. Washington, D.C.: U.S. Atomic Energy Commission, Division of Technical Information.

Cimorelli, A.J., L.K. Felleisen and P.K. Finkelstein 1977. Bethlehem Steel Sparrows Point Particulate Modeling Study. Philadelphia: U.S. EPA Region III.

Holzworth, G.C. 1972. Mixing Heights, Wind Speeds and Potential for Urban Air Pollution Throughout the Contiguous United States. Publication No. AIP-101. Research Triangle Park, NC: U.S. Environmental Protection Agency.

Lyons, W.A. and H.S. Cole 1973. Fumigation and Plume Trapping on The Shores of Lake Michigan During Stable Onshore Flow. Journal of Applied Meteorology 12:494-510.

Maryland State Department of Health and Mental Hygiene 1978. Plan for Implementation of NAAQS for TSP, Photochemical Oxidants and CO for the Metropolitan Baltimore Interstate Air Quality Control Region.

Maryland State Implementation Plan, 1980 Revisions (proposed to Maryland State Implementation Plan of 1978).

Panofsky, H.A., A.K. Blackadar and G.E. McVehil 1960. The Diabatic Wind Profile. Quarterly Journal of the Royal Meteorological Society 86:390-98.

United States Coast Pilot 3, Atlantic Coast, Sandy Hook to Cape Henry, 1976. 14th edition. Washington, D.C.: National Ocean Survey, National Oceanographic and Atmospheric Administration.

Stern, A.C., ed. 1976. Air Pollution (3rd edition). Vol. 1. New York: Academic Press.

Venkatram, A. 1977. A Model of Internal Boundary Layer Development. Boundary-Layer Meteorology 11:419-37.

Landsberg, H.E. 1981. The Urban Climate. New York: Academic Press.

PART II: ANNOTATED BIBLIOGRAPHY

INTRODUCTION

For many years the influence of the urban area has been studied in detail, both observationally and theoretically. Higher nighttime temperatures, which are well documented, are caused by changes both in surface characteristics and from the addition of heat from combustion. The climatic impact during the daytime, and particulary in summer, is much smaller.

The field of urban climatology has grown rapidly over the past decade. The purpose of the initial phase of the project was to review the literature relating to urban effects and to prepare an annotated biblography. A comprehensive bibliography was prepared by Chandler (1970) for the World Meteorological Organization (WMO) and contained 1,800 titles; Oke (1974, 1979) reviewed the progress made to 1976 and found an additional 800 titles. A recent review of the urban climate was given by Landsberg (1981). In view of the large number of sources, their repetitive character, and extensive bibliographical resources, references were selected from those appearing after 1970 that apply to urban climate and its effect on the dispersion of pollutants within the urban environment.

TRC assembled the material based upon a computerized search using key words such as heat island or model heat island. TRC obtained copies of applicable references from the computer-generated abstract. When the lists were complete, it was evident that few references are available from 1979 to the present. Therefore recent scientific journals were searched. The articles selected are those which address the impacts of a heat island on atmospheric pollution distribution patterns in and around urban areas. The articles are divided into three groups and listed alphabetically by author.

Section A consists of articles relating to meteorological observations of the urban heat island. Many of the observations relate to METROMEX, an

observational program in St. Louis. Many other cities are also represented by the references. Section B lists numerical studies undertaken on heat islands. In those cases where both observations and modeling are discussed, the article is listed in section C. In view of similar thermal differences between urban and rural areas and land and water areas, articles relating to land and water thermal differences in the past few years are listed in section C.

A. OBSERVATION OF THE URBAN HEAT ISLAND

Ackerman, B. and B. Wormington 1971.
Some Features of the Urban Heat Island. Illinois: Argonne National Laboratory. Radiological Physics Division. Report ANL-7860, pp. 183-92.

Climatological records from Chicago Midway Airport and Argonne National Laboratory are used to study daily and seasonal variations in the strength of the urban heat island.

Bhumralker, C.M., A.J. Slemmons, and K.C. Nitz 1981.
"Numerical Study of Local/Regional Atmospheric Changes Caused by a Large Solar Central Receiver Power Plant." Journal of Applied Meteorology 20(6):660-77.

The potential local and regional atmospheric changes caused by the installation of a large solar central receiver power plant were modeled. The results show that such a facility could increase local humidity levels and wind circulation in a typical summer and even induce the formation of clouds and precipitation under certain conditions in an atypical summer.

Bornstein, R.D. and D.S. Johnson 1977.
"Urban-Rural Wind Velocity Differences." Atmospheric Environment 11(7):597-604.

Wind speeds along a streamflow line through New York City are decreased below (increased above) those at sites outside the city during periods with regional wind speeds above (below) about 4 m/sec. The decrease is attributed to increased values of the surface roughness parameter in the city, as compared with values in nearby nonurban regions. The increase is associated with accelerations produced by a well-developed urban heat island.

Chandler, T.J. 1971.
"Air Pollution and Urban Climates." Brighton, England: National Society for Clean Air, part 1, pp. 44-55; part 2, pp. 23-32 (Preprint).

