Topoclimatic Aspects of Developmental Suitability in the Metropolitan Landscape

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ABSTRACT. — A computer-based procedure for geographically identifying rating, and ranking topoclimatic characteristics is described. The influences of topography, land use, and soils are considered and combined into a single composite topoclimate developmental suitability map drawn by a Cal Comp plotter. By allocating development to the most suitable topoclimate areas, the long-term energy costs of maintaining human health and comfort could be minimized.

THE GROWTH OF METROPOLITAN REGIONS in North America has not profited from the potential topoclimatic benefits offered by the natural landscape. With the increasing concern for conservation of our energy resources, the long-term costs of ignoring the potential benefits of locating developments, in the most suitable topoclimates becomes inexcusable. Basic principles of applied climatology should be integrated into the physical, social, and economic principles of landscape planning to increase human health and comfort at least cost.

At the University of Massachusetts an interdisciplinary planning research group, operating under the acronym METLAND (Metropolitan Landscape Planning Model), has been working on a system of integrated, computer-based landscape-assessment procedures *(Fabos 1973)*.

The METLAND model is composed of three major assessment procedures, defined as components. The first component identifies and evaluates special-value resources such as prime agricultural lands. The second component identifies and evaluates hazards such as high noise-pollution areas. Together, the special-value resource and hazard components identify and evaluate environmental constraints to development. The third component is the developmental-suitability component, which strives to identify and evaluate those landscape parcels possessing positive intrinsic attributes that offer maximum benefits and least cost to the resident, community, and developer.

Within the developmental-suitability component there are three variables which are assessed. These are physical (slope, depth to bedrock, etc.) visual (land-use compatibility) and topoclimatic. By assessing the physical, visual, and topoclimatic attributes of the landscape, the most intrinsically suitable areas for development may be identified, rated, and ranked. The purpose of this paper is to report on the initial procedure and results of the topoclimate developmental suitability variable of the METLAND model.

The goal of the topoclimatic assessment research was to design and implement a procedure, using established principles of applied climatology, to assess the topoclimatic suitability within a town or region for various development and planning purposes. A review of current literature was made to clarify and define the characteristics of optimum topoclimatic areas that would be most suitable for development. It was found that the most suitable topoclimatic areas would support metropolitan growth that minimizes long-term costs of maintenance over the short-term costs of development. Specifically, we should aim for long-range stability through low energy maintenance demands for artificial heating and cooling of the built environment *(Knowles 1974)*.

In addition to energy savings, we should also strive for maximizing human comfort, safety and health by taking full advantage of natural topoclimatic opportunities and minimizing regional or mesoclimatic stresses *(Mather 1974)*.

In the terminology of Olgyay *(1963)*, the most important topoclimatic objective for the New England region is to minimize underheated areas. By locating development to maximize exposure to winter solar receipts and to minimize the effects of winter winds, underheated areas can be avoided. Areas susceptible to overheating should also be avoided, although these are less significant in the New England region.

A final objective to be considered concerns fog, frost, and excessive moisture. Frequent fogs and high humidity enhance the danger of moisture damage to building materials and paint. Critchfield *(1966)* reports that, where air pollution is common, the chemical effects of moisture damage is much greater when associated with dirty fog particles.

Our task required the translation of these objectives into landscape subvariables which could be measured and used to interpret probable topoclimatic conditions within a region.

METHODOLOGY

Selection of Subvariables

Recorded climatic data for assessing towns of 10 to 40 square miles or regions of hundreds of square miles are scarce because the number of recording stations is limited. Consequently, variations in local topoclimate must be derived indirectly. Interpreting topoclimate from variations in topography (slope, orientation, elevation) has received considerable attention. The early works of Geiger *(1965)* and Olgyay *(1963)* provide much of the basis for interpreting local climatic conditions resulting from variations in topography.

Another important influence on topoclimate is land use, reflecting various heat-capacity and heat-conductivity capabilities. Nicholas *(1971)*, Landsberg *(1969)*, and Mitchell *(1962)* have reported on the temperature differences over different surfaces resulting in urban heat islands. These are characteristic of most North American cities for at least part of the year. Even in the new town of Columbia, Maryland, where efforts to reduce the heat-island effect have been made, a measurable heat island has already been detected by Landsberg *(1969)*. Surface temperature values measured from a helicopter, using infrared instrumentation over Columbia on a sunny morning, recorded differences of up to 8.5°C between forested and builtup areas.

Together, the influence of topography and land use were thus recognized as major contributors to topoclimatic differences within our study area. The problem was to determine which specific subvariables of topography and land use had the greatest effect on overheating, underheating, and moisture. In addition, these subvariables had to be measurable from existing and easily available data sources.

