

METROPOLITAN PLANNING AND DESIGN

A Computerized Model for Integrating the Physical Environmental Factors into Metropolitan Landscape Planning

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ABSTRACT.—This paper justifies and illustrates (in simplified form) a landscape planning approach to the environmental management of the metropolitan landscape. The model utilizes a computerized assessment and mapping system, which exhibits a recent advancement in computer technology that allows for greater accuracy and the weighting of different values when mapping at the regional scale. It assesses resource, hazardous, and developmentally suitable areas in order to determine the consequences of development in these areas, and to channel development to the most environmentally appropriate of these areas.

PHYSICAL ASSESSMENT and planning models have traditionally been developed to deal with four aspects of landscape resources. These are quality, quantity, location, and distribution. When these four aspects of the physical environmental resources are known, decision-makers are able to make better trade-off decisions.

Landscape-planning procedures during the 1960s provided decision-makers with relatively useful composite maps showing where higher-quality landscape resource occurred in large quantities. These early planning processes, however, were not able to distinguish the values of the various resources. The computerized model described here represents a parametric approach to land-

scape planning that has the capability of weighting the values derived from perceived environmental quality. The model was designed primarily for those landscapes that are experiencing major development pressures at this time.

This paper is a summary of the most recent assessment model developed by a University of Massachusetts research team named METLAND. Its objective is to present an environmental/landscape assessment procedure that can be used to estimate: those special resource values thought to be essential for metropolitan population; potential natural and man-made hazards resulting from poor land-use decisions; an assessment of environmental opportunities for development termed developmental suit-

ability and the production of an ecologically acceptable use type, development, density, and distribution plan of the Boston metropolitan region.

Since the second world war, metropolitanization has been one of the major contributors to environmental degradation. In contrast to the highly concentrated cities of the early industrial nations, which comprised only a few square miles, this new metropolitan growth extends its effects for several thousand square miles. Metropolitan regions are often interconnected to form megalopolitan regions such as the urbanized Northeastern Seaboard of the United States (*Gottman 1961*). Since the 1950s this region has spread over more than 35,000 square miles of the landscape.

This mammoth metropolitanization has precipitated many undesirable side effects. It has eliminated or impaired untold acres of valuable natural resources such as water, upon which all life depends. Much of the development has occurred in areas subject to hazards such as flooding, noise, or air pollution. Developers selecting sites for development often did so in blatant disregard of existing site characteristics. As a result, wetlands have been filled, unnecessary erosion problems have occurred, and developments have been located in climatically disadvantageous areas such as slopes facing into prevailing winter winds. Moreover, esthetic opportunities of developing areas have largely been ignored. Finally, the natural energy flow of existing ecological systems has been seriously taxed because of an almost total lack of concern for basic ecological principles in the planning of metropolitan landscapes (*Odum 1969*). In responding to these problems, a sub-field of planning or regional design has emerged under the name of *landscape planning*.

The METLAND research group noted above, comprised of over 16 researchers, is concerned with these landscape-plan-

ning problems. The group has been developing and refining landscape-assessment procedures since 1971 (*Fabos 1973*). These procedures are aimed at providing a meaningful and useful tool to aid all regions exposed to metropolitan growth pressures. More specifically, however, the study focuses on the problems of the Boston Metropolitan region, which has relentlessly expanded to engulf over 2,500 square miles, or almost half of the State of Massachusetts (*Ferris and Fabos 1974*).

The model, although still in the process of development, is sufficiently advanced to show the step-by-step procedure used in its four components. The specific purpose of this paper is to put into perspective and illustrate in simplified form the significance of synthesizing the information generated by these components. Examples of some of the specific procedures for gathering assessment information may be seen in other METLAND papers included in these proceedings (*Caswell and Jakus, Fahrer and Peters, Hendrix, and Joyner and others*).

An additional specific aim is to show the capabilities of the second generation computer graphic tools. These are used to integrate the values of the many landscape variables and the four components listed above and to study the cause-effect relationships of development and impact prior to implementation. In addition, these tools demonstrate how the existing research results of several disciplines can be used as input in an environmental or landscape-planning model.

