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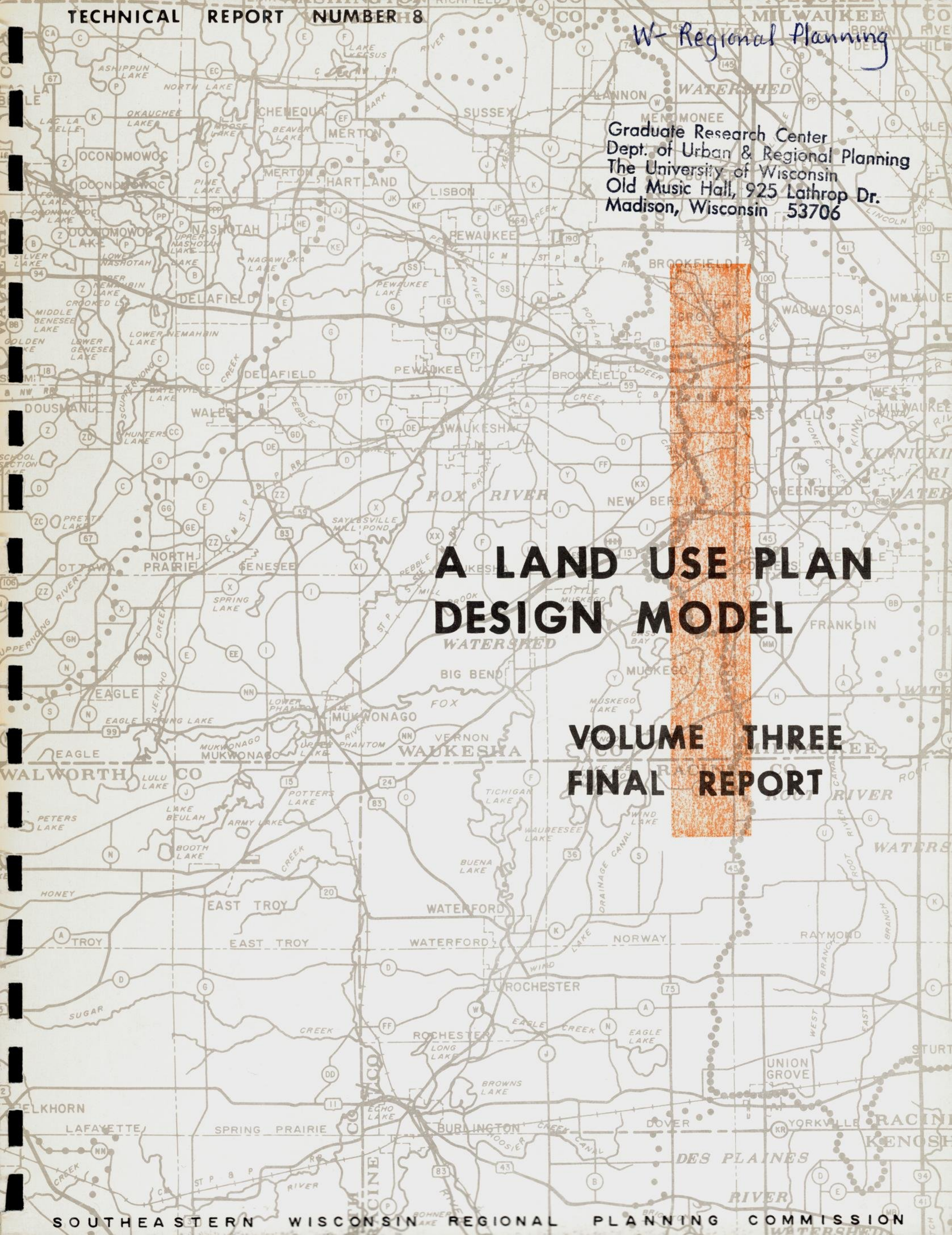

A LAND USE PLAN DESIGN MODEL

VOLUME THREE
FINAL REPORT

SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

COMMISSION MEMBERS

COMMISSION STAFF

Special acknowledgement is due Mr. Kenneth J. Schlager, former SEWRPC Systems Engineer, under whose direction the Land Use Plan Design Model has been developed, Dr. Kumares C. Sinha, SEWRPC Systems Engineering Consultant, and Mr. James W. Engel, former SEWRPC Data Processing Manager, for their extensive participation in the conduct of this study and the preparation of this report.

SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

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February 18, 1974

Graduate Research Center
Department of Urban and Regional Planning
The University of Wisconsin-Madison
Madison, Wisconsin 53706

Gentlemen:

Pursuant to your postal card requests received in our office on February 6, 1974, and through the courtesy of the U. S. Department of Housing and Urban Development which agency fully funded the program under which this report was prepared, we are sending to you herewith one complimentary copy of SEWRPC Technical Report, A Land Use Design Model, Volume Three, Final Report. We are also enclosing herewith a list of the publications prepared by the Commission to date which list indicates the availability of the publications as well as the cost of those publications which are still available. Out of Region prices would apply to any publications you may wish to order.

We appreciate your interest in the work of the Regional Planning Commission.

Sincerely,

Donald N. Drews

Donald N. Drews
Administrative Officer

DND/lt
Enclosures

TECHNICAL REPORT

NUMBER 8

A LAND USE PLAN DESIGN MODEL
VOLUME THREE—FINAL REPORT

Prepared by the

Southeastern Wisconsin Regional Planning Commission

for the

U. S. Department of Housing and Urban Development

Copies of Volumes I and II of this report, entitled, respectively, Model Development (Accession No. NTIS PB-18042) and Model Test (Accession No. NTIS PB-194772) are available from the National Technical Information Exchange, 5285 Port Royal Road, Springfield, Virginia, 22151, at a cost of $3 per volume.

The development of the land use plan design model described in this report and the publication of the report were made possible through a grant from the Office of Policy Development and Research of the United States Department of Housing and Urban Development under the Comprehensive Planning Research and Demonstration Program as authorized under the provisions of Section 701 of the Housing Act of 1954, as amended.

April 1973

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STATEMENT OF THE EXECUTIVE DIRECTOR

On October 28, 1966, the U. S. Department of Housing and Urban Development awarded to the Southeastern Wisconsin Regional Planning Commission a federally funded contract for the development of a mathematical model which could be used to design land use plans which would meet stated development objectives at a minimum cost. This emphasis on plan design was unusual, since mathematical model development efforts in the area of land use planning had up until that time been directed primarily at producing forecasts of future land use patterns rather than at producing optimal designs for such patterns.

Complete development of the land use plan design model was to be accomplished in three phases, with the results of each phase being reviewed upon completion of that phase and a decision being made by the U. S. Department of Housing and Urban Development as to whether or not to pursue the next phase of the research program. The first phase was directed at a review of the literature on land use modeling, the development of the design model concepts previously advanced by the Regional Planning Commission into a computer program for the execution of the design model itself, the initial identification of model input data requirements and means for satisfying these requirements, and the application of the model to an area as a pilot test. The first phase was completed on December 7, 1967 and the findings were documented in SEWRPC Technical Report No. 8, A Land Use Plan Design Model, Volume 1, Model Development, published in January 1968. Since the results of the first phase were encouraging, it was decided to proceed with the second phase.

The second phase of the work was directed at the refinement of the model, with particular attention to more specifically defining the input data requirements, developing a computer program for the efficient reduction of input data, and, based upon the findings of the first phase, improving the mathematical structure of the model itself. In addition, the refined model was to be tested for internal consistency and workability and applied to the design of a land use plan for an urban region. This model-generated land use plan was to be compared with a land use plan developed for the same urban region by more conventional graphic and analytical land use planning techniques. The second phase of the model development program was completed on October 12, 1969, and the findings were documented in SEWRPC Technical Report No. 8, A Land Use Plan Design Model, Volume 2, Model Test, published in October 1969. The results of the second phase indicated that the model could produce land use plans that were reasonable and with certain improvements could be developed into a flexible and useful planning tool capable of application at both the regional and community levels. The work indicated, however, that the module placement algorithm initially used in the model did not produce the desired results and that a new algorithm for module placement was required. It was accordingly decided to proceed with the third phase.

The third phase of the work was directed at the final development and test of the land use plan design model, including the incorporation of a new module placement algorithm, further improvement and refinement of the data reduction and model computer programs, further testing of the model, and the development of a user's manual.

The results of the third and final phase of the programs are described herein. By way of summary, the research project has produced a model which is conceptually sound and internally consistent. The model, however, requires certain additional improvements and refinements if it is to provide a truly useful operational planning tool. The improvements and refinements needed are clearly set forth in the concluding chapter of this report. None of these improvements or refinements relate in any way to the basic concept or structure of the model, but rather to the model inputs and to the manner in which the model is applied. To effect the improvements and refinements necessary to produce a truly operational model will now require the extensive application of the model to actual land use plan design by a team, preferably consisting of a knowledgeable land use planner and an experienced systems engineer.

The model is sufficiently developed and potentially useful enough to warrant this additional effort. Moreover, this report provides, in effect, a user's manual which should permit the ready application of the model by any interested design team. As such it presents necessary background information, specifies input data requirements, provides output interpretation guidelines, and documents model operations procedures, all as necessary to use the model for experimental land use plan design.

Respectfully submitted,

Kurt W. Bauer

Kurt W. Bauer
Executive Director

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Chapter I

THE LAND USE PLAN DESIGN PROBLEM

INTRODUCTION

Urban planners today must cope with a multiplicity of problems ranging from designing new towns to combatting the decay and poverty of the inner cores of established cities. The planners' problems are compounded by a shifting population, a changing economy, and diminishing resources. The planner must design urban environments using one of the most precious resources—land—while considering the effects of the design on other resources and, most importantly, on the people who will live in the environment created by implementation of the design.

In the past 50 years, the population of the United States has increased from about 100 to about 200 million people. Conceivably, another 100 million persons may be added to the population by the year 2000. Significantly, this population increase may be expected to be not only almost entirely urban, but largely metropolitan. Moreover, within the metropolitan areas of the United States this population growth may be expected to occur primarily in the suburban and rural-urban fringe areas. This growth, if poorly planned, may be expected to create serious developmental and environmental problems in both the growing outlying areas and in the declining central city areas. Furthermore, the continued move to the suburban and rural-urban fringe areas will create an urban sprawl which will diminish the available land and press heavily on the natural resource base.

In addition to allocating this scarce land to various uses, the planner must investigate the effects of various spatial arrangements of the land uses on resources and on people. Regardless of the size of the area being planned, the pattern of interaction between land uses is exceedingly complex and constantly changing. Poor land use plan design may impose physical and phychological stresses on the population. A cluster of industrial areas may create unnecessary air pollution and a group of dense residential areas may cause water pollution. The land use pattern must serve the social and economic needs of the population by enabling people to live in close cooperation while pursuing a wide variety of interests. It must minimize conflicts between population growth and limited land and water resources while maintaining an ecological balance within the environment.

In the past 15 years urban planning has changed drastically. The increased use of mathematical and statistical techniques and the subsequent use of the computer to implement these techniques have virtually revolutionized several steps in the planning process, most notably in the inventory and data gathering phase but also in the analysis and forecast phase, and even the plan testing and evaluation phase. Until the present research effort, however, there has been no real improvement in the largely intuitive process of land use plan design.

It is the purpose of this report to describe in practical terms the background of and procedures for a land use plan design model which can bring the combined power of mathematics and the computer to aid the planner in coping with the complexity of land use plan design.

OBJECTIVE OF LAND USE PLAN DESIGN

Simply stated, the aim of urban land use plan design is the optimization of the use of land space. More specifically, it involves the placement of discrete land use activities or elements such as schools, residential neighborhoods, and parks in topographic space. In placing these elements, the designer must consider the following factors:

1. The physical and functional characteristics of the elements.

2. The physical characteristics of the land space in which the elements may be located.

3. The design standards or criteria as reflected in constraints to the placement process.

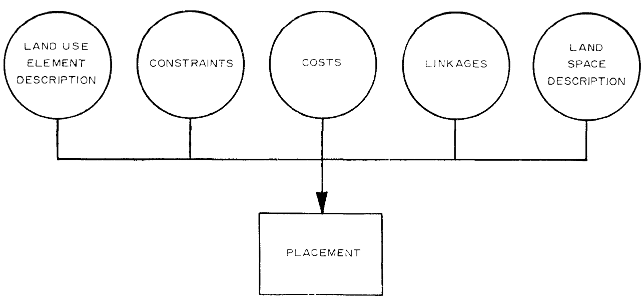
4. The linkages, such as streets and water lines, necessary to connect the elements.

5. The costs (site and linkage) associated with the placement of elements in a spatial configuration.

Through this placement process (see Figure 1), the desired land use plan design model guides the optimum use of a particular land space.

Figure I

ELEMENTS OF THE PLACEMENT PROCESS



Source: SEWRPC.

The Scope of the Mathematical Model

This land use plan design model is a mathematical model which is intended to aid the planner in creating a land use plan that defines a desired spatial distribution of land use activities in a given land area. In this way, the model seeks to provide a design solution that will satisfy market demands while complying with community development objectives and minimizing public and private development costs. While generating and evaluating a large number of land use patterns, the model also searches for the optimal design that satisfies the stated development objectives while minimizing development costs.

Although the final output of the model is a land use plan, the model is really a comprehensive planning model since it considers the construction, operation, and maintenance costs of the public works facilities which serve and support the land use pattern, as well as the development costs of the land use pattern itself.

A Comprehensive Design System

A land use plan design model alone, however, does not provide a comprehensive design system. Without supporting input data and computer programs capable of efficient operation, the model cannot be used effectively in plan design. Present traditional intuitive planning design procedures are complete design systems since an entire set of procedures facilitates their application. Any system, however automatic or optimal, developed to supplement or even replace existing traditional methods at a minimum must provide for all of the elements of a workable design system. Many urban planning models and models in other areas of application have been relegated to the category of academic curiosities because their development was not accompanied by the supporting peripheral procedures to make their application practical.

A workable urban design system, moreover, must consider not only input data, computer programs, and computer equipment, but also the relationship between the planner and the system. A proper man-machine interface greatly increases the effectiveness of the design system. This report attempts to provide for just this interaction between the planner and the model by presenting instructional material in the theory of the model, on the collection and preparation of input data, on the operation of the model, and on the interpretation of the model output data. Therefore, the objective of this report is to provide the planner, even with no previous experience with computer or mathematical terminology, with the necessary background information and instructions necessary to operate the model and interpret the output.

From Inventory to Implementation

Plan design is only one of the functions that comprise the total sequence of developing and implementing an urban land use plan. The major steps in the land use planning process are (see Figure 2):

1. Inventory—in this step the present status of a planning area is determined by collecting, processing, and analyzing data on natural resources, land use activities, and existing support facilities.

2. Forecast—in this step the elements exogenous to the system being planned are forecast, such as future levels of population and economic activity and related demand for land and resources within the planning area.

3. Formulation of development objectives and supporting plan design standards.

4. Plan design—in this step one or more alternative spatial configurations are formulated.

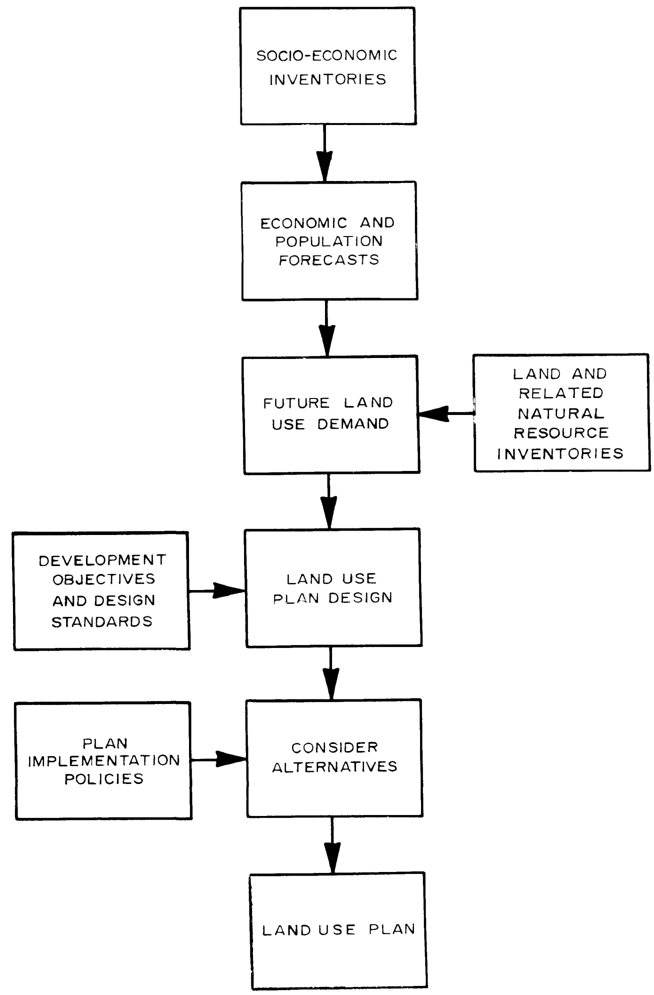
5. Testing the plans for feasibility of implementation.

6. Actual implementation of the plan.

Plan design is, however, a crucial function in this process since it interacts strongly with all of the other functions. It establishes the data requirements and level of data necessary in the inventory phase and the classification and accuracy requirements of the forecasting function. It determines the necessary mode of expression of design standards. It develops the plans for testing, and finally, it determines the rationale for plan implementation.

Figure 2

THE LAND USE PLANNING PROCESS



Source: SEWRPC.

THE MODULE: BUILDING BLOCK OF PLAN DESIGN

In the placement process, the planner first defines the characteristics of the elements to be used in the plan design. In the land use plan design model, these elements are discrete land use activities such as schools, hospitals, and residential neighborhoods, and are termed modules. The module concept is not new to planning. It is an important part of existing planning theory. For instance, the residential neighborhood unit (see Figure 3) has served as a basic module in the formulation of many community plans. In a similar manner, although a more recent concept, the planned industrial district is considered a complete planning unit with the inclusion of parking, access, and rail and truck loading docks in addition to streets and building areas. Whether residential, commercial, industrial, or public, a module, to be used in the plan design model, must be a complete planning unit.

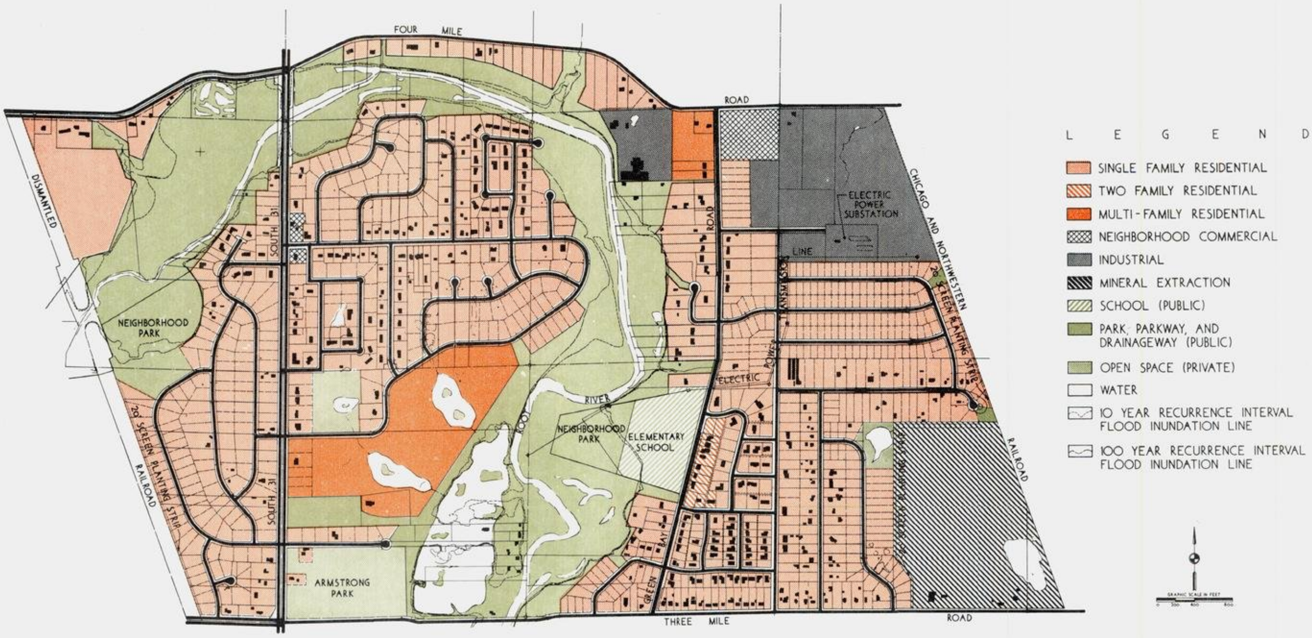
Since the module is the most basic unit of the plan design model, it is the building block manipulated in the placement process in model operation. Also, it is the vehicle for the expression of design standards in the form of constraints to this spatial manipulation. The module is a physical entity since it has spatial dimension and associated costs of development, and a functional entity since it has a defined activity (land use) and specified relationships with other modules.

The Module as a Physical Unit

As a physical entity, the module is described in terms of the total of the space requirement for each physical unit comprising the module. The module consists of a primary land use activity, and the contiguous

Figure 3

ILLUSTRATIVE PRECISE NEIGHBORHOOD UNIT DEVELOPMENT PLAN--ROOT RIVER NEIGHBORHOOD, TOWN OF CALEDONIA, RACINE COUNTY, WISCONSIN



Source: SEWRPC.

relevant areas necessary for its proper functioning. For example, a medical center module may consist of a hospital building site as the primary area, an off-street parking area, heating plant and accessory buildings, internal vehicular circulation areas, pedestrian circulation areas, open space and landscape areas, ingress-egress zones, and the module share of the arterial street and collector street rights-of-way which serve the medical center as supporting areas.

This approach, which includes the accessory functions within the module serves two purposes. First, it ensures that the facilities required to serve each activity or module, and the costs of imposing desirable design constraints, are charged against that activity. Second, it facilitates the control of the gross acreage to be assigned to development. In defining the modules, an attempt must be made to minimize the size of the module within the limitation that each module must represent a self-sufficient, viable unit.

The Module as a Functional Unit

Since, as a functional entity, the module is described in terms of its purpose based on the principal land use activity, the locational requirements depend on the function of the module. In fact, the function of the module generates the need for accessibility and compatibility to other modules. For example, the function or purpose of a Neighborhood Commercial Center module is to provide the area necessary to house convenience goods and service establishments needed for day-to-day living requirements of the family within the immediate vicinity of its dwelling unit. The function, then, limits the permitted land uses within the module, and indicates the locational requirements (contiguous to a residential module).

Module Types

Along with the development of the land use plan design model, a set of module types was identified and defined as a part of the research reported on herein using a standard format. Although the actual module types used in any application of the model in a region or community may vary from the list below, the present module type set is considered typical. Definition of modules and preparation of module data as inputs to the models are discussed in Chapter III.

The following modules have been selected, defined, and dimensioned for use as model inputs:

1. Residential (low-density) (see Appendix A).
2. Residential (medium-density) (see Appendix A).
3. Residential (high-density).
4. Neighborhood commercial center (low-density) (see Appendix A).
5. Neighborhood commercial center (medium-density).
6. Neighborhood commercial center (high-density).
7. Community commercial center (see Appendix A).
8. Regional commercial center.
9. Highway commercial center (center auxiliary).
10. Highway commercial center (arterial auxiliary).
11. Highway commercial center (freeway and expressway auxiliary).
12. Highway commercial center (recreational auxiliary).
13. Planned industrial district (light) (see Appendix A).
14. Planned industrial district (heavy).
15. Junior high school (public).
16. Junior high school (private).
17. Senior high school (public) (see Appendix A).
18. Senior high school (private).
19. Medical center (short term).
20. Medical center (long term).
21. Medical center (nursing and related).
22. Public college.
23. Private college.
24. Library (regional).
25. Library (community).
26. Library (branch).
27. Church.
28. Cemetery.
29. Police station.
30. Fire station.
31. Community recreational center.
32. Regional recreational center.
33. Community cultural center (intensive).
34. Regional cultural center (intensive).
35. Regional cultural center (extensive).
36. Incinerator and sanitary land fill.
37. Institutional center (regional).
38. Municipal hall (community) (see Appendix A).
39. Municipal hall (regional).
40. Airport (community).
41. Airport (regional).
42. Intraregional rapid transit terminal (rail).
43. Interregional rail transit terminal (passenger).
44. Intraregional rapid tranist terminal (bus).
45. Interregional bus transit terminal.
46. Gas storage and distribution terminal.
47. Water treatment plant.
48. Water pumping plant.
49. Water source.
50. Sewage treatment plant.
51. Electric power generation plant.
52. Electric power substation.

THE LAND SPACE

After determining the nature of the land use activities or modules, the designer must next consider the land space in which they will be located. In order to generate locations for the placement of these modules, the total area being planned must be subdivided into smaller areas called cells. The type of plan to be produced influences the size and shape of the cells. For example, the cells for a regional plan will be much larger than the cells for a city plan.

Cell Size and Shape Requirements

Although the size and shape of the cells may assume almost any pattern, the smallest cell should be large enough in size to hold at least one of the largest modules, and preferably large enough to hold two or three modules of that size. In the set of modules defined for the Southeastern Wisconsin Region, the largest module (which was the low-density residential module, 2,500 acres) was approximately four times as large as the next largest module (the medium-density residential and light industrial modules).

Although one possible and convenient cell shape is the form of a grid pattern overlayed on a map of the area as shown in Figure 4, the cells may have an irregular shape, allowing cell boundaries to follow natural boundaries or define areas of topographic or soil similarities as shown in Figure 5.

DESIGN STANDARD AND CONSTRAINTS

Once the module type set is defined and the cell pattern selected, the planner next determines the specific design standards and constraints based on the general planning objectives for the area. Since the terms "objective" and "standard" are subject to a wide range of interpretation and application, the following definitions, used by the Southeastern Wisconsin Regional Planning Commission in all of its work, provide a common frame of reference.

1. Objective—a goal or end toward the attainment of which plans are directed.

2. Standard—a criterion used as a basis of comparison to determine the adequacy of plan proposals to attain objectives.

The role of design standards in the model is best demonstrated from the aspect of the design model as a placement process as illustrated in Figure 2. In the placement process, design standards act as constraints on the design solution by reducing the number of feasible solutions, that is, the number of combinations the model must examine in order to attain an optimal solution.

Design Standard Definition

The model, however, dictates a definite requirement as to the manner in which the design standards must be defined. The most fundamental requirement is that the standards be quantifiable at least in the binary (yes/no) sense. Either a particular plan satisfies a binary standard ("yes"), or it does not ("no"). Some standards, however, may be quantified to a higher degree in that an actual number may be provided to express the degree to which a particular plan complies with a standard.

Types of Design Standards

Different types of design standards tend to affect the operation of the model in different ways. For this reason, the standards must be classified operationally, that is, by the way in which they affect the operation of the model. The following classification framework was developed based on the principal inputs to the model.

1. Module Standards

   a. Module definition standards

   b. Module quantity standards

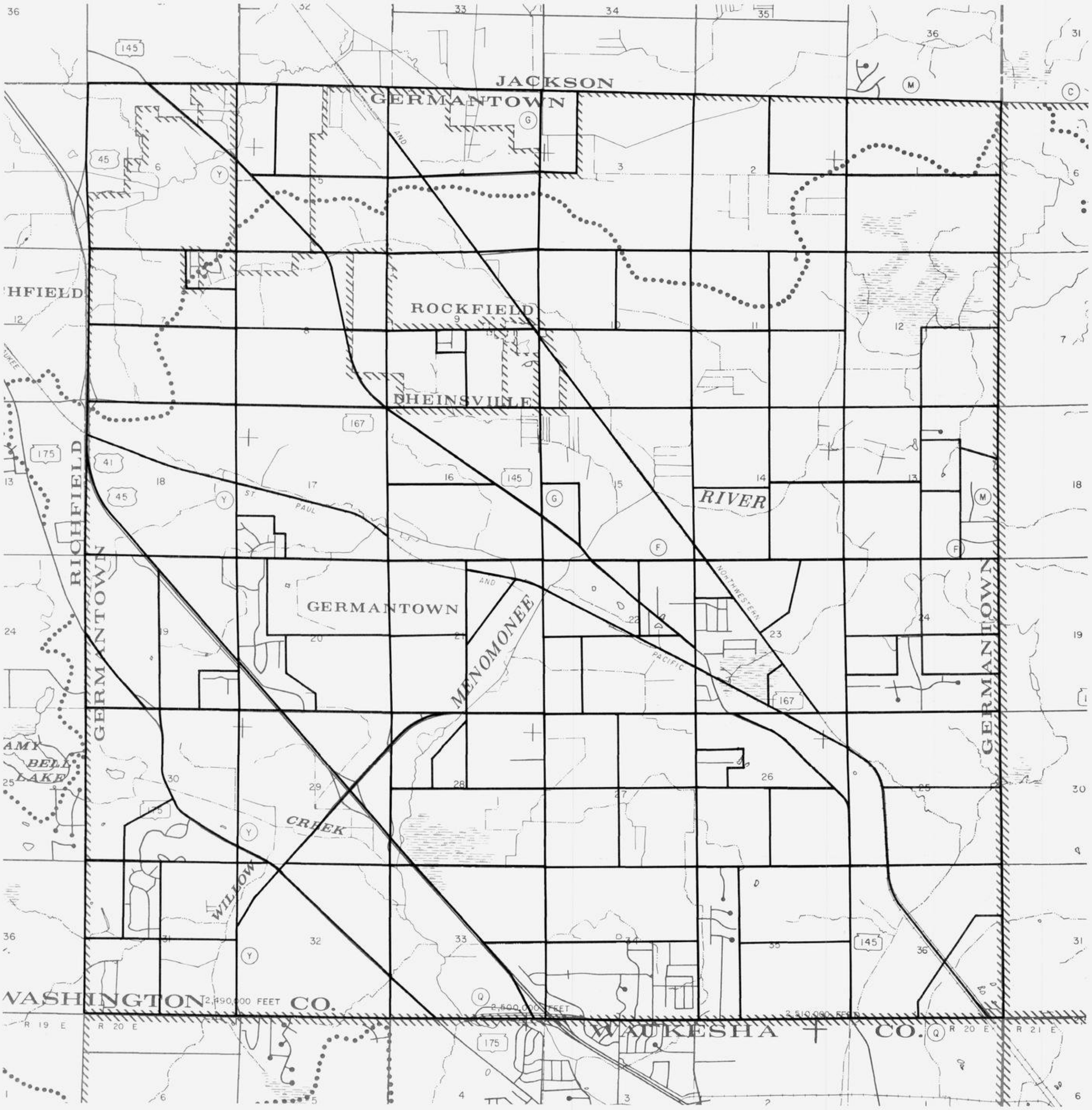
Figure 4

DELINEATION OF CELLS IN A GRID PATTERN

Source: *SEWRPC.*

Figure 5

DELINEATION OF CELLS IN AN IRREGULAR PATTERN



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Costs of construction have been compiled for intramodule elements and intermodule linkages. All intramodule cost data has been formulated as a function of soil texture, slope, depth to water table, and depth to bedrock. The common unit of cost evaluation is dollars per linear foot for linkages such as water or sewer lines, and dollars per acre for modular elements such as parking lots.

After all modules have been placed in cells and all intercell constraint tests performed, the site and linkage costs for each experimental plan are calculated. These costs are calculated for infeasible plans as well as feasible plans for the later sensitivity analysis of the effects of the constraints. Chapter III contains a detailed discussion of the sources of soil and cost data.

Table I

COMPARISON OF CAPITAL AND OPERATING COSTS FOR SELECTED LINKAGE TYPES

Type of Facility	Capital Cost (Per Mile)	Vehicle Operating Cost (Per Mile)[1]	Road User Cost[2]
Rural Freeway (four-lane)	$1,100,000	$20,300,000	$49,000,000
Rural Standard Arterial	300,000	3,760,000	10,200,000
6-Inch Diameter Water Main	40,000	- -	- -

[1]*Vehicle operating costs shown are calculated for the assumed life of the facility, or 20 years, at a 6 percent interest rate.*

[2]*Road user cost types consists of present value of vehicle operating cost plus depreciation plus time cost.*

Source: SEWRPC.

MODEL BASED PLANNING VERSUS TRADITIONAL PLANNING

In the past decade the use of nondesign mathematical models such as economic forecasting models, population forecasting models, land use simulation models, flood flow simulation models, water quality simulation models, trip generation models, trip distribution models, and traffic assignment models, has become rather commonplace. The models differ fundamentally from the land use plan design model in that they attempt to explain or describe how things are happening or may be expected to happen rather than how they should happen. In other terms, these models are positivistic while the land use plan design model is normative in nature.