The interrelationship of pollution, temperatures and airflow on urban atmospheres are discussed as well as the mean and turbulent structure of the wind over heat islands which is important to the transport and diffusion of pollution.

Chandler, T.J. 1970.
Selected Bibliography on Urban Climate. Geneva: World Meteorological Organization. WMO-276, Technical Publication 155.

Comprehensive bibliography consisting of 1,800 titles.

Changnon, S.A. Jr. 1980.
"Evidence of Urban and Lake Influences on Precipitation in the Chicago Area." Journal of Applied Meteorology 19(10):1137-59.

Precipitation data for 1931-77 were analyzed along with data of a denser network obtained for 1975-78 to determine the influence of the urban heat island on precipitation patterns. An area of 15 percent greater rainfall was identified in central Chicago. Summer precipitation increased more than winter precipitation over the 1931-76 period.

Cech, I., R. Weisberg, C. Hacker and R. Lane 1976.
"Relative Contribution of Land Uses to the Urban Heat Problem in the Coastal Subtropics." International Journal of Biometeorology 20(1):9-18.

The microclimatic patterns of a large, metropolitan center situated in a warm and humid climatic zone are investigated in relation to various forms of land use. The survey was conducted in Houston, Texas in the fall and summer of 2 consecutive years.

Ching, J.K.S., J.F. Clarke and J.M. Godowitch 1978.
"Variability of the Heat Flux and Mixed-Layer Depth over St. Louis, Missouri." Papers Presented at the WMO Symposium on Boundary Layer Physics Applied to Specific Problems of Air Pollution, Norrkoping, 19-23 June 1978. Geneva: World Meteorological Organization. WMO-510, pp. 71-78.

Based on boundary-layer field observations, an extensive study was performed for the temporal variations of heat flux. Details of the spatial and temporal variations of the surface sensible heat flux and mixed-layer growth are discussed with regard to the urban heat island. Accurate modeling of the transport and dispersion of pollutants in urban areas requires knowledge of heat flux and thickness of the mixed layer.

Colancino, M. 1980.
"Some Observations of the Urban Heat Island in Rome during the Summer Season." Il Nuovo Cimento (Bologna) 3C(2):165-79.

The effect of the urban heat island on temperature, humidity and wind patterns over the city of Rome is analyzed. One of the findings is that the heat dome reaches more than 300 meters and alters the wind flow.

Dilley, J.F. and K.T. Yen 1971.
"Effect of a Mesoscale Type Wind on the Pollutant Distribution from a Line Source." Atmospheric Environment 5:843-51.

The effects of mesoscale winds on the diffusion and dispersion of pollutants in the atmosphere are studied. Pollutant concentrations downwind from an infinite crosswind line source on the ground are computed. Large-scale and mesoscale winds, both chosen to simulate a local wind produced by urban heat island effects, are analyzed.

Eagleman, J.R. 1974.
"A Comparison of Urban Climatic Modifications in Three Cities." Atmospheric Environment 8:1131-42.

An investigation of climatic modifications in three urban areas over a 16-month period indicates a systematic increase in temperature, comfort index and potential evapotranspiration and a reduction in the relative humidity.

Gibrat, R. 1977.
"The Iron and Steel Industry, the Environment and Climatology." Quality of the Environment and the Iron Steel Industry, Results and Prospects. Commission of the European Communities. Pergamon Press, pp. 109-161.

The effects on the environment and on climate of air pollution from the iron and steel industry are discussed, including pollution and the heat island and the formation of heat islands and their effects on environmental factors.

Guedalia, D., Ntsila, A., Druilhet, A. and Fontan, J. 1980.
"Monitoring of the Atmospheric Stability Above An Urban and Suburban Site Using Sodar and Radon Measurements." Journal of Applied Meteorology 19(7):839-48.

Two methods of determining atmospheric stability and equivalent mixing height were compared for an urban and a suburban site. These determinations were made using acoustic soundings (sodar) and a method that relates ground-level radon concentrations to the value of a global exhange coefficient of the inversion layer. Vertical stability above a site was best determined using a combination of the two methodologies. Diurnal changes in stability were found and stability at the urban site is weaker in all seasons of the year.

Harrison, R. and McGoldrick, B. 1981.
"Mapping Artificial Heat Release in Great Britain." Atmospheric Environment 15(5):667-74.

Heat release from anthropogenic sources is mapped for Great Britain. Diffuse sources (domestic heat, transportation and so on) are mapped by grid. Intense sources, (steel mills, power plants) are mapped as discrete points. Heat flux from high-intense sources exceeds the solar flux by up to three orders of magnitude in Great Britain.

Henderson-Sellers, A. 1980.
"A Simple Numerical Simulation of Urban Mixing Depths." Journal of Applied Meteorology 19(2):215-18.

The increase in mixing height over an urban heat island may be calculated using the relatively simple numerical model that was developed. The model has been partially validated by comparisons with other models and ground-level pollutant concentrations. The model may be used in real-time applications.