Topography.—The subvariables of topography having major effects on topoclimate are slope, aspect, and elevation with respect to sun and wind. The relative differences of sun and wind in turn have major impacts on overheating and underheating.

Effects of topography on wind can be of an active or passive nature. For example, an active topographic influence results from differences of air temperature and pressure, which causes cool air to flow down slopes. This phenomenon is known as katabatic wind. Passive effects of topography on wind are demonstrated by the behavior of an airstream over or around an obstacle.

In New England, exposure to strong northerly winter winds increases convective cooling. By avoiding windward slopes, summits, and large unprotected open spaces, convective cooling can be minimized. Topographic features such as low-lying or basin areas surrounded by higher elevations should also be avoided because they induce drainage of cool air, which is a prime cause of frost and fog formation *(Critchfield 1966)*.

Topography has a major influence on the total solar radiation (insolation) that a site receives. The amount of solar radiation received by a surface is determined by: (1) compass orientation, which determines the number of hours of sunshine received and the time of day when it is received; (2) the slope of the surface, which determines the amount of energy received per unit area; (3) the shadowing effect of adjacent relief, which blocks out portions of direct sunshine during the day; and (4) the relative elevation of the surface above sea level, which reflects the reduction of atmospheric absorption of incoming radiation.

Significant differences in solar radiation receipts resulting from topography have long been recognized, particularly in agriculture. Benefits from reduced heating costs to homeowners and industry can be achieved by locating developments where maximum amounts of solar radiation are available during underheated periods *(Olgyay 1963)*.

Calculating the distribution of solar radiation has been accomplished by using a computer program developed by Williams and others *(1972)*. Data input requirements are a grid of elevations, the solar declination, latitude, transmissivity, and day of the year. Direct, diffuse, and total global radiation can be calculated, as well as absorbed radiation if albedos are specified at the grid points. A contour map is produced by using the Harvard SYMAP program or a similar contouring program that geographically locates the distribution of solar radiation.

Moderating effects of land use. — Grass, pavement, soil, or trees, differ widely in their ability to conduct and store heat. Forests and buildings also have significant effects on local winds. Some surfaces, such as forest canopies, tend to moderate topoclimatic stresses by minimizing extremes. Natural opportunities to control extreme wind velocities and temperatures should be taken advantage of wherever possible.

Recognition and use of moderating factors is included in our assessment by differentiating between various land uses. Forests or even a few rows of trees will greatly reduce wind speed. Based on 10 years of wind records at a height of 4.6 m inside and outside a maple-beech-birch forest, the wind speed in the forest was less than 50 percent of the speed outside for 11 months of the year *(Zon 1941)*. In fact the reduction of winds by 50 percent reduced residential heating requirements by 30 percent. Critchfield *(1966)* noted that the major climatic effect of trees is roughly proportional to the density of the forest cover, but forest can modify the climate of adjacent areas as well. Generally it is assumed that the downwind zone of protection from winds offered by trees is equal to 20 times the height of the tree barrier.

In the model, two categories of forest are identified to reflect their moderating climatic effects: (1) forests with a crown density greater than 80 percent and a height greater than 41 feet, and (2) forests with a crown density between 30 and 80 percent and height between 20 and 41 feet. Although it was recognized that a greater differentiation of forests into hardwood and softwood categories would improve the accuracy of the assessment, we believed two forest categories were sufficient for metropolitan planning purposes.

Nonforested areas are divided into two other categories to reflect differences in their heat absorptivity and conductivity: (1) densely urbanized areas with large amounts of paving, which increase the stress of overheating, and (2) remaining open lands believed to have little moderating or stress-increasing effects on topoclimate.

Numerous other subvariables were investigated, but were not incorporated into our assessment chiefly because we wanted to keep the procedure as simple as possible and still provide sufficiently accurate information to aid those making planning decisions. The influence of major water bodies and extreme differences in elevation are special instances where new subvariables would be required. Other topoclimatic conditions, especially those relating to city climates and air pollution, were not considered in the procedure.

Procedural-framework

Although space does not permit us to go into sufficient detail to explain the intricacies of the assessment procedure, we can provide a general overview. The procedure can be organized into three basic steps.