IMPETUS FOR THE METLAND STUDY

The environmental or landscape planning considerations discussed here are certainly not new. Charles Eliot II, the founder of the first metropolitan system of parks, for example, frequently expressed great concern for the public values of wetlands, water and scenic values, during the late 19th century (*Newton 1971*). The famous landscape

planner, Benton MacKaye, voiced similar concerns during the 1920s (MacKaye 1962). Nevertheless, systematic landscape resource, hazard, and suitability assessment was not practiced until the 1950s and 1960s.

One of the most outstanding members of this generation of landscape planners is Ian McHarg. In his book, *Design with Nature*, he proposed a generalized landscape approach for assessing large landscape such as metropolitan regions (McHarg 1969).

Simultaneously, by the late 1960s the first generation of computer graphic techniques was being widely used for the data manipulation of landscape variables (IRIS 1972). This technique was applied manually by overlaying a grid on the various resource and data maps of a given region. For each grid cell several types of resource data were processed into the computer. Once in this form, the data could be manipulated to provide print-outs of assessment maps. This technique is still valuable for some generalized regional assessment such as air pollution. It is less useful, however, for manipulating more detailed data such as soil, vegetation, or land-use types.

Remote-sensing capabilities and other land-use survey techniques also began providing landscape planners with relatively accurate data during this period. Although the data were quite accurate, the smallest land-use map units (grid cells) which could be realistically prepared by the computer use from air-photos were about one hectare (MacConnell 1956).

Soils, surficial geologic, and other pertinent environmental data were also available at a high degree of accuracy, but they too could be practically manipulated only at the 1-hectare size. While all these pieces of information are meaningful for landscape resource, hazard, and suitability assessment, the first generation 1-hectare grid cell is too gross to assess them accurately. If grid cells smaller than 1-hectare were used in

this process, the data processing would be overly costly and extremely tedious.

For this reason the METLAND team searched for computer software more responsive to its landscape-planning needs. Among all the computer graphic techniques surveyed in 1973, the Computer Mapping for Land Use Planning (COMLUP) system (Allen 1973) seemed most appropriate for our study.

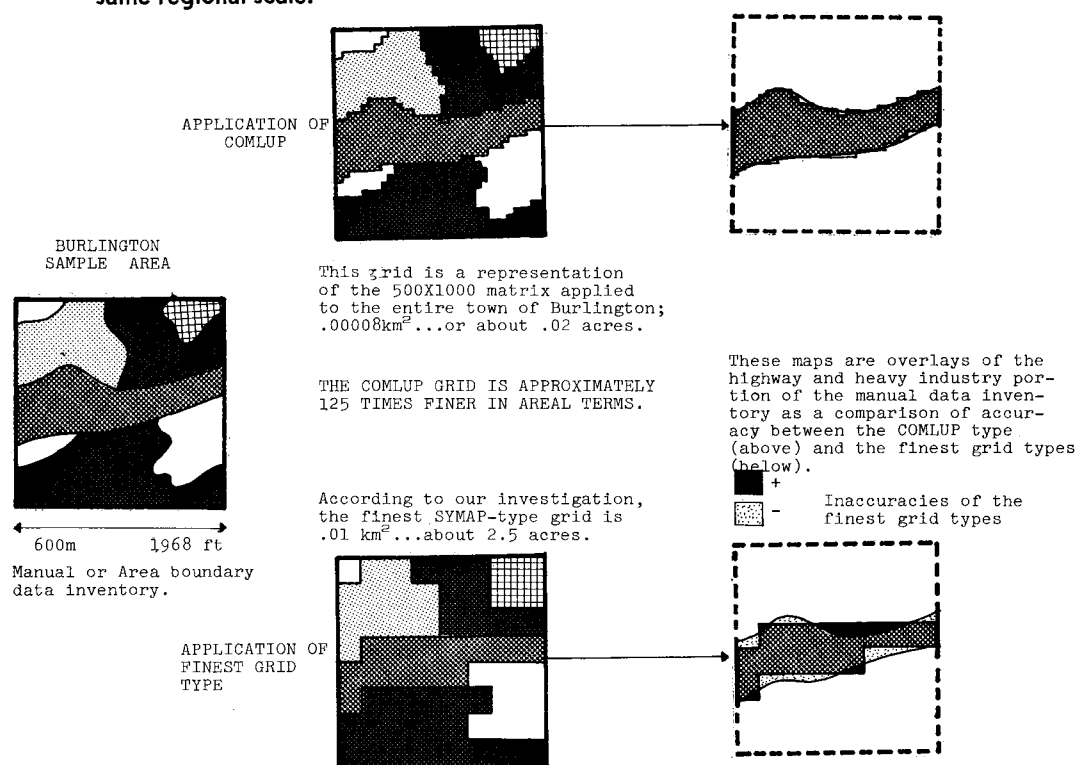
The advantage of this computer graphic technique is that any shape and size of polygon can be directly input and stored in the computer, by image digitizer, without subdividing the polygon into grid cells. For data manipulation, the digitized area still must be subdivided into cells, but this is now done in a second step by the computer automatically, instead of as a first step and manually. In addition a much finer cell granularity with a grid matrix of 500 X 1,000 cells is now possible.