Hogstrom, V. 1978.
"Uppsala Urban Meteorology Project." Boundary-Layer Meteorology 15(1):69-80.

An extensive urban meteorological project in Uppsala, Sweden is described. The city itself is considered a model city, being almost circular, having sharp urban-rural boundaries, and located in a relatively flat area.

Hosler, C.L. and H.E. Landsberg 1977.
"Effect of Localized, Man-Made Heat and Moisture Sources in Mesoscale Weather Modification." Energy and Climate. Washington, D.C.: Academy of Sciences, pp. 96-105.

The effect of localized manmade heat and mositure sources on local weather and climate, such as the urban heat island, is reviewed. Mathematical modeling is discussed as a method of quantifying such changes. A study on the effects of atmospheric heating by large power plants is described.

Landsberg, H.E. 1981.
The Urban Climate. International Geophysics Series, vol. 28. New York: Academic Press.

An overview of urban meteorological observations with chapters on selected meteorological parameters and their modifications in urban areas. Extensive bibliography.

Landsberg, H.E. 1975.
"Atmospheric Changes in a Growing Community (The Columbia, Maryland Experience)." Institute for Fluid Dynamics and Applied Mathematics. Maryland University, College Park. Technical Note BN-823.

This is an account of 7 years of meteorological observations in the growing town of Columbia, Howard County, Maryland. Information was collected from fixed stations and mobile surveys. All findings support earlier studies on town climate and reveal considerable detail on the progress of atmospheric modification in the urbanization process.

Landsberg, H.E. 1974.
"Inadvertent Atmospheric Modification through Urbanization." Weather and Climate Modification. New York: John Wiley and Sons, pp. 726-63.

Inadvertent modification of the atmosphere through urbanization is reviewed, including the urban temperature field and secondary effects of the urban heat island.

Lee, D.O. 1979.
"Contrasts in Warming and Cooling Rates at an Urban and a Rural Site." Weather (Bracknell, England) 34(2):60-66.

The warming and cooling rates at an urban and a rural site are investigated on the basis of temperature observations obtained from thermographs exposed in central London and at a rural site 17 kilometers north. Rural cooling rates are found to be the main determinant of heat island intensity, especially during summer so that rural atmospheric stability is strongly correlated with heat island intensity.

Lee, D.O. 1979.
"The Influence of Atmospheric Stability and the Urban Heat Island on Urban-Rural Wind Speed Differences." Atmospheric Environment 13(8):1175-80.

Mean hourly wind speed data for several sites in and near London are examined to determine the relative effects of the seasonal and diurnal variation of atmospheric stability and the urban heat island on urban-rural wind speed differences. A "critical" wind speed exists below which urban wind speeds are faster, and above which urban speeds are slower than rural wind speeds.

Lee, D.O. 1977.
"Urban Influence on Wind Directions Over London." Weather 32(5):162-70.

Discusses the modification of airflow within cities and how urban airflow exerts a strong influence on the form of the urban heat island and the spatial distribution of humidity.

Ludwig, F.L. and W.F. Dabberdt 1973.
"Effects of Urbanization on Turbulent Diffusion and Mixing Depth." International Journal of Biometeorology 17(1):1-11.

This paper discusses some of the ways that urbanization affects the concentrations that man introduces into the atmosphere from, for example, 1) emissions 2) wind 3) mixing depth, and 4) atmospheric stability.

Martin, F.P. and P.M. Evans 1975.
"Heat Island Effect of a Large Shopping Mall in Akron Ohio." Weatherwise 28:(6):254-55, 219.

The ambient temperature differential created by the warming effect of Summit Mall, a large shopping mall located in the northwest corner of Akron, Ohio, is investigated.

Nkemdirim, L.C. 1976.
"Dynamics of an Urban Temperature Field, A Case Study." Journal of Applied Meteorology 15(8):818-28.

Surface and airborne temperature and air pollution data collected in Calgary's urban area show the formation of a multiple-celled heat island at street level. Temperature gradients and their variability correlated with wind speed. Air pollution patterns over the city reflected land use and the strength of the boundary layer, which was well-defined over the city in early morning hours.

Norwine, J.R. 1973.
"Heat Island Properties of an Enclosed Multilevel Suburban Shopping Center." Bulletin of the American Meteorological Society 54(7)637-41.

Through sampling on and near the grounds of the Woodfield Mall complex, the nation's largest enclosed multilevel shopping mall, it was concluded that a totally enclosed shopping center does create a definite heat island under proper meteorological conditions, but that the effect is probably less than that of comparable "traditional" shopping centers, which consist of numerous scattered buildings of various shapes and sizes.

Oke, T.R. 1979.
"Review of Urban Climatology." Geneva: World Meteorological Organization, Technical Note 169.

Cites 434 references appearing between 1973 and 1976.

Oke, T.R. 1977.
"Urban Atmosphere as an Environment for Air Pollution Dispersion." Geneva: World Meteorological Organization. WMO-493, pp. 315-41.