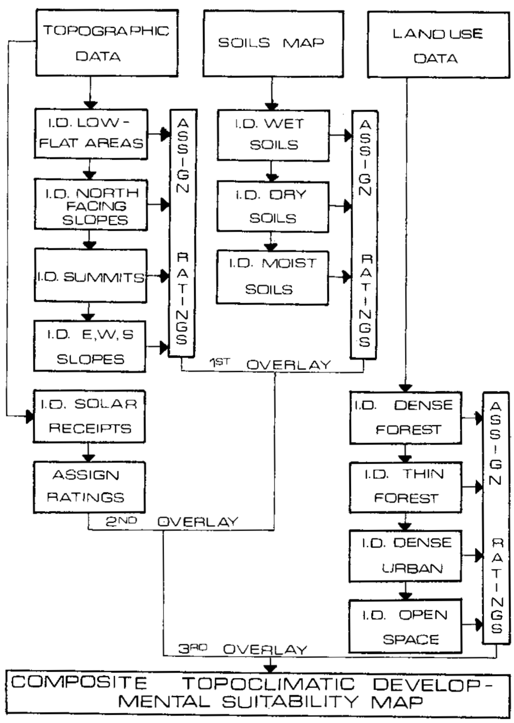
1. Data collection.—Topographic data may be obtained manually from USGS topographic maps or directly from magnetic tape available from the USGS National Cartographic Center at Reston, Va. Land-use data may be obtained from interpreted aerial photographs and soils data from detailed SCS soil maps.

2. Source-map preparation. — The second step is really a two-stage procedure. Once the data have been collected, they must be put into a mapped format, which is then digitized and stored on magnetic tape. Using the COMLUP computer mapping system, as described by Ferris and Fabos *(1974)*, and the assessment procedure presented here, a series of source maps are then produced.

3. Overlay procedure.—The third and final step produces a series of composite overlay maps culminating in a composite topoclimatic developmental-suitability map. Again, the computer is used to overlay the maps.

A procedural flow chart (fig. 1) shows the assessment process from data ac-

Figure 1.—Topoclimate developmental suitability assessment procedure.



quisition to the final topoclimate suitability assessment map. Preparation of each source map and the overlay procedure will be briefly described next.

Source-Map Preparation

The topoclimate developmental-suitability-assessment map is generated from four source maps: (1) a topograhic map, (2) a land-use map, (3) a soils map, and (4) a solar-radiation receipt map. Source map information is digitized into computer manipulatable format so that overlays or composite assessments and evaluations can be made.

The following discussion briefly outlines the general procedures for preparing each source map, using the town of Burlington, Massachusetts, for demonstration purposes.

Topographic source map. — Using topographic data from one of the previously identified sources, we identified low-lying, relatively flat areas, summit areas, north-facing slopes, and remaining areas of south, west, and east slopes. These areas may be identified by interpreting 10- or 20-foot contours or with computer assistance using a 200- or 500-foot grid network. Low-lying, relatively flat areas are given a 1_f rating because potential fog and frost conditions may exist in these areas. Summits are given a value of 1_s because potential high wind conditions may be expected in these areas. North-facing slopes are given a value of 1_n because this orientation to winter winds is least suitable for comfort and heating in cold temperate climates. All other areas are assigned a rating of 2, which reflects their minimum influence on topoclimate; the higher ratings indicating the most desirable areas for development.

Land-use source map.—Land use can have a significant effect on local topoclimate. These differences are reflected in the following land-use aggregations. All urban/commercial/industrial uses are given a 1_u value because of their potential for overheating in summer. Forested areas are recognized for their moderating effect on climate in both winter and summer by assigning a value of 3 to those areas having a crown density between 30 and 80 percent and a height of 21 to 41 feet. A value of 4 is given to forests with a crown density greater than 80 percent and height greater than 41 feet. Remaining open space and crop and pasture lands are considered to have no significant moderating effect and are given a value of 2.

Soils source map.—The tendency of moist soils to remain cooler during the day and warmer during the night is included in the assessment by giving moist soils (soils with moderate to slow percolation) a value of 2 and dry soils (soils with excessive percolation) a value of 1_d. Soils with a seasonally high water table or very poorly drained soils are given a value of 1_w. These wet soils, in combination with relatively low-lying and flat areas, are susceptible to fog and frost in relation to other areas.

Solar radiation source map. — The radiation source map depicts the distribution of global radiation for a given period and transmissivity over an area at a given latitude, the topography of which is specified. Areas of high, medium, and low global radiation are given values of 3, 2, and 1_r respectively for winter since maximum radiation is needed at this time. For our study areas a maximum difference of 98 langleys per day between areas for 21 December were obtained, assuming a sunny day. This range was divided into three categories of 0 to 30, 31 to 60, and 61 to 98 to reflect the relative contribution of solar receipts during underheated periods.

During the summer a minimum of solar radiation is needed. If desired, the high, medium, and low areas of summer solar receipts can be given values of 1_{sr}, 2, and 3 respectively.