Figure 1 shows the advantage in accuracy of COMLUP (an example of this second generation) over the first-generation computer grid technique when applied at the regional scale. With this new capability the more accurate data being produced may be better used by landscape planners.

While landscape planners are utilizing this second generation of technology, computer programmers are working on a third generation, which is being designed to overlay polygon areas directly without the interim step of converting it back to grid cells for manipulation. The Canada Geographic Information System Group of the Canadian Federal Government and the U.S. research firm Raytheon are among those in the process of developing this more advanced third generation of computer graphic software systems.

The remainder of this paper focuses on the METLAND environmental/landscape-planning model, with special emphasis on the assessment procedure, including some sample results. The model is presented by first examining its

Figure 1.—The relative accuracy of the first generation (grid type) and second generation (modified grid type) computer mapping systems when applied at the same regional scale.



overall framework. Then the synthesis of the special resources component of the assessment phase is presented, and the significance of the results is discussed. A comprehensive report is now being prepared on the entire assessment procedure.

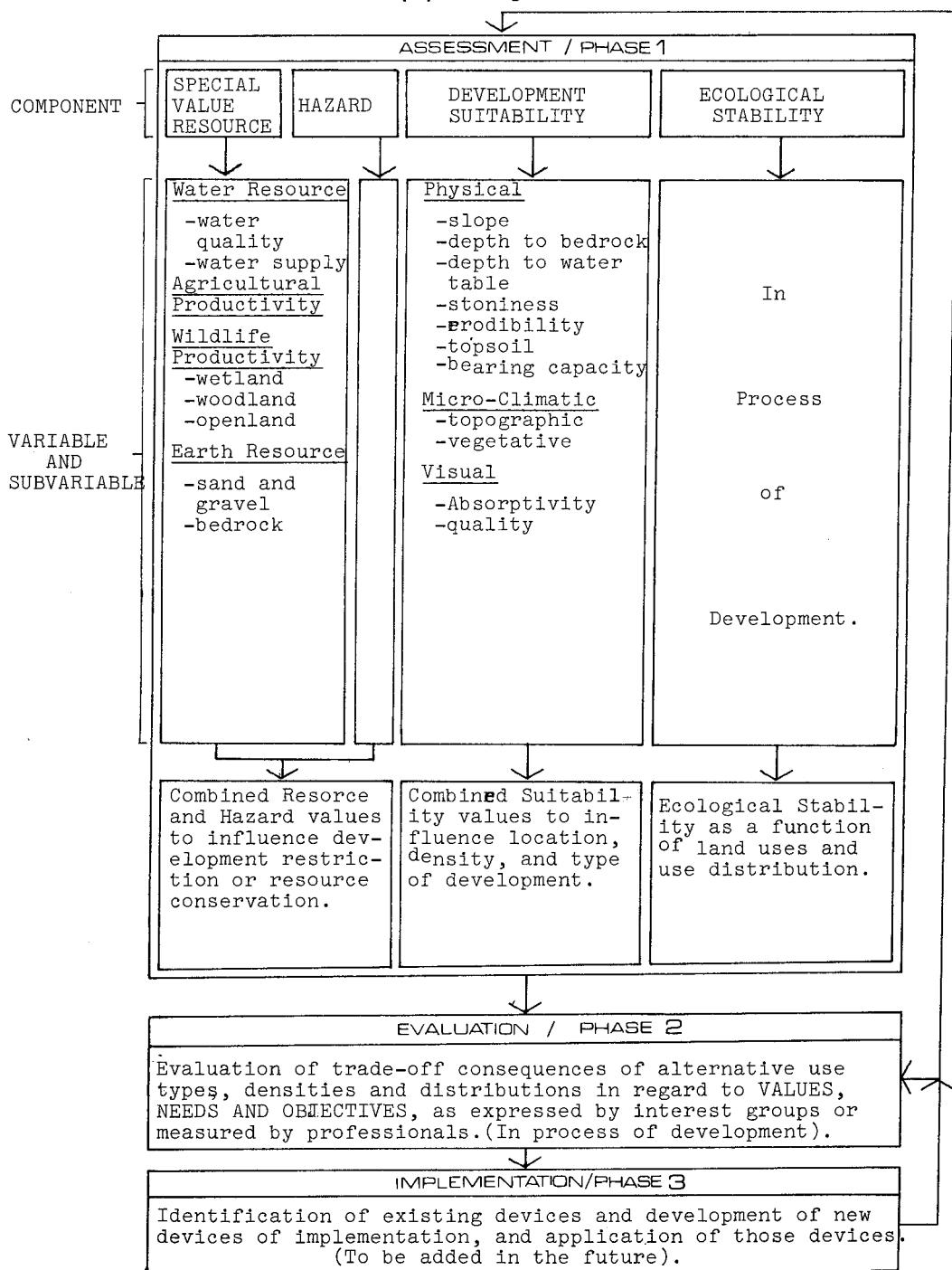
FRAMEWORK OF THE METLAND (ENVIRONMENTAL/LANDSCAPE) PLANNING MODEL

To deal adequately with environmental issues of the metropolitanized landscape, the METLAND team has proposed a three-phase planning model including assessment, evaluation, and implementation phases (fig. 2). At this point the assessment phase is close to completion, and some work has begun on the evaluation phase; the implementation phase is planned for later development.

The assessment phase consists of a selection of variables analyzing the intrinsic value of landscape resources which may provide societal benefits. This phase also analyzes natural or man-effected hazards that may cause harm to people or property. These several resource and hazard analyses are mapped and organized into four groups, called components. While each individual variable has a specific value, this grouping helps to identify complementary relationships and to provide combined values, which are useful in making decisions. The four components of the assessment phase are: special value resources, hazards, development suitability, and ecological stability.

The special value resource component (fig. 2) includes those natural renewable, nonrenewable, and esthetic resources whose maintenance is essential