The characteristics of the urban atmosphere which are relevant to the dispersion of pollutants are reviewed. Contents include modification of temperature, wind and turbulence induced by a city, including a conceptual framework for the development of a heat island, and determination of wind fields in the urban boundary mixing layer and computation of pollutant concentrations.

Oke, T.R. 1974.
"Review of Urban Climatology." 1968-73. Geneva: World Meteorological Organization, Technical Note 134.

Cites 377 papers appearing on the urban climate during the period from 1968 to 1972.

Peterson, J.T. 1973.
"Energy and the Weather." Environment 15(8):4-9.

The small- and large-scale effects of urban heat islands are presented in relation to atmosphere temperature, convection and vertical motion.

Sakurai, K. 1979.
"Relation Between the Air Pollution and the Meteorological Condition at Asahikawa, On the Heat Island Effect." Journal of the Faculty of Science, Hokkaido University, serial VII (Geophysics) VI(1):115-25.

This paper discusses the convective motion that exists in the transition region between a rural and urban (heat island) area. It was found from horizontal and vertical distributions of lower-atmosphere temperature that Asahikawa City serves as a typical heat island.

Segal, M. and R.A. Pielke 1981.
"Numerical Model Simulation of Human Biometeorological Heat Load Conditions, Summer Day Case Study for the Chesapeake Bay Area." Journal of Applied Meteorology 20(7):735-49.

Meteorological data for air temperature, air humidity, air velocity and sunshine have been used in a mesocale meteorological model to predict the occurrence of those climatic conditions which produce thermal stress on the population in the Chesapeake Bay area. Isopleth maps are included for temperature, temperature-humidity index and wind flow for the Chesapeake Bay climate.

Shreffler, J.H. 1979.
"Heat Island Convergence in St. Louis during Calm Periods." Journal of Applied Meteorology 18(12):1512-20.

Five calm periods in 1976 were studied using wind flow, heat island intensity and solar radiation data. Heat-island-induced wind flow convergence periods were noted. Wind flow convergence was stronger in the daytime than at night. One daytime event resulted in storm-cell development.

Shreffler, J.H. 1978.
"Detection of Centripetal Heat-Island Circulations from Tower Data in St. Louis." Boundary-Layer Meteorology 15(2):229-42.

Hourly averaged meteorological data gathered by a 25-tower network about St. Louis during 1976 are used in a search for centripetal circulations generated by the urban heat island. Two classes of heat island are formed when network resultant speeds are less than 1.5 m/s: weak heat island (daytime/convective instability) and strong heat island (nighttime/extreme rural stability). Mean centripetal flows are clearly discernible from data of both classes, but convergence is stronger for the flows associated with the weaker heat islands.

Taesler, R. 1978.
"Observational Studies of Three-Dimensional Temperature and Windfields in Uppsala." Geneva: World Meteorological Organization. WMO-510, pp. 23-30.

An experimental study was performed of the development and three-dimensional structure of the urban heat island and associated effects on airflow. Results support the conceptual idea of a distinction between an urban canopy layer and an urban boundary layer separated by a transitional layer immediately above roof level.

Tyson P.D., W.J.F. Dutoit and R.F. Fuggle 1972.
"Temperature Structure Above Cities: Review and Preliminary Findings From the Johannesburg Urban Heat Island Project." Atmospheric Environment 6:533-42.

Information concerning the development of heat islands over South African cities is presented. The literature of the vertical temperature structure above cities is briefly reviewed and the complexity of the structure existing over Johannesburg is illustrated.

Unwin, D.J. 1980.
"The Synoptic Climatology of Birmingham's Urban Heat Island, 1965-74." Weather (Bracknell, England) 35(2):43-50.

The climatology of the urban heat island of Birmingham, England is outlined by a comparison of daily maximum and minimum temperatures. It was found that the negative temperature anomalies which exist between the heat island and the rural surrounding area are associated with disturbed airflow types; which suggests that vertical mixing is an important factor in heat island development.

Wark, K. and C.F. Warner 1976.
"Meteorology." Air Pollution, Its Origin and Control, chapter 3. New York: A. Dun-Donnelley Publisher (The IEP Series in mechanical engineering), pp. 69-107.

The heat island effect found in urban areas, which is caused by winds interacting with topographical features, is described.

Wong, K.K. and R.A. Dirks 1978.
"Mesoscale Perturbations on Air Flow in the Urban Mixing Layer." Journal of Applied Meteorology 17(5):677-88.

Simultaneous airborne wind and temperature measurements on the mixing layer airflow over St. Louis were made to determine the role of urban mesoscale influences on the inadvertent modification of local weather. The relationship of airfow to the thermal field, surface land use and terrain is considered.

Yap, D. 1977.
"Preliminary Investigation of the Nocturnal Temperature Structure Above the City of Edmonton, Alberta." United States Forest Service Northeastern Experi- ment Station, Upper Darby, PA. General Technical Report NE-25, pp. 77-87.