In order to compare traditional planning techniques with the utilization of the land use plan design model, the principal steps in the land use planning process may be examined and the differences noted at each point. While the land use plan design process has remained a largely intuitive process, a whole body of methods and techniques has been developed to support its use. In changing from an intuitive design process to the use of the land use plan design model, what changes are necessary at other steps in the planning process ?

Old and New Planning Processes

At the first step in the process, the inventory difference can be substantial. Since the model has sharply defined data needs, in general less data gathering should be required. A great wealth of collected data characterizes many efforts in traditional planning. Unfortunately, even though other governmental agencities may use some of this data, the cost and man-hours required for its collection are charged against the planning effort.

The second step in the planning process is the forecast stage, where economic and population forecasts are made and converted into future demand for various kinds of land uses. Although utilization of the model requires that this demand for various land uses be converted into modules, this stage of the process is basically unchanged.

The third step in the planning process is the formulation of objectives and standards. At this stage in the process a significant difference between the two methods occurs. Utilization of the design model requires a careful and explicit definition of objectives and design standards.

Although descriptive literature relating to planning objectives and design standards is plentiful and the better community and regional planning reports today make some statement regarding objectives and standards, the literature usually lacks a comprehensive statement relating the design standards utilized in the plan to the overall objectives of the community. In order to utilize the model successfully, the community or regional development objectives must be translated into specific design standards which affect the spatial placement of the modules.

In traditional planning, the planner may have intuitive ideas concerning standards and constraints. For example, he may "know" (based on his knowledge of general planning principles) that a residential subdivision should be located "close" to an arterial street linkage. Application of the design model, however, requires that "close" be precisely defined: one mile, two miles, half a mile—is the requirement the same for all densities of development? In the model, all standards must be as precise as possible.

An inherent difficulty here is that the planner may not know precisely what the standards should be. It becomes a relatively easy matter, however, to test the impact of any specific standards on the output of the model by changing that particular input and rerunning the model. In this way, the cost and the effect of imposing a particular set of standards can be readily analyzed—a process which cannot be performed easily using traditional planning methods.

The Advantages of Plan Design Modeling

In the next step of the process, plan design, the planner spatially locates the various land use activities in accordance with the demand for space determined in step two and the objectives and standards formulated in step three. By traditional methods, this process is lengthy and usually permits considerations of only two or three alternatives. In utilizing the plan design model, however, this step is performed by the computer. Therefore, the number of alternatives considered is substantial and, in fact, virtually unlimited. First of all, when the number of plans necessary to conclude a run has been completed, additional runs can be made. Since the basis of the model is a random placement, the output will be totally different for each run. Furthermore, constraints can be changed which will generate a different output. The result is alternatives which can number in the millions, although it is unlikely that any planner would have the energy to sift through and evaluate even 10. Here, too, the model aids the planner. By ranking the plans in order of cost, the planner need only consider the lowest cost plans. While the planner utilizing traditional techniques may also attempt to consider costs, such as excluding steeply sloped areas from development, usually no comprehensive attempt is made to minimize the overall cost of development.

The last two steps in the process are testing the plan for feasibility of implementation and the actual implementation of the plan. At this point, again the model offers definite advantages. First of all, the cost of implementing the plan is already available and does not need to be calculated. Second, as discussed above, the design model prepares a large number of alternatives for consideration. This may be particularly valuable if elected officials and citizen leaders are to be involved in a meaningful way in the planning process.

The Limitations of the Modeling Approach

There are certain important limitations to the model approach. First of all, there may be an inability to express design criteria precisely. A planner may intuitively be able to produce or recognize a good design, but may be unable to express the criteria for the design in terms of quantifiable standards and necessary constraints on model operation. In this case, the output of the model would be unsatisfactory.

Second, the model is totally dependent on the input data. If the quality of this data is poor, the model's output also will be poor. The planner in the traditional role again has intuition to tell him if something is wrong with his data. The planner using the model has only the output. Cost data also play a significant role in the model; if they are poor, again the output of the model will be poor. Since this type of data has not been used extensively in the past, it has not been possible to determine the necessary accuracy requirements under this research effort. It does, however, appear that the model will be fairly insensitive to small inaccuracies in costs.

Finally, the operation of the model limits its usefulness. As will be explained later in this report, the model uses a random approach to find an optimal solution. Consequently, if a good design is rare or unique, the model would have difficulty in finding such a design through its random placement process. For instance, if the number of good plan designs was only 10 out of a million possible plans, the probability of the model finding one of 10 would be very low.

Chapter II

THE LAND USE PLAN DESIGN MODEL

INTRODUCTION

The first chapter of this report examined the nature of land use plan design, developed the concept of the module as the basic unit for model manipulation, considered the definition of land space for the model, introduced the concept of costs as an input to the model, examined the role of objectives and standards as constraints to the design process, and examined the differences between traditional planning techniques and use of the planning model. In this chapter the rationale and the methodology of the design model, together with an explanation of the inputs to the model, an outline of the model computer program, and the expected output are presented.

THEORY OF MODEL OPERATION

The land use plan design model aims to provide an "optimal" land use plan, "optimal" meaning a plan with the lowest overall cost of development and operation that meets the specified design criteria. In this way, the problem can be considered as one of a class of "maximum-seeking" experiments to find the combination of factors which produce this "best" or lowest cost result. The factor combination producing the best result is termed the "optimal factor combination."

A variety of modeling techniques exists that can be used to determine an optimal land use plan design. Initially in the plan design model development effort a linear programming approach was proposed.[1] This approach was found to be impractical, however, because land use plan design involves manipulation of discrete elements, while the linear programming algorithm is generally capable of handling only continuous variable quantities. Apart from the model being a finite model rather than a variable model, land use plan design also requires consideration of linkages. Accordingly, it was decided as the research effort progressed to explore the applicability of linear graph theory in the development of the necessary algorithm for model operation.[2]

The model algorithm prepared on the basis of linear graph theory consists essentially of a set decomposition technique. In the model operation, the planning area is successively divided into a series of subareas. Initially the algorithm provides for the placement of the modules into one of two halves of the planning area. The model then tests a series of successive adjacent subsets in an attempt to improve the initial allocation using a hill-climbing technique which searches for the best allocation. The best allocation is the one which produces the minimum combined site and linkage costs. Such an evaluation continues until no improved partition can be obtained by shifting a unit element from one half of the partition to the other half. After a best partition of modules has been achieved, each module is located in one of the two halves of the planning area. The entire sequence of partitioning then continues within each of the halves of the preceding scanning process to generate another series of half areas when a new optimal partition is determined. This partitioning process continues until the area is subdivided to the degree of detail desired.

The details of the algorithm for model operation based on set decomposition technique have been described in the first two volumes of this report. Although the model programs developed under this research permitted satisfactory application of the model, as described in the second volume of this report, it became evident upon evaluation of actual model runs that certain serious weaknesses exist in that part of the model algorithm which deals with the placement of modules in cells. The technique of set decomposi-

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[1]See SEWRPC Technical Report No. 3, A Mathematical Approach to Urban Design, January 1966.

[2]See SEWRPC Technical Report No. 8, Volume 1, A Land Use Plan Design Model--Model Development, January 1969.

tion in a series of binary partitions was found to fail to account for the possibility that a particular module element might have been better placed in a different topographic area after the initial partitioning had placed it earlier in a less desirable half area. Moreover, the model algorithm could consider only those linkage costs resulting from the latest division and not the cost of all the linkages required.

To eliminate the weaknesses associated with the use of set decomposition techniques, a new placement algorithm based on random search techniques was then developed. In this procedure a set of experimental plans is developed through the combination of module-cell arrangement designed in a random fashion. The "best" plan is that experimental plan for which the random assignment of module-cell combinations produces the lowest total cost satisfying the design constraints. A description of this procedure is presented in the following paragraphs.

Random Selection

In a random method of selection, all items of a group have an equal chance of selection. Visualize a checkerboard. Number each square as shown at the right:

1	2	3	4	5
6	7	8	9	10
11	12	13	14	15
16	17	18	19	20
21	22	23	24	25

The object is to select one square, with each square having an equal chance of selection. One method would be to write the numbers of all of the squares on slips of paper, toss them in a hat, mix well, and have someone draw them one at a time. In this way, their selection would be random. This random selection process is basically the same as that used in the national draft lottery, where birthdates are drawn from one hat and priority numbers drawn from another. Bingo uses the same method by mixing all the numbers in a drum and drawing them out one at a time.

Cell Selection by Random Method: In the model, modules and cells are selected by this same process. In fact, it would be possible to select the modules and the cells manually, by drawing them from a hat. The computer program uses a random number list to assure that they are drawn randomly, just as though the numbers were being pulled from a hat.

Cell numbers are selected in the same manner with one exception. When the list of modules is input to the model, there may be 19 residential, five commercial, three industrial modules, etc. When the computer selects one of these modules for placement, and places it in a cell, the module is not tossed back into the hat. For example, if the first module selected were a commercial module, 19 residential, four commercial, and three industrial modules remain for the next selection. When a cell is selected for placement, however, and an acceptable placement of a module made in that cell, the cell number is tossed back into the hat and has an equal chance of being selected at the next draw. Theoretically then, it would be possible for the same cell to be drawn again and again and all the modules located in one cell. However, each cell has a land capacity which cannot be exceeded; once this capacity is reached, the placement is rejected and another cell selected at random, until one is selected which has the capacity to hold the module selected for placement.

If the model were simple, module cell placements would be selected in the preceding manner, costs calculated, and the plans printed. However, the model must obtain not only the lowest cost plan, but the lowest cost plan which meets all previously specified design standards and constraints. When each module initially is placed in a cell, it is first determined whether all intracell constraints are met. If not, the placement is rejected, and new placement made. After all placements are complete and a design designated, intercell constraints are tested for violations. If no violations occurred, the design is designated feasible. If violations did occur, the design is designated infeasible. Then, costs are calculated for all designs, both feasible and infeasible. When the required numbers of designs have been generated, the designs, or plans, are printed beginning with the lowest cost design.

Number of Experimental Plans

The main reason for using the random method in experiments is its success in problems involving such a large number of factor combinations that other methods cannot be applied due to the excessive number of trials necessary. For example, if the area being planned were divided into only 10 cells, and 10 modules were to be located in those cells, the total number of possible combinations would be 10! or 3,628,800.

In utilizing the random method, however, the number of experimental plans required is not a direct function of the number of possible module-cell combinations. Regardless of the size of the design area and the number of modules to be placed, the number of experimental plans required to obtain an optimal cost plan will not exceed 919 even for a very small optimal zone and a very high probability of success, as demonstrated in the following discussion.

In applying the random method to any problem, two things must be decided by the planner/experimenter:

1. Plan Accuracy—The planner/experimenter must define the successful experiment or the plan accuracy desired. Since the objective of the model is to design an optimal land use plan, "optimal" must be predefined in terms of cost. One definition might be the optimum or absolutely lowest cost plan. However, it is readily seen that given the large number of factors involved, this optimum may not be attainable. In addition, if a very large number of plans are prepared, the differences in cost may become insignificant. The definition of success used in this model is to obtain a plan within an optimal or lowest cost zone. This optimal zone, then, is a subset of all experimental plans such that those experimental plans included in the subset have the least costs of all experimental plans. For example, the desired plan accuracy could be to obtain an experimental plan with a cost within the lowest 5 percent of all possible plan costs.

2. Probability of Success—The planner/experimenter must also determine the desired possibility of obtaining an optimal land use plan. In other words, the planner also must determine what assurance he would like to have of obtaining a plan within the cost range previously selected.

The random method may be viewed as being applied in the following manner: the factors to be considered are selected, i.e., modules and cells. The experimenter then selects combinations of factors at random. He conducts a trial, or prepares a plan, with each randomly selected factor combination. The best combination, i.e., the plan with the lowest overall cost, is declared to be the best design, in this case, the optimal lowest cost design or plan.

By this procedure, the planner/experimenter hopes to find some module-cell placement combination characterized by a low cost, if not the lowest possible cost; that is, he hopes to find a plan in the subset of all possible plans where the overall cost is lowest.

The next question, then, is how many experimental plans must be prepared to attain reasonable certainty of finding one in the subset where cost is lowest. The number of experimental plans needed in order to have the desired probability of selection of a near optimal design plan can be determined by the following equations:

Where: n = the number of experimental plans required to obtain a plan with accuracy of "a" and probability of success of "s"

a = plan accuracy, that is, the ratio of the optimal zone[3] to the total number of possible experimental plans

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[3] *The optimal zone is a subset of experimental plans such that those experimental plans included in the subset have the least cost of all experimental plans.*

$s =$ probability of success; that is the probability that the lowest cost plan obtained by means of the algorithm will actually be among the "a" best plans represented by the optimal zone.

Then: $s = 1 - (1 - a)^n$

or

$n = \log (1 - s)/\log (1 - a)$

Intercell Constraint Tests

The number of experimental plans required, however, cannot be predetermined in actual practice because of the effect of intercell constraints. Once all modules are placed in cells, the result is designated a design or plan. If the algorithm ended at this point, the preceding equations in fact would predetermine the number of experimental plans needed in order to have the desired probability of obtaining at least one in the optimal zone. The algorithm, however, does not end there; the next step in the algorithm is the testing for intercell constraints. If any of the intercell constraints are not met, the plan is designated infeasible. Only those plans which satisfy all of the intercell constraints are designated feasible.

The object of the experiment, then, is not merely to obtain a plan with costs of development in the optimal zone, but to obtain a "feasible" plan (feasible being one which meets all intercell constraints) in the optimal zone. Therefore, the probability (a') of obtaining an optimal feasible solution is:

$a' = (a)\ (Pf)$

Where: $a =$ plan accuracy

$Pf =$ probability that a plan is feasible

The effect is to change the original formula to:

$s = 1 - (1 - a')^n$

or

$n = \log (1 - s)/\log (1 - a')$

Therefore: if $a = 0.05$, $s = 0.90$, and $Pf = 1$

then: $a' = 0.05$

and $n =$ 45 experimental plans

However, if $Pf = 0.1$

then, $a' = 0.005$

and $n =$ 460 experimental plans

The existence of design constraints has the effect of increasing the number of experimental plans necessary to achieve a given level of accuracy. In the example above with a feasibility probability of 0.1, the number of plans increases to 460 from 45 to achieve the same plan accuracy.

But since the probability of feasibility is not known, it must be determined experimentally during the model run. Therefore, it is not possible to determine the number of experimental plans needed before the run. In order to do this, a running value (moving average) for Pf must be maintained during the model run, and the calculation of the number of plans to be run must be made by the program after each plan is completed.

Table 2 gives the values of "n" (number of plans necessary) corresponding to selected values of "s" and "a." However, the number of experimental plans required is not a direct function of the number of possible module-cell combinations. Regardless of the size of the design area and the number of modules to be placed, however, the number of experimental plans required to obtain a plan within the optimal zone will not exceed 919 for even a very small optimal zone (a = 0. 005) and a very high probability of success (s = 0. 99).

Table 2

NUMBER OF TRIALS REQUIRED
IN A MAXIMUM-SEEKING EXPERIMENT
CONDUCTED BY THE RANDOM METHOD

	s			
a	0.80	0.90	0.95	0.99
0.10	16	22	29	44
0.05	32	45	59	90
0.025	64	91	119	182
0.01	161	230	299	459
0.005	322	•460	598	919

Source: Samuel Brooks, "A Discussion of Random Methods for Seeking Maxima," Journal of Operation Research, Vol. 7, 1958.

VALIDATION OF THE RANDOM TECHNIQUE

The ideal model operation would be an exhaustive search to develop a series of experimental plans by placing each of the modules in each of the cells and sequentially evaluating the respective costs in order to arrive at an optimal design. Such an operation is practically impossible with an even moderately complex system involving a relatively large number of cells and modules. The random search procedure, however, can eliminate the large number of trials required in such an exhaustive search. The validity of the random placement algorithm has been investigated elsewhere and the results are reported in a recent paper.[4] A series of small-scale controlled experiments was conducted by considering a number of hypothetical study areas consisting of 10 to 15 cells and five modules. The results obtained from the random algorithm were compared with the results generated by an algorithm based on the exhaustive search technique. In general, the probability obtained experimentally of a given plan falling within the optimal zone was observed to be greater than the theoretical value. This provides an overall indication that the random procedure of module placement can be used with a good degree of success. Apart from the testing of the validity of the random technique, the controlled experiment procedure was also used to estimate the optimal values of the parameters involving the plan effectiveness. A more detailed description of the experiments and their results are discussed in Highway Research Record No. 422, "Use of Random Search Technique to Obtain Optimal Land Use Plan Design" by Sinha, et al.

OUTLINE OF THE MODEL ALGORITHM

In the beginning of this chapter, the theoretical basis of the model was examined. In this section, an outline of the basic steps of the model algorithm is presented, including random placement of module in cell, test for intracell constraints, test for intercell constraints, calculation of site and linkage costs, and calculation of the number of plans required. A flow chart of the computer program is shown in Figure 6.

Step 1: Initial Random Placement of Modules in Cells

Each module is selected in random sequence and assigned to one of the geographic cells by means of a random number generator program. Each module has an equal chance of being selected for placement, and each cell has an equal chance of being selected for the choice of location. A random sequence must be used as well as random placement in order not to bias the placement process. Once a module is located in a particular cell, step two determines whether or not the placement in that particular cell is valid.

Step 2: Intracell Constraint Test

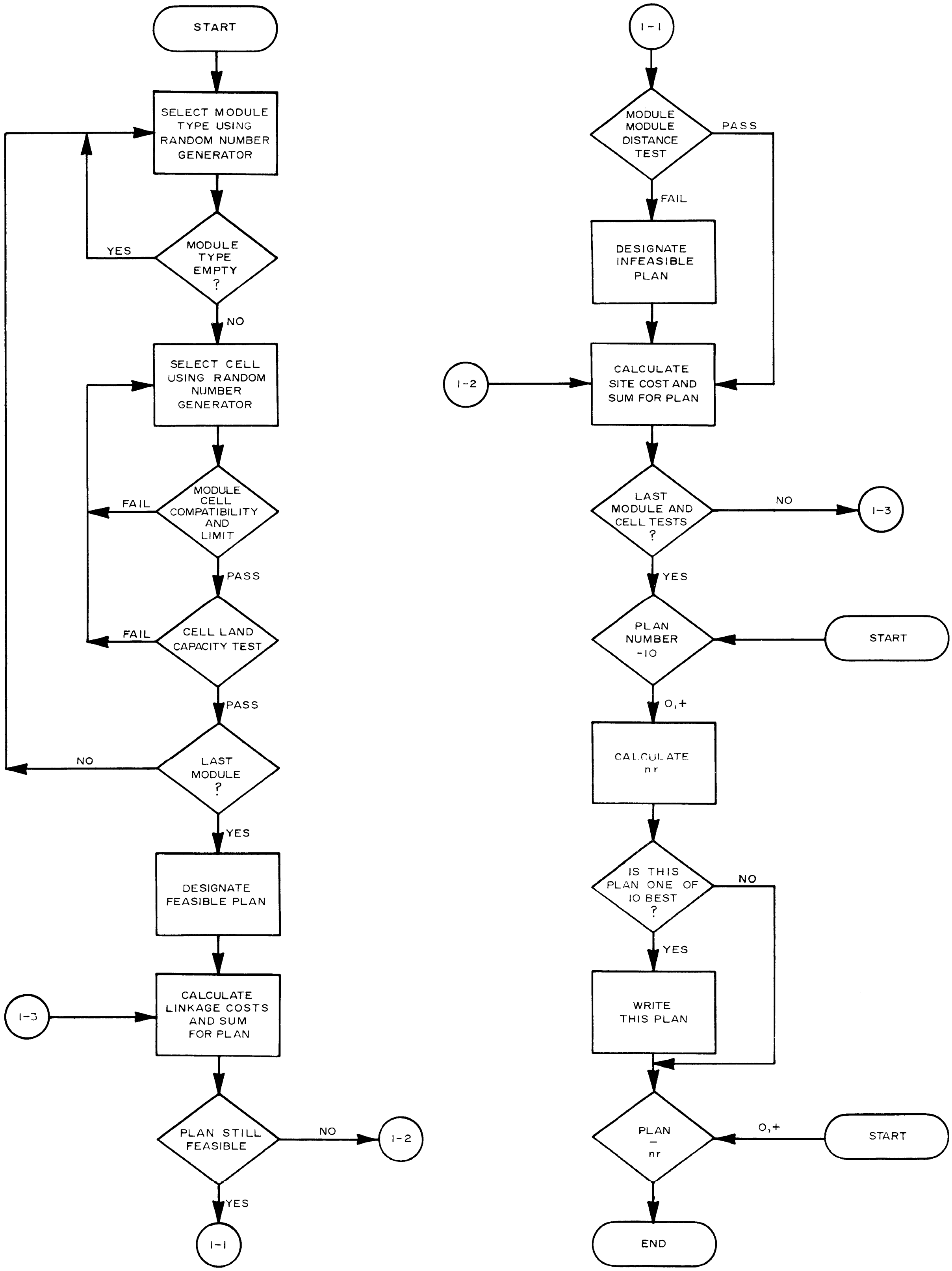
Certain constraints prevent the location of designated modules in designated cells. These constraints are of two types: Module-Cell Constraints and Module-Cell Limits.

The Module-Cell Constraint Test prevents certain types of modules from being located in certain cells. This constraint is independent of all other modules in a cell and prevents all modules of a type from

[4] *K. C. Sinha, J. T. Adamski, and K. J. Schlager, "Use of Random Search Technique to Obtain Optimal Land Use Plan Design," Highway Research Record Number 422, Highway Research Board, Washington, D. C., 1973.*

Figure 6

LAND USE PLAN DESIGN MODEL PROGRAM FLOW CHART



Source: SEWRPC.

placement in a particular cell since some cells are not suitable for certain types of development. This constraint is indicated by the Module-Cell Matrix in which a "1" indicates a valid placement and a "0" indicates an invalid placement.

The Module-Cell Limit Test depends on the other modules previously located in a particular cell. First of all, each cell has a land capacity which cannot be exceeded. If the area utilized by the previously located modules is such that the new module's area would exceed the total area of the cell, the new module will be rejected. Finally the module-cell limit vector designates the maximum number of a given module which may be placed in any one cell. For example, certain modules such as a secondary school will be limited to one per cell. Other modules may also be limited in quantity in each cell.

If a module placement is acceptable, the random placement process selects the next module for placement. If the module placement is rejected, a new random placement is generated. New placements are generated until the module is located in a valid cell.

Step 3: Last Module Test

The last module test is a simple test that determines whether all modules have been placed. If they have not, steps one and two are repeated. When the last module has been placed, an experimental plan has been designed. This plan must now be tested for intercell constraints.

Step 4: Intercell Constraint Tests

Intercell constraints pertain to the spatial relationships between modules in different cells. Since these constraints depend upon the geographic distances between cells, these distances must first be determined. For each cell, the distance between it and every other cell must be calculated. This is repeated until distances have been calculated for each cell to all other cells. These distances are fixed and need not be calculated again.

For each cell, other cells then are ordered in sequence by their distance from the cell. Each module in the cell is then examined to determine if there is a module within the constraint distance requirement. These intercell constraints are specified by the Module-Module Matrix which specifies the maximum or minimum distance required between modules. The process then is repeated for each additional cell.

If all of the modules tested satisfy the intercell constraints, the experimental plan is designated feasible. If not, the plan is designated infeasible. The ratio of feasible plans to total plans is stored for future reference since it will be used to determine the number of experimental plans required for the specified design accuracy.

Step 5: Site and Linkage Cost Calculation

The next step in the model is the calculation of site and linkage for each experimental plan. Costs are calculated for infeasible as well as feasible plans for the later sensitivity analysis of the effects of constraints. The site costs are derived from the Module-Cell Site Cost Matrix. Then, the linkage costs are calculated for connecting each module to its closest module of each type using the Module-Module Linkage Cost Matrix. All feasible and infeasible plans then are stored in rank order with the lowest cost plans first.

Step 6: Calculation of the Number of Plans Required

The next step in the model operation is the determination of the number of plans which should be run. As stated in the beginning of this chapter, this is a function of the desired plan accuracy, the desired probability of achieving a plan with said accuracy, and the probability that a plan is feasible. While the desired plan accuracy and the probability of achieving a plan with this particular accuracy are constant throughout the run, the probability that a plan is feasible must be determined experimentally during the run.

When the required number of plans, as calculated, has been run, the program ranks the plans in order with the lowest cost plan first. Finally, results are printed and the program halts. The complete computer program is presented in Chapter V. In the remainder of this chapter, the data inputs to the model and the output format are presented.

DATA INPUT

This section provides a general description of the types of data used as inputs to the model. A more detailed description, including sources and required format for input to the model, will be provided in Chapter III.

Module-Module Constraint Matrix

This matrix indicates the maximum distance (or the minimum distance, designated by a minus sign) permitted between one module and the next closest module. This matrix is based on spatial accessibility and compatibility standards as enumerated in module definitions. For example, a residential module may have as a spatial accessibility standard that it be within five miles of a high school module. Or, an incinerator-sanitary landfill module may have as a compatibility standard that it not be located contiguously to a residential module. This input affects model operation directly since a plan not meeting the constraints is termed infeasible by the model.

Module-Cell Site Cost Matrix

Each module contains several elements, each of which serves as a functional component of the module. Costs of construction are prepared for each of the elements as a function of soil texture, slope, depth to water table, and depth to bedrock. The result is a matrix which shows the cost of locating any given module in any given cell, based on the costs of the components of the module, and the particular site conditions in each cell.

One may visualize, for example, a high-density residential module of approximately 150 acres containing certain facilities in fixed quantities and arrangements. As this module is moved in the planning area, the costs of construction of all soil-related components of the facilities, and hence the site development cost will continually change with variations in soil type and topography. These costs for each module are indicated in the Module-Cell Site Cost Matrix.

Module-Module Linkage Cost Matrix

Cost inputs to the model consist of two basic types. The first, as enumerated above, consists of the costs of development for functional elements of each module. The second type consists of the cost for linkages. Each module has specific linkage requirements as designated in its design standards. For each type of linkage, construction and operating costs are calculated. Construction costs are the costs of building the linkage per unit distance of construction. Operating costs, or the cost of using the linkage, are discounted to present value. Finally, based upon the linkage requirements for each module to the closest second module, the matrix is compiled.

Plan Accuracy and Success Probability Requirements

As stated in the beginning of this chapter, in utilizing the random method, the planner must specify what the desired plan accuracy is. Does he wish to obtain a plan within the lowest 10 percent of all possible plan costs? Or does he wish to obtain a plan within the lowest 5 percent of all costs? Next, the planner must determine what assurance he would like to have of obtaining a plan within the previously selected cost range. Does he wish an 80 percent chance of obtaining a plan within the desired cost range, or would he prefer to have a 99 percent probability of success? These two factors must be included as inputs to the model in order to determine the number of plans the model makes. As previously stated, the number of plans to be made cannot be determined before the run, but must be determined during the run.

Modules (Number and Area by Type)

The first set of input data indicates the number of each type of module and the land area required by each. For example:

Module Type Code	Description	Number of This Type Required	Acres
1.	Residential (low-density)	35	2,521.6
2.	Community Commercial Center	37	28.2

The number of each module is determined externally to model operation based upon the stated allocation standards while the size is determined in the process of module definition. The size (area) of the modules affects module operation directly in terms of module-cell placement. If the size of a module exceeds the available land remaining in a cell, its placement will be rejected. In addition, the number and size of modules will affect model output in terms of cost in the sense that the greater the area indicated for development, the greater the cost.

Cells (Number Designation, Area, and Geographic Coordinates)
Each cell is assigned a number designation with which the land areas and geographic coordinates of the cell comprise the second set of input data.

The Module-Cell Constraint Matrix
This input designates which module may be located in which cell. The matrix is binary in that a "1" designates an acceptable module-cell placement, while a "0" indicates an unacceptable or invalid placement. The purpose of this input is to prevent either certain types or all types of modules from being located in specified cells. For example, this matrix could prevent the location of any module in a given cell which was presently fully developed; or, it could permit a low-density residential module to be located in a cell which contained a major natural watershed boundary, while prohibiting the placement of a medium- or high-density residential module in that cell.

Module-Cell Limit Vector
The module-cell limit vector simply limits the number of a particular type of module which may be placed in any one cell. While for some types of modules, such as the residential modules, location of more than one in a cell may be acceptable, or even desirable, for others, this type of clustering would be meaningless. Examples would include almost all of the various service modules which logically would be dispersed throughout the Region in order to service the residential areas.

MODEL OUTPUT

The model generates three categories of output reports:

1. Module-Cell Placement Matrix

2. Plan Costs

3. Constraint Schedule Analysis

Module-Cell Placement Matrix
This report, which is the most basic output of the module run, is essentially a land use plan design in tabular form, indicating which modules are located in which cells. The number of modules by type in each cell is tabulated and the data are printed beginning with the lowest cost plan. Higher cost plans also can be printed at the option of the user. Based on this report, the traditional plan presentation maps can be prepared by the planner or draftsman.

Plan Costs
This report details the site and linkage costs of each plan, along with a total cost for each plan. Here again the lowest cost plan is printed first.

Constraint Schedule Analysis
There is a special set of reports detailing the effects of the intercell constraints on the feasibility of an experimental plan. Each violation of the module-to-module distance constraints is reported along with the locations of each pair of modules under consideration, and the actual distance between these modules as well as the specified distance constraint for this set of modules.

Chapter III

INPUT DATA REQUIREMENTS

INTRODUCTION

Since the planner-user of the land use plan design model may be expected to spend most of his time either preparing input data for the model or interpreting its output results, this chapter on input data and Chapter VI on model output interpretation are most important to the planner. Chapters I and II of this report provide important background for understanding the land use plan design problem and the theory of model operation. Chapters IV and V on computer operations are only of background interest to the planner, as these chapters provide working information for the computer programmer and computer operator.

NATURE OF MODEL INPUT DATA

Prior to any detailed discussion of the nature and format of model input data, some general considerations relative to the input data and its effect on model operations are appropriate. The input data requirements are summarized and presented in tabular form beginning with Table 3. As previously presented in Chapters I and II, model input data may be considered in four categories:

1. Module Data

2. Land Data

3. Constraint Data

4. Cost Data

All four of the above categories of data affect model operation and output either directly or indirectly. Since input data completely determine the output of the model, the input data and its accuracy are crucial to the effective use of the model in planning.

Input Data Accuracy

Because the costs of data collection and reduction are high, it is important to understand the difference between required data accuracy and unnecessary data accuracy. Improved accuracy of input data, like most commodities, has a point of diminishing returns. Beyond this point, the costs of data collection and reduction exceed the benefits of improved input data accuracy.

The concept of sensitivity analysis aids in understanding data accuracy requirements. In this application sensitivity analysis is concerned with determining the effect of variations of model input data on model output results. For example, what is the effect of a 10 percent error in a module site cost parameter? How would such an error affect the model output plan? If a 10 percent site cost error does not significantly change the output plan design, attempts at reducing the site cost error to 5 percent are not worthwhile.

Although operational experience with the model to date has not been sufficient to permit expression of any firm generalizations about input data sensitivity, some general observations resulting from early experience with the application of the model may be appropriate.

1. Most model input parameter errors have little effect as long as they are small, but once the error reaches a certain size, its effect increases sharply as illustrated in Figure 7.

Table 3

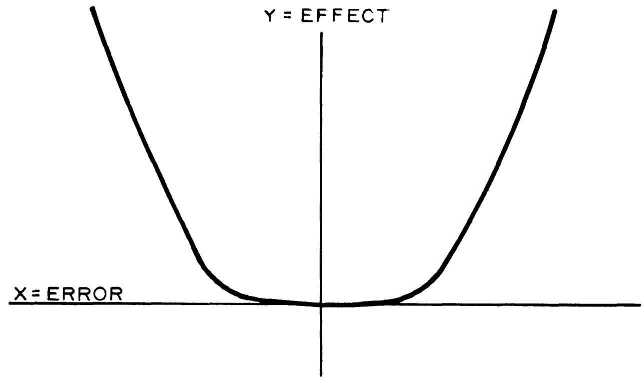
MODULE/ALLOCATION STANDARDS

Module Type	Allocation Standard	Number of Required Modules
Low-Density Residential	8,200 Residents	1
Medium-Density Residential	6,500 Residents	1
Neighborhood Commercial Center (low density)	Low-Density Residential Module	2
Community Commercial Center	71,500 Residents	1
Senior High School	63,000 Residents	1
Planned Industrial District (Light)	9,100 Employed Persons	1
Municipal Hall	14,000 Residents	1

Source: SEWRPC.

Figure 7

ERROR PARAMETER FUNCTION



Source: SEWRPC.

2. The planner defines some of the model input data such as constraint data and most module data. Other model input data such as most land data and cost data are not defined by the planner but must be observed or measured. The previous observations about sensitivity analysis and the economics of data accuracy apply mostly to this second category, since no data collection in the measurement sense is involved in definitions data.