In some regions of little topographic variety, the difference in solar receipts is relatively insignificant (less than 30 langleys per day). In other cases the differences in solar receipts are so large that the solar-radiation values become the major contribution to topoclimate differences.

Composite Overlay Preparation

First, the topographic source map is overlaid with the soils source map. Areas possessing a high water table or poorly drained and low-lying and flat are susceptible to fog and frost.

The topographic and soils source map is next overlaid with the solar-radiation source map. Potentially overheated and underheated areas can now be identified. Overheated areas will be identified by combinations of maximum summer solar receipts and dry soils. Underheated areas will be areas of minimum winter solar receipts, dry soils, and exposure to cold winter winds along ridges and north-facing slopes.

Finally the land-use source map is overlaid with the series to produce a final composite topoclimate suitability map. The land-use source map reflects the effect forests and heavily builtup areas have on topoclimate. The moderating effect of a forest improves both a potentially overheated area as well as an underheated area. Surfaces that are paved and highly urbanized exacerbate the overheating problem:

In summary, the following subvariables are identified and rated:

Topographic	*Rating*	*Land use*	*Rating*
North slope	1_n	Urban	1_u
Summit	1_s	Open rural	2
Low & flat	1_f	Forest (thin)	3
E,W,S slopes	2	Forest (dense)	4

Solar	*Rating*	*Soils*	*Rating*
Low	1_r	Dry	1_d
Medium	2	Wet	1_w
High	3	Moist	2

After all four maps have been overlaid, the total range of values for an area with little topography is from 4 to 9. This condition results when there is no significant effect of topography on solar receipts, and the entire study area receives a single value of 1. However, in an area with significant topography, the composite value range is from 4 to 11. Both value ranges are divided into three suitability categories to reflect a hierarchy of suitability: (A) most suitable, (B) marginally suitable, and (C) least suitable.

For an area with little topography, the influences of land use (such as forests) and of soils become dominant, resulting in the following suitability categories:

8 to 9 — most suitable (A)
6 to 7 — marginally suitable (B)
4 to 5 — least suitable (C)

For an area with significant topography (when the solar ratings are from 1 to 3), the suitability categories are:

9 to 11 — (A)
6 to 8 — (B)
4 to 5 — (C)

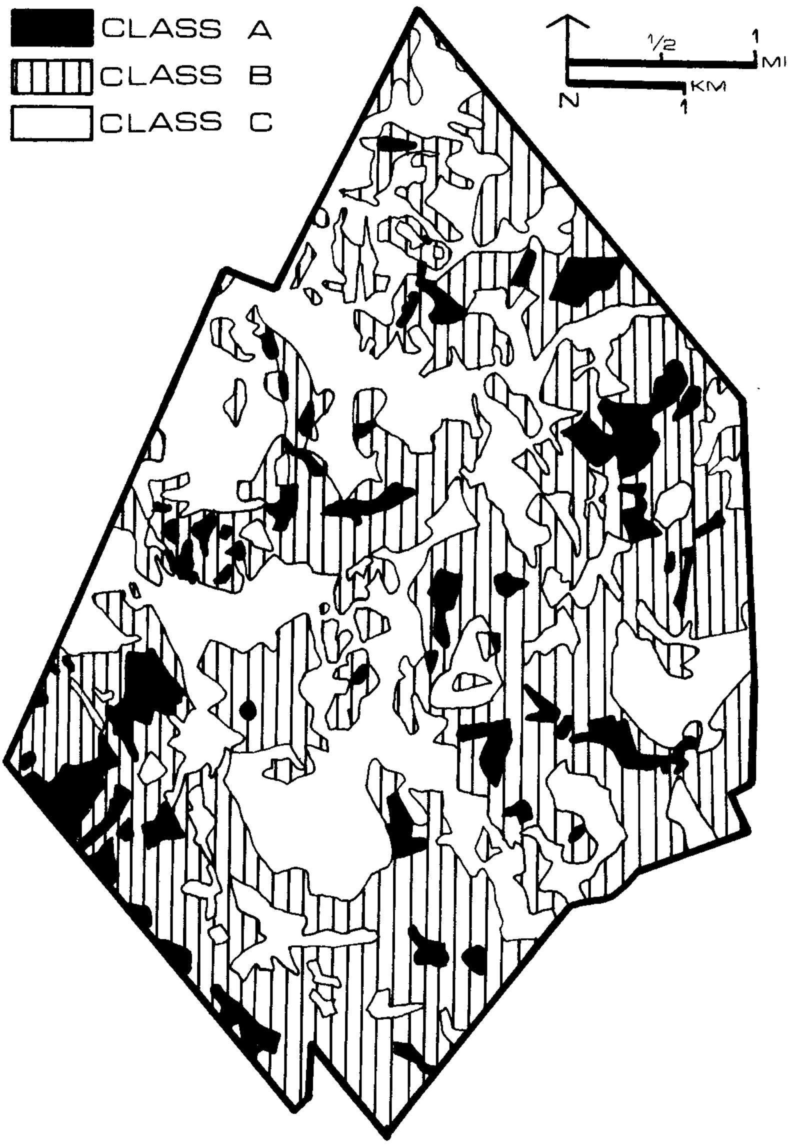
For the Burlington area (in 1971) 9 percent of the area was given a rating of A, 52 percent a rating of B and 39 percent a rating of C. Further work on identifying which suitability categories have been most intensively developed since 1952 is presently under way.