Two and three-dimensional forms of the nocturnal heat island are obtained from minisonde ascents, an instrumented helicopter and towers during an urban air pollution field study. The effects of the urban-induced temperature and stability modification on air pollutants are discussed.

B. MODELS TO SIMULATE THE URBAN HEAT ISLAND

Atwater, M.A. 1977.
"Urbanization and Pollutant Effects on the Thermal Structure in Four Climatic Regimes." Journal of Applied Meteorology 16(9):888-95.

A numerical model based on the Eulerian conservation equation simulates the urban heat island in tropical, desert, midlatitude and tundra climatic regimes in a two-dimensional mode.

Atwater, M.A. 1975.
"Thermal Changes Induced by Urbanization and Pollutants." Journal of Applied Meteorology 14:(6)1061-71.

A numerical model developed for the study of a wide range of atmospheric processes in the boundary layer is applied to the thermal changes induced by urbanization and pollutants. The simulated urban heat island and vertical thermal structure and pollutant concentrations compare realistically with observations.

Atwater, M.A. 1972.
"Thermal Effects of Urbanization and Industrialization in the Boundary Layer. A Numerical Study." Boundary-Layer Meteorology 3(2):229-45.

A primative equation model is used to compute changes in temperature resulting from changes in the physical characteristics of the surface due to urbanization. The results show that changes in the physical properties of the surface, not pollutants, are the dominant factors in creating the urban heat island.

Ball, R.J., C.A. Jacobs and J.P. Pandolfo 1980.
"Development of a Combined Numerical Boundary Layer-Gaussian Puff Model." Final report to U.S. EPA. Hartford, Connecticut: The Center for the Environment and Man, 88 pp.

A Gaussian and a Eulerian model are combined to examine meteorology on a large-scale grid (10 km) and pollutant concentrations from point sources on a 1-kilometer grid. Twenty-seven levels in the vertical to 3 kilometers were used with data obtained at St. Louis in 1976 during the Regional Air Pollution Study. One 24-hour and one 48-hour simulation were made and results compared with observations.

Bhumralkar, C.M. 1972.
"An Observational and Theoretical Study of Atmospheric Flow Over a Heated Island." Thesis, Miami University, Department of Environmental Sciences. University Microfilms, Inc. (Ann Arbor, MI).

The paper discusses a numerical model constructed to study atmospheric flow over a heat island and its effects on changes in pollutant distributions.

Clarke, J.F. and J.T. Peterson 1973.
"An Empirical Model Using Eigenvectors to Calculate the Temporal and Spatial Variations of the St. Louis Heat Island." Journal of Applied Meteorology 12(1):195-210.

Eigenvectors are used to study the relationship between the St. Louis heat island and land use, and meteorological parameters. The magnitude of the heat island is shown to have a significant positive correlation with the vertical temperature gradient outside the city.

Delage, Y. and P.A. Taylor 1970.
"Numerical Studies of Heat Island Circulations." Boundary-Layer Meteorology 1(2):201-26.

A two-dimensional model is employed to study the circulation induced by an urban heat island in the absence of synoptic winds. The influence on the steady-state circulation of various parameters is examined, among which are eddy transfer coefficients, heat island intensity, initial temperature stratification and heat island size.

Garstang, M., P.D. Tyson and G.D. Emmitt 1975.
"The Structure of Heat Islands." Reviews of Geophysics and Space Physics 13(1):139-65.

The juxtaposition of ocean and city islands are used to compare and contrast the induced atmospheric fields and the observed behavior of the atmosphere. The observed fields are then presented in terms of various numerical models.

Ikeda, Y., M. Hiraoka and Y. Ichikawa 1977.
"Analyses of Air Current and Pollution on Heat Island." Proceedings of the International Clean Air Congress, 4th, Tokyo, Japan, May 16-20, 1977, pp. 142-45.

The air currents and atmospheric pollution over a heat island are investigated by means of a field survey, a water tunnel experiment, and a numerical experiment involving the computation of natural convection by the finite-difference method.

Kimura, R. 1977.
"Effects of General Flows on a Heat Island Convection, Part 2, Numerical and Laboratory Experiments for the Shear Flow." Journal of the Meteorological Society of Japan 55(1):32-51.

Characteristics of two-dimensional heat-island convection under general flows are investigated by numerical and laboratory experiments, and the results compared with those of the linear theory in Part 1 (Kimura 1976). Part 2 examines the effects upon the heat island convection of 1) self-advection resulting from convective motion, 2) vertical shear of the general flow, 3) Prandtl number, and 4) ground temperature distribution.

Kimura, R. 1976.
"Effects of General Flows on a Heat Island Convection, Part 1, Linear Theory for the Uniform Flow." Journal of the Meteorological Society of Japan 54(5):308-20.

Effects of uniform flows on a two-dimensional heat island convection model were investigated by obtaining the steady solutions of the linearized vorticity and thermodynamic equations. The calculations were performed for fluids whose values of Prandtl number (Pr) are unity and zero.