3. Soil data accuracy does not appear to be crucial since it primarily determines site costs, which are small in relation to linkage costs, and establishes certain module cell constraints which usually depend only on a broad classification of soil types. This low accuracy requirement should not diminish the importance of soil data, since without it, the land resource base would be ignored by the model.

4. The largest single cost factor is the travel linkage costs. This operations cost is significantly larger than the largest linkage construction cost: highway construction. Both of these transportation costs overshadow any of the site costs.

5. Many constraint restrictions are crucial in determining plan design output. Since the complexity of model interrelationships prevents generalizations, experimentation provides the only reliable avenue for determining the effects of individual constraints. A systematic approach to such experimentation should involve statistical techniques such as experimental design.

With these general considerations in mind, the details of input data content and format will now be explored.

MODULE DATA

Module data may be classified in three categories:

1. Data which directly affect model operations as primary inputs.

2. Data which indirectly affect model operation by their influence on module site and linkage costs.

3. Data which aid in module definition but do not directly affect model operations.

Obviously, accuracy considerations are important only in the first two categories of data. Data in the third category, from a model point of view, are important only in their indirect effect on the first two categories. Module data described in the paragraphs below will be simplified by reference to the module descriptions for the low-density residential module and the neighborhood commercial center module.

Primary Module Data

Direct module data consist of only two elements:

1. The number of each type of module.

2. The land area of each module.

The number of modules in each type category is determined by a primary variable such as population or industrial employment, or by a service ratio based on the number of service modules needed to service the primary modules as shown in Table 3. The factors shown in the table are meant to be illustrative only. Even the method may be modified easily by the model user. In the low-density residential module, the ratio used to determine the number of this module is designated under Allocations Standards (under Design Standards—2, Intermodule Standards): one module is allocated for each 8,200 people in the community or region.

By way of contrast, the association standard for the neighborhood commercial center module depends on a service ratio to the number of low-density residential modules. Two centers are allocated for each low-density residential module.

The gross land area of each module is listed in Appendix A. The gross area is, of course, the sum of all of the component areas comprising the module.

Module Site Construction Elements and Linkage Requirements

Site construction elements, expressed in terms of land area acreage, such as building areas, open-space areas, and parking service areas, fall into the second category of module data since they influence module costs. Along with two other determinants, soil and topography, site construction elements determine the Module-Cell Site Cost Matrix. The methods used for the summation of construction elements to determine site costs will be discussed later in this chapter under Costs. Similar data is illustrated under the Area section of the neighborhood commercial center. These area data serve as direct input for module site cost determination in the data reduction computer programs.

Module linkage requirements establish the basis for calculating the Module-Module Linkage Cost Matrix. Details of this calculation are presented under Costs. The linkage requirements standards, enumerated under Intermodule Standards for both module type examples, not only determine the linkage cost matrix, but also influence the site cost matrix for the linkages internal to a mdoule; e.g., the streets of a residential module.

Module Definition Detail

Some of the descriptive material in the module data such as the purpose of the module and comments on land use characteristics are only of indirect importance to model operation. However, this does not diminish their significance since they aid in understanding the function of the module and often directly influence data in the direct categories previously described.

LAND RESOURCE DATA

Since one of the primary objectives of land use plan design is the conservation of a scarce resource—land—it follows that data on the land resource are an important part of model input data. Although land data are not a direct input to the model, they achieve their importance through their indirect influence on other primary input data. Three such indirect effects should be noted:

1. The topographic and soil characteristics of the land may significantly influence the spatial organization of cells used for module placement in model operation.

2. Land data have an important influence on constraint inputs to the model, particularly the Module-Cell Constraint Matrix. For instance, land subject to periodic flooding and land covered by wet soils would be excluded from consideration for many forms of development.

3. Land data in the form of soil characteristics provide the primary input for calculating module site costs. This use of land data is the most demanding in terms of its need for detail and accuracy.

The Soil Survey—Basic Land Data Source

All of the above three uses of land data depend to a greater or lesser extent on the basic source for land resource data: the soil survey. Cell delineation often requires only crude information on soil characteristics, while constraint data inputs need more precise soil information. Site cost determination presents even more stringent requirements for soil data to produce accurate module site costs.

Since this report is not intended as a basic reference in conducting soil surveys or even in the manipulation of soil data, the model user is referred to publications such as the Soils Development Guide published by the Southeastern Wisconsin Regional Planning Commission for a detailed understanding of soil data and their applications in land development. It is useful here, however, to provide a brief summary of the background of soil surveys and their usefulness in land use planning.

Soil surveys are concerned with identifying, classifying, mapping, and interpreting one of the most important of all natural resources—the soil. Soil has been defined in an engineering sense as any earth material except embedded rock. Although soil scientists more narrowly define soil in terms of a shallow layer of the earth's crust, soil, in the sense of the data for the land use plan design model, is more closely related to the engineering definition. In fact, to the lay observer unfamiliar with soil terminology, the definition might seem to embrace characteristics such as topographic slope not generally connects with soil. As used in the land use plan design model, soil encompasses the following characteristics:

1. Soil texture (fine, coarse, organic, bedrock)
2. Slope
3. Depth to water table
4. Depth to bedrock

Soil surveys have been conducted on an organized basis in the United States since 1899. A publication of the U. S. Department of Agriculture, "List of Published Soil Surveys," tabulates those soil surveys completed since 1899. Although early emphasis in the use of soil survey data was agricultural, soil interpretation in recent years has been used to guide land development for a broader range of activities, including residential, industrial, and recreational land development. The effects of land (soil) data on each of the remaining three categories of model input data will be discussed in turn.

Cell Patterns

Land data can play a significant role in the cell pattern selected for a land use plan design model application. Cell patterns may ignore topography and soil conditions through the use of regular geometric patterns of rectangular cells of equal or unequal size, but it is often useful to consider topography and soil in a cell pattern configuration. For example, in a wet marsh area, it is natural to consider the marsh as a cell (or group of cells) since the topographic and soil conditions are fairly uniform throughout the area. The same situation would hold true for a mountain range. In an area with slight variations in topography or soil conditions, a regular, geometric pattern may be quite appropriate. For areas with significant topographic or soil change, cell boundaries should be drawn with a view to maintaining uniform conditions throughout each cell.

Determining Cell Size: The planner also determines the cell size, which is a function of the size of the modules. The smallest cell should be at least four times as large as the largest module, which, in most cases, will be the low-density residential module. While the maximum size of cells is not restricted if cells are too large, the resulting plan will be too granular, and the results difficult to interpret with any degree of accuracy.

It is not necessary that all cells be the same size; however, a great disparity in cell size will serve to discriminate against the smaller cells in module placement. It will also affect cost calculations since linkage costs are based on distances measured from the center of one cell to the center of another.

The following may serve to indicate possible cell size. At the regional level, in applying the model to the Southeastern Wisconsin Region with an area of 2,689 square miles, the Region was divided into 347 cells. The standard cell size was six U. S. Public Survey Sections (approximately six square miles), though cell size did vary from four to eight such sections. In applying the model to the Village of Germantown, Wisconsin, with an area of 36 square miles, the definition of cells was based on U. S. Public Land Survey one-quarter sections. Within the Village of Germantown 144 such cells, each one-quarter square mile in area, were used.

Designating Cell Numbers: After determining the type of cell pattern to be used, and the approximate size of the cells, the next step is to draw the actual cell pattern on a map of the area, and provide each cell with a number designation.

The actual data needed as input to the model are the number designation, area, and geographic coordinates of the center of each cell. Cell areas are determined in the data reduction program by summarizing the soil inventory in each cell.

Cell (Geographic) Unit: Often, the areal unit for which soil and other data are available is not the unit appropriate for a cell. As long as the areal unit is smaller than any cell unit desired, cell areal combinations of data areas may be accumulated as part of the data reduction process described in Chapter IV. It is only necessary that the model user designate the cell in which each data areal unit is to be located by creating the Geographic Unit Cell Cross Reference Cards.

Soil Interpretation and Module-Cell Constraints

The use of soil data for module-cell constraint determination requires the interpretation of the suitability of soils for various forms of land development. Since such interpretation has been the primary end-product of all previous soil surveys, the planner is able to make use of the wealth of knowledge accumulated in this field over the past years.

The previously mentioned Soils Development Guide published by the Southeastern Wisconsin Regional Planning Commission provides background material on soil survey procedures, but it is of primary value in its interpretation of soil data in terms of the suitability of various soils for various types of land development. This information can lead directly to the development of the Module-Cell Constraint Matrix since each module-cell combination can be examined in terms of the suitability of soil conditions for the development of each type of module. Such an approach imposes a requirement that the cell pattern be organized with reasonably homogeneous soil patterns, since it is not possible to constrain modules from development in certain cells if the cells have a widely varying soil pattern.

Ultimately, the whole question of soil constraints on land development in the framework of the modules and cells of the Land Use Plan Design Model reduces to another matrix which includes soil types as one axis and modules as the other. However, if soil type were the only reason to constrain placement of certain modules or certain cells, the Module-Cell Constraint Matrix would be only a simple transformation of a module soil type matrix; that is, specification of the soil typology of each cell would automatically determine the module cell constraints. But, even though nonsoil and module-cell constraints influence the final determination of constraints, soil conditions remain the primary determinants of the Module-Cell Constraint Matrix.

Soil Characteristics and Module Site Costs

A detailed discussion of the methodology for developing module site costs will be reserved for a later section of this chapter on costs, but at this point it is important to understand the land (soil) data base classification used to determine module site costs.

Because of the errors inherent in other input data used in site cost determination, a more general classification of soil types is completely adequate for site cost calculation. Four soil characteristics having important effects on site development costs are used in the soil category classification illustrated in Table 4. These elements are:

1. Soil Grain

2. Topographic Slope

3. Depth to Bedrock

4. Depth to Water Table

As shown in the table, four classes of soil grain are used: fine grain, coarse grain, organic, and bedrock.

Eight slope categories are distinguished, ranging from flat terrain (Group A—less than 0.5 percent slope) to slopes with an average grade of 37.5 percent (Group F).

Three classes of depth to water table (less than 1 foot, 1 to 5 feet, 5 feet or more) and three classes of depth to bedrock (less than 2 feet, 2 to 5 feet, 5 feet or more) are included.

Table 4

SOIL CATEGORY RELATIONSHIP MATRIX

Unified Soil Classification	Slope Group[1]	Less Than 1 ft. To Water Table			1 ft. To 5 ft. To Water Table			5 ft. And Over To Water Table		
		Less than 2 ft. to Bedrock	2 ft.-5 ft. to Bedrock	5 ft. and over to Bedrock	Less than 2 ft. to Bedrock	2 ft.-5 ft. to Bedrock	5 ft. and over to Bedrock	Less than 2 ft. to Bedrock	2 ft.-5 ft. to Bedrock	5 ft. and over to Bedrock
Fine Grained Soils	A B C_1 C_2 D_1 D_2 E F	1111[2]	1121	1131	1211	1221	1231	1311	1321	1331
		1112	1122	1132	1212	1222	1232	1312	1322	1332
		1113	1123	1133	1213	1223	1233	1313	1323	1333
Coarse Grained Soils	A B C_1 C_2 D_1 D_2 E F	2111	2121	2131	2211	2221	2231	2311	2321	2331
		2112	2122	2132	2212	2222	2232	2312	2322	2332
		2113	2123	2133	2213	2223	2233	2313	2323	2333
Organic Soils	A B C_1 C_2 D_1 D_2 E F	3111	3121	3131	3211	3221	3231	3311	3321	3331
		3112	3122	3132	3212	3222	3232	3312	3322	3332
		3113	3123	3133	3213	3223	3233	3313	3323	3333
Bedrock	A B C_1 C_2 D_1 D_2 E F	---	---	---	---	---	---	4311	---	---
		---	---	---	---	---	---	4312	---	---
		---	---	---	---	---	---	4313	---	---

[1] *The percent average slope for each slope group is as follows: A equals 0.5 percent, B equals 3.5 percent, C_1 equals 7 percent, C_2 equals 10 percent, D_1 equals 13 percent, D_2 equals 17 percent, E equals 24.5 percent, F equals 37.5 percent.*

Source: SEWRPC.

[2] *This four digit code number synthesizes four significant soil characteristics deemed requisite for cost estimation. Critical ranges of these characteristics; soil texture, depth to water table, depth to bedrock, and slope; are represented by the first, second, third, and fourth digits, respectively.*

CONSTRAINT DATA

As explained previously in Chapter I, constraints are the reflections of the basic goals of objectives of the plan design. Other than costs, all other plan objectives must be reflected in the plan constraints.

Two broad classes of constraints are implemented in plan design model operation:

1. Site constraints (Module-Cell Constraint Matrix and Module-Cell Limit Vector)

2. Accessibility Constraints (Module-Module Constraint Matrix)

Site Constraints

The first of the above two classes excludes the placement of certain modules on certain cells.

The primary determinants of site constraints are the soil characteristics discussed previously in this chapter. Furthermore, in some instances, soil characteristics may be the only determinant of soil constraints in a design model application.

Since the other possible nonsoil determinants of site constraints are too numerous and varied to classify, they do not provide a convenient structure such as a soil typology. For this reason, it is only possible to suggest other criteria for site constraints. These suggestions may do no more than suggest other more suitable reasons for site constraints, or they may be directly useful as constraints in the application in question. In either case, they will have served their purpose.

The following nonsoil criteria for site constraints are suggested:

1. The desire to preserve prime agricultural land for farming and to exclude it from residential development.

2. The desire to reserve certain land exclusively for recreational and related open space use.

3. The need to exclude certain land from development because of the potential for flooding.

4. The need to exclude certain land that is not available for development (such as a military reservation).

Many other varied reasons for site constraints may be pertinent in other planning applications.

Accessibility Constraints

These constraints reflect the need for easy accessibility between modules which render frequent service to each other. Residential modules must have accessibility to shopping centers, schools, hospitals, and certain government services. However, these accessibility constraints must be consistent with the number of modules determined during the placement process. For example, a high school cannot be located within five miles of every residential module if enough high school modules are not available. In such a case, an infeasible solution will result. Sometimes, determining the quantity of each module that is consistent with the accessibility constraints may necessitate experimenting with varying quantities of a service module until a feasible solution is obtained.

Beyond the above general counsel, it is not possible to detail the accessibility constraints in this manual since the accessibility constraints are derived from planning standards which are beyond the scope of this manual. Such accessibility standards are available, however, in the planning literature.

COST DATA

The primary objective of the land use plan design model is to spatially allocate land uses within the planning area so as to minimize development costs within the constraints imposed by the stated development objectives. The model thus requires two sets of cost input data: site cost data and linkage cost data. Site cost data input consists of construction costs for each of the elements associated with site development within a module such as grading, building foundations, and parking lots. The costs of elements associated with site development must be related to various possible spatial locations within the planning area; that is, all site development elements are soil-related. The second set of cost data linkage costs consists of costs of construction, maintenance, and operation for each of the required communication links between modules such as streets, sewer lines, and water mains.

The Soil Survey and Cost Tables

The two primary data bases used to estimate both site and linkage costs are:

1. The soil survey.

2. The development cost tables (see Tables 5 through 11).

The soil survey is the primary input in the determination of site costs. An inventory of the soil typology in a given cell coupled with an enumeration of the elements making up a module permits a direct calculation of the site costs for that module-cell combination using the development cost tables. The lack of a suitable soil survey would severely limit the compilation of module-cell site cost data. As previously noted, however, the precision of the soil survey need only classify land according to the soil category relationship matrix (see Table 4). Such a survey, designated as general rather than detailed, can be completed at less cost than a detailed soil survey.

Only the development cost tables are used in the compilation of linkage construction costs since it is not practical to consider soil conditions along all possible route locations for all linkages. The inaccuracies introduced by the use of an "average" soil condition are reduced in importance by the fact that the operating cost component of linkage costs tends to be much larger than the construction costs for the major linkage: highways and other roads.

The second class of linkage costs, operating linkage costs, depends only on the cost of travel, since non-transportation operating linkage costs are ignored in model usage. Annual operating travel costs are reduced to a present value using an estimated interest rate.

Site Cost Development

Each module consists of elements which occur in one or more of the several module types and in combination with one or more of the other elements as a functional subcomponent of the module. Also, a number of common linkages serve to interconnect a number of different modules.

It is these intramodular elements and intermodule linkages for which costs of construction have been prepared. All intramodule element costs have been formulated within the framework of Table 4; that is, all costs are a function of soil grain, slope, depth to water table, and depth to bedrock. The common unit of cost evaluation is dollars per linear foot for linkages or elements such as water mains or sewer lines, and dollars per acre for elements such as parking lots.

To eliminate the need to perform numerous tedious manual computations, computer programs were written to generate costs in the format of Table 4 for most of the elements and linkages. Using these tables, site costs may be summarized by adding all of the element site costs for all of the soil conditions existing within the cell. It should be emphasized that the development costs in the tables are expert estimates for a given location, Metropolitan Milwaukee, for a given time period, 1967. Use of these tables in other areas and other time periods will require the use of an index. An excellent source for these time and place construction indexes is the Engineering News-Record magazine. Indexes for both time and place are presented on a regular basis in this publication. Study of the computer analysis revealed certain consistent and predictable patterns of variation in costs. Generally, costs increased as depth to bedrock decreased and depth to water decreased. In those instances where grading or right-of-way or site entered as a cost factor, such as a highway right-of-way or a paved play area, cost increased with increase of slope due to the greater quantities of material to be moved.

A sample site cost compilation for a residential (low-density) module is shown in Table 12. Although site costs would normally be automatically compiled on the computer using the data reduction program package, this manual tabulation is used to provide the user with an understanding of the site cost compilation process.

Table 12

SITE COST COMPILATION FOR
LOW-DENSITY RESIDENTIAL MODULE

Module Element	Units	Unit Cost	Site Cost
1. Arterial Street	10,560 feet	$ 52/foot	$ 549,120
2. Collector Street	10,560 feet	28/foot	295,680
3. Local Street	245,000 feet	23/foot	5,635,000
4. Building Area	114.1 acres	704/acre	80,326
5. Parking Area	11.4 acres	3205/acre	36,537
6. Playgrounds	12.6 acres	3022/acre	38,077
7. On-Site Sewage Disposal	2,485 installations	1260/installation	3,131,100
8. Water Supply	150,000 feet	14/foot	2,100,000
9. Gas Supply	150,000 feet	8/foot	1,200,000
10. Electric Power Lines	75,000 feet	12/foot	900,000
11. Telephone	75,000 feet	12/foot	900,000
12. Storm Drainage	266,720 feet	4/foot	1,066,880
		Total Site Cost	$15,932,720

Source: SEWRPC.

Linkage Cost Development

Linkage costs are compiled from three components: cost of construction, cost of maintenance, and cost of operation.

Operating linkage costs are separated from construction and maintenance costs not only for data collection purposes but because of their different effect on model operation. A construction-maintenance linkage of the highway type requires only a single linkage between cells no matter how many modules of each type are in the interconnected cells. While the capacity of this link varies with the number and type of modules, only a single linkage is required.

For purposes of comparison, let us examine the costs of construction of some of the linkages. For water distribution lines, costs ranged from about $40,000 per mile to $500,000 per mile for pipe diameters from 6 to 60 inches. Storm sewer costs ranged from $28,000 to $200,000 per mile for pipe diameters from 8 to 54 inches. For sanitary sewer pipe diameters of 8 to 24 inches, construction costs were found to range from about $48,000 to $190,000 per mile.

Construction costs of thoroughfares ranged from about $200,000 to $5,000,000 per mile for facilities ranging from urban lane access streets to urban 8-lane freeways, respectively. The equivalent rural facility costs were found to range from $250,000 to $950,000 per mile. Railroad line costs were found to range from $100,000 per mile for single track industrial sidings to $200,000 per mile for single track main line.

The construction cost ranges given as examples for water lines and sewers are for an assumed field condition of fine grained soil, slope group A (0.5 percent slope), and more than five feet to water table and bedrock. Other soil categories would yield different cost values for each of the linkages.

Thoroughfare and railroad mainline costs are averages of the costs per mile based on the most favorable and the most adverse categories of Table 4. In addition, the three highest figures for thoroughfares and railroads include factors of about 25 percent for bridges, interchanges, and/or other right-of-way structures.

Road User and Operating Costs: A comparison of construction costs with vehicle operating and road user costs on several urban and rural freeways is of interest. To make a direct comparison, the annual road user cost of each facility based upon capacity was discounted to its present value. The discounting was calculated using an interest rate of 6 percent and a term of 20 years. The results are tabulated in Table 1. The present value of vehicle operating cost is many times greater than street and highway construction cost. In the operation of the model, when linkage costs are calculated for each plan, the present value of vehicle operating cost generally comprises a large percentage of the total linkage cost. The range of difference between vehicle operating costs and other linkage costs can be illustrated as follows. If one of the largest unit construction costs of about $1,100,000 per mile for an 4-lane rural freeway and one of the smallest unit capital costs of about $40,000 for a 6-inch diameter water main are compared with the present value of vehicle operating cost only on a rural standard arterial, the operating cost is 3.4 and 94 times as large, respectively.

The construction costs of other linkages fall between those of 8-lane urban freeway and 6-inch diameter water main, and yield operating cost/capital cost ratios within the range 3.4 to 94. If the two capital costs given above are compared with any one of the three remaining values in Table 1, considerably larger ratios would result.

Although the above analysis aids in understanding the comparative importance of operating versus construction costs, it does not directly aid the model user in calculating the Module-Module Linkage Cost Matrix used as input to the model. To determine this input data matrix, the following questions must be answered:

1. What linkages are required between modules? (e.g. roads, water lines, sewer lines)

2. What are the construction costs for these linkages per unit distance?

3. What are the operating maintenance costs per unit distance?

Linkage Requirements: Linkage requirements for each module are delineated in the module definition as part of the intermodule design standards. For instance, a typical low-density residential module would require arterial street, water supply, sanitary sewer, gas, telephone, and electric power linkages.

Construction Costs: The construction costs for each linkage then are obtained by extracting the linkage cost per unit distance from the development cost tables that best typify the soil conditions in the area of interest. This unit cost then is converted into linkage cost during model operation by multiplying the unit cost by the distance separating the modules in the experimental plan being costed.

Maintenance Costs: Maintenance costs of all linkages except highway appear to be insignificant. Even highway maintenance costs only amount to about 25 percent of construction costs when discounted to present value. For most users of the model, a maintenance construction cost ratio based on the present value of future maintenance costs is of sufficient accuracy.

Operating Costs: Operating costs of nonhighway linkages also appear to be insignificant. While it is true that water pumping costs are not insignificant in hilly terrain, the effect on overall linkage costs is still trivial. Highway operating costs, however, are the predominant linkage costs between most modules.

Travel Costs: Travel costs are a function of three primary variables:

1. Travel cost per unit distance (e.g. 10 cents per mile).

2. Number of trips performed between modules in a given time period.

3. The interest rate used to determine the present value of future travel costs.

Many studies have been made of travel costs for automobile users and the rate of 10 cents per mile is used on a fairly wide basis for business travel expenses and tax deductions. Different rates may be appropriate in different areas and to allow for the persistent inflation of travel costs.

Trip data should be obtainable from local origin-destination surveys conducted for transportation studies. If local data are not available, data from surveys in other communities similar in size and characteristics often can be used with confidence.

The interest rate used for present value calculations again depends on time and place. With the wild fluctuations in interest rates in recent years, a long-time average interest rate (such as 6 percent) is probably most appropriate.

Development Cost Data

Due to its large bulk, all of the development cost data are not included in this volume. The complete development cost data include cost data for each of the 224 soil categories within each of the 141 linkage and element categories. Cost development tables (see Tables 5 to 11) are included in this manual for eight of the linkage and element categories. A complete list of the linkage and element categories is provided in Table 13.

Table 5

LAND USE DESIGN MODEL CONSTRUCTION COSTS

LATERALS — SANITARY SEWERS, GRAVEL BACKFILL

$ PER FOOT[3]

	Slope[4]	Less Than 1 ft. To Water Table			1 To 5 ft. To Water Table			More Than 5 ft. To Water Table		
		Less Than 2 To Bedrock	2-5 To Bedrock	More Than 5 To Bedrock	Less Than 2 To Bedrock	2-5 To Bedrock	More Than 5 To Bedrock	Less Than 2 To Bedrock	2-5 To Bedrock	More Than 5 To Bedrock
Fine Grained Soils[1]	A	27.08	23.14	19.20	23.70	18.64	13.58	23.70	18.45	13.20
	B	27.08	23.14	19.20	23.70	18.64	13.58	23.70	18.45	13.20
	C1	27.08	23.14	19.20	23.70	18.64	13.58	23.70	18.45	13.20
	C2	27.08	23.14	19.20	23.70	18.64	13.58	23.70	18.45	13.20
	D1	27.08	23.14	19.20	23.70	18.64	13.58	23.70	18.45	13.20
	D2	27.08	23.14	19.20	23.70	18.64	13.58	23.70	18.45	13.20
	E	27.08	23.14	19.20	23.70	18.64	13.58	23.70	18.45	13.20
	F	27.08	23.14	19.20	23.70	18.64	13.58	23.70	18.45	13.20
Coarse Grained Soils[2]	A	27.08	25.39	23.70	23.70	21.45	19.20	23.70	20.33	16.95
	B	27.08	25.39	23.70	23.70	21.45	19.20	23.70	20.33	16.95
	C1	27.08	25.39	23.70	23.70	21.45	19.20	23.70	20.33	16.95
	C2	27.08	25.39	23.70	23.70	21.45	19.20	23.70	20.33	16.95
	D1	27.08	25.39	23.70	23.70	21.45	19.20	23.70	20.33	16.95
	D2	27.08	25.39	23.70	23.70	21.45	19.20	23.70	20.33	16.95
	E	27.08	25.39	23.70	23.70	21.45	19.20	23.70	20.33	16.95
	F	27.08	25.39	23.70	23.70	21.45	19.20	23.70	20.33	16.95
Organic Soils	A	27.08	25.39	23.70	23.70	22.58	21.45	23.70	19.20	14.70
	B	27.08	25.39	23.70	23.70	22.58	21.45	23.70	19.20	14.70
	C1	27.08	25.39	23.70	23.70	22.58	21.45	23.70	19.20	14.70
	C2	27.08	25.39	23.70	23.70	22.58	21.45	23.70	19.20	14.70
	D1	27.08	25.39	23.70	23.70	22.58	21.45	23.70	19.20	14.70
	D2	27.08	25.39	23.70	23.70	22.58	21.45	23.70	19.20	14.70
	E	27.08	25.39	23.70	23.70	22.58	21.45	23.70	19.20	14.70
	F	27.08	25.39	23.70	23.70	22.58	21.45	23.70	19.20	14.70

[1]This texture subclass is based on the unified classifications of CL, CH, and ML as described in SEWRPC Planning Report No. 8, Soils of Southeastern Wisconsin.

[2]This texture subclass is based on the unified classifications of GP, SM, GW, GM, SP, and SC as described in SEWRPC Planning Report No. 8, Soils of Southeastern Wisconsin.

[3]Costs are in Dollars Per Lineal Foot.

[4]Slope categories A, B, C1, C2, D1, D2, E, and F have average slopes of 1, 5, 8, 11, 15, 19, 26, and 30 percent respectively.

Source: SEWRPC.

Table 6

LAND USE DESIGN MODEL CONSTRUCTION COSTS

RAILROAD MAIN LINE

$ PER FOOT[3]

	Slope[4]	Less Than 1 ft. To Water Table			1 To 5 ft. To Water Table			More Than 5 ft. To Water Table		
		Less Than 2 To Bedrock	2-5 To Bedrock	More Than 5 To Bedrock	Less Than 2 To Bedrock	2-5 To Bedrock	More Than 5 To Bedrock	Less Than 2 To Bedrock	2-5 To Bedrock	More Than 5 To Bedrock
Fine Grained Soils[1]	A	20.38	20.30	20.22	20.38	20.27	20.16	20.38	20.26	20.14
	B	22.28	21.80	21.32	22.28	21.62	20.96	22.28	21.56	20.84
	C1	24.56	23.60	22.64	24.56	23.24	21.92	24.56	23.12	21.68
	C2	26.46	25.10	23.74	26.46	24.59	22.72	26.46	24.42	22.38
	D1	28.36	26.60	24.84	28.36	25.94	23.52	28.36	25.72	23.08
	D2	31.02	28.70	26.38	31.02	27.83	24.64	31.02	27.54	24.06
	E	36.34	32.90	29.46	36.34	31.61	26.88	36.34	31.18	26.02
	F	45.84	40.40	34.96	45.84	38.36	30.88	45.84	37.68	29.52
Coarse Grained Soils[2]	A	20.38	20.30	20.22	20.38	20.27	20.16	20.38	20.26	20.14
	B	22.28	21.80	21.32	22.28	21.62	20.96	22.28	21.56	20.84
	C1	24.56	23.60	22.64	24.56	23.24	21.92	24.56	23.12	21.68
	C2	26.46	25.10	23.74	26.46	24.59	22.72	26.46	24.42	22.38
	D1	28.36	26.60	24.84	28.36	25.94	23.52	28.36	25.72	23.08
	D2	31.02	28.70	26.38	31.02	27.83	24.64	31.02	27.54	24.06
	E	36.34	32.90	29.46	36.34	31.61	26.88	36.34	31.18	26.02
	F	45.84	40.40	34.96	45.84	38.36	30.88	45.84	37.68	29.52
Organic Soils	A	20.38	20.44	20.50	20.38	20.37	20.37	20.38	20.35	20.32
	B	22.28	22.65	23.02	22.28	22.24	22.21	22.28	22.10	21.92
	C1	24.56	25.30	26.05	24.56	24.49	24.42	24.56	24.20	23.84
	C2	26.46	27.51	28.57	26.46	26.36	26.26	26.46	25.95	25.44
	D1	28.36	29.72	31.09	28.36	28.23	28.10	28.36	27.70	27.04
	D2	31.02	32.82	34.62	31.02	30.85	30.67	31.02	30.15	29.28
	E	36.34	39.01	41.67	36.34	36.08	35.82	36.34	35.05	33.76
	F	45.84	50.06	54.27	45.84	45.43	45.02	45.84	43.80	41.76

[1]This texture subclass is based on the unified classifications of CL, CH, and ML as described in SEWRPC Planning Report No. 8, Soils of Southeastern Wisconsin.

[2]This texture subclass is based on the unified classifications of GP, SM, GW, GM, SP, and SC as described in SEWRPC Planning Report No. 8, Soils of Southeastern Wisconsin.

[3]Costs are in Dollars Per Lineal Foot.

[4]Slope categories A, B, C1, C2, D1, D2, E, and F have average slopes of 1, 5, 8, 11, 15, 19, 26, and 30 percent respectively.

Source: SEWRPC.

Table 7

LAND USE DESIGN MODEL CONSTRUCTION COSTS

SANITARY SEWAGE COLLECTION LINES — 10 DIA. MAIN ONLY, EARTH BACKFILL | $ PER FOOT[3]

		Less Than 1 ft. To Water Table			1 To 5 ft. To Water Table			More Than 5 ft. To Water Table		
	Slope[4]	Less Than 2 To Bedrock	2-5 To Bedrock	More Than 5 To Bedrock	Less Than 2 To Bedrock	2-5 To Bedrock	More Than 5 To Bedrock	Less Than 2 To Bedrock	2-5 To Bedrock	More Than 5 To Bedrock
Fine Grained Soils[1]	A	21.10	17.82	14.55	16.74	13.87	11.00	16.74	13.53	10.33
	B	21.10	17.82	14.55	16.74	13.87	11.00	16.74	13.53	10.33
	C1	21.10	17.82	14.55	16.74	13.87	11.00	16.74	13.53	10.33
	C2	21.10	17.82	14.55	16.74	13.87	11.00	16.74	13.53	10.33
	D1	21.10	17.82	14.55	16.74	13.87	11.00	16.74	13.53	10.33
	D2	21.10	17.82	14.55	16.74	13.87	11.00	16.74	13.53	10.33
	E	21.10	17.82	14.55	16.74	13.87	11.00	16.74	13.53	10.33
	F	21.10	17.82	14.55	16.74	13.87	11.00	16.74	13.53	10.33
Coarse Grained Soils[2]	A	21.10	21.10	21.10	16.74	18.92	21.10	16.74	15.64	14.55
	B	21.10	21.10	21.10	16.74	18.92	21.10	16.74	15.64	14.55
	C1	21.10	21.10	21.10	16.74	18.92	21.10	16.74	15.64	14.55
	C2	21.10	21.10	21.10	16.74	18.92	21.10	16.74	15.64	14.55
	D1	21.10	21.10	21.10	16.74	18.92	21.10	16.74	15.64	14.55
	D2	21.10	21.10	21.10	16.74	18.92	21.10	16.74	15.64	14.55
	E	21.10	21.10	21.10	16.74	18.92	21.10	16.74	15.64	14.55
	F	21.10	21.10	21.10	16.74	18.92	21.10	16.74	15.64	14.55
Organic Soils	A	21.10	21.10	21.10	16.74	18.92	21.10	16.74	14.12	11.50
	B	21.10	21.10	21.10	16.74	18.92	21.10	16.74	14.12	11.50
	C1	21.10	21.10	21.10	16.74	18.92	21.10	16.74	14.12	11.50
	C2	21.10	21.10	21.10	16.74	18.92	21.10	16.74	14.12	11.50
	D1	21.10	21.10	21.10	16.74	18.92	21.10	16.74	14.12	11.50
	D2	21.10	21.10	21.10	16.74	18.92	21.10	16.74	14.12	11.50
	E	21.10	21.10	21.10	16.74	18.92	21.10	16.74	14.12	11.50
	F	21.10	21.10	21.10	16.74	18.92	21.10	16.74	14.12	11.50

[1] *This texture subclass is based on the unified classifications of CL, CH, and ML as described in SEWRPC Planning Report No. 8, Soils of Southeastern Wisconsin.*

[2] *This texture subclass is based on the unified classifications of GP, SM, GW, GM, SP, and SC as described in SEWRPC Planning Report No. 8, Soils of Southeastern Wisconsin.*

[3] *Costs are in Dollars Per Lineal Foot.*

[4] *Slope categories A, B, C1, C2, D1, D2, E, and F have average slopes of 1, 5, 8, 11, 15, 19, 26, and 30 percent respectively.*

Source: SEWRPC.