Figure 2.—The structural framework of the METLAND (Environmental/Landscape) Planning Model.



for metropolitan populations. Development of these resource areas would eliminate or greatly impair their value. Though these resources are ubiquitous, their quality and quantity range from the insignificant to the critical. The assessment of this component is based on the premise that if a portion of a landscape possesses high quality and quantity of one or more of these resources, those areas should receive special consideration or even protection from development. If immediate need for the resources is not apparent, they should be protected or conserved much as capital resources are saved in a bank until they are needed.

The hazard component (fig. 2) includes air and noise pollution, both of which are direct human byproducts, and flood hazard which, although it is a natural phenomenon, is both aggravated and intensified by human activity. Flooding becomes harmful only when development is in nature's way.

The assessment of these three hazard component variables provides spatial information on both the type and magnitude of hazards. Areas where one or more hazards occur are obviously less valuable for development than areas free from hazards. This is true even if the harmful effects may be corrected, because those corrective devices are usually very costly and often ineffective. In short, the assessments of special-value resources and hazards imply development restrictions in those portions of the metropolitan landscape where assessed values or hazards are high.

The development suitability component is the obverse of the previous two components. Its objective is to identify the most suitable areas for development from the point of view of physical, climatic, and visual characteristics. Highly suitable areas for development are less costly to build upon and provide increased amenities and comfort when developed.

The ecological stability component represents another essential consideration. Exploration of special resource-value areas, such as gravel quarries, production of environmental hazards such as air pollution, and even extensive development on highly suitable lands may have greater negative effects on the metropolitan ecosystem than desired. A preliminary objective of this component is to determine the amount and distribution of land uses in what Odum (1969) terms "protective", "productive", "compromise" (suburban), and "urban-industrial" zones. One purpose of this classification would be to understand the structure and function of the land uses within these zones. (The research in this component began only recently and as yet is not as developed as that of the other components.)