Leahey, D.M. and J.P. Friend 1971.
"Model for Predicting the Depth of the Mixing Layer Over an Urban Heat Island with Applications to New York City." Journal of Applied Meteorology 10(6):1162-73.

An advective thermodynamic model is used to predict the depth of the urban mixing layer, which is important for air pollution predictions. The model is essentially the same as the one proposed by Summers except for the addition of two "heat-sink" terms.

Lee, R.L. and D.B. Olfe 1974.
"Numerical Calculations of Temperature Profiles over an Urban Heat Island." Boundary-Layer Meteorology 7:39-52.

Nonlinear two-dimensional calculations have been carried out to estimate the temperature and velocity changes induced in air flowing over an urban heat island. Of particular interest is the destruction of a nocturnal inversion and the crossover to cooler temperatures aloft.

McElroy, J.L. 1973.
"A Numerical Study of the Nocturnal Heat Island Over a Medium-Sized Mid-Latitude City (Columbus, Ohio)." Boundary-Layer Meteorology 3:442-53.

A numerical investigation was conducted of the nocturnal heat island over Columbus, Ohio. Specifically, a cross-sectional steady-state numerical model to simulate the thermal structure of the nocturnal urban boundary layer was developed from a one-dimensional, time-dependent model developed by Estoque. Numerical simulations agree well with observed data with respect to the detailed spatial form of the surface-based thermal boundary layer across the city.

Melgarejo, J.W. and S. Bodin 1978.
"Numerical Simulation of Local Flows Caused by Differential Heating and Roughness Change at the Surface." Geneva: World Meteorological Organization. WMO-510.

Three-dimensional modeling efforts are underway to study local flows caused by the differential heating and roughness change at the surface, such as in coastal regions (land and sea breezes) and in heat islands.

Nkemdirim, L.C. 1980.
"A Test of A Lapse Rate/Wind Speed Model for Estimating Heat Island Magnitude in an Urban Airshed." Journal of Applied Meteorology 19(6):748-56.

Temperature profiles across the city of Calgary, Alberta (Canada) were obtained by helicopter and were used with upwind measurements of wind speed and lapse rate to test a model for estimating heat island magnitude. It was found that a model based on the ratio of lapse rate to wind speed was not as effective as a model based on lapse rate alone, but was more effective than a model based on wind speed alone.

Nkemdirim, L.C. and P. Truch, 1978.
"Variability of Temperature Fields In Calgary, Alberta." Atmospheric Environment 12(4):809-22.

A case for a daytime maximum in heat-island intensity is substantiatied by a year-round observation of the phenomenon in Calgary. A windflow model of heat-island formation, with possible relevance to cities in areas of strong topography, is presented.

Oke, T.R. 1976.
"The Distinction Between Canopy and Boundary-Layer Urban Heat Islands." Atmosphere (Toronto, Canada) 14(4):268-77.

Air temperature measurements from car traverses in and near Vancouver, British Columbia, are used to test two urban heat-island models: one an empirical model, the other, a theoretical advective model.

Oke, T.R. and C. East 1971.
"The Urban Boundary Layer in Montreal." Boundary-Layer Meteorology 1(4):411-37.

The urban heat island effect upon horizontal and vertical temperature structure, and its role in buoyancy and stability considerations when formulating atmospheric dispersion models is discussed. It is shown that under conditions of strong rural stability, the lowest layers of the urban atmosphere become progressively modified as air moves toward the city center. The change in the form of the potential temperature profile is in good agreement with Summers' internal boundary-layer hypothesis.

Olfe, D.B. and R.L. Lee 1971.
"Linearized Calculations of Urban Heat Island Convection Effects." Journal of the Atmospheric Sciences 28:1374-88.

Steady linearized flow calculations are carried out to estimate vertical temperature profiles over a heated area representing a city. The calculations predict the main effects observed over urban areas:

1) positive temperature perturbations near the ground which tend to cancel the early morning radiation inversion and 2) negative temperature perturbations aloft which tend to produce one or more weak inversions several hundred meters above the city.

Outcalt, S.I. 1972.
"A Synthetic Analysis of Seasonal Influences in the Effects of Land Use on the Urban Thermal Regime." Arch. Met. Geoph. Biokl. (Germany), ser. B, 20, 253-60.

A simple digital surface climate simulator is employed as the vehicle for the exploration of some relationships between land use and the urban climate. Specifically, the simulator indicates that the physical roots of the urban heat island effect are significantly seasonally variable.

Price, J.C. 1979.
"Assessment of the Urban Heat Island Effect Through the Use of Satellite Data." Monthly Weather Review 107:1554-57.

Quantitative estimates of the extent and intensity of urban surface heating are obtained by analysis of digital data acquired over the New York City-New England area.

Saito, N. 1976.
"Numerical Experiments of the Land and Sea Breeze Circulation." Papers in Meteorology and Geophysics (Japan) 27(4):99-117.

The effect of the urban heat island upon the modification of land and sea breeze circulations by making a differential diurnal temperature change between urban and suburban areas is dicussed. A two-dimensional numerical model was applied using the following assumption: a higher daily mean temperature and a smaller diurnal change in the urban area, and a colder mean temperature and larger diurnal change in the suburban area.