Table 8

LAND USE DESIGN MODEL CONSTRUCTION COSTS

SITE GRADING — ALLOWABLE SLOPE 7 PERCENT | MULTIPLY ALL FIGURES BY $10 PER ACRE[3]

		Less Than 1 ft. To Water Table			1 To 5 ft. To Water Table			More Than 5 ft. To Water Table		
	Slope[4]	Less Than 2 To Bedrock	2-5 To Bedrock	More Than 5 To Bedrock	Less Than 2 To Bedrock	2-5 To Bedrock	More Than 5 To Bedrock	Less Than 2 To Bedrock	2-5 To Bedrock	More Than 5 To Bedrock
Fine Grained Soils[1]	A									
	B									
	C1									
	C2	342.00	270.00	198.00	342.00	243.00	144.00	342.00	234.00	126.00
	D1	684.00	540.00	396.00	684.00	486.00	288.00	684.00	468.00	252.00
	D2	1140.00	900.00	660.00	1140.00	810.00	480.00	1140.00	780.00	420.00
	E	1995.00	1575.00	1155.00	1995.00	1417.50	840.00	1995.00	1365.00	735.00
	F	3477.00	2745.00	2013.00	3477.00	2470.50	1464.00	3477.00	2379.00	1281.00
Coarse Grained Soils[2]	A									
	B									
	C1									
	C2	342.00	270.00	198.00	342.00	243.00	144.00	342.00	234.00	126.00
	D1	684.00	540.00	396.00	684.00	486.00	288.00	684.00	468.00	252.00
	D2	1140.00	900.00	660.00	1140.00	810.00	480.00	1140.00	780.00	420.00
	E	1995.00	1575.00	1155.00	1995.00	1417.60	840.00	1995.00	1365.00	735.00
	F	3477.00	2745.00	2013.00	3477.00	2470.50	1464.00	3477.00	2379.00	1281.00
0 Soils	A									
	B									
	C1									
	C2	342.00	397.80	453.60	342.00	336.60	331.20	342.00	315.00	288.00
	D1	684.00	795.60	907.20	684.00	673.20	662.40	684.00	630.00	576.00
	D2	1140.00	1326.00	1512.00	1140.00	1122.00	1104.00	1140.00	1050.00	960.00
	E	1995.00	2320.50	2646.00	1995.00	1963.50	1932.00	1995.00	1837.50	1680.00
	F	3477.00	4044.30	4611.60	3477.00	3422.10	3367.20	3477.00	3202.50	2928.00
Bedrock	A									
	B									
	C1									
	C2							342.00		
	D1							684.00		
	D2							1140.00		
	E							1995.00		
	F							3477.00		

[1] *This texture subclass is based on the unified classifications of CL, CH, and ML as described in SEWRPC Planning Report No. 8, Soils of Southeastern Wisconsin.*

[2] *This texture subclass is based on the unified classifications of GP, SM, GW, GM, SP, and SC as described in SEWRPC Planning Report No. 8, Soils of Southeastern Wisconsin.*

[3] *Costs are in Tens of Dollars per Acre Graded.*

[4] *Slope categories A, B, C1, C2, D1, D2, E, and F have average slopes of 1, 5, 8, 11, 15, 19, 26, and 30 percent respectively.*

Source: SEWRPC.

Table 9

LAND USE DESIGN MODEL CONSTRUCTION COSTS

STORM SEWER COLLECTION LINES — 54 DIA. MAIN ONLY, GRAVEL BACKFILL | $ PER FOOT[3]

		Less Than 1 ft. To Water Table			1 To 5 ft. To Water Table			More Than 5 ft. To Water Table		
	Slope[4]	Less Than 2 To Bedrock	2-5 To Bedrock	More Than 5 To Bedrock	Less Than 2 To Bedrock	2-5 To Bedrock	More Than 5 To Bedrock	Less Than 2 To Bedrock	2-5 To Bedrock	More Than 5 To Bedrock
Fine Grained Soils[1]	A	65.30	63.80	62.30	61.30	56.80	52.30	57.30	50.80	44.30
	B	65.30	63.80	62.30	61.30	56.80	52.30	57.30	50.80	44.30
	C1	65.30	63.80	62.30	61.30	56.80	52.30	57.30	50.80	44.30
	C2	65.30	63.80	62.30	61.30	56.80	52.30	57.30	50.80	44.30
	D1	65.30	63.80	62.30	61.30	56.80	52.30	57.30	50.80	44.30
	D2	65.30	63.80	62.30	61.30	56.80	52.30	57.30	50.80	44.30
	E	65.30	63.80	62.30	61.30	56.80	52.30	57.30	50.80	44.30
	F	65.30	63.80	62.30	61.30	56.80	52.30	57.30	50.80	44.30
Coarse Grained Soils[2]	A	65.30	65.80	66.30	61.30	58.80	56.30	57.30	51.30	45.30
	B	65.30	65.80	66.30	61.30	58.80	56.30	57.30	51.30	45.30
	C1	65.30	65.80	66.30	61.30	58.80	56.30	57.30	51.30	45.30
	C2	65.30	65.80	66.30	61.30	58.80	56.30	57.30	51.30	45.30
	D1	65.30	65.80	66.30	61.30	58.80	56.30	57.30	51.30	45.30
	D2	65.30	65.80	66.30	61.30	58.80	56.30	57.30	51.30	45.30
	E	65.30	65.80	66.30	61.30	58.80	56.30	57.30	51.30	45.30
	F	65.30	65.80	66.30	61.30	58.80	56.30	57.30	51.30	45.30
Organic Soils	A	65.30	71.80	78.30	61.30	61.80	62.30	57.30	52.80	48.30
	B	65.30	71.80	78.30	61.30	61.80	62.30	57.30	52.80	48.30
	C1	65.30	71.80	78.30	61.30	61.80	62.30	57.30	52.80	48.30
	C2	65.30	71.80	78.30	61.30	61.80	62.30	57.30	52.80	48.30
	D1	65.30	71.80	78.30	61.30	61.80	62.30	57.30	52.80	48.30
	D2	65.30	71.80	78.30	61.30	61.80	62.30	57.30	52.80	48.30
	E	65.30	71.80	78.30	61.30	61.80	62.30	57.30	52.80	48.30
	F	65.30	71.80	78.30	61.30	61.80	62.30	57.30	52.80	48.30

[1]*This texture subclass is based on the unified classifications of CL, CH, and ML as described in SEWRPC Planning Report No. 8, Soils of Southeastern Wisconsin.*

[2]*This texture subclass is based on the unified classifications of GP, SM, GW, GM, SP, and SC as described in SEWRPC Planning Report No. 8, Soils of Southeastern Wisconsin.*

[3]*Costs are in Dollars Per Lineal Foot.*

[4]*Slope categories A, B, C1, C2, D1, D2, E, and F have average slopes of 1, 5, 8, 11, 15, 19, 26, and 30 percent respectively.*

Source: SEWRPC.

Table 10

LAND USE DESIGN MODEL CONSTRUCTION COSTS

THOROUGHFARES URBAN STANDARD ARTERIAL | $ PER FOOT[3]

		Less Than 1 ft. To Water Table			1 To 5 ft. To Water Table			More Than 5 ft. To Water Table		
	Slope[4]	Less Than 2 To Bedrock	2-5 To Bedrock	More Than 5 To Bedrock	Less Than 2 To Bedrock	2-5 To Bedrock	More Than 5 To Bedrock	Less Than 2 To Bedrock	2-5 To Bedrock	More Than 5 To Bedrock
Fine Grained Soils[1]	A	52.22	52.22	52.22	52.22	52.22	52.22	52.22	52.22	52.22
	B	52.22	52.22	52.22	52.22	52.22	52.22	52.22	52.22	52.22
	C1	52.27	52.26	52.25	52.27	52.25	52.24	52.27	52.25	52.24
	C2	52.31	52.29	52.27	52.31	52.29	52.26	52.31	52.28	52.25
	D1	52.36	52.33	52.30	52.36	52.32	52.28	52.36	52.31	52.27
	D2	52.42	52.37	52.33	52.42	52.36	52.30	52.42	52.35	52.29
	E	52.53	52.46	52.40	52.53	52.44	52.35	52.53	53.43	52.33
	F	52.72	52.62	52.51	52.72	52.58	52.43	52.72	52.56	52.40
Coarse Grained Soils[2]	A	52.22	52.22	52.22	52.22	52.22	52.22	52.22	52.22	52.22
	B	52.22	52.22	52.22	52.22	52.22	52.22	52.22	52.22	52.22
	C1	52.27	52.26	52.25	52.27	52.25	52.24	52.27	52.25	52.24
	C2	52.31	52.29	52.27	52.31	52.29	52.26	52.31	52.28	52.25
	D1	52.36	52.33	52.30	52.36	52.32	52.28	52.36	52.31	52.27
	D2	52.42	52.37	52.33	52.42	52.36	52.30	52.42	52.35	52.29
	E	52.53	52.46	52.40	52.53	52.44	52.35	52.53	52.43	52.33
	F	52.72	52.62	52.51	52.72	52.58	52.43	52.72	52.56	52.40
Organic Soils	A	52.22	52.22	52.22	52.22	52.22	52.22	52.22	52.22	52.22
	B	52.22	52.22	52.22	52.22	52.22	52.22	52.22	52.22	52.22
	C1	52.27	52.27	52.28	52.27	52.26	52.26	52.27	52.26	52.26
	C2	52.31	52.32	52.34	52.31	52.31	52.31	52.31	52.30	52.30
	D1	52.36	52.38	52.40	52.36	52.35	52.35	52.36	52.34	52.33
	D2	52.42	52.45	52.48	52.42	52.41	52.41	52.42	52.40	52.38
	E	52.53	52.58	52.63	52.53	52.52	52.52	52.53	52.50	52.48
	F	52.72	52.80	52.89	52.72	52.71	52.71	52.72	52.68	52.64
Bedrock	A							52.22		
	B							52.22		
	C1							52.27		
	C2							52.31		
	D1							52.36		
	D2							52.42		
	E							52.52		
	F							52.72		

[1]*This texture subclass is based on the unified classifications of CL, CH, and ML as described in SEWRPC Planning Report No. 8, Soils of Southeastern Wisconsin.*

[2]*This texture subclass is based on the unified classifications of GP, SM, GW, GM, SP, and SC as described in SEWRPC Planning Report No. 8, Soils of Southeastern Wisconsin.*

[3]*Costs are in Dollar Per Lineal Foot.*

[4]*Slope categories A, B, C1, C2, D1, D2, E, and F have average slopes of 1, 5, 8, 11, 15, 19, 26, and 30 percent respectively.*

Source: SEWRPC.

Table II

LAND USE DESIGN MODEL CONSTRUCTION COSTS

FOUNDATIONS–RESIDENCES

MULTIPLY ALL FIGURES BY $100 PER ACRE[3]

		Less Than 1 ft. To Water Table			1 To 5 ft. To Water Table			More Than 5 ft. To Water Table		
	Slope[4]	Less Than 2 To Bedrock	2-5 To Bedrock	More Than 5 To Bedrock	Less Than 2 To Bedrock	2-5 To Bedrock	More Than 5 To Bedrock	Less Than 5 To Bedrock	2-5 To Bedrock	More Than 5 To Bedrock
Fine Grained Soils[1]	A	78.54	362.40	659.40	63.40	171.40	302.90	48.47	107.40	166.20
	B	227.80	584.80	952.80	146.85	225.65	434.65	67.77	116.00	166.20
	C1	392.40	826.40	1258.40	239.40	284.90	570.90	90.35	126.40	166.20
	C2	426.60	853.40	1278.20	273.60	308.90	585.30	124.55	149.40	178.80
	D1	460.80	880.40	1298.00	307.80	332.90	599.70	158.75	173.10	191.40
	D2	506.40	916.40	1324.40	353.40	365.90	618.90	204.35	204.40	208.20
	E	592.40	984.40	1373.90	439.40	426.90	654.90	290.35	266.40	239.70
	F	740.40	1101.40	1458.40	587.40	524.90	717.30	438.35	364.40	294.20
Coarse Grained Soils[2]	A	78.54	682.40	1296.40	63.40	415.40	793.90	48.47	107.40	166.20
	B	227.80	984.80	1784.80	146.85	549.65	1079.65	67.77	116.00	166.20
	C1	392.40	306.40	2286.40	239.40	679.90	1364.90	90.35	126.40	166.20
	C2	426.60	333.40	2306.20	273.60	703.90	1379.30	124.55	149.40	178.80
	D1	460.80	360.40	2326.00	307.80	727.90	1393.70	158.75	173.10	191.40
	D2	506.40	396.40	2352.40	353.40	760.90	1412.90	204.35	204.40	208.20
	E	592.40	464.40	2401.90	439.40	821.90	1448.90	290.35	266.40	239.70
	F	740.40	581.40	2486.40	587.40	919.90	1511.30	438.35	364.40	294.20
Organic Soils	A	78.54	132.00	1410.90	63.40	565.00	1094.90	48.47	305.00	559.90
	B	227.80	244.40	1903.30	146.85	724.25	1433.15	67.77	364.60	661.90
	C1	392.40	366.00	2404.90	239.40	889.50	1783.40	90.35	425.00	762.90
	C2	426.60	406.00	2450.30	273.60	923.15	1816.50	124.55	456.50	791.70
	D1	460.80	446.00	2495.60	307.80	956.80	1849.60	158.75	488.00	820.60
	D2	506.40	498.50	2556.00	353.40	1001.50	1893.40	204.35	530.00	858.90
	E	592.40	598.50	2669.90	439.40	1086.00	1976.40	290.35	609.00	930.90
	F	740.40	771.00	2866.40	587.40	1232.00	2120.40	438.35	745.00	1055.90
Bedrock	A							48.47		
	B							67.77		
	C1							90.35		
	C2							124.55		
	D1							158.75		
	D2							204.35		
	E							290.35		
	F							438.35		

[1] *This texture subclass is based on the unified classifications of CL, CH, and ML as described in SEWRPC Planning Report No. 8, Soils of Southeastern Wisconsin.*

Source: SEWRPC.

[2] *This texture subclass is based on the unified classifications of GP, SM, GW, GM, SP, and SC as described in SEWRPC Planning Report No. 8, Soils of Southeastern Wisconsin.*

[3] *Costs are in Hundreds of Dollars per Acre of Building Coverage.*

[4] *Slope categories A, B, C1, C2, D1, D2, E, and F have average slopes of 1, 5, 8, 11, 15, 19, 26, and 30 percent respectively.*

Table 13

LINKAGE AND ELEMENT CATEGORIES

1. Airport Runways, Asphalt*
2. Airport Runways, Concrete*
3. Electric Power Production Plant*
4. Electric Power Transmission Lines*
5. Foundations, Commercial Buildings*
6. Foundations, Industrial Buildings*
7. Foundations, Residences (See Table 11)
8. Laterals, Storm and Sanitary Sewers and Water Lines, Earth Backfill
9. Laterals, Storm and Sanitary Sewers, Earth Backfill
10. Laterals, Storm Sewers and Water Lines, Earth Backfill
11. Laterals, Sanitary Sewers and Water Lines, Earth Backfill
12. Laterals, Storm Sewers, Earth Backfill
13. Laterals, Sanitary Sewers, Earth Backfill
14. Laterals, Water Lines, Earth Backfill
15. Laterals, Storm and Sanitary Sewers and Water Lines, Gravel Backfill
16. Laterals, Storm and Sanitary Sewers, Gravel Backfill
17. Laterals, Storm Sewers and Water Lines, Gravel Backfill
18. Laterals, Sanitary Sewers and Water Lines, Gravel Backfill
19. Laterals, Storm Sewers, Gravel Backfill
20. Laterals, Sanitary Sewers, Gravel Backfill (See Table 5)
21. Laterals, Water Lines, Gravel Backfill
22. Parking Area, Automobiles
23. Parking Area, Trucks
24. Play Area, Paved
25. Railroad, Main Line (See Table 6)
26. Railroad, Spur Line
27. Sewage Disposal Units, On Site Septic Tanks
28. Sewage Sanitary Collection Lines, 8 Inch Diameter Main Only, Earth Backfill
29. Sewage Sanitary Collection Lines, 10 Inch Diameter Main Only, Earth Backfill (See Table 7)
30. Sewage Sanitary Collection Lines, 12 Inch Diameter Main Only, Earth Backfill
31. Sewage Sanitary Collection Lines, 15 Inch Diameter Main Only, Earth Backfill
32. Sewage Sanitary Collection Lines, 18 Inch Diameter Main Only, Earth Backfill
33. Sewage Sanitary Collection Lines, 21 Inch Diameter Main Only, Earth Backfill
34. Sewage Sanitary Collection Lines, 24 Inch Diameter Main Only, Earth Backfill
35. Sewage Sanitary Collection Lines, 8 Inch Diameter Main Only, Gravel Backfill
36. Sewage Sanitary Collection Lines, 10 Inch Diameter Main Only, Gravel Backfill
37. Sewage Sanitary Collection Lines, 12 Inch Diameter Main Only, Gravel Backfill
38. Sewage Sanitary Collection Lines, 15 Inch Diameter Main Only, Gravel Backfill
39. Sewage Sanitary Collection Lines, 18 Inch Diameter Main Only, Gravel Backfill
40. Sewage Sanitary Collection Lines, 21 Inch Diameter Main Only, Gravel Backfill
41. Sewage Sanitary Collection Lines, 24 Inch Diameter Main Only, Gravel Backfill
42. Sewage Sanitary Interceptor Lines, Larger Than 24 Inch Diameter, Gravel Backfill*
43. Sewage Treatment Plant*
44. Site Grading, Allowable Slope 0 Percent
45. Site Grading, Allowable Slope 1 Percent
46. Site Grading, Allowable Slope 2 Percent
47. Site Grading, Allowable Slope 3 Percent
48. Site Grading, Allowable Slope 4 Percent
49. Site Grading, Allowable Slope 5 Percent
50. Site Grading, Allowable Slope 6 Percent
51. Site Grading, Allowable Slope 7 Percent (See Table 8)
52. Site Grading, Allowable Slope 8 Percent
53. Site Grading, Allowable Slope 9 Percent
54. Site Grading, Allowable Slope 10 Percent
55. Site Grading, Allowable Slope 11 Percent
56. Site Grading, Allowable Slope 12 Percent
57. Site Grading, Allowable Slope 13 Percent
58. Site Grading, Allowable Slope 14 Percent
59. Site Grading, Allowable Slope 15 Percent
60. Site Grading, Allowable Slope 16 Percent
61. Site Grading, Allowable Slope 17 Percent
62. Site Grading, Allowable Slope 18 Percent
63. Site Grading, Allowable Slope 19 Percent
64. Site Grading, Allowable Slope 20 Percent
65. Site Grading, Allowable Slope 21 Percent
66. Site Grading, Allowable Slope 22 Percent
67. Site Grading, Allowable Slope 23 Percent
68. Site Grading, Allowable Slope 24 Percent
69. Site Grading, Allowable Slope 25 Percent
70. Site Grading, Allowable Slope 26 Percent
71. Site Grading, Allowable Slope 27 Percent
72. Site Grading, Allowable Slope 28 Percent
73. Site Grading, Allowable Slope 29 Percent
74. Site Grading, Allowable Slope 30 Percent
75. Site Grading, Allowable Slope 31 Percent
76. Site Grading, Allowable Slope 32 Percent
77. Site Grading, Allowable Slope 33 Percent
78. Site Grading, Allowable Slope 34 Percent
79. Site Grading, Allowable Slope 35 Percent
80. Site Grading, Allowable Slope 36 Percent
81. Site Grading, Allowable Slope 37 Percent
82. Storm Sewer Collection Lines, 8 Inch Diameter Main Only, Earth Backfill
83. Storm Sewer Collection Lines, 10 Inch Diameter Main Only, Earth Backfill
84. Storm Sewer Collection Lines, 12 Inch Diameter Main Only, Earth Backfill
85. Storm Sewer Collection Lines, 15 Inch Diameter Main Only, Earth Backfill
86. Storm Sewer Collection Lines, 18 Inch Diameter Main Only, Earth Backfill
87. Storm Sewer Collection Lines, 21 Inch Diameter Main Only, Earth Backfill
88. Storm Sewer Collection Lines, 24 Inch Diameter Main Only, Earth Backfill
89. Storm Sewer Collection Lines, 27 Inch Diameter Main Only, Earth Backfill
90. Storm Sewer Collection Lines, 30 Inch Diameter Main Only, Earth Backfill
91. Storm Sewer Collection Lines, 36 Inch Diameter Main Only, Earth Backfill
92. Storm Sewer Collection Lines, 42 Inch Diameter Main Only, Earth Backfill
93. Storm Sewer Collection Lines, 48 Inch Diameter Main Only, Earth Backfill
94. Storm Sewer Collection Lines, 54 Inch Diameter Main Only, Earth Backfill
95. Storm Sewer Collection Lines, 8 Inch Diameter Main Only, Gravel Backfill
96. Storm Sewer Collection Lines, 10 Inch Diameter Main Only, Gravel Backfill
97. Storm Sewer Collection Lines, 12 Inch Diameter Main Only, Gravel Backfill
98. Storm Sewer Collection Lines, 15 Inch Diameter Main Only, Gravel Backfill
99. Storm Sewer Collection Lines, 18 Inch Diameter Main Only, Gravel Backfill
100. Storm Sewer Collection Lines, 21 Inch Diameter Main Only, Gravel Backfill
101. Storm Sewer Collection Lines, 24 Inch Diameter Main Only, Gravel Backfill
102. Storm Sewer Collection Lines, 27 Inch Diameter Main Only, Gravel Backfill
103. Storm Sewer Collection Lines, 30 Inch Diameter Main Only, Gravel Backfill
104. Storm Sewer Collection Lines, 36 Inch Diameter Main Only, Gravel Backfill
105. Storm Sewer Collection Lines, 42 Inch Diameter Main Only, Gravel Backfill
106. Storm Sewer Collection Lines, 48 Inch Diameter Main Only, Gravel Backfill
107. Storm Sewer Collection Lines, 54 Inch Diameter Main Only, Gravel Backfill (See Table 9)
108. Storm Drainage Ditches, Surface*
109. Telephone Transmission Lines*
110. Thoroughfares, Rural Freeway 8 Lane
111. Thoroughfares, Rural Freeway 6 Lane
112. Thoroughfares, Rural Freeway and Expressway 4 Lane
113. Thoroughfares, Rural Standard Arterial
114. Thoroughfares, Rural Collector Street
115. Thoroughfares, Rural Local Street
116. Thoroughfares, Urban Freeway 8 Lane
117. Thoroughfares, Urban Freeway 6 Lane
118. Thoroughfares, Urban Standard Arterial (See Table 10)
119. Thoroughfares, Urban Collector Street
120. Thoroughfares, Urban Local Street
121. Thoroughfares, Urban Alley
122. Water Transmission Lines, 6 Inch Diameter Main Only, Separate
123. Water Transmission Lines, 8 Inch Diameter Main Only, Separate
124. Water Transmission Lines, 12 Inch Diameter Main Only, Separate
125. Water Transmission Lines, 16 Inch Diameter Main Only, Separate
126. Water Transmission Lines, 20 Inch Diameter Main Only, Separate
127. Water Transmission Lines, 24 Inch Diameter Main Only, Separate
128. Water Transmission Lines, 30 Inch Diameter Main Only, Separate
129. Water Transmission Lines, 36 Inch Diameter Main Only, Separate
130. Water Transmission Lines, 42 Inch Diameter Main Only, Separate
131. Water Transmission Lines, 48 Inch Diameter Main Only, Separate
132. Water Transmission Lines, 54 Inch Diameter Main Only, Separate
133. Water Transmission Lines, 60 Inch Diameter Main Only, Separate
134. Water Transmission Lines, Hydrant Leads, Branches, Earth Backfill
135. Water Transmission Lines, Hydrant Leads
136. Water Transmission Lines, Hydrant Leads, Branches, Gravel Backfill
137. Water Transmission Lines, Manholes Blowoff, 8 Inch Drain Pipe
138. Water Transmission Lines, Manholes, Inspection Used With 24 Inch Or Larger Mains
139. Water Transmission Lines, Manholes, Blowoff, 6 Inch Drain Pipe
140. Water Treatment Plant*
141. Water Well*

*Construction cost data not available.

Source: SEWRPC.

Chapter IV

DATA REDUCTION OPERATIONS

DATA REDUCTION SEQUENCE

Data reduction for the land use plan design model is the process of developing data files by converting the raw data (supplied by the user) into a form that is usable by the model program.

The method of changing the information from raw data to data file has been defined into five phases. The five phases are as follows:

Phase 1—Mathematical parameters from which the model will operate.

Phase 2—Requirements of the various module types to be placed by the model.

Phase 3—Geographical information of each cell and cell information needed in Phase 5.

Phase 4—Cost to link each module type to every other module type and distance constraints between module types.

Phase 5—Place the initial conditions, determine maximum module placements, and develop module site costs.

The data reduction input and output file structure is summarized in Tables 14 and 15, respectively, in order to present the data reduction as an entity. A review of these files will aid in grasping the overall data reduction process.

COMPUTER SYSTEM REQUIREMENTS

Each of the five phases of data reduction will be presented in terms of input data formats and operating procedures.

Table 14

DATA REDUCTION PROGRAM INPUT

Input Data	Code	Origin	Required
1. Model Parameters (General Information)	File01	User	Yes
2. Module Area Requirements	File02	User	Yes
3. User Soil Inventory	UR11	User	Yes
4. Geographic Unit Cell Assignment	UR12	User	Yes
5. Soil Code Cross Reference	UR13	User	Yes
6. Slope Code Cross Reference	UR14	User	Yes
7. Cell Location Reference	UR15	User	Yes
8. Accessibility Annuity Factors	UR3P	User	No
9. Trip Interchanges Between Modules	UR30	User	No
10. Incremental Cost of Linkage	UR31	User	Yes
11. Module Linkage Requirements (Internal Length)	UR32	User	Yes
12. Module Span	UR33	User	Yes
13. Module Distance Constraints	UR34	User	Yes
14. Module Element Requirements	UR22	User	Yes
15. Element Site Cost Table	SR21	Supplied	Yes
16. Initial Conditions	UR23	User	No
17. Module Description	UR24	User	Yes

Source: SEWRPC.

Table 15

DATA REDUCTION PROGRAM OUTPUT

1. General Information File – 5 records
   a. Plan Accuracy
   b. Success Probability
   c. Random Number Residule
   d. Number of Module Types
   e. Number of Cells
2. Module Type Requirements – 1 per module
   a. Module Area
   b. Number Required per Cell
3. Cell Geographic Information – 1 per cell
   a. Cell Area
   b. Cell Location (x-y coordinates)
4. Module Linkage File – (no. of modules)
   a. Module Distance Constraints
   b. Module Linkage Costs
5. Cell Module Information (no. of cells x no. of modules)
   a. Initial Conditions
   b. Limits that can be placed
   c. Site Cost

Source: SEWRPC.

The data reduction program operates on an IBM 360/22 computer system with the following configuration:

1. One 2022 C.P.U., 32,000 bytes of core memory.

2. One 1403 line printer.

3. One 2311 disk storage drive.

4. One 1442 card reader.

5. Four 2415 magnetic tape transports.

The programs operate under the Disk Operating System. Since the design model program requires a disk storage drive, it is not practical to use a card-oriented or a magnetic tape-oriented system.

DATA REDUCTION PROCESS

Each of the five phases of data reduction will be presented in terms of input data formats and operating procedures.

Data Reduction—Phase 1

The operations of the Phase 1 data reduction sequence are illustrated in the program flow chart as Figure 8.

The purpose of Phase 1 is to supply the land use design model with the constraints under which it must function. None of the data entered in Phase 1 requires extensive data processing. The following items entered as card input are transferred to the disk using the file organization defined in Tables 14 and 15:

1. Plan accuracy required.

2. Success probability required.

3. Number of Modules by type.

4. Number of Cells.

5. Random number residual.

Data Reduction—Phase 2

The purpose of Phase 2 is to present data to the land use design model about each module type used. None of the data entered on Phase 2 requires extensive data processing. However, data required is user coded and presented in the format:

1. Module Number.

2. Area required for one module of this type.

3. Number of modules of this type required.

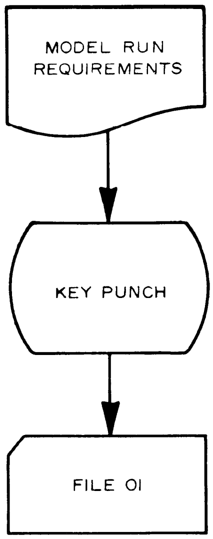
The operations of the Phase 2 data reduction sequence are illustrated in the program flow chart as Figure 9.

Data Reduction—Phase 3

The operations of the Phase 3 data reduction sequence are illustrated in the program flow chart as Figure 10.

Figure 8

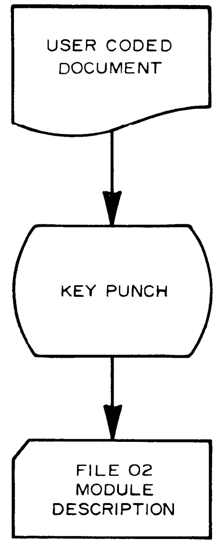
DATA REDUCTION FLOW CHART
PHASE I



Source: SEWRPC.

Figure 9

DATA REDUCTION FLOW CHART
PHASE 2



Source: SEWRPC.

Phase 3 presents geographic information about each cell. A by-product of this phase is a file containing the percent of each soil in each cell which will be used in Phase 5. Primary data handling operations in Phase 3 are related to the manipulation of the soil data. The Phase 3 program first converts the soil inventory data into a soil index using the soil cross reference matrix. Great flexibility is provided since a wide variety of soil data may be used as long as it is referenced to the soil cross reference matrix. Each soil type in the basic soil inventory must be classified by soil grain, depth to water table, and depth to bedrock in the soil cross reference matrix. In a separate slope vector, each soil type is classified by slope category. Using these cross reference data, the Phase 3 program develops a soil index for each geographic unit. Each geographic area selected by the user is then cross-referenced in a second matrix to a cell. The data is then combined to produce a soil index inventory for each cell area. The total area of each cell is a by-product of the soil index inventory.

The cell area and location file is produced with the following divisions of information:

1. The user soil inventory control fields (Geographic unit, Soil description, and Slope) are converted to a form usable by the data reduction system and design model.

2. An index of the amount of each soil type present in each cell is developed.

3. User coded cell location is added to the total area calculated for each cell.

The input data formats are shown in Table 16. The operating procedures are detailed in Table 17.

Data Reduction—Phase 4

The operations of the Phase 4 data reduction sequence are shown in the program flow chart (see Figure 11). The input data formats are tabulated in Table 18 and the operations procedures in Table 19.

Phase 4 produces the linkage cost file (incremental cost to link each module type to every module type). It also brings the distance constraints between modules types into the model.