Detailed analysis and substantiation of values is conducted at the variable and subvariable level of phase I (fig. 2). Although original research to substantiate values is infrequently conducted, normally the team is dependent on the research finding of other scientists. For example, in the case of the *physical variable* of the development suitability component, values have been derived from the work of environmental geologists such as Flawn (1970), scientists of the Soils Conservation Service (Bartelli et al. 1966), or cost estimates of builders McKeever (1968).

From these kinds of research results, the significance and magnitude of such subvariables as degree of slope or depth to water table for various developments are estimated. The resulting suitability assessments are analyzed in regard to short-range effects on construction costs to the developer, and long-range effects of these costs both to the community (e.g., in the form of siltation problems) and to the occupant (who in the case of high water table, would frequently need to pump water out of his basement.)

PARTIAL APPLICATION OF THE ASSESSMENT PHASE

Before we discuss the results of the application and synthesis of qualitative environmental assessments, a discussion of the preparation of data used in the step-by-step procedure used in the COMLUP computer manipulation is desirable. As mentioned earlier, the Computer Mapping for Land Use Planning (COMLUP) system of USDA Forest Service is the system used and adopted in the assessment phase.

DATA Preparation and the COMLUP Process

All of the assessment procedures in all of the assessment components are essentially composed of two elements: pregathered data in mapped form and the manipulation of those data according to a defined metric. The data are obtained from reliable sources. For example, the Soil Conservation Service supplies detailed soils maps or the U.S. Geologic Survey provides data obtained from aerial photogrammetry and ground truth validation.

These data are termed source maps for the purposes of the METLAND study. They are manipulated and aggregated in different ways according to the precise requirements of each assessment variable and its metric needs. Nevertheless, the procedure for the preparation of these source maps for manipulation, the actual procedure for manipulation, and the procedure for the final plotting of variable assessment maps is common to all. That procedure is basically as follows:

STEP 1: Digitize, edit and store on magnetic tape all the information contained on the source maps. (This is the function of the first third of the COMLUP programs.)

STEP 2: Aggregate the digitized source-map data according to the needs of the variable or subvariable assessment pro-

cedure, and make any overlays that are required by that procedure. (Second third of COMLUP.)

STEP 3: Plot the results. (Final third of COMLUP.)

Internally the COMLUP programs take the digitized data in line-segment form and overlay a grid of extremely fine granularity (500 x 1000 cells) on those data. With the data in this gridded format, the overlays required in Step 2 may be made with no difficulty. Step 3 reconverts these data to line format so that they may be plotted on a drum or flat-bed plotter. It would also be possible to use some of the newer plotting techniques such as three-dimensional plotting of the SYMVU type if desired.

Some Composite Results and Planning Considerations

Of the four components noted above, the special-value-resource component was selected to illustrate the results of synthesizing the assessment values. Assessments utilizing the COMLUP technique were prepared for four special-resource-value areas: agricultural productivity, wildlife productivity, water resources, and sand and gravel. These were composited for two points in time — 1952 and 1971 (*Fabos 1973*).

Early landscape-planning procedures simply identified landscape values or hazard potentials. When they were thought to be significant they were handled as co-equals (each having equal importance). Resulting high- and low-value areas could be depicted.

With the numerous problems sure to beset us in the last quarter of this century, it will become increasingly difficult to defend environmental landscape values, when pressured for trade-offs by economical, political, and social values by simple statements such as high value, as concluded by the landscape approach. When making trade-off decisions, most commonly accepted values are expressed in monetary terms.

A pound of meat costs more than a pound of bread, even though both are of high value as food. Similarly, value differences exist among special environmental resources and all other categories discussed.

It has been implied that these value differences can be based on social/political and economic values. Political decisions often express composite values of subgroups or interest groups of the society. Through survey research techniques and observation, planners can estimate the values of pertinent subgroups. Economists also have developed numerous procedures to distinguish among values.

In environmental planning, several sets of values should be established. Social/political and economic values should be expressed for both short-range and long-range goals. Though planners have experimented with this idea, prior to the advancement of the parametric planning approach, the adaptation of this concept to decision-making was not feasible. In the near future, however, the rapid computerized, quantitative information of the consequences of trade-offs among alternative sets of values will be readily available for decision makers.