Santomauro, L., R. Gualdi and G. Tebaldi 1977.
"Air Pollution Behaviour in Milan (Italy) Metropolitan Area through a Diffusion Model." Proceedings of the International Clean Air Congress, 4th, Tokyo, Japan, May 16-20, 1977, pp. 251-54.

The diffusion of SO_2 in the lower atmosphere layer over Milan and the ground-level concentration of SO_2 are determined by means of the mathematical ATDL model (Gifford and Hanna). Air pollution results confirm that the circulation in the atmospheric layers over Milan is influenced by the local heat island.

Sawai, T. 1978.
"Formation of the Urban Air Mass and the Associated Local Circulation." Journal of the Meteorological Society of Japan 56(3):159-74.

A two-dimensional numerical model is designed to investigate the phenomena of urban heat islands under a steady condition. The model describes temperature and wind velocity distributions in the Ekman layer under a certain combination of factors, which include roughness and prevailing flow.

SethuRaman, S. and J.E. Cermak 1975.
"Mean Temperature and Mean Concentration Distributions Over a Physically Modelled Three-Dimensional Heat Island for Different Stability Conditions." Boundary-Layer Meteorology 9:427-40.

Results of flow visualization and the mean temperature measurements over a physically modeled three-dimensional heat island in a wind tunnel capable of simulating stratified atmospheric boundary layers are presented. Results indicate the features of three-dimensional flow over a heat island, lateral low-level convergence, upward vertical motions and upper-level horizontal divergence.

SethuRaman, S. and J.E. Cermak 1974.
"Physical Modeling of flow and Diffusion Over an Urban Heat Island." Advances in Geophysics 18(B):223-40.

Physical modeling of an idealized three-dimensional heat island in a wind tunnel capable of simulating the stratified atmospheric boundary layer is described. Three different approach flows over smooth and rough heat islands are investigated: neutral, ground-based stable stratification and elevated inversion. Flow observations reveal that buoyancy forces produced by heating cause larger perturbation in the oncoming, two-dimensional flow than those produced by the roughness of the heat island.

Tapper, N.J., P.D. Tyson, I.F. Owens and W.J. Hastie 1981.
"Modeling the Winter Urban Heat Island over Christchruch, New Zealand." Journal of Applied Meteorology 20(4):365-76.

A model based on energy balance has been used to predict surface temperatures observed over Christchurch in winter. Differences between observed and predicted temperatures differ by less than 1°C. The model effectively simulates the spatial variability in energy fields in considerable detail.

Viskanta, R., R.W. Bergstrom and R.O. Johnson 1977.
"Effects of Air Pollution on Thermal Structure and Dispersion in an Urban Planetary Boundary Layer." Contributions to Atmospheric Physics 50(3):419-40.

An unsteady two-dimensional transport model was used to study the short-term effects of urbanization and air pollution on the transport processes in the urban planetary boundary layer.

Vukovich, F.M. 1979.
"Observations and Simulations of the Diurnal Variation of the Urban Heat Island Circulation and Associated Variations of the Ozone Distribution. A Case Study." Journal of Applied Meteorology 18(7):836-54.

Observed surface and upper-air temperature and wind field patterns are analyzed and compared with simulation results from a three-dimensional hydrodynamic model. The highest concentrations of ozone at the surface are found in the zone of convergence associated with the urban heat island circulation immediately downwind of the center of the city. As the heat island circulation dissipates during early evening, the area of high-ozone concentration is displaced further downstream.

Vukovich, F.M. 1975.
"Study of the Effect of Wind Shear on a Heat Island Circulation Characteristic of an Urban Complex." Monthly Weather Review 103(1):27-33.

Simple linear models are used to study the effect of wind shear on the nocturnal urban heat island circulation. It is shown that the intensity of the urban heat circulation decreases by increasing the magnitude of the bulk shear through the boundary layer if the heating rate is constant. However, if the difference between the mean temperature in the urban and environmental boundary layer and the stabilities are identical in two separate cases, the case with the stronger shear will have a stronger urban heat island circulation.

Vukovich, F.M. and J.W. Dunn 1978.
"A Theoretical Study of the St. Louis Heat Island: Some Parameter Variations." Journal of Applied Meteorology 17(11):1585-94.

A sensitivity analysis was performed to determine the more important parameters affecting the urban heat island circulation in St. Louis. The effects of heat island intensity, surface roughness, horizontal diffusion and boundary-layer stability on the heat island circulation are studied using a three-dimensional primitive equation model. The results indicate that heat-island intensity and boundary-layer stability play dominant roles in heat-island circulation.

Vudovich, F.M., and W.J. King 1980.
"A Theoretical Study of the St. Louis Heat Island: Comparisons Between Observed Data and Simulation Results on the Urban Heat Island Circulation." Journal of Applied Meteorology 19(7):761-70.