Figure 10

DATA REDUCTION FLOW CHART
PHASE 3

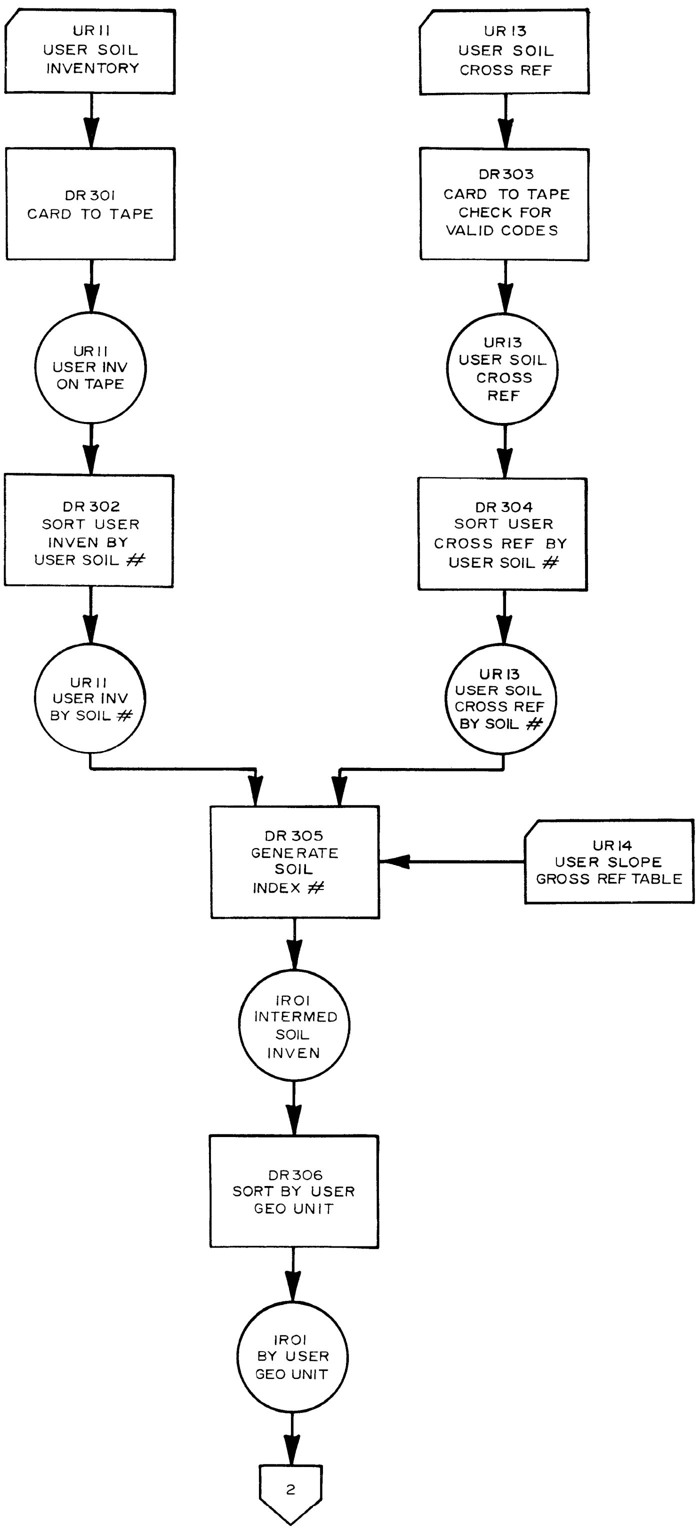
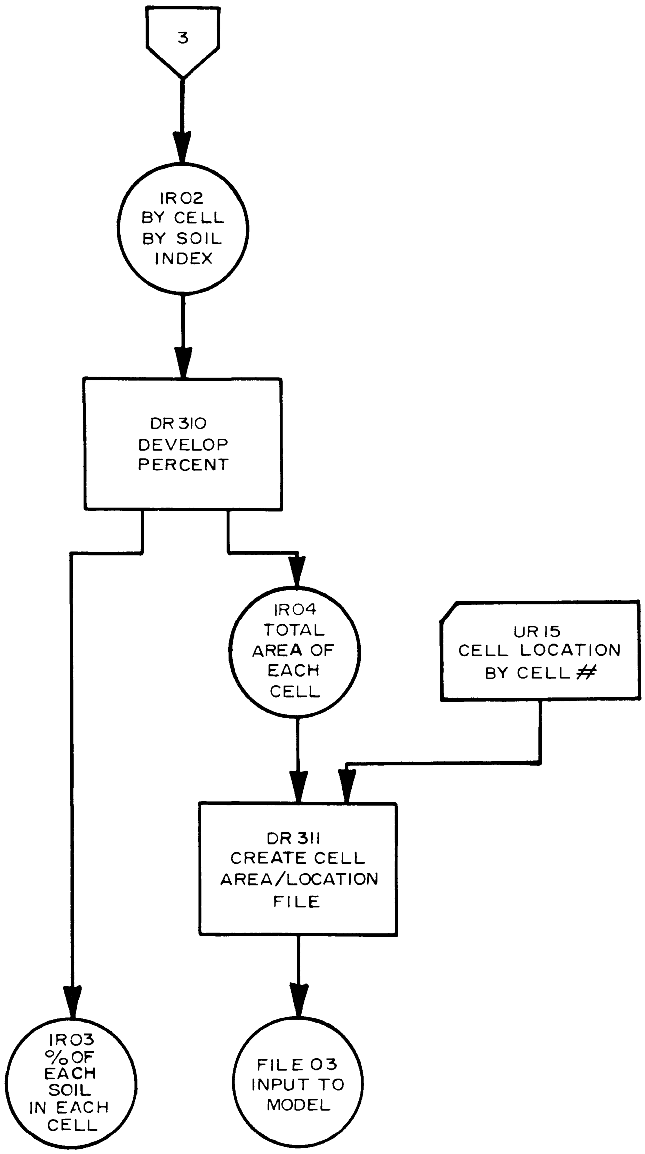


Figure 10 (continued)



Source: ***SEWRPC.***

Table 16

DATA REDUCTION PROGRAM INPUT
PHASE 3

REQUIRED INPUT:

1. User Soil Inventory Data Cards (or Tape-Card Image Blocked 20)
   cols 1-20 User Geographic Unit
   21-30 User Soil Identification
   31-35 User Slope Identification
   36-45 Area of this Soil Type within this Geographic Unit
2. Geographic Unit Cell Cross Reference Cards
   cols 1-20 User Geographic Unit
   21-25 Cell to which this Geographic Unit is to be assigned
3. Soil Cross Reference Cards
   cols 1-10 User Soil Identification
   11 Texture of this Soil
   1 = Fine Grained Soils
   2 = Coarse Grained Soils
   3 = Organic Soils
   4 = Bedrock
   12 Depth to Water Table for this Soil
   1 = Less than 1 ft.
   2 = 1 to 5 ft.
   3 = More than 5 ft.
   13 Depth to Bedrock for this Soil
   1 = Less than 1 ft.
   2 = 1 to 5 ft.
   3 = More than 5 ft.
4. Slope Cross Reference Cards (58 Cards)
   cols 1- 5 User Slope Identification
   6 Slope Code
   1 = 0- 2%
   2 = 3- 6%
   3 = 7- 9%
   4 = 10-12%
   5 = 13-16%
   6 = 17-20%
   7 = 21-30%
   8 = 30+ %
5. User Cell Location Cards
   cols 1- 5 Cell Number
   17-29 North/South Coordinate
   30-42 East/West Coordinate

Source: SEWRPC.

Operation costs for the linkages are restricted to travel costs since operation costs of other linkages are not significant enough to merit their inclusion. In fact, travel costs are so large that they tend to be much larger than the largest construction linkage cost: highway construction. Travel costs are determined by using a travel cost per mile factor in conjunction with a trip interchange matrix between modules that expresses number of annual trips traveled between the modules. The resulting annual travel cost then is combined with an annuity parameter based on an interest rate that converts a series of annual costs into a present value. The operation costs for each module-module combination comprise the Module-Module Operation Linkage Matrix.

The file is developed in the following manner:

1. Total incremental cost per foot of a linkage is developed by multiplying incremental cost per foot of a linkage by the length of that linkage required in each module.

Table 17

DATA REDUCTION PROGRAM OPERATIONS PROCEDURE
PHASE 3

OPERATING PROCEDURE:

1. Load User Soil Inventory on tape
   a. Program DR301-Utility card to tape
   b. UR11 cards in card reader
   c. Output UR11 file on 181
   (Note: Format of UR11 tape file is UR11 card image blocked 20. If User chooses he can reformat his existing soil inventory to the UR11 tape format and enter procedure at this point.)
2. Sort UR11 file by User Soil I.D.
   a. Program DR302
   b. Input UR11 tape file on 181
   c. Output sorted UR11 on 180
3. Load User Soil Cross Reference List on tape
   a. Program DR303
   b. UR13 cards in card reader
   c. Output UR13 file on 180
4. Sort UR13 file by User Soil I.D.
   a. Program DR304
   b. Input UR13 file on 180
   c. Output sorted UR13 on 181
5. Generate Soil Index Number
   a. Program DR305
   b. Input
      1. UR11 sorted by User Soil I.D. on 180
      2. UR13 sorted by User Soil I.D. on 181
      3. UR14 (User Slope Cross Reference Table) in card reader
   c. Output IR01 (Intermediate Soil Inventory) on 182
6. Sort IR01 by User Geographic Unit
   a.• Program DR306
   b. Input IR01 on 182
   c. Output sorted IR01 on 183
7. Load User Geographic Unit Cross Reference file on tape
   a. Program DR301
   b. Input UR12
   c. Output UR12 tape file on 181
8. Sort UR12 file by User Geographic Unit
   a. Program DR307
   b. Input UR 12 file on 181
   c. Output sorted UR12 on 180
9. Insert Cell Number in Soil Inventory
   a. Program DR308
   b. Input
      1. IR01-Intermediate Soil !nventory on 183
      2. User Geographic Unit Cross Reference Table on 180
   c. Output IR02 Intermediate Soil Inventory on 182
10. Sort IR02 by Soil Index Number within Cell Number
    a. Program DR309
    b. Input IR01 on 182
    c. Output IR02 on 181
11. Develop Percent of each Soil in each Cell
    a. Program DR310
    b. Input IR02 by Cell by Soil Index on 181
    c. Output
       1. Percent of each soil in each cell (used in Phase 5) on 180
       2. Total area of each cell on 183
12. Develop File 03 - Input to Model
    a. Program DR311
    b. Input
       1. Total area of each cell on 183
       2. Cell coordinates on 182 (or card)
    c. Output - File 03, Input to Model

Source: SEWRPC.

Table 18

DATA REDUCTION PROGRAM INPUT
PHASE 4

REQUIRED INPUT:

1. Incremental cost per foot of linkage
   cols 1- 3 Linkage type number
   9-18 Incremental cost per foot of linkage
2. Length of linkage required internal to a module (distance of separation for accessibility)
   cols 1- 3 Linkage type number
   4- 8 Module number
   9-18 Length of this linkage required by this module
3. Span of module
   cols 4- 8 Module number
   9-18 Distance to span this module
4. Distance constraint
   cols 1- 3 From module
   4- 6 To module
   7-15 Distance constraint

OPTIONAL INPUT:

(Used to develop accessibility cost per foot of separation as the present value of the number of foot trips at a given rate over a term)

1. Annuity parameters
   cols 1- 2 Term of annuity
   3- 6 Interest rate (xx.xx%)
   7-15 Cost per mile per trip
2. Annual number of trips between modules
   cols 1- 3 Linkage type number
   4- 8 From module number
   9-13 To module number
   14-23 Annual number of trips

Source: SEWRPC.

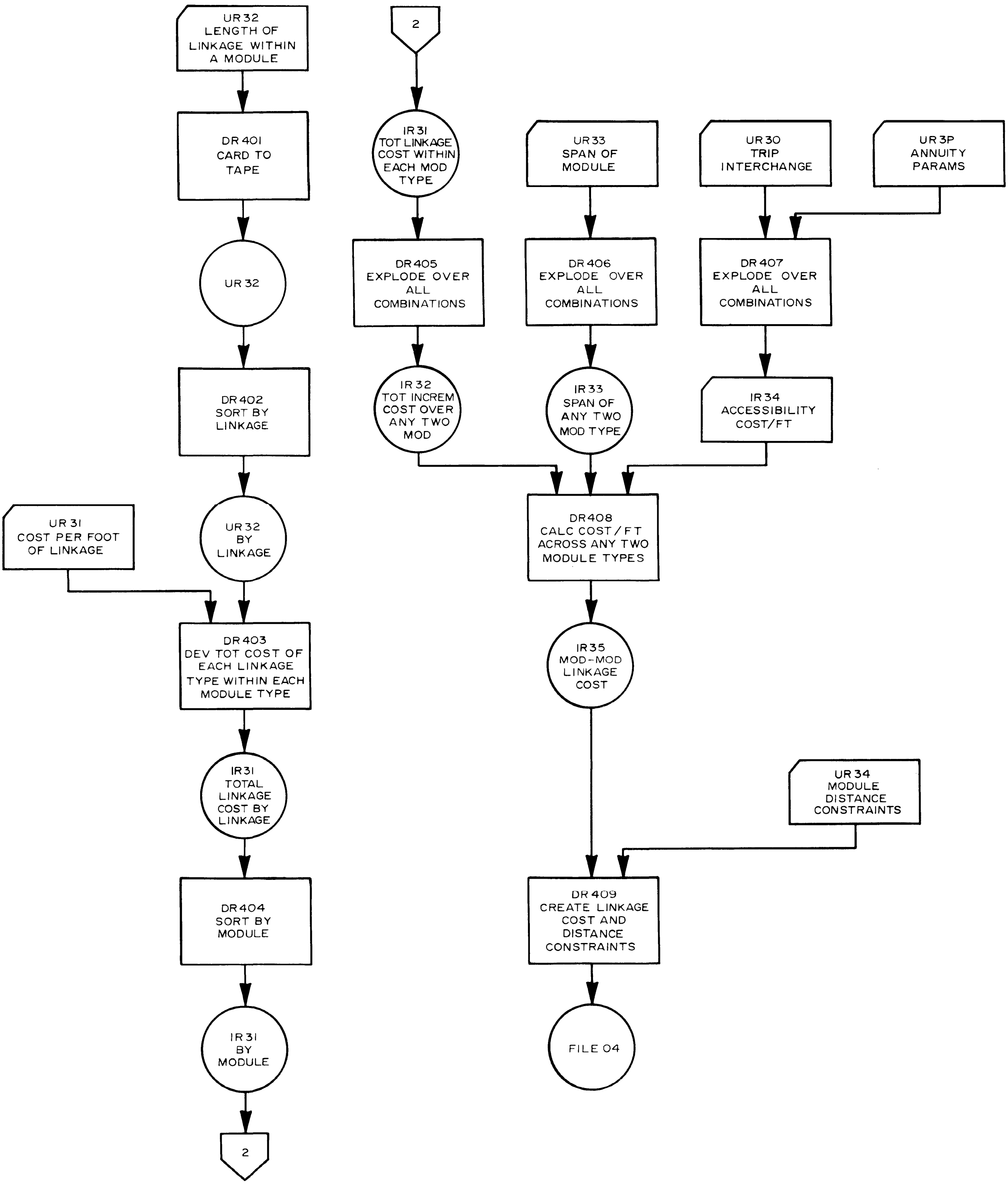
2. Incremental cost of linking is developed by dividing the total incremental cost of all linkage in any two modules by the total span of the same two modules.

3. The distance constraints, which are user coded, are added to the linkage cost file.

Note: An optional linkage (accessibility) can be added to all other linkages. The accessibility linkage is developed by applying the present value of trip interchange over a given term to the number of annual trips between modules.

Figure II

DATA REDUCTION FLOW CHART
PHASE 4



Source: SEWRPC.

Data Reduction—Phase 5

The operations of the Phase 5 data reduction sequence are shown in the program flow chart (see Figure 12). The input data formats are tabulated in Table 20 and the operations procedures in Table 21.

Phase 5 creates model input data required by module within the cell. The following list describes the data needed.

1. The initial conditions of each cell.

2. The maximum number of each module type that may be placed in each cell. An explosion of each module type to each cell is available or a user coded method may be used on a module basis.

3. The site cost of each module type in each cell is calculated. Input is used from Phase 3 to develop the cost. A procedure is included for the user to modify the supplied module soil cost table.

4. The final step in Phase 5 is to bring all the previous phases together to create the final model input file.

Table 19

DATA REDUCTION PROGRAM OPERATIONS PROCEDURE
PHASE 4

OPERATING PROCEDURE:

1. Load UR32 File on tape
   a. Program DR401
   b. Input UR32 file in card reader
   c. Output UR32 file on tape drive 180
2. Sort UR32 File by Linkage
   a. Program DR402
   b. Input UR32 file on 180
   c. Output UR32 file on tape drive 181
3. Develop Total Incremental Cost of Linkage within a Module
   a. Program DR403
   b. Input
      1. Sorted UR32 file on tape drive 181
      2. UR31 cards by linkage in reader
   c. Output IR31 file (Total Incremental Cost) on tape drive 180
4. Sort IR31 by Module
   a. Program DR404
   b. Input IR31 on drive 180
   c. Output IR31 on drive 181
5. Explode Total Cost of Linkage over all combinations of Modules
   a. Program DR405
   b. Input IR31 by Module on 181
   c. Output IR32 (Total Incremental Cost of Linking) on 182
6. Explode Span of Modules over any two Modules
   a. Program DR406
   b. Input UR33 cards in card reader
   c. Output IR33 (Span Table) on tape 180
7. Determine Accessibility Cost per foot (Optional)
   a. Program DR407
   b. Input
      1. UR3P Annuity Parameters in card reader
      2. UR30 Trip Interchanges between Modules
   c. Output IR34 cost cards
8. Calculate Total Incremental Cost per foot of linking
   a. Program DR408
   b. Input
      1. IR32 Total Incremental Cost of Linking
      2. IR33 Span of Modules
      3. IR34 Accessibility Cost per foot (Optional)
   c. Output
      1. List of Incremental Cost on Printer
      2. High Cost in Table on printer
      3. Incremental Cost Table on 183
9. Create File 04, Input to Model
   a. Program DR409
   b. Input Module-Module Linkage Costs on 183
   c. Input Module-Module Distance Constraints from card reader
   d. Output Model File 04 on 181

Source: SEWRPC.

Table 20

DATA REDUCTION PROGRAM INPUT
PHASE 5

REQUIRED INPUT:

1. Module Construction cards
   cols 1- 5 Module Number
   6- 8 Element Number
   9-18 Units of this element required to construct this Module
2. Soil Distribution in each Cell (output from Phase 3)
3. Initial Conditions by Cell Number
   cols 3- 5 Cell Number
   6- 7 Module Number
   8-12 Quantity placed
4. Module Description Card
   cols 6-10 Module Number
   25-29 Maximum number of this Module type in one Cell

OPTIONAL INPUT:

1. Factor Cards to adjust supplied element cost tables
   cols 1- 3 Element Number
   4 Operation
   x = Multiply
   y = Add
   5-14 Factor to be applied to every entry in table

SUPPLIED INPUT:

1. Element Cost Table
   Element Number
   Description
   Cost of Element on each of the 224 Soil Types

Source: SEWRPC.

Figure 12

DATA REDUCTION FLOW CHART
PHASE 5

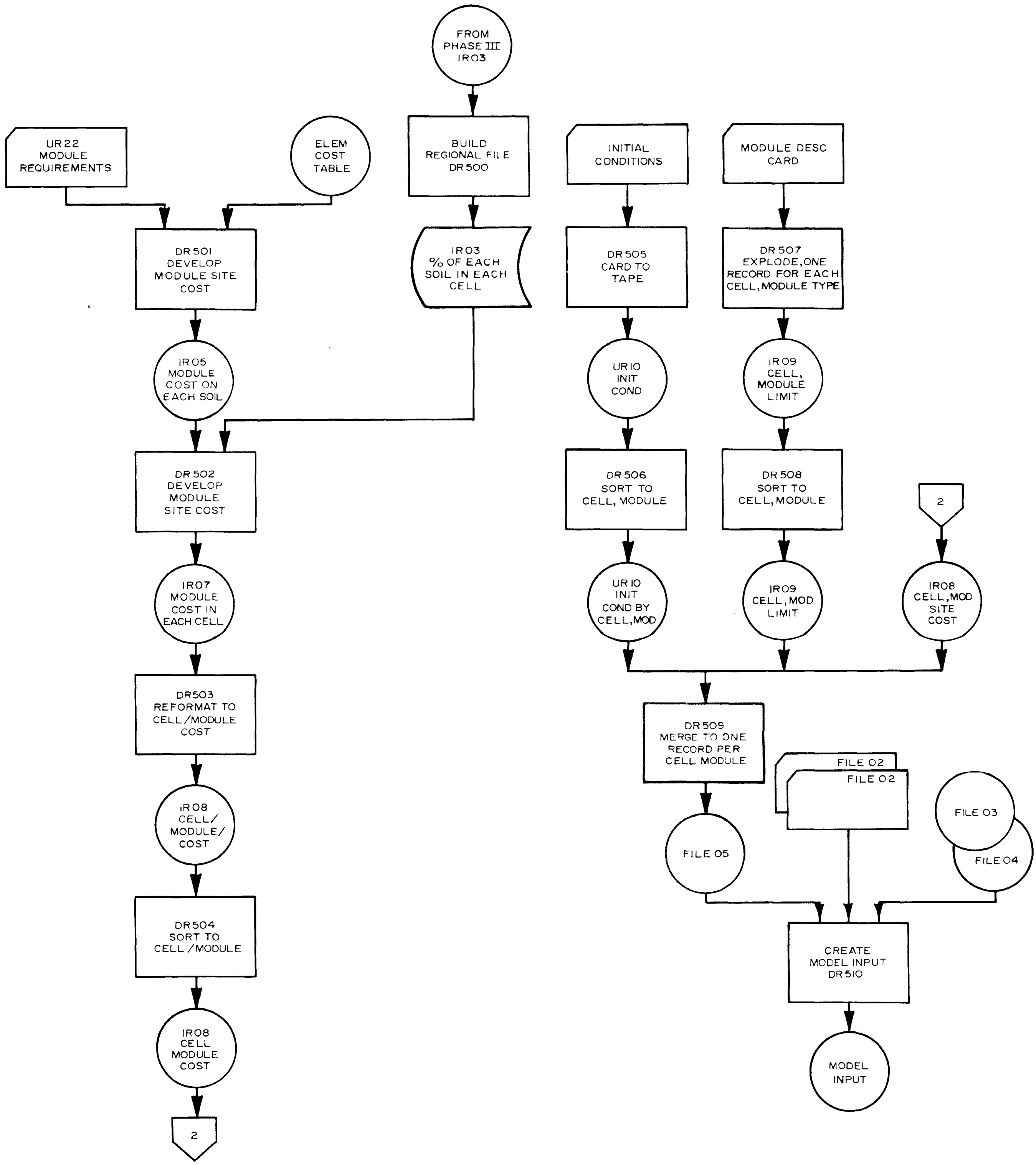
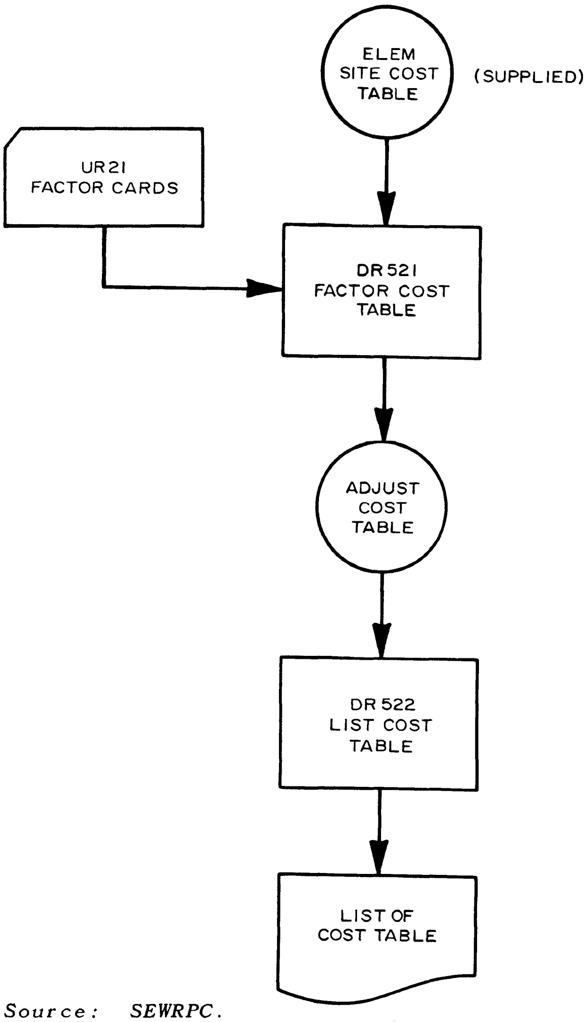


Figure 12 (continued)
(Optional)



Source: SEWRPC.

Table 21

DATA REDUCTION PROGRAM OPERATIONS PROCEDURE
PHASE 5

OPERATING PROCEDURE:

1. Develop Module Site (Soil) Cost
   a. Program DR501
   b. Input
      1. Module Requirements (UR22)
      2. Element Cost Table on 180
   c. Output Module Soil Cost Table on 181
2. Build Regional (1) File - Percent of each Soil in each Cell
   a. Program DR500
   b. Input - Percent of each Soil in each Cell (from Phase 3) on 183
   c. Output - Percent of each Soil in each Cell (Regional [1]) on 191
3. Develop Module Cost (Average Cell Placement Cost)
   a. Program DR502
   b. Input
      1. Module Soil Cost Table on 181
      2. Percent of each Soil in each Cell (from Phase 3) on 190
   c. Output Module Cost in each Cell on 180
4. Explode to Cell, Module Cost
   a. Program DR503
   b. Input Module Cost in each Cell on 180
   c. Output Module Cost in each Cell on 181
5. Sort IR08 File by Cell by Module
   a. Program DR504
   b. Input IR08 File on 181
   c. Output sorted IR08 File on 182
6. Load Initial Conditions on Tape
   a. Program DR505 - Card to Tape
   b. Initial Conditions card in card reader
   c. Output UR10 File on 180
7. Sort Initial Conditions to Module within Cell
   a. Program DR506
   b. Input UR10 File on 180
   c. Output sorted UR10 File on 181
8. Explode Module Limit card for each Cell
   a. Program DR507
   b. Input Module Description card
   c. Output IR09 on 183
9. Sort Cell, Module Limit File (IR09)
   a. Program DR508
   b. Input IR09 File on 183
   c. Output sorted IR09 File on 180
10. Combine Cell, Module Data
    a. Program DR509
    b. Input
       1. IR09 - Cell Module limit on 180
       2. UR10 - Initial Conditions on 181
       3. IR08 - Cell Module Site Cost on 182
    c. Output File 05 - Input to Model on 183
11. Bring All Phases together for Model Input
    a. Program DR510
    b. Input
       1. Model Parameters - from card reader (first five cards)
       2. Module description - from card reader (last card = 050 in cols. 1-3)
       3. File 03 - Phase 3 output on 180
       4. File 04 - Phase 4 output on 181
       5. File 05 - from Phase 5 on 182
    c. Output is Model Input - Output on 183

Source: SEWRPC.

Chapter V

DESIGN MODEL OPERATION

MODEL FLOW CHART

As an understanding of the program in detail is useful for intelligent use of the model and its results, a detailed flow chart describing the model operation is presented in Figure 13. The entire model operation is divided into five programs which are briefly described below.

Program 1 initializes storage locations and reads the input data including the cell-module information, constraint data, unit site and linkage costs, and the values for desired plan accuracy and the probability of success. This program also points out a list of the relevant data for checking.

Program 2 reads the cell coordinates and computes the cell-to-cell distances for each cell it sorts the distances from this cell to all other cells in an ascending order and stores this information for constraint evaluation as well as for linkage cost computation purposes.

Program 3 consists of the random placement algorithm. Modules and cells are selected through two separate random number generators, and a placement is made after testing the module-cell compatibility as well as the cell areal capacity.

Program 4 computes the total cost of a plan including the site and costs. In addition, the intermodule distance constraints are tested in this program to determine the constraint violations.

Program 5 is the updating program; it recomputes the number of plans required and it also updates the information about the 10 lowest cost feasible plans and 10 lowest cost infeasible plans. If the plan generated shows any improvement in cost for either the feasible or infeasible 10 lowest cost plans, the program points out the detailed information about the plan.

A complete list of the FORTRAN programs mentioned above is included in Appendix B of this report.

OUTPUT REPORTS

The model generates three categories of output reports:

1. Cell-module placements and associated cost information.

2. Plan cost and feasibility information.

3. Constraint schedule analysis.

The cell-module placement matrix contains the primary output information, since the primary function of the model is to place modules in cells. In addition to this basic information, the model provides associated cost, constraint, and plan rank (as compared to other plans) information to aid the interpretation of the primary plan output.

Constraint schedule information permits the planner to understand the effect of adding or removing a constraint (set of constraints) on the plan design output. Such sensitivity analysis is quite important in arriving at a final plan, since that plan often compromises the ideal system to relate to political and economic realities.