RESULTS

The composite topoclimate suitability map (fig. 2) shows the distribution of topoclimates in Burlington, Massachusetts. Topoclimate differences in Burlington are minimal primarily because there is little topographic change within the town. Most of the topoclimate differences result from the distribution of land-use types. Dense forest areas contrast sharply with the extensively built-up areas along Route 128.

In addition to mapped output, tabular information on each parcel is also available. This information is extremely important because it provides an account-

Figure 2.—Topoclimate developmental suitability map, Burlington 1971.



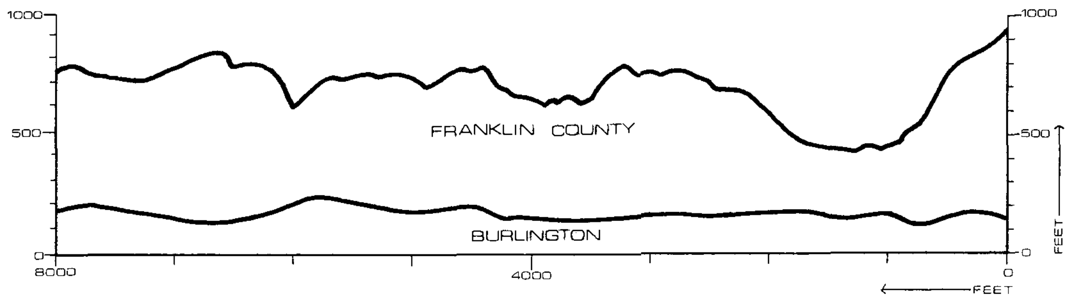
ing of the various values received by the parcel. For example, a developer has submitted a subdivision plan to Burlington in a C-rated area and wishes to know why the town fathers tell him that the site is topoclimatically least suitable. The developer may then be shown a map and a print-out with the following information:

Parcel No.	*Topo*	*Land use*
18	1_n	2

Soils	*Solar*	*Total*	*Rating*
1_d	1_r	5	C

From this information, both the town and the developer know that the site is on a north-facing slope, in a rural open non-forested area with dry soils and a

Figure 3.—Topographic cross-sections of Burlington and a portion of Franklin Co., Massachusetts.



minimum amount of solar radiation receipts in winter. Such information indicates increased heating costs and a reduced outdoor comfort season to the potential homeowners; increased costs to the town for winter road maintenance for sand, salt, and snow removal; and increased costs to the developer through a reduced construction season.

The significance of topographic change to topoclimate can be seen between two areas in Massachusetts. The range in Burlington is from 135 langleys to 170 langleys for the 21 December. For a portion of Franklin County the range is from 100 to 195 langleys under similiar conditions except for topography. A comparison of the topography of the two areas is shown in the topographic cross-sections (fig. 3). It is clear that the greater range in solar radiation receipts in Franklin County is the result of the greater relief in that area.

CONCLUSIONS

The purpose of this paper has been to describe a topoclimate developmental suitability assessment procedure. The procedure has been applied to Burlington, Massachusetts, and partially to an area in Franklin County, Massachusetts. Topoclimatic differences were mapped, using a computer-based mapping system.

Although complete field checks with the mapped assessments have not been completed, preliminary comparisons are encouraging. Instrumentation to measure wind speed and solar radiation is now being set up in Franklin County by the Department of Mechanical and Aerospace Engineering at the University of Massachusetts. These data will be used to test the accuracy of the present procedure and to quantify potential cost savings among identified topoclimates.

The information provided by the procedure will be useful to decision-makers who must make land-use-management decisions. Once areas that minimize the long-term costs of maintenance and maximize the intrinsic capability of the landscape to provide health and comfort have been identified, planning decisions may then anticipate and reflect present and future costs prior to actual development.

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