To illustrate how a single-purpose value differentiation can provide an input to environmental/landscape planning, the value differences among the assessed special resources are shown in figure 3 in economic terms. The resource economists of the METLAND team (Foster, Torla, and Whaley) have provided value estimates for the resource, hazard, and development suitability variables listed under the heading phase I in figure 2.

The preparation of the composite special-resource-value map is similar to that used in the landscape approach. As a first step, high yield and quality water-resource areas, high-quality and usable agriculture lands, areas of high-quality wildlife, and areas with good sand and

gravel potential were located and mapped.

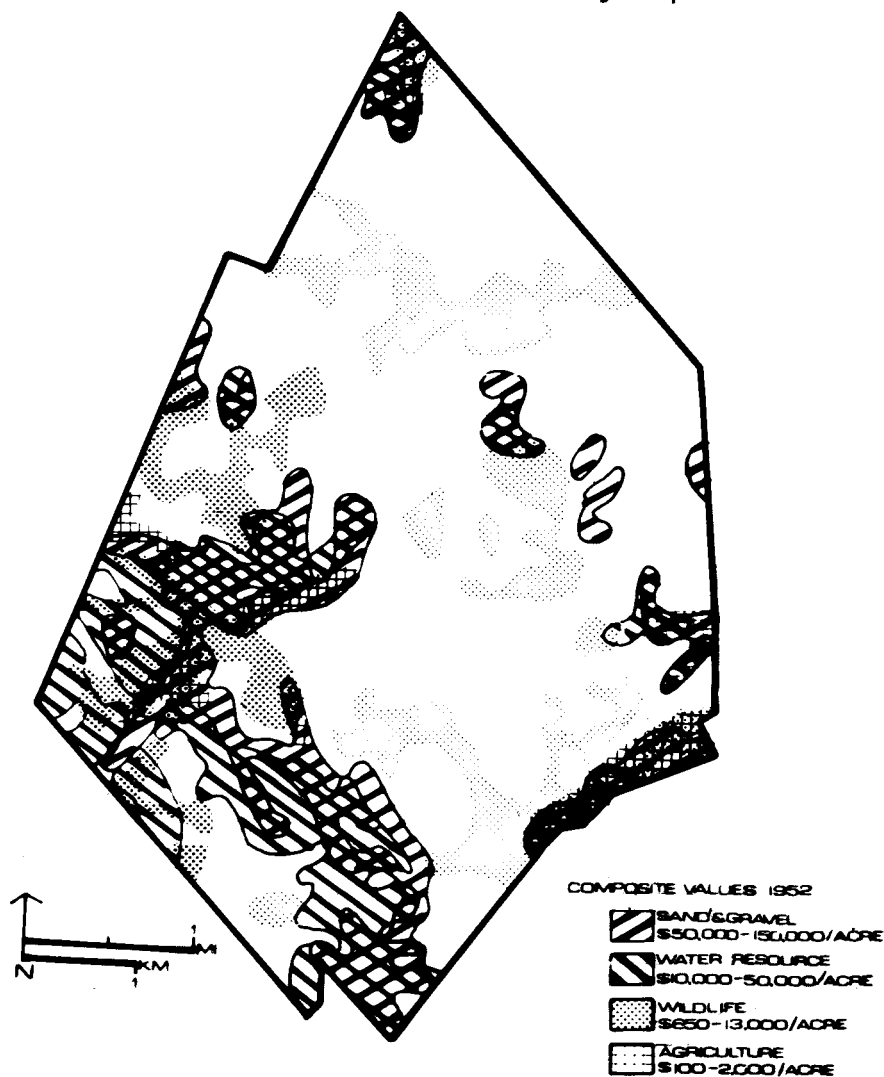
The difference between this and the landscape-planning approach, however, is twofold. First, the overlaying process is done rapidly and accurately by computer; and second, each area with high values may be assessed in terms of the estimated combined dollar value of the resource present.

Because of the scale of the maps presented in figure 3, the composite map has been simplified for visual display. Instead of the actual estimates, only ranges from low to high values are shown. The computer, however, is capable of calculating the composite estimate values per acre or per parcel of each combination.