Airflow over and around the St. Louis urban complex was predicted using a three-dimensional primitive equation model. Results were compared with observed data from the METROMEX network. The model worked well except when synoptic-scale changes and other circumstances occurred which the model was not designed to handle.

Yu, T. and N.K. Wagner 1975.
"Numerical Study of the Nocturnal Urban Boundary Layer." Boundary-Layer Meteorology 9(2):143-62.

A two-dimensional model was developed and applied to the study of atmospheric boundary-layer flows which originate from surface roughness and temperature inhomogeneities. The main application of the model is to explore the governing physical mechanisms of nocturnal urban atmospheric boundary-layer flow.

C. LAND/WATER THERMAL DIFFERENCES AND ATMOSPHERIC EFFECTS

Gamo, M., S. Yamamoto and O. Yokoyama 1977.
"Airborne Measurements of the Internal Boundary Layer Above the Coastal Area." Proceedings of the International Clean Air Congress, 4th, Tokyo, Japan, May 16-20, 1977. pp. 157-61.

Airborne measurements of the internal boundary layer (IBL) are made above the Kashima Ura coastal area. The IBL is classified according to insolation rate the structure of which is related to that of a heat island which appears above and surrounding big cities.

Jehn, K.H. and M.S. Jehn 1979.
"Beach Atmosphere." Weather (Bracknell, England) 34(6):223-32.

It was found that an observed internal boundary on a beach is caused by the interaction of thermal and mechanical processes. The effect of onshore flow at midday is to establish a sloping internal boundary layer that separates the undisturbed marine air from the sun-heated air on the beach.

Joffre, S.M. and L. Makkonen 1981.
"Comments on 'Comparison of Mean Wind Speeds and Turbulence at a Coastal Site and An Offshore Location'." Journal of Applied Meteorology 20(7):835-38.

Comments are provided on the mean wind speed and turbulence measurements reported in the referenced paper. The reported ratios of ocean to beach wind speeds is larger for onshore than offshore winds when the beach wind speeds are less than 9 m/s, which contradicts generally observed results. This result is attributed to data representativeness problems caused by the wind speed measurement height being too near the edge of the internal boundary layer.

Misra, P.K. 1980.
"Dispersion from Tall Stacks Into a Shoreline Environment." Atmospheric Environment 14(4):397-400.

A model has been developed to predict the ground-level concentrations of pollutants in the fumigation zone within a thermal internal boundary layer. The model assumes that dispersion of the pollutants in the stable layer aloft and the thermal internal boundary layer below proceed independently.

Raynor, G.S., P. Michael and S. SethuRaman 1980.
"Meteorological Measurement Methods and Diffusion Models for Use at Coastal Nuclear Reactor Sites." Nuclear Safety 21(6):749-64.

A literature review study shows that existing diffusion models do not adequately simulate coastal meteorological conditions. Models used at coastal sites should account for internal boundary layers in

the atmosphere as well as plume meander and horizontal and vertical diffusion parameters. On-site meteorological measurements, appropriately designed, are needed for developing model input data.

Ryznar, E. 1981.
"Characteristics of True Lake Breezes Along the Eastern Shore of Lake Michigan." Atmospheric Environment 15(7):1201-5.

One hundred eighty-seven true occurrences of lake breezes were documented for the period 1973 to 1978. Lake breezes occurred most frequently in July and August during days with the highest daytime temperatures, least daytime cloudiness and lowest wind speeds. Lake breezes often moved inland as much as 19 kilometers, but later retreated due to an increase in offshore wind speed or cloudiness.

SethuRaman, S. and G.S. Raynor 1981.
"Reply to Comments on 'Comparison of Mean Wind Speeds and Turbulence at A Coastal Site and An Offshore Location'." Journal of Applied Meteorology 20(7):838-39.

The issue of the ratios of ocean to beach wind speeds is discussed. The larger ratios for onshore (as opposed to offshore) flows are attributed to differences in atmospheric stability. The authors maintain that the wind speed measurement height was within the internal boundary layer.

SethuRaman, S., and G.S. Raynor 1980.
"Comparison of Mean Wind Speeds and Turbulence at a Coastal Site and An Offshore Location." Journal of Applied Meteorology 19(1):15-21.

Wind speed and turbulence measurements were compared for a site 5 kilometers off Long Island, New York at a height of 8 meters to a site on the beach. Mean wind speeds over the water were 15 to 100 percent higher than those at the beach. Differences in wind speed and turbulence could be predicted reasonably using the wind profile relationship.

Sryning, S.E. and E. Lyck 1980.
"Medium-Range Dispersion Experiments Downwind From a Shoreline in Near Neutral Conditions." Atmospheric Environment 14(8):923-31.

Estimates of σ_y, σ_z, and χ/Q were obtained from five atmospheric dispersion experiments at a coastal site in Denmark. Variations of more than 50 percent in σ_y and adjustments to account for the internal boundary layer showed predicted χ/Q using the EPA method was always larger than measured χ/Q. Using the Draxler (1976) method χ/Q predictions were adjusted, which produced better agreement with measured χ/Q.