Figure 13

LAND USE PLAN DESIGN MODEL FLOW CHART

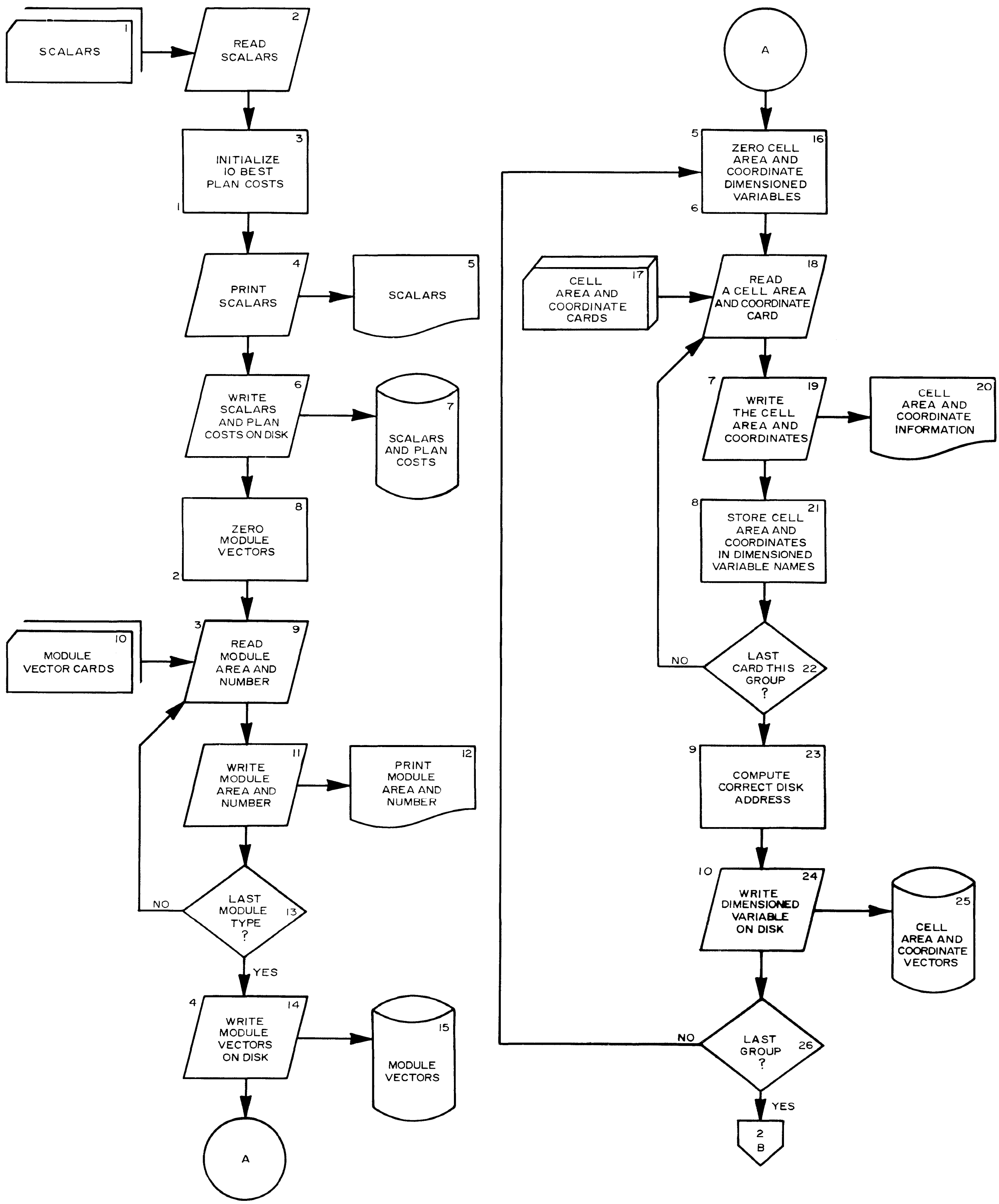


Figure 13 (continued)

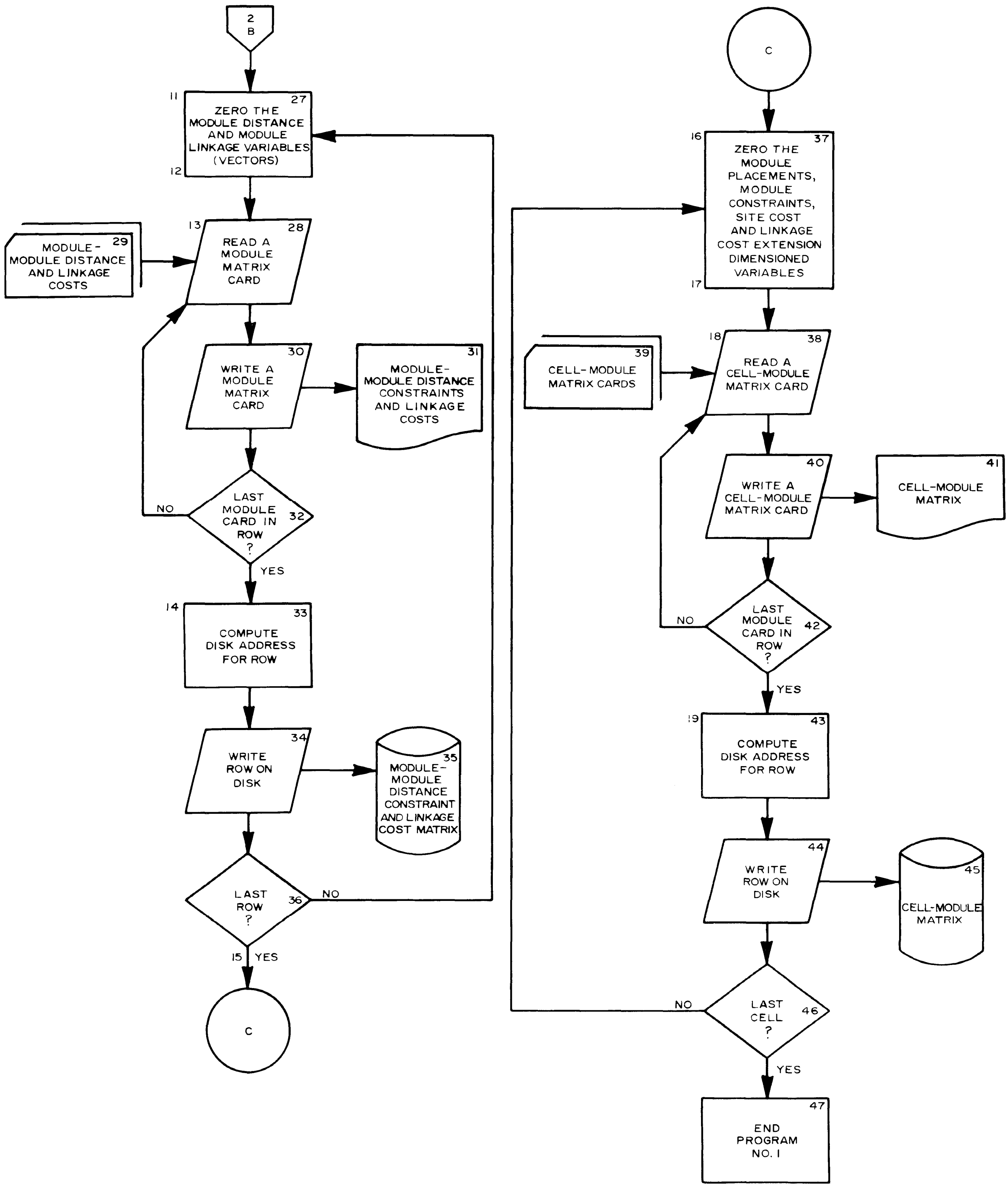


Figure 13 (continued)

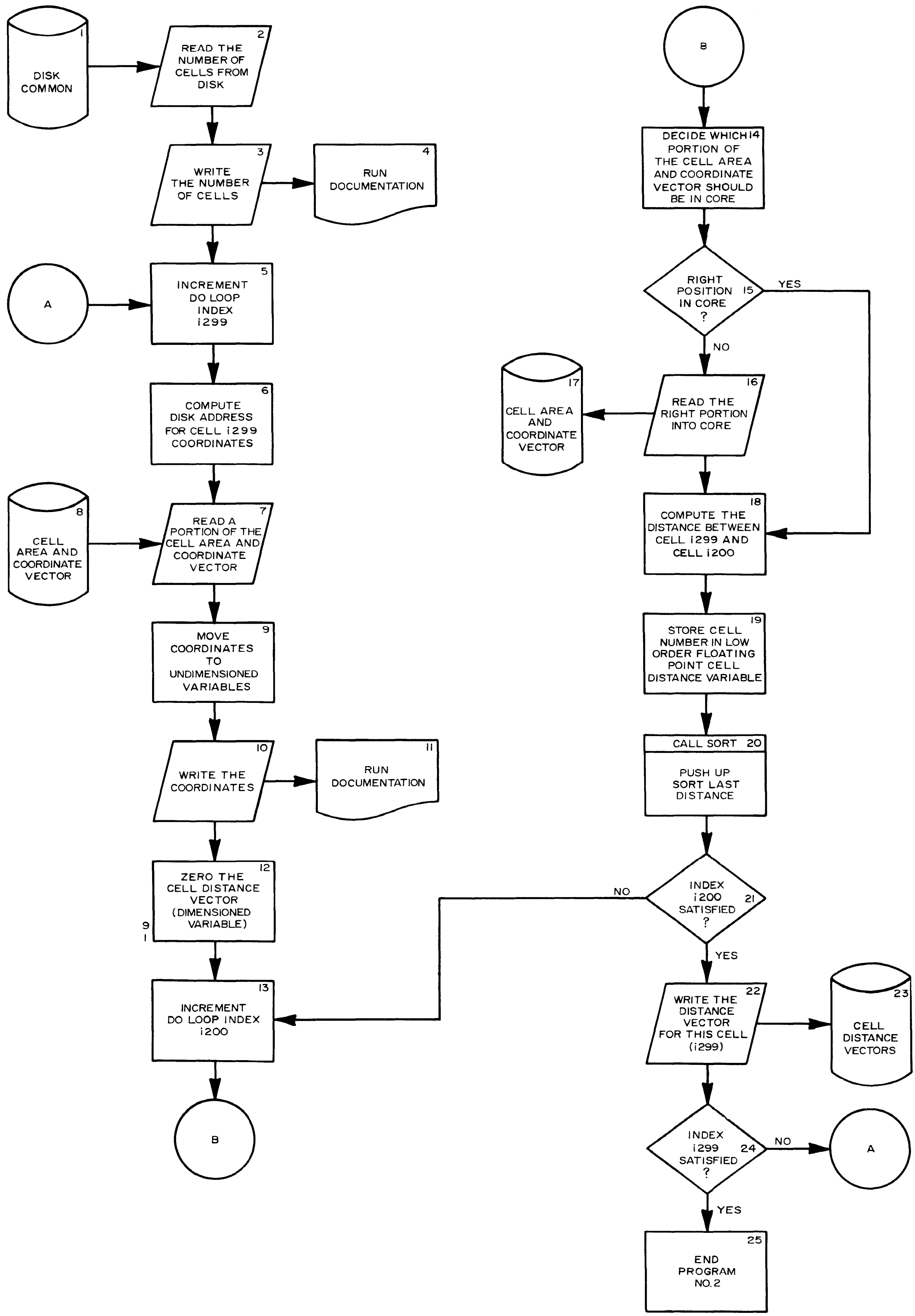


Figure 13 (continued)

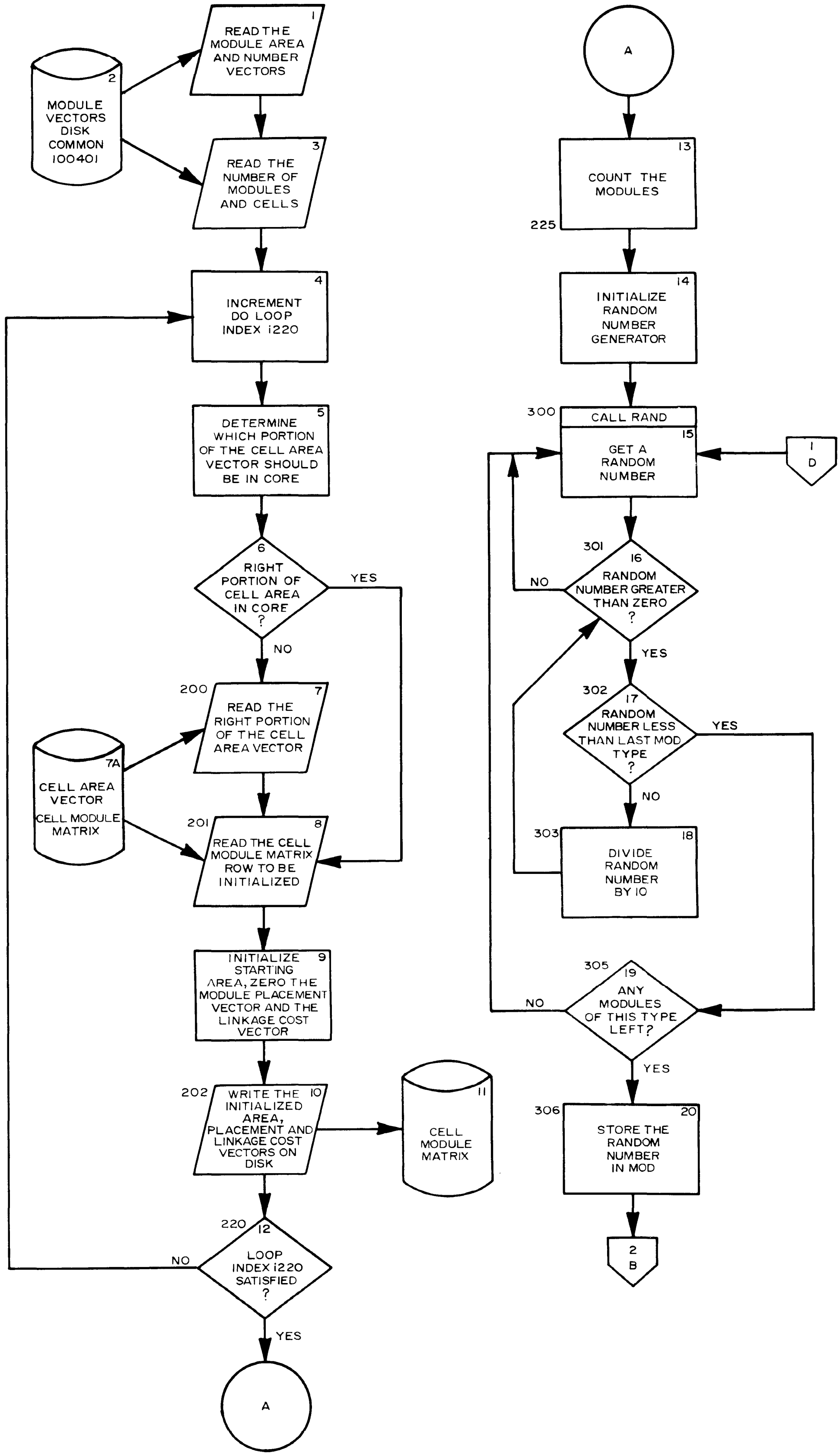


Figure 13 (continued)

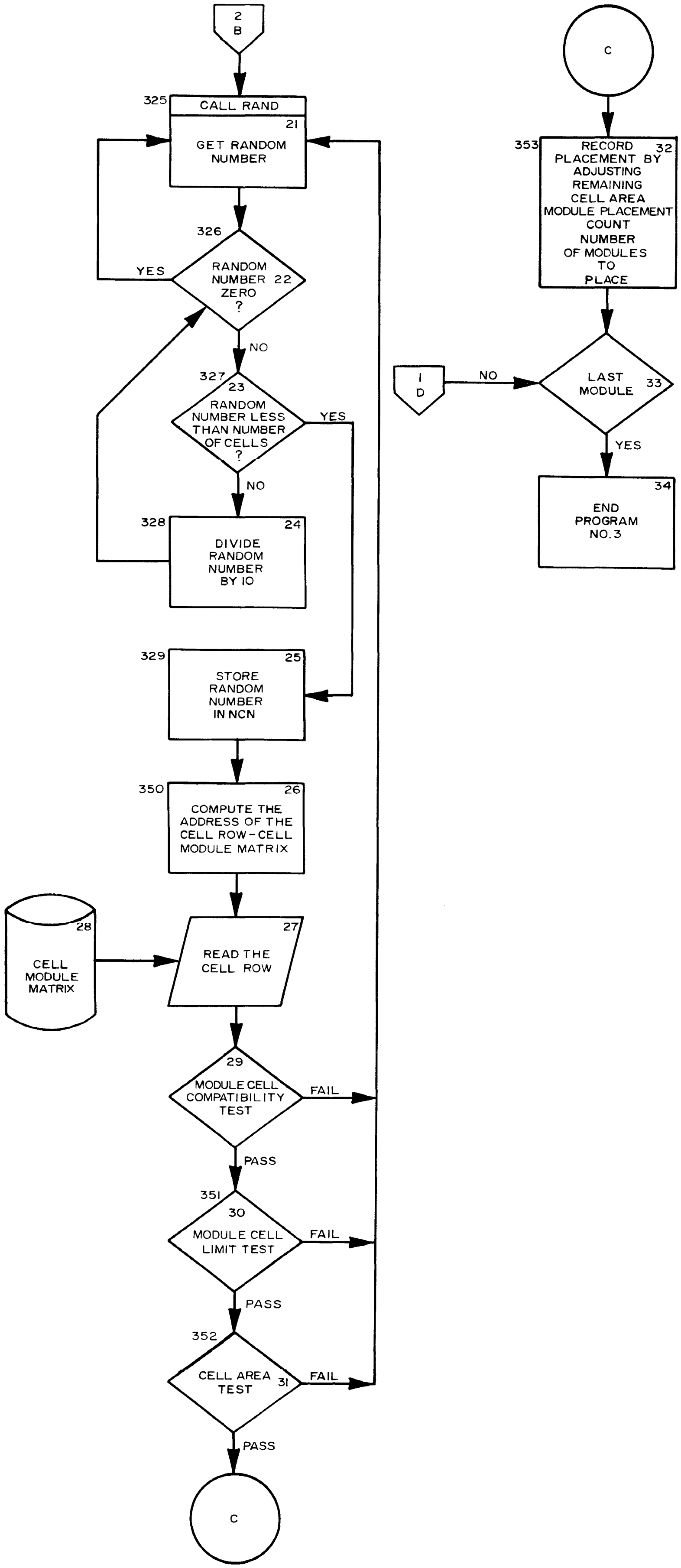


Figure 13 (continued)

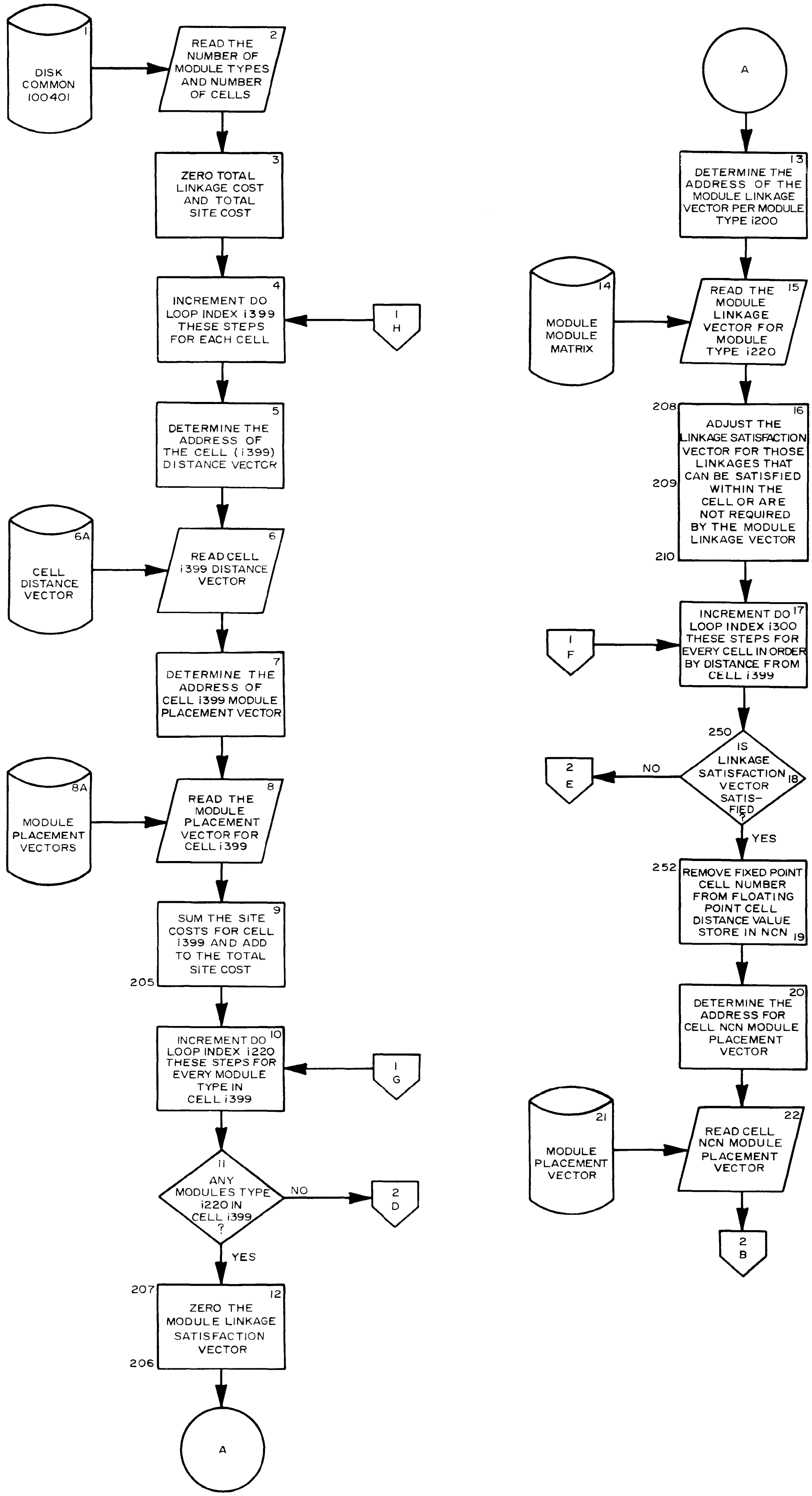


Figure 13 (continued)

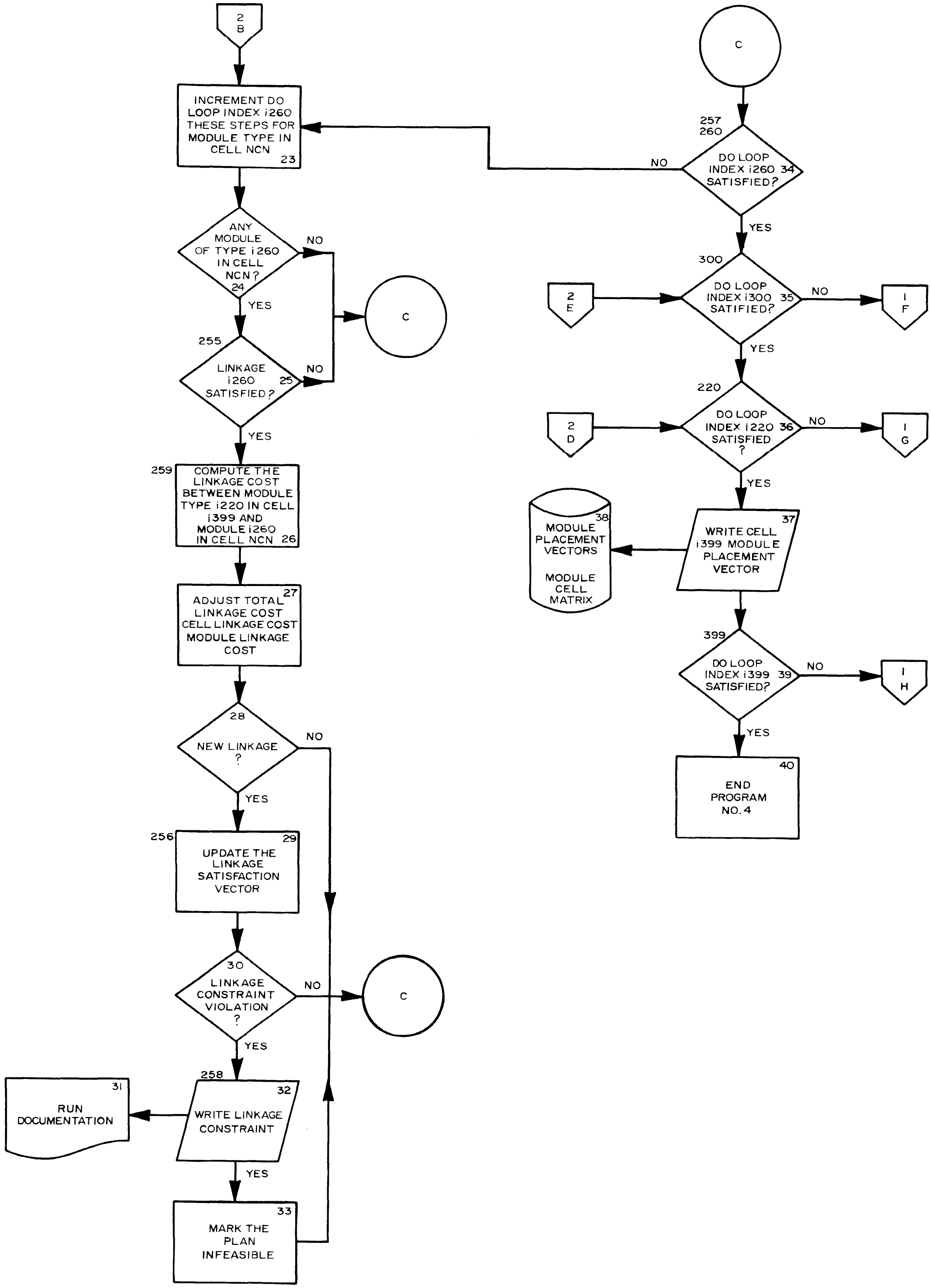


Figure 13 (continued)

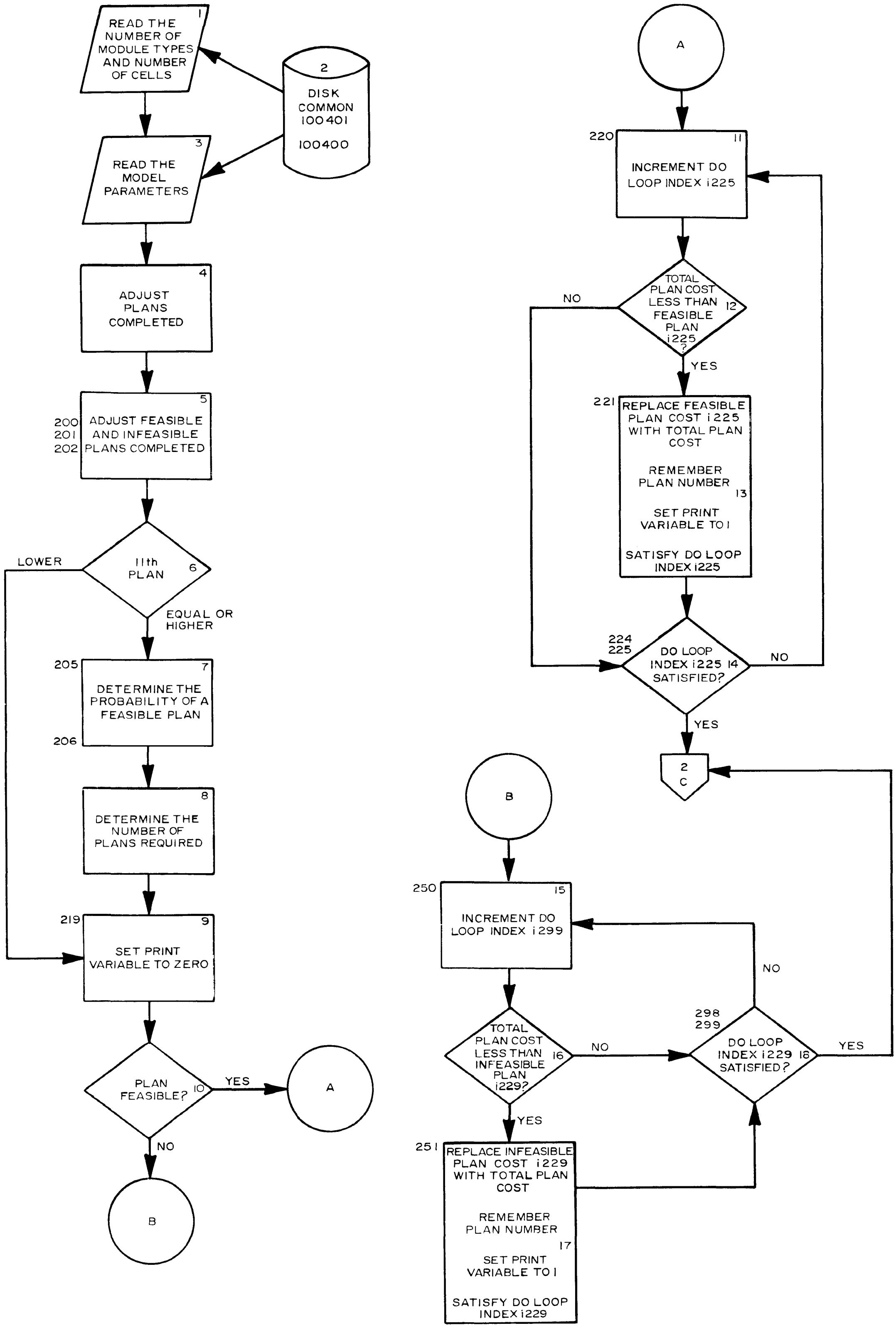
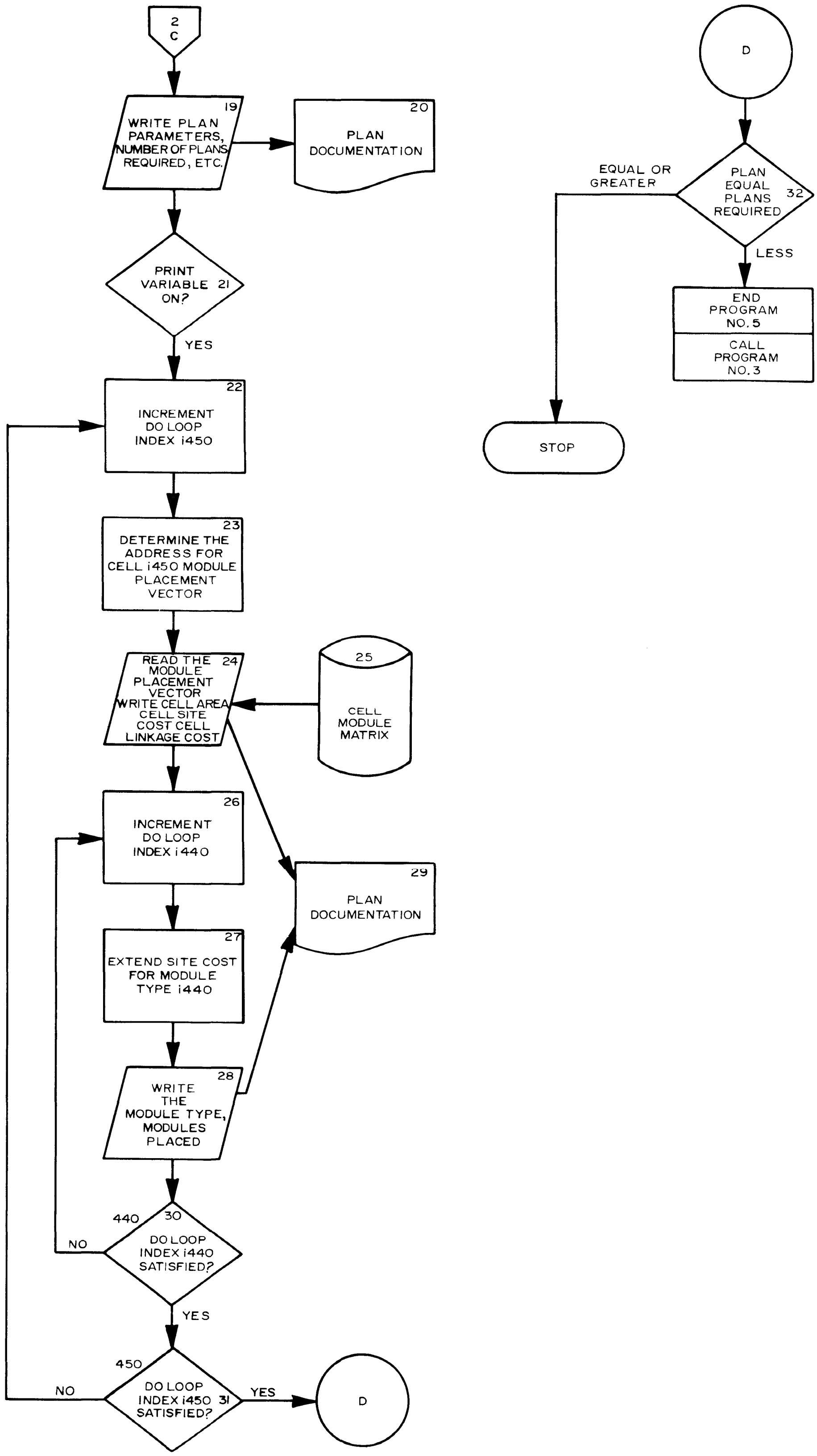


Figure 13 (continued)



Source: *SEWRPC.*

Cell-Module Placement Matrix

The cell-module placement section of the output contains the following information:

1. Module Placement Count (MPC)—The number of module types in a particular cell is indicated in a separate vector for each cell. These vectors comprise the Cell-Module Placement Matrix.

2. Module-Cell Constraints (MC)—The module-cell constraints indicating the maximum number of modules permitted in each cell, provided in the input data, are duplicated in the output so that the planner can ascertain simultaneously the effects of these constraints on the output.

3. Site Cost Accumulations (SC)—The accumulated site costs for each module type in each cell are displayed in the output. This information allows the planner to evaluate the components of total site costs in each cell. Such an evaluation in the light of total costs and total site costs will permit an understanding of the relative importance of individual site costs.

4. Linkage Cost Extensions (LCE)—The linkage costs (both construction-maintenance and operation) associated with each cell are accumulated in the cell-module matrix data to enable the planner-user to appreciate the impact of linkage costs on the plan design.

Plan Cost and Feasibility Information

The second class of plan output information relates to total plan cost and feasibility. As the model generates each experimental plan, the cell-module matrix data described above is printed in addition to the following information on plan costs and feasibility:

1. Plan Accuracy Required (a)—The original input plan accuracy requirement which indicates the ratio of the required optimal or "best plan" zone to the total number of possible experimental plans is reprinted in the output for convenience.

2. Probability of Success (s)—This input data parameter, which indicates the probability of producing a plan in zone "a," also is reprinted for the user's convenience.

3. Total Plan Costs (TPC)—The total site and linkage costs required to implement the plan are provided. This variable is used to rank feasible plans in order to select the best plan which is the feasible plan with the lowest costs.

4. Total Linkage Costs (TLC)—Two kinds of linkage costs (construction-maintenance and operation) are tabulated separately for each plan to provide a measure of the influence of each class of linkage costs on the overall plan design.

5. Total Site Costs (TSC)—A summation of the total site costs which is similar to total linkage costs is provided.

6. Probability of a Feasible Plan (PF)—Based on the number of feasible experimental plans generated as compared to the number of experimental plans generated, a probability of a feasible plan is calculated. As explained in Chapter II, this probability determines the number of plans required to achieve a specified plan accuracy with a specified probability of success.

7. Plans Required (NR)—The probability of a feasible plan, which varies during the model run, determines the number of experimental plans necessary to achieve plan accuracy with the required probability of success, since "a" and "s" are constant. During the run, this value indicates how many experimental plans are needed to complete the run.

8. Plans Completed (n)—The number of experimental plans completed as of the plan just completed is printed. This value subtracted from the plans required determines the number of plans needed to complete the run.

9. Ten Lowest-Cost Feasible Plan Numbers and Their Costs (NFP and TPCF)—The 10 lowest cost, feasible plans are tabulated. This information is updated during each pass with a past plan being replaced if the most recent experimental plan has a lower cost. This table enables the planner to understand the relative superiority of the best plans.