The composite values of the special resources shown in figure 3 are most impressive. If these values, which are estimates, were confirmed, the cost of metropolitan growth, when implemented without regard to environmental values, would be shown to be very high indeed. The reader is cautioned, however, not to take these value estimates as conclusive evidence of resource loss. A more appropriate use of this information lies in two areas. First, when probable areas of resource-value concentration are known, growth can be directed away from these areas, assuming that sufficient alternative land is available. When and if at a later date these values are confirmed by detailed assessment techniques, such as drilling to find out actual depth and quality of sand and gravel resources, more permanent management decisions may be made for their use.

A second consideration in the use of this information lies in the recognition that these overlapping values are not always additive. For example, excavation of sand and gravel in areas of high water-supply potential may impair the rechargeability of ground water or destroy certain wildlife-habitat areas. As

Figure 3.—This simplified composite special-resource-value assessment illustrates an application of the parametric approach to Burlington, Massachusetts. The values listed are estimates of 1952 composite resource values. These estimated values range from \$100/acre to a possible \$203,300/acre (where water, wildlife, agriculture, and sand and gravel resource areas overlap). Notice that a great portion of these valuable resource areas were developed by housing, commercial, and industrial uses from 1952 to 1971. The impact on these areas led to an estimated loss of over \$30 million dollars in foregone special-resource value.



a result, the value of the area may not represent the sum of the value of each resource when considered individually.

The significant point to be gleaned from this information is that models are being constructed to examine these relationships and environmental/landscape parameters. The METLAND model illustrated here is a reflection of the

dynamic nature of this new field. Both are growing rapidly in an effort to deal with the problem of decentralized metropolitan growth. The example illustrated here portrays an interim step, useful today, while the more sophisticated computer assessment techniques are being developed.

We believe that this new parametric

approach will provide better and more diversified information on the qualitative aspects of the environment to decision-makers. Resource qualities and quantities together, with their location and distribution patterns, may now be assessed and manipulated by this process which, we believe, is a significant improvement in the state of the art of physical/landscape planning.

LITERATURE CITED

- Allen, Neil.
1973. COMPUTER MAPPING FOR LAND USE PLANNING: COMLUP. USDA For. Serv. Intermt. Region. 140 p.
- Bartelli, L. T., Klingebrel, A. A., Baird, J. V., and Heddleson, M. R.
1966. SOIL SURVEY AND LAND USE PLANNING. Soil Sci. Soc. Am. and Am. Soc. Agron. Madison, Wisc. 196 p.
- Fabos, Julius Gy.
1973. MODEL FOR LANDSCAPE RESOURCE ASSESSMENT. Univ. Mass. Agric. Exp. Stn. Res. Bull. 602. Amherst. 141 p.
- Ferris, Kimball H., and Fabos J. Gy.
1974. THE UTILITY OF COMPUTERS IN LANDSCAPE PLANNING. Univ. Mass. Agric. Exp. Stn. Res. Bull. 617. Amherst. 116 p.
- Flawn, Peter.
1970. ENVIRONMENTAL GEOLOGY. Harper and Row, Inc., New York, 313 p.
- Gottman, Jean.
1961. MEGALOPOLIS THE URBANIZED NORTHEASTERN SEABOARD OF THE UNITED STATES. MIT Press, Cambridge, Mass. 810 p.
- Illinois Resource Information System, IRIS.
1972. FINAL REPORT, VOL. 3 AND 4. Univ. Ill. Cent. Adv. Comput. Urbana. 120 p.
- MacConnell, William P., and Garvin, L. E.
1956. COVER MAPPING A STATE FROM AERIAL PHOTOGRAPHY. Photogram. Eng. 22 (9): 702-707.
- MacKaye, Benton.
1962. THE NEW EXPLORATION: A PHILOSOPHY OF REGIONAL PLANNING. Univ. Ill. Press. Urbana. 243 p.
- McHarg, Ian L.
1969. DESIGN WITH NATURE. Natural History Press, Garden City, N.Y. 197 p.
- McKeever, J. R.
1968. COMMUNITY BUILDERS HANDBOOK. Urban Land Institute, Wash., D.C., 525 p.
- Newton, N. T.
1971. DESIGN ON THE LAND. Belknap Press, Harvard Univ., Cambridge, Mass. 714 p.
- Odum, Eugene P.
1969. THE STRATEGY OF ECOSYSTEM DEVELOPMENT. Science 164 (4): 262-270.