10. Ten Lowest-Cost Infeasible Plan Numbers, Their Costs, and Their Causal Constraints (NOIFP) – Although infeasible plans are not candidates for the "best plan," a comparison of their costs with the best of the feasible plans provides some indication of the importance of the constraints in increasing costs. This output also provides the data base for sensitivity analysis.

11. The Number of Feasible and Infeasible Plans (NOFP and NOIFP)—These are running totals of the numbers of feasible and infeasible plans.

The above information in each experimental plan enables the user-planner to diagnose the status of the plan design as the experimental plans are generated by the model. After some experience with the model, the planner will develop a "feel" or intuition that will enable him to use the model as a powerful tool in plan design.

With all of the above available information, the user still needs some guidelines for expected plan characteristics. The latter part of this chapter is devoted to alerting the user to some of the characteristics of model output plans.

Constraint Analysis

The NOIFP output previously described provides the basis for a sensitivity analysis of the effect of various constraints on plan design and plan cost. A review of this tabulation will reveal the causal constraint that prevented the plan from achieving feasibility and the total cost of the infeasible plan. If the plan observed is the lowest cost plan with the particular causal constraint, then the difference in plan costs between the best feasible plan and the selected infeasible plan is the cost of the constraint.

Chapter VI

DESIGN MODEL APPLICATIONS

Although the discussions of module definition, constraints, and costs have focused on the community and regional level, the following levels of application of the land use plan design model are theoretically possible:

1. Site (e.g. large housing complex).
2. Neighborhood.
3. Shopping center.
4. Industrial park.
5. Community (city, village, or town).
6. Central business district (CBD).
7. Regional (metropolitan).
8. State.
9. National.

At all of the above levels, the basic principles of the placement process remain the same, but the nature of the modules, constraints, and the form and detail of the costs change considerably. When using the land use plan design model for any application, module definitions, space patterns, site costs, linkage costs, and constraints must be consistent with the nature of the design problem. Substantive material in this report directly applies only to the community and regional levels; other applications would require additional efforts to develop model parameters and probably some changes to model operation.

The commentary in the chapter will attempt to highlight the nature of the model parameters for each application and to evaluate the potential effectiveness of the model in each case.

SITE LEVEL PLAN DESIGN

Site planning may be defined as the organization of the external physical environment up to the largest scale at which it is still subject to unified and complete control. This definition establishes site planning as a general class of spatial design including residential subdivisions (neighborhoods), shopping centers, industrial parks, and urban renewal projects. To assist in understanding the problems of implementation for site plan design, each of the model parameters is briefly discussed below.

Modules in Site Planning

Modules at this level of planning would consist of buildings, parts of large buildings (such as a store), groups of small buildings, or areas of human activity (such as a small park). However, the concepts of module area, site costs, and linkages would remain the same only on a smaller scale. In most aspects, the problem of module definition would be simplified since the module would typically be a single entity rather than a collection of entities.

Spatial Cells in Site Planning

Cell pattern definition becomes more difficult as the spatial scale of the problem is reduced. Since large cells will destroy design precision and clarity of definitions, and small cells will bias the design by arbitrarily excluding large modules, the problem of cell size becomes a formidable one. In this case, a model modification may be required to allow a module to be placed in a number of small cells simultaneously if it can not fit into one cell.

Constraints in Site Planning

Some of the objectives and constraints in site planning relate to visual form. This objective is added to the two present in larger scale plan design: the pattern of activity and the pattern of circulation. Difficulties occur in developing constraints relating to visual form because:

1. Visual form involves three-dimensional considerations, whereas the present plan design model is two-dimensional.

2. The principles of visual form may not be sifficiently understood to be expressed as specific constraints.

Module-cell constraints are similar in concept and practice at this level to those at the urban level. It is interesting to note that soil-topographic conditions are perhaps even more important here than at the community-city-regional level.

Costs in Site Planning

Although site costs become more important at the site planning level, particularly in sites involving large structures, the problem of site cost estimation for large buildings becomes one of soil mechanics rather than soil surveys.

Construction linkage costs grow in relative importance because of the reduced linkage costs due to smaller travel distances. Since much travel is pedestrian at this level, the value of personal time becomes the main criterion; therefore, the travel linkage costs become more difficult to quantify.

Site Planning Summary

A significant effort in module definition, constraint determination, and cost estimation would be required to implement the model at the site planning level. This effort would differ for residential subdivisions, shopping centers, and industrial parks, since these applications are special cases of site planning and, therefore, will not be treated separately.

COMMUNITY LEVEL PLAN DESIGN

This application has received considerable emphasis in the research effort reported herein, and is probably one of the potentially best applications of the land use plan design model. Primary differences between this level and the higher level of region relate to the size of the modules. For example, at the community level, a low-density residential module is a subdivision covering perhaps 150 acres, while the same type of module at the regional level may cover 2,500 acres.

In reality, a community level application consists of a region in minature. For the most part, the module differences between the regional and community level applications are ones of scale, similar to the low-density residential module. Of course, some of the larger modules, such as regional commercial centers, are not appropriate at the community level. Also, differences in the cell pattern and size, as well as accessibility constraints, are ones of scale. Unlike site planning, there are no fundamental differences in the concepts or applications of modules, cell patterns, constraints, and costs.

Plan design at the community level in a metropolitan area faces certain conceptual difficulties, since such a community isolated from its ever-present other communities is not really an entity capable of isolated design treatment. The interaction between a city and its suburbs is so strong that only a design treatment of the metropolitan area has any real significance. Even though all levels of urbanization are interdependent with outside areas, the strong bonds between city and suburbs require treating the city and its suburbs as a unit. Since the metropolitan area as a subject for plan design is only another name for a region, it will be discussed in the regional level plan design section of this chapter. However, the central business district (CBD), which is a special subregion of the city, must be considered separately.

Central Business District (CBD)

Although the land use plan design model was not developed with the application to a central business district (CBD) in mind, the CBD application appears to be a pertinent one since one of the major problems of CBD design and renewal is that of land assembly. The inability to assemble the land required for projects of major scope often destroys the best intentions of planners. The objectives of urban design must be accomplished within the constraints of land availability. Land availability restrictions may be implemented as module-cell constraints in the land use plan design model. Theoretically, design within the complex constraints of the urban central business district appears to be a powerful application of the land use plan design model. However, there has not been any model experience with CBD design.

To illustrate the application of the model to urban design of a CBD, each of the model elements from modules to constraints will be examined briefly. In order to be more meaningful, this examination is based on a specific example, Midtown Manhattan in New York City, which was documented in the book Urban Design Manhattan. This book, published under the auspices of the Regional Plan Association (of the New York metropolitan region), is particularly noteworthy since it illustrates urban design at three levels: Midtown Manhattan, Forty-Second Street, and "A New Office Cluster." This variation in scale aids in understanding smaller central business districts which are equivalent in size to a single street in Manhattan. Furthermore, an excellent set of design principles is developed which could easily serve as a constraint for the land use plan design model. The publication, however, says little or nothing about costs which remain a key problem in design implementation.

Modules in CBD Design: Like the site planning example, many of the modules would be buildings. In the cases of the office cluster and Forty-Second Street, all of the facility modules would consist of buildings, whereas at the Midtown Manhattan level, some modules probably would consist of office clusters of some other type of building clusters. Nonfacility modules such as parks would be appropriate at all three levels. Within the CBD design, the basic concepts of module area, site costs, and linkages would remain the same.

Spatial Cells in CBD Design: The land ownership patterns comprise the most significant determinant of cell pattern. Since many cells would be quite small to be consistent with the ownership areas, many modules would not fit into many cells. In model operation, the module-cell constraints would assure module-cell exclusion.

Constraints in CBD Design: Various restrictions, or constraints, in CBD design, such as land ownership, provide a challenge to model operation. But, since it is likely that only the land use plan design model is capable of recognizing all the constraints present, the rewards will be high. Accessibility constraints in terms of travel by varous means also play a key role since the model of travel provided can have a dramatic effect on the final design.

Costs in CBD Design: In site costs, land purchase and land rennovation costs play a major role in CBD application. Because of the foundation problems characteristic of constructing large buildings, the analysis of effects of soil on costs must be more detailed.

In linkage costs, operation costs in the form of travel costs also will be important since pedestrian travel costing requires evaluating a pedestrian's time.

CBD Design Summary: The application of the land use plan design model to CBD design seems to be appropriate even though some effort in cost data collection may be necessary to make the application practical.

REGIONAL LEVEL PLAN DESIGN

In this volume of this report and in the previous volumes of this report, the application of the model has focused on the regional level of design. Therefore, no further elaboration will be provided at this point. The potential applicability of the model to the regional level of plan design has greatly influenced the development of the land use plan design model as presented herein.

STATE LEVEL PLAN DESIGN

Small- and medium-sized states have applications similar to those of a region while larger states have problems closer to those at the national level. Because of these similarities, the state level of application will not be discussed as a separate entity. The characteristics of the state level plan design application may be viewed from the regional or national level of application.

NATIONAL LEVEL PLAN DESIGN

One of the frequent criticisms of the federal government is its lack of a national land use policy or program. With all of the current problems in large urban areas and with all of the rich land resources available in the United States, a case certainly can be made for a national land use development program. Since the same concepts of modules, cells, constraints, linkages, and costs can be applied at the national level as at other levels, a fruitful application of the land use plan design model may be possible at this level. Although detailed examination of such a national level application lies beyond the scope of this report, such application would provide an interesting area of further research.

Chapter VII

MODEL RESULTS: AN EXAMPLE PROBLEM

INTRODUCTION

The land use plan design model, incorporating the set decomposition algorithm, was applied to the design of a land use plan for the Southeastern Wisconsin Region as a part of the second phase of the research project. The results obtained from this application are documented in Volume 2 of this report. For this application the Region was divided into 347 cells. The standard size of a cell was six U. S. Public Land Survey sections (approximately six square miles), although cell size was varied from four to 18 such sections, with one of the cells consisting of approximately 135 such sections. A total of 2,321 modules, representing 34 module types, were supplied as input data along with the area and linkage requirements of each module type. The module types used, the number of each type, sample module definitions, and sample linkage requirements are all set forth in the appendices to Volume 2 of this report. The results of this application indicated the need to revise the placement algorithm.

In the third phase of the research project, the new random placement algorithm was incorporated into the model. The model was then again applied to the design of a land use plan for the Region, using the same sets of cells, modules, and associated cost data as used in the previous model application. The computer time required to run the algorithm, however, was excessively high. It was decided to reduce the total number of cells to 75 by increasing the cell areas, while retaining the total number of modules. Although this decreased the computer running time substantially, the time remained high for operational purposes. It was, therefore, decided to apply the model to a smaller geographical area with a still smaller number of modules. Accordingly, the Village of Germantown, also used in an earlier hypothetical model application, was selected as the study area.

STUDY AREA DESCRIPTION

The Village of Germantown, located in Washington County in southeastern Wisconsin, covers an area of about 36 square miles and in 1970 had a population of 7,000 persons. The village, which occupies almost all of what was the U. S. Public Land Survey Township of Germantown situated in the southeastern part of Washington County, is located in a still rural but rapidly urbanizing area.

The Village of Germantown has in recent years experienced a higher rate of increase in population than other similar areas in the Southeastern Wisconsin Region as a result of urbanizing pressure which can be attributed to the location and character of the village. From the locational aspect, the village is situated approximately 30 minutes driving time from Milwaukee's Central Business District (CBD) along the USH 41 freeway which traverses the southwest corner of the village. In addition, the village is relatively close to the retail centers and industrial parks of the northwestern portion of the Milwaukee urbanized area. In terms of existing land uses, the village is principally comprised of open, agricultural, or agricultural-related land uses and low-density urban land uses. Some manufacturing and quarrying activities are present in the western part of the village. The Village of Germantown currently has extended municipal water and sanitary sewerage service systems to over 360 acres and has proposed an additional service area of over 5,000 acres. Other utilities such as gas and electricity are available to developing areas of the village on demand.

INPUT DATA

The available land area of the Village of Germantown was divided into 36 cells with each cell being one square mile, or 640 acres, in area. The land use requirements for the forecast year of 1990 were expressed in terms of 11 module types. The module types used, area of each module, number of modules in the initial condition, and the additional number to be placed are presented in Table 22. The location of the existing modules is shown on Map 1.

Site and Linkage Costs

For the purpose of the computation of site development and linkage costs, the cells were classified into three groups: cells which lie predominantly in environmental corridors, cells which lie predominantly in agricultural areas, and cells which lie in both agricultural areas and in environmental corridors. Site costs were based on a per acre construction cost for the first seven module types. This per acre cost was varied with the soil type in three different groups of cells. The three per acre site costs used were \$178,340, \$57,090, and \$136,490, respectively, for cell groups of environmental corridor, agricultural land, and combined types. Total site cost of a particular module with respect to a given type of cell was then computed by multiplying the appropriate per acre cost by the number of acres contained in the module. Total site costs used for module type eight were \$90,000 for agricultural and combined types of cells, and \$120,000 for the environmental corridor cells. As no new module of types nine, ten, and eleven were to be placed in the forecast year, no cost for these types was provided in the input data.

The module-to-module linkage costs were computed by using the data reduction routines previously discussed in the report. The cell-module site costs and module-to-module linkage costs as used in the example run are presented in Appendix C of this report.

Constraint Data

As discussed previously in the report, the constraints imposed on the model operation involve module-cell compatibility as well as intermodule distance requirements. The Module-Cell Compatibility Matrix combines two types of constraints—a site constraint, which excludes the placement of certain modules in certain cells, and a module limiting constraint, which specifies the maximum number of units of a certain type that can be located in a certain cell. The design constraints for the example problem are listed in Appendix C along with other input data. Several sets of intermodule distance constraints were used to run the model for the study area. It was observed that with all other input information remaining the same, the performance of the model depends entirely on the types of distance constraints imposed. Consequently, the distance constraints were adjusted to obtain a reasonable number of feasible plans. The distance constraints used to generate the plans presented on Maps 2 through 11 are presented in Table 23.

RESULT OF THE MODEL RUN

The model was run to obtain an optimal land use plan design for the Village of Germantown for the design year 1990. Five feasible lowest cost plans, as well as five infeasible lowest cost plans, were recorded as the model was run, and these plans were then displayed graphically as shown on Maps 2 through 11. Infeasibility indicated that one or more of the distance constraints imposed could not be satisfied by the placement of the modules in the given plan.

Table 22

MODULE INPUT DATA FOR LAND USE
DESIGN MODEL EXAMPLE RUN
VILLAGE OF GERMANTOWN,
WASHINGTON COUNTY, WISCONSIN

Module No.	Module Description	Area (Acres)	Number in Initial Condition	Additional Number to Be Placed
1	Residential (Medium Density)	315.0	2	12
2	Local Commercial Center	6.4	3	5
3	Regional Commercial Center	90.0	0	1
4	Highway Commercial Center	13.8	1	1
5	Industry (Light)	315.0	0	2
6	Industry (Heavy)	315.0	1	0
7	Jr. High School	27.5	1	1
8	Agriculture	627.0	0	0
9	Sewage Treatment Plant	50.0	1	0
10	Major Highway	5.0	16	0
11	Environmental Corridor	150.0	34	0

Source: SEWRPC.

Table 23

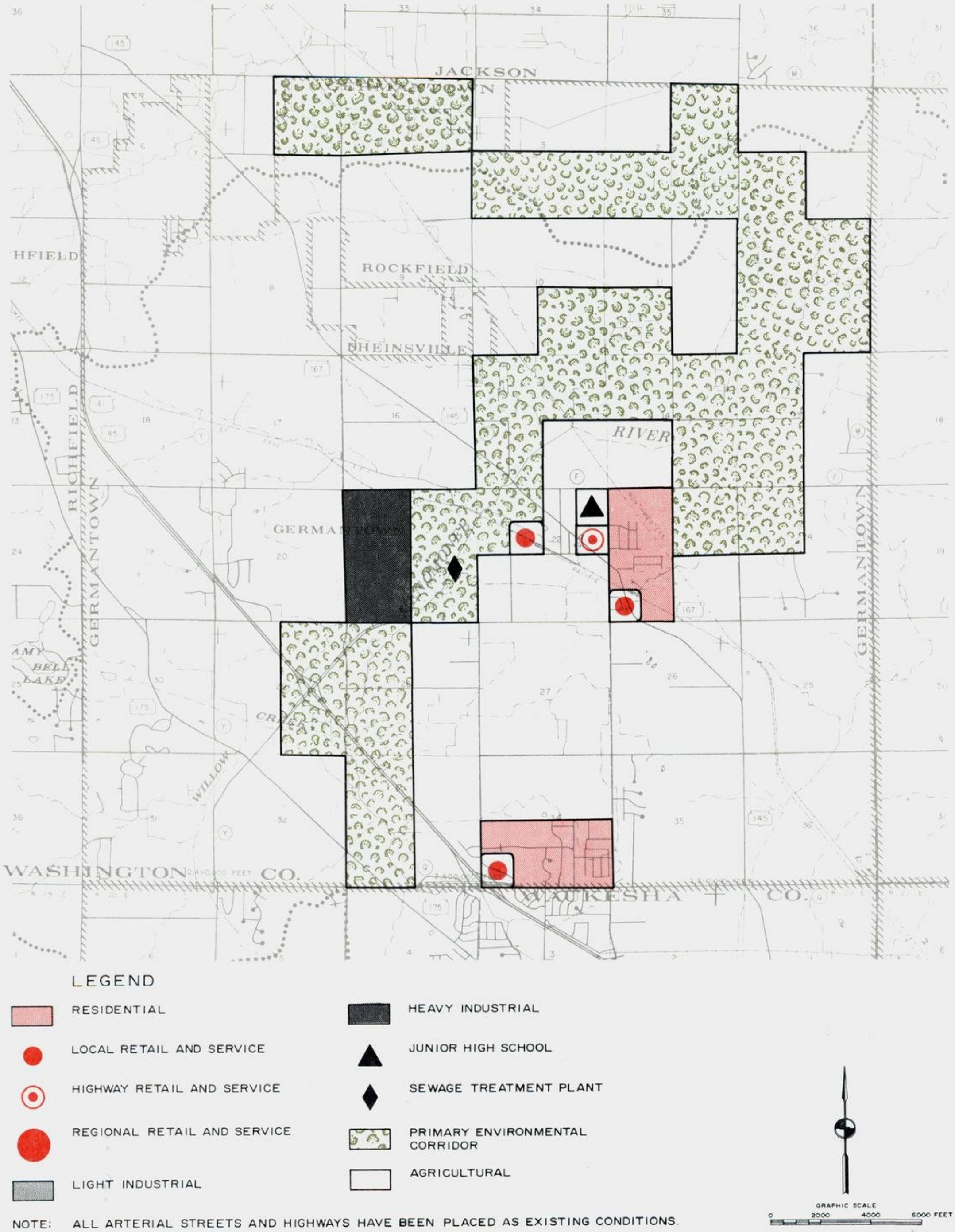
DISTANCE CONSTRAINTS FOR LAND USE
DESIGN MODEL EXAMPLE RUN
VILLAGE OF GERMANTOWN,
WASHINGTON COUNTY, WISCONSIN

From Module	To Module	Distance (Miles)
1	2	3.0
1	3	6.0
1	5	5.0
1	7	2.5
5	6	3.0

Source: SEWRPC.

Map 1

EXISTING CONDITIONS

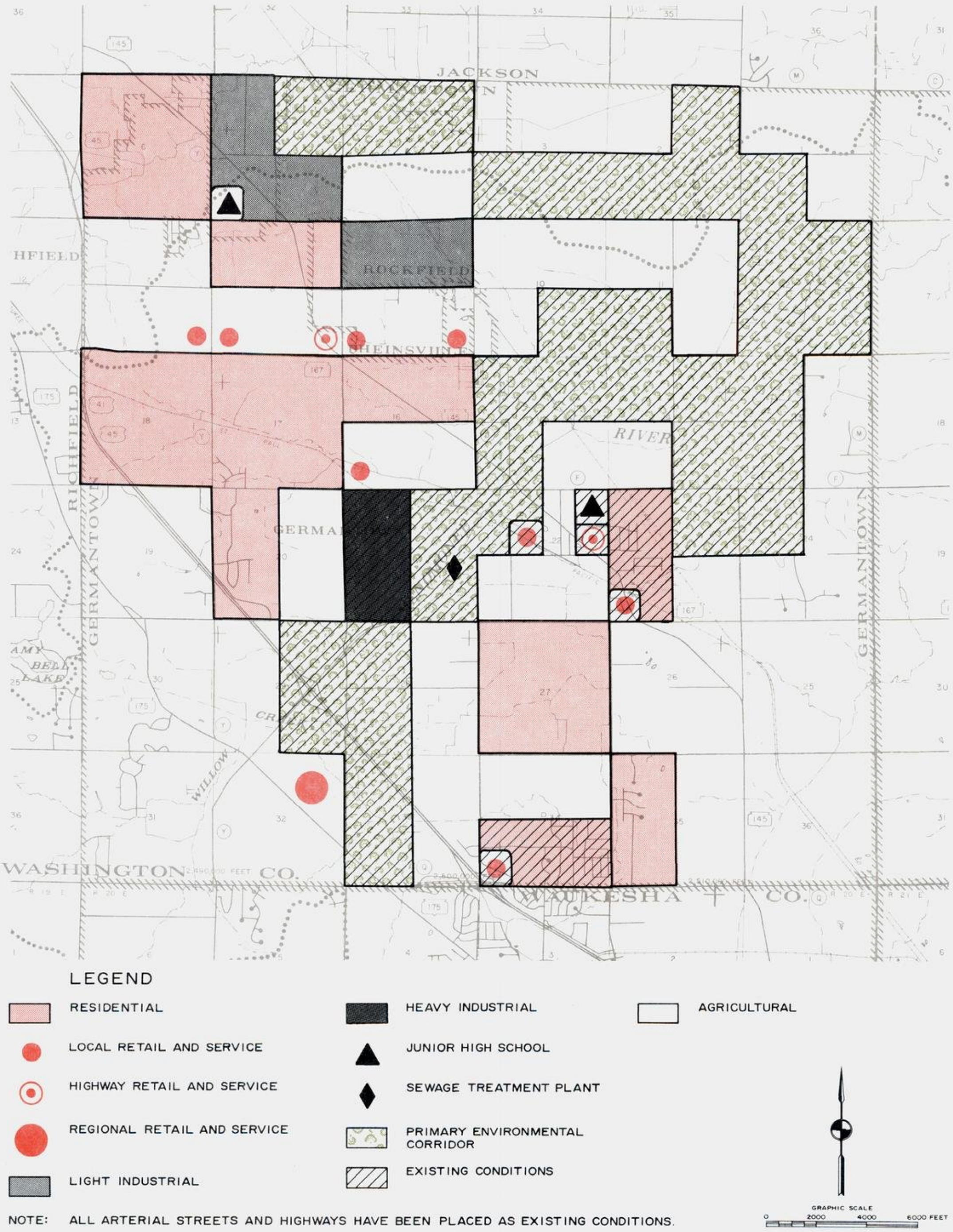


This map depicts the existing conditions that were placed by "hand" prior to plan module placement and represent not only areas of general existing urban land uses but also plan modules that would not normally be placed as a part of the operation of the model. These latter modules would include primary environmental corridors which must be placed where the resources which make up the environmental corridors exist and a sewage treatment plant which can not or should not be randomly placed within the community.

Source: SEWRPC.

Map 2

PLAN 84 OF 118

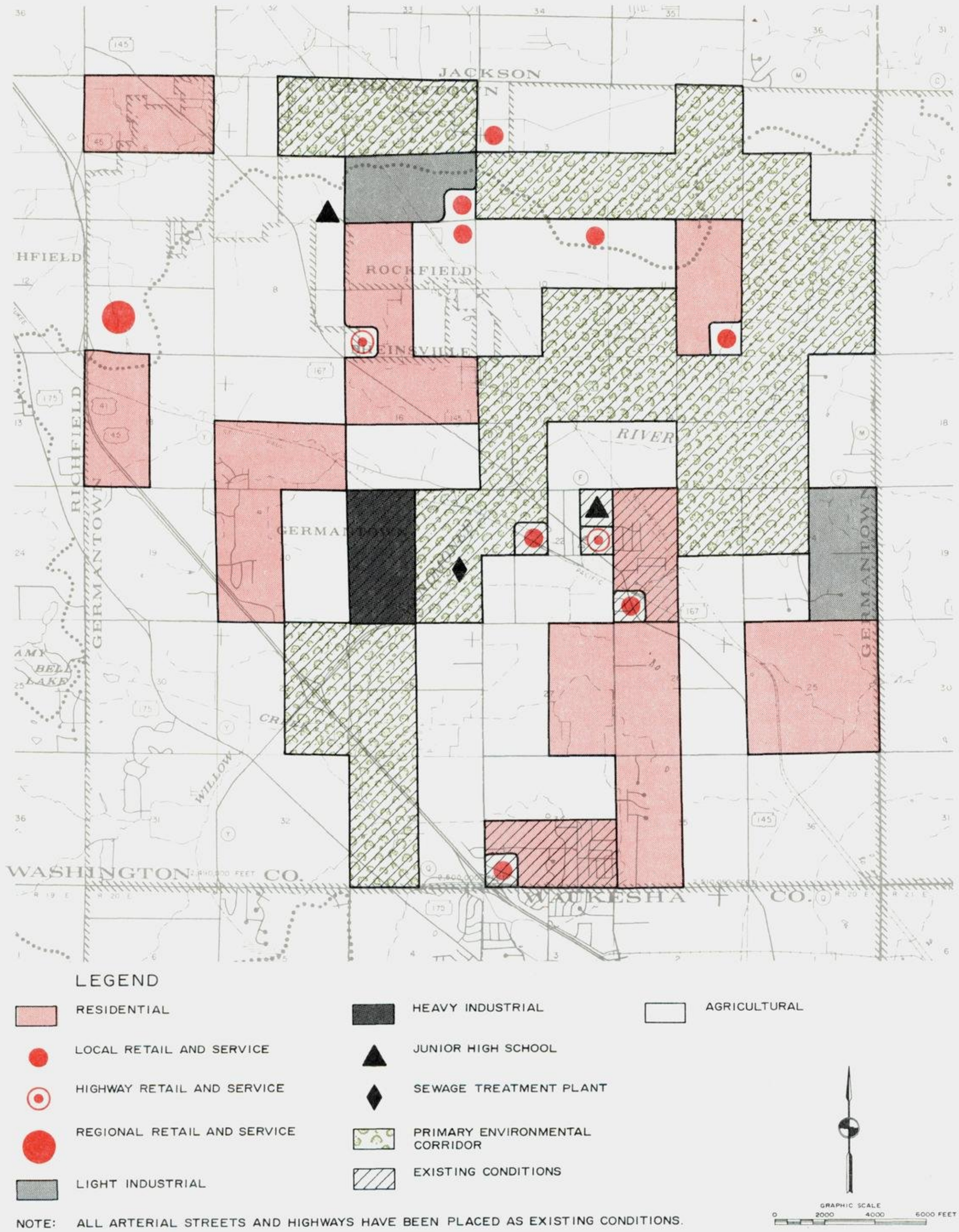


This map depicts the "best" feasible plan based on lowest cost within the constraints imposed as a part of the model operation.

Source: SEWRPC.

Map 3

PLAN 23 OF 118

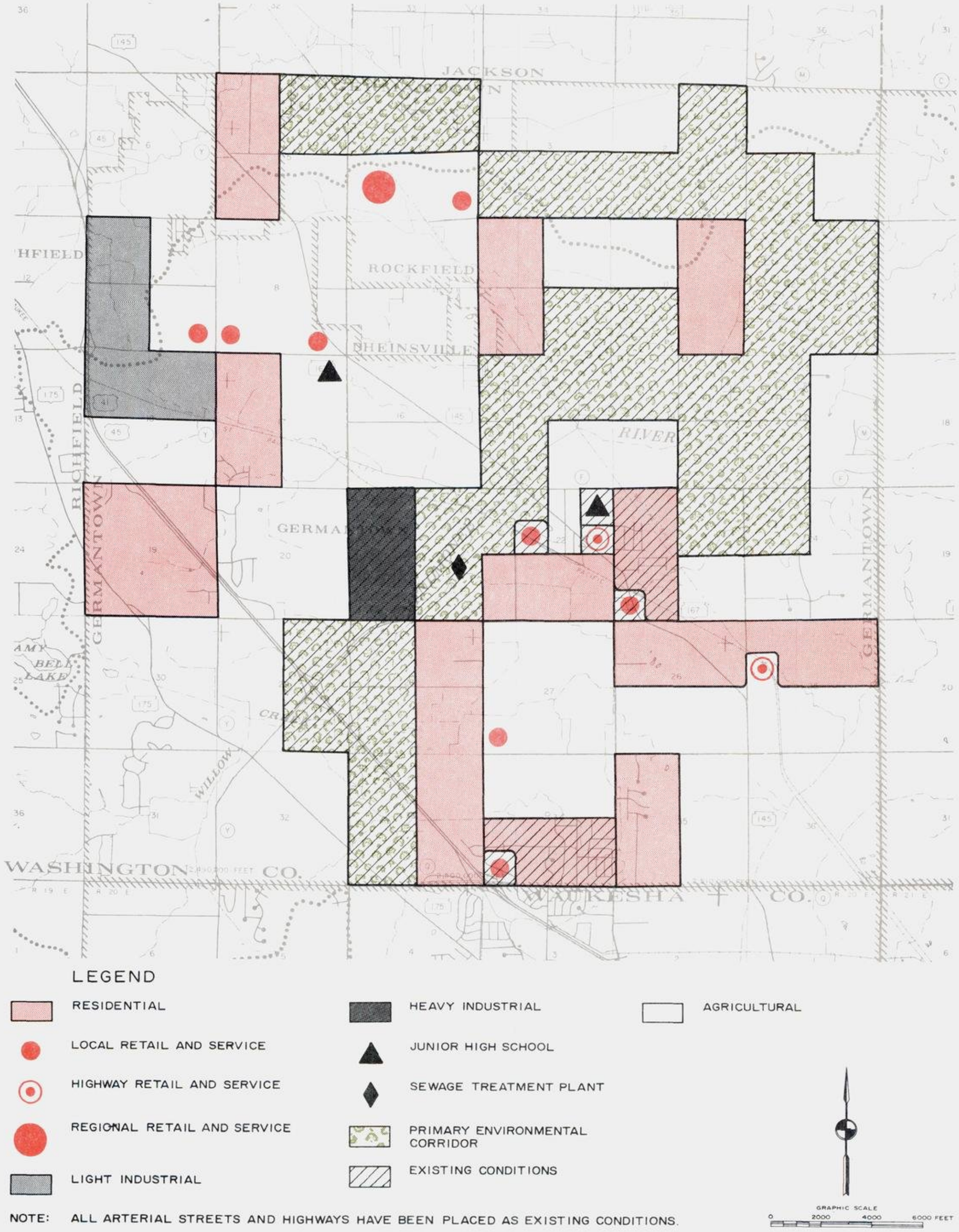


This map depicts the "second best" feasible plan based on lowest cost within the constraints imposed as a part of the model operation.

Source: SEWRPC.

Map 4

PLAN 112 OF 118

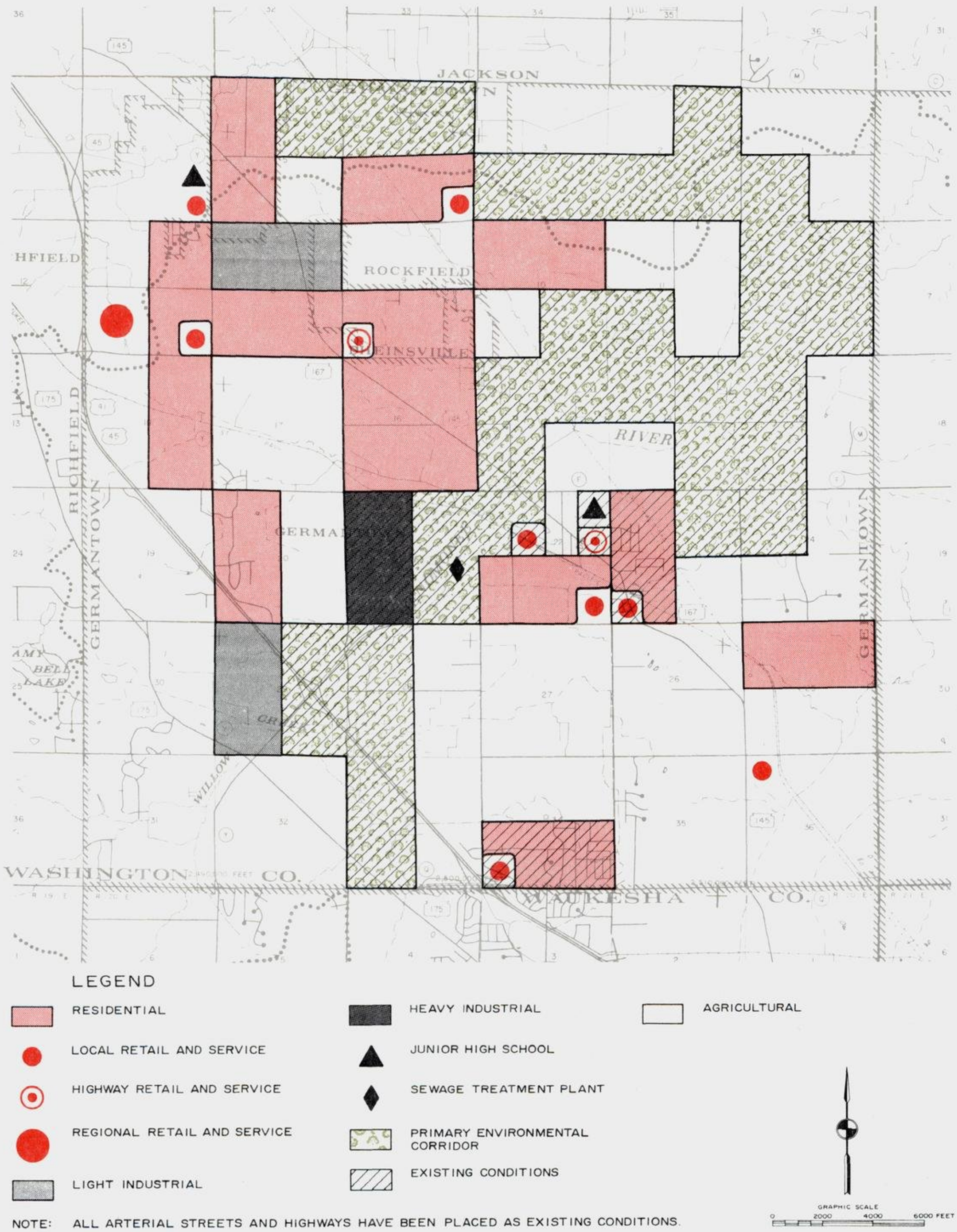


This map depicts the "third best" feasible plan based on lowest cost within the constraints imposed as a part of the model operation.

Source: SEWRPC.

Map 5

PLAN 58 OF 118



This map depicts the "fourth best" feasible plan based on lowest cost within the constraints imposed as a part of the model operation.

Source: SEWRPC.

Map 6

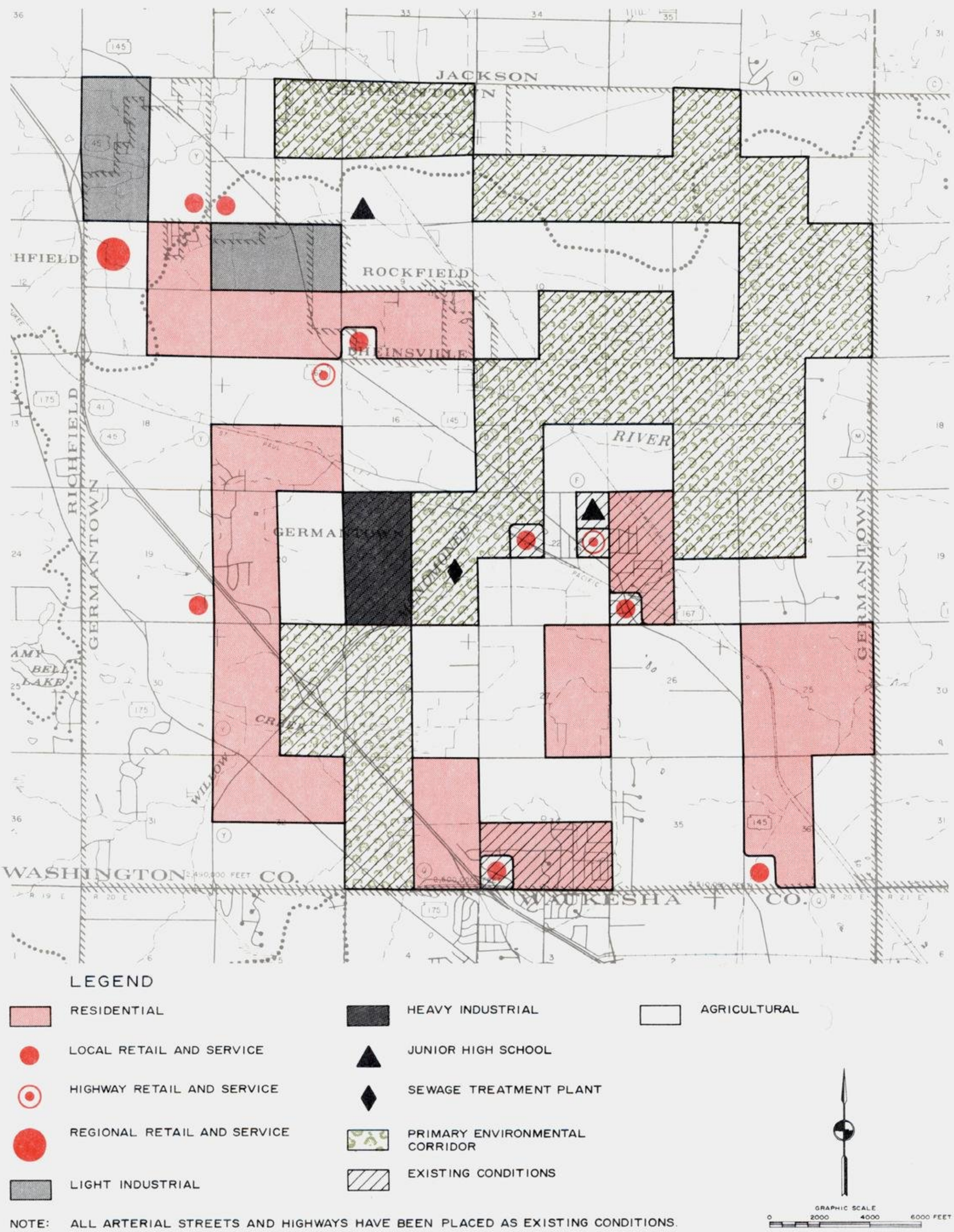
PLAN 17 OF 118

This map depicts the "fifth best" feasible plan based on lowest cost within the constraints imposed as a part of the model operation.

Source: SEWRPC.

Map 7

PLAN 92 OF 118

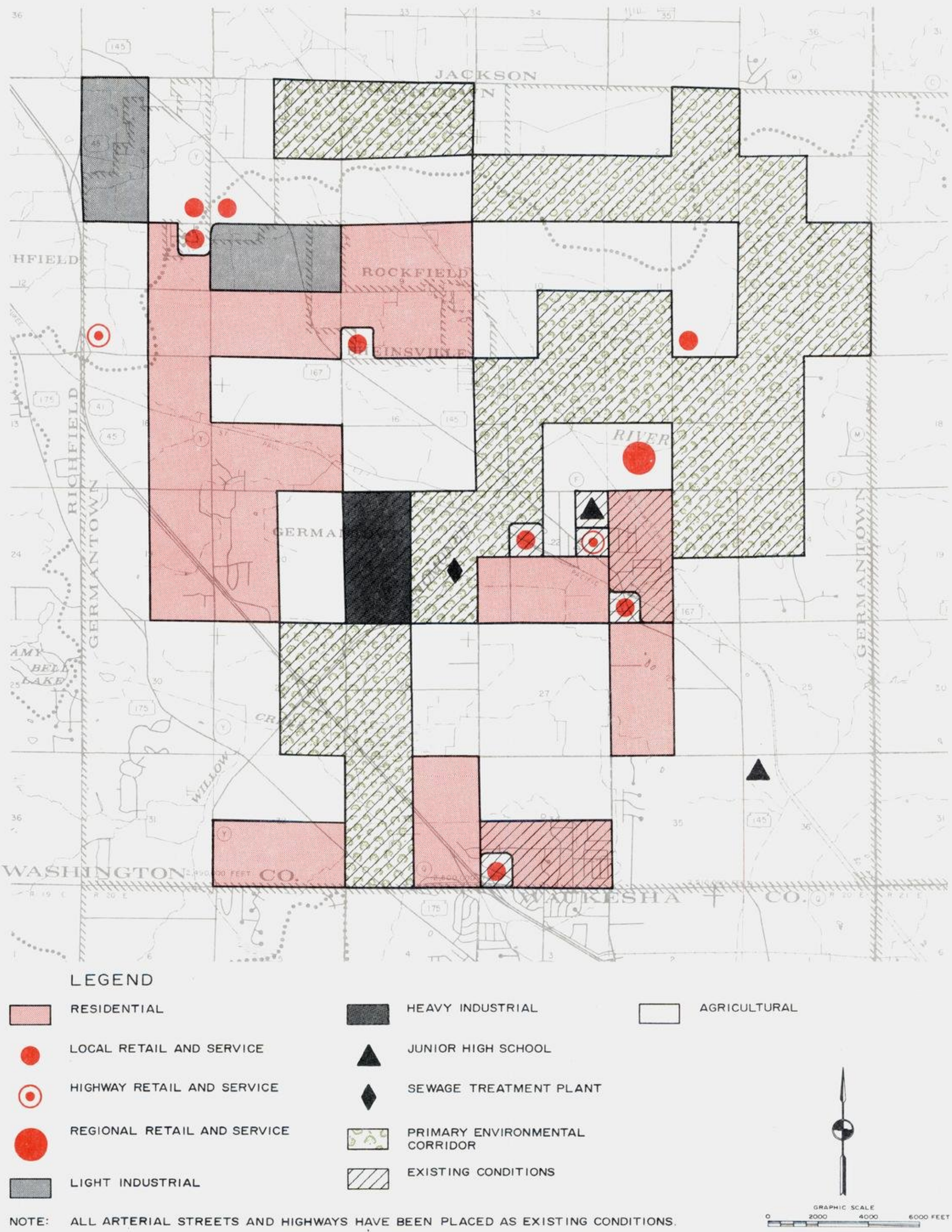


This map depicts the "best" infeasible plan based on the constraints imposed as a part of the model operation.

Source: SEWRPC.

Map 8

PLAN 47 OF 118

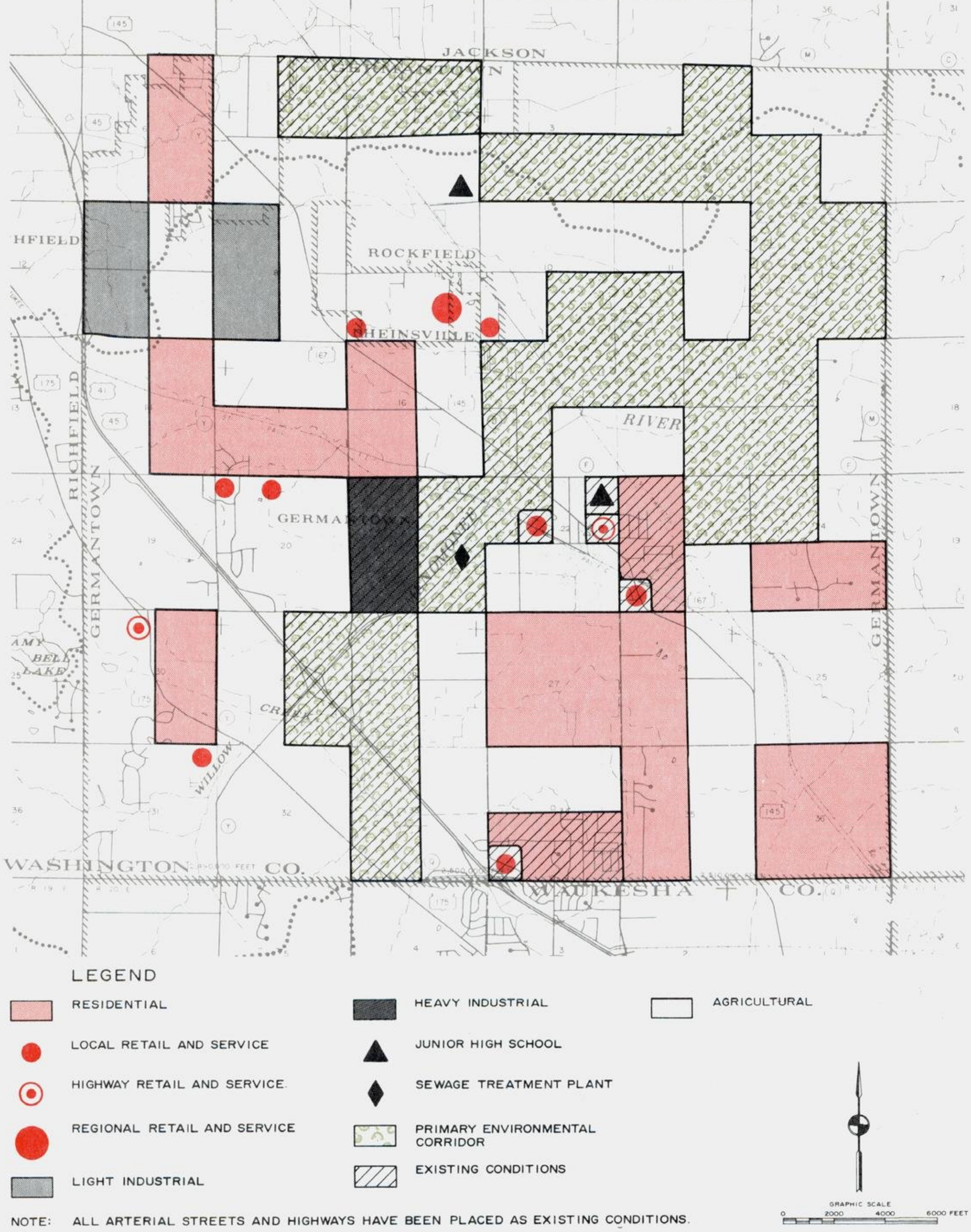


This map depicts the "second best" infeasible plan based on the constraints imposed as a part of the model operation.

Source: *SEWRPC*.

Map 9

PLAN II OF 118

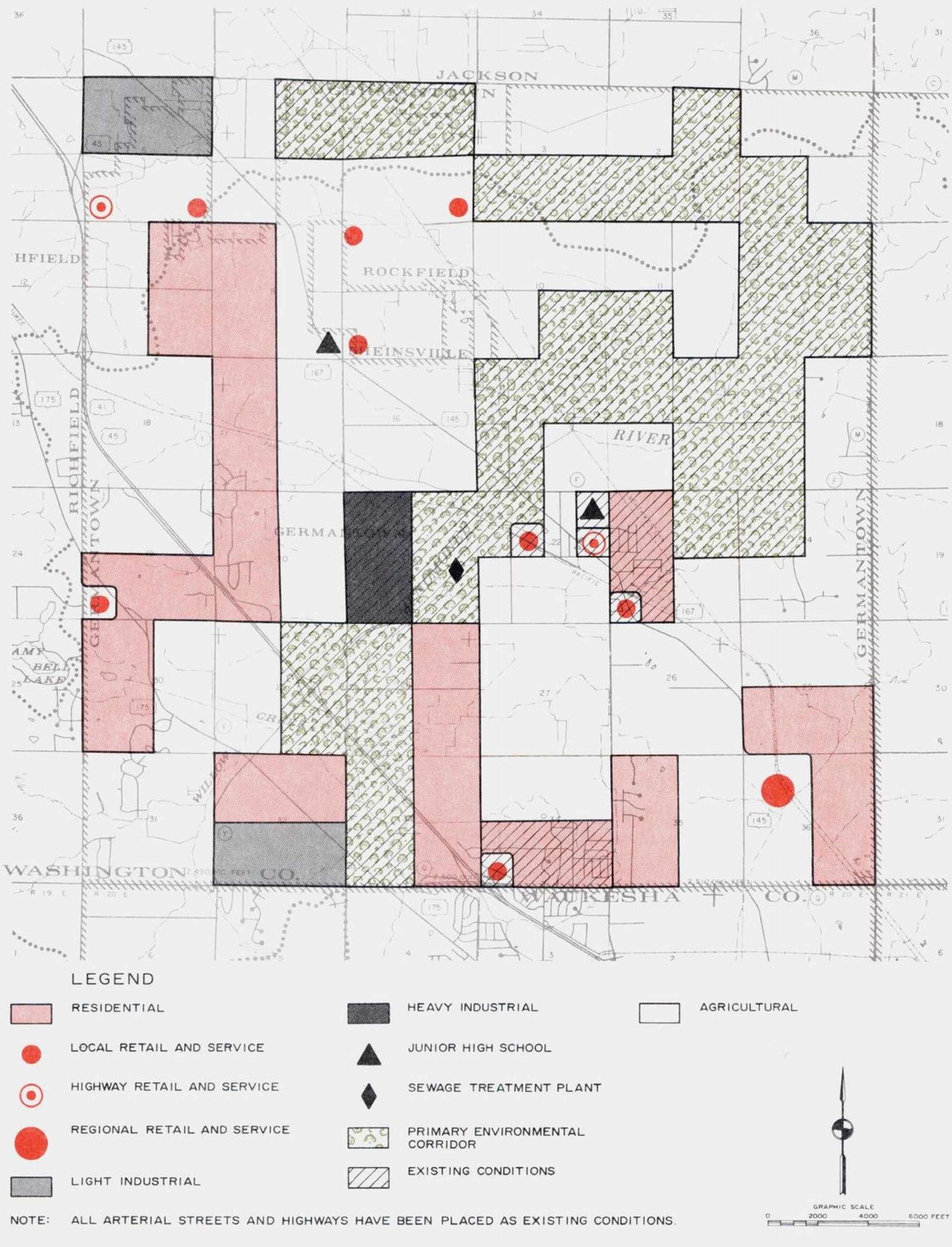


This map depicts the "third best" infeasible plan based on the constraints imposed as a part of the model operation.

Source: SEWRPC.

Map 10

PLAN 85 OF 118

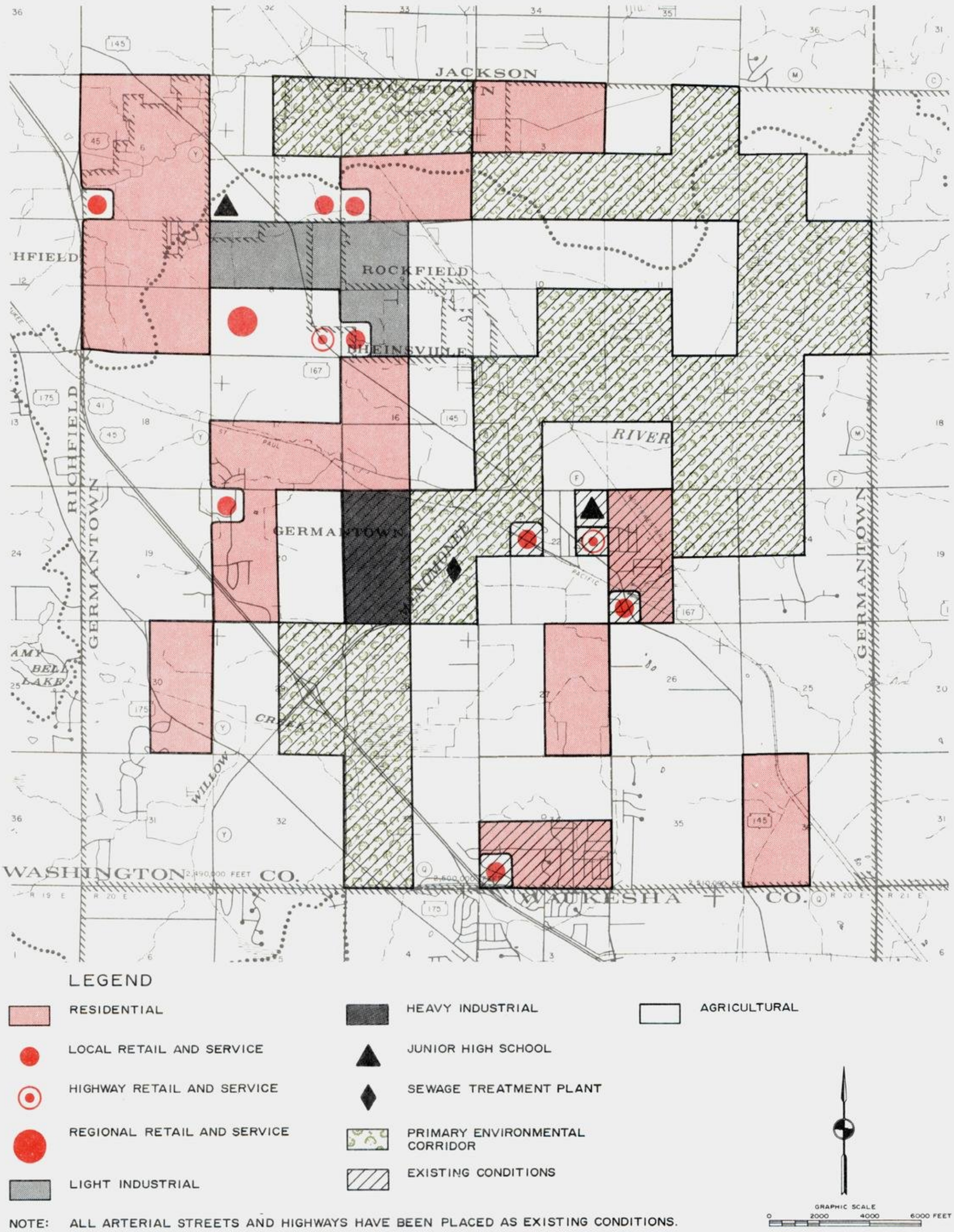


This map depicts the "fourth best" infeasible plan based on the constraints imposed as a part of the model operation.

Source: SEWRPC.

Map 11

PLAN 8 OF 118



This map depicts the "fifth best" infeasible plan based on the constraints imposed as a part of the model operation.

Source: SEWRPC.

The plans were generated with the value for plan accuracy as 0.05 and the probability of success as 0.95. The total number of experimental plans prepared was 118. The results of the model run are summarized in Table 24, which presents the site development cost, linkage cost, and total cost of the five lowest cost plans in both feasible and infeasible groups. The total number of times any of the distance constraints were violated in each of the five best infeasible plans is shown in Table 24. More detailed information about the distance constraint violation for each of the five infeasible least cost plans is given in Table 25. The lowest cost plan which satisfies all constraints as designated by the model run was plan number 84, which is shown on Map 2. The total cost of this plan is computed to be $412,151,000, with site development costs of $313,715,000 and linkage costs of $98,436,000.

COMPARISON TO CONVENTIONAL DESIGN

For the purpose of comparison with a plan prepared by conventional land use design techniques, that portion of the adopted 1990 regional land use plan which encompasses the geographic area included in the Village of Germantown was costed out (see Map 12). Both the site and linkage costs were obtained for this plan using the same number of modules as allocated in the design model run. The only difference was in the placement of modules. In computing the site and linkage costs for the adopted land use plan the same procedure and the same unit cost figures used in the design model run were employed. The total cost of the conventional land use plan for the Village of Germantown as a part of the regional land use plan prepared conventionally by the Commission staff was found to be $437,979,000, with site development costs of $352,934,000 and linkage costs of $85,045,000.

Comparing these cost figures with the least cost plan generated by the model, it will be noted that the total site cost of the model-generated plan is about $39 million less than that of the conventionally designed plan, while the linkage cost of the model-generated plan is about $13 million more than that of the conventional plan. These results are as expected and can be well explained. As the model attempts to minimize the total cost, of which the site cost constitutes the largest portion, the modules are placed in those cells which would give lower site development costs. Consequently, most of the plans generated by

Table 24

RESULTS OF LAND USE DESIGN MODEL EXAMPLE RUN
VILLAGE OF GERMANTOWN,
WASHINGTON COUNTY, WISCONSIN

	Plan Number	Site Cost (In Millions)	Linkage Cost (In Millions)	Total Plan Cost (In Millions)	Total Number of Times Distance Constraints Violated
Feasible Plans	84	313.715	98.436	412.151	0
	23	365.291	115.607	480.898	0
	112	418.244	112.406	530.651	0
	58	436.498	99.535	536.033	0
	17	437.595	104.344	541.938	0
Infeasible Plans	92	313.716	114.017	427.732	3
	47	322.952	108.708	431.660	5
	11	313.715	119.087	432.803	3
	85	311.532	122.038	433.569	4
	8	339.114	99.751	438.865	2

Source: SEWRPC.

Table 25

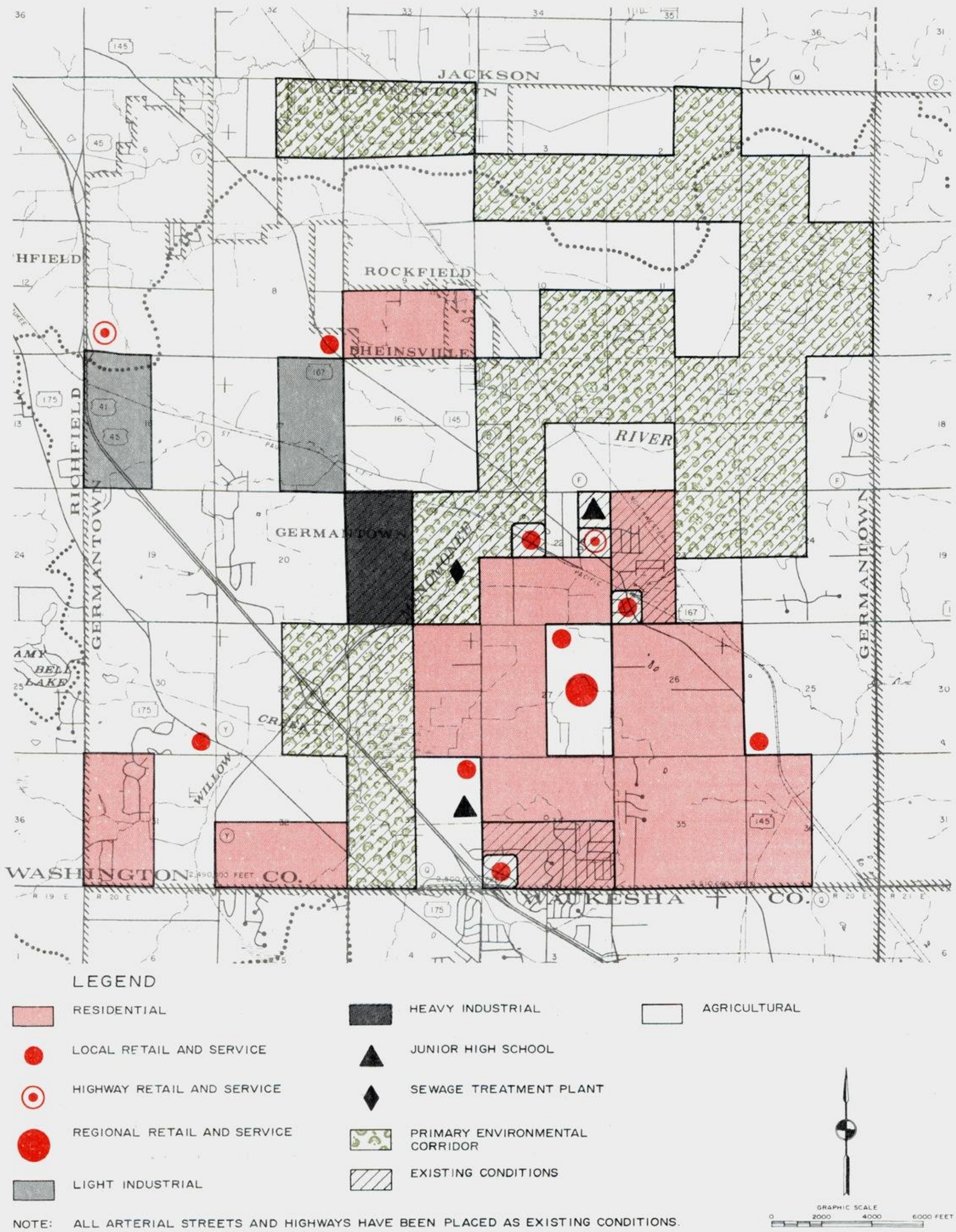
DISTANCE CONSTRAINT VIOLATION SCHEDULE
BEST FIVE INFEASIBLE PLANS
VILLAGE OF GERMANTOWN,
WASHINGTON COUNTY, WISCONSIN

Plan Number	From Module Type	Cell Location	To Module Type	Cell Location	Actual Distance (Miles)	Allowable Distance (Miles)
92	1	32	7	22	2.83	2.50
	1	36	7	22	2.83	2.50
	1	36	3	7	6.40	6.00
47	1	7	7	22	3.61	2.50
	1	8	7	22	2.83	2.50
	1	18	7	22	3.16	2.50
	1	19	7	22	3.00	2.50
	1	32	7	22	2.83	2.50
11	1	18	7	4	2.83	2.50
	1	30	7	22	3.16	2.50
	1	36	7	22	2.83	2.50
85	1	7	3	36	6.40	6.00
	1	30	7	8	3.16	2.50
	1	32	7	22	2.83	2.50
	1	36	7	22	2.83	2.50
8	1	30	7	22	3.16	2.50
	1	36	7	22	2.83	2.50

Source: SEWRPC.

Map 12

THE REGIONAL LAND USE PLAN FOR 1990 FOR THE VILLAGE OF GERMANTOWN



This map depicts the adopted regional land use plan as it would be delineated using the module types and definitions as set forth in this and previous volumes of this report, and is presented here for comparison with the plans depicted on Map Nos. 2 through 11, which plans resulted from the running of the land use plan design model.

Source: SEWRPC.

the model do not show any strong clusterings around the existing development in the old village center, but rather tend to follow a somewhat scattered pattern covering those cells which provided lower site cost. In general, the western part of the study area along with the southeastern corner would give lower site costs for residential development, and the plans generated by the model would show a tendency for placement of residential modules in these areas. The model-generated plan shows a more scattered pattern and therefore the linkage costs are higher in the model-prepared plans than those obtained from a conventionally prepared plan which attempts to locate the modules in a more clustered pattern, thus minimizing the linkage costs.

Moreover, the conventionally prepared plan has taken the probability of implementation into consideration and therefore has placed the future residential modules around the existing development as a realistic approach in land use planning. In doing so, the site cost in the conventional plan has risen to about $39 million more than that in the lowest cost model-generated plan, because the cells immediately adjacent to the existing development show higher site development costs. Since the model does not consider the probability of implementation of a plan, a large number of residential modules are located in the cells around the southeastern corner of the study area because of lower site development costs. If the nature of the soil and other characteristics of the cells were such as to give lower site development costs around the old village center, the model-generated plans could be expected to show a strong clustering pattern around the existing development.

Ideally, a model-generated plan should resemble a cluster pattern. These clusters consist of a set of modules that service each other. In an areawide plan design a hierarchy of such clusters will exist, consisting of small clusters at the neighborhood level, larger clusters at the community level, and very large clusters at the regional level. Since the model attempts to minimize the total cost of a plan, the distance between modules is consequently minimized in a given condition of soil and other site characteristics. If in a particular planning situation linkage cost appears to be more critical than the site development cost, the cost minimization process of the model would produce strong cluster patterns in a plan. There are, however, several forces which affect an ideal cluster pattern, and some of these forces which affect this basic pattern of a land use plan design are mentioned below:

1. The finite size of the cells tends to produce "lumpy" clusters. Very small cells, however, would produce more perfect clusters. Also, the areal limitations of cells may force a module into an adjacent cell, distorting the cluster pattern to an even greater degree.

2. The module-cell constraint matrix distorts the cluster pattern by eliminating certain cells as placement candidates.

3. Module site costs interact with linkage cost minimization so the areas with lower site costs may be selected even though the module-to-module distances are greater.

4. Module-to-module distance constraints tend to eliminate certain experimental plans from the feasibility class, but should not distort the basic cluster pattern.

The end result of the basic clustering effect modified by the cell pattern, constraints, and costs is a modified cluster pattern. The general cluster pattern should be observable, and the deviations should be explainable in terms of the cell pattern and module-cell constraints and site costs.

Chapter VIII

SUMMARY AND CONCLUSIONS

INTRODUCTION

The potential usefulness of a land use plan design model in land use planning is obvious: an operational and flexible plan design model could be used to generate a set of least cost plans for a series of forecast years, ranging from five to 30 years, with each design being developed independent of the others and based only on the initial conditions and the forecast requirements. The series of land use plan designs derived from the model will then display the most economic and efficient land use pattern that can be obtained at a particular design year. This, in turn, will aid in making decisions concerning the development of public and private policies regarding the development and use of land in a systematic and efficient way. Furthermore, the model can be well utilized in capital works programming in the time-simulation framework. By running a series of design model runs on a five-year time increment starting from the target year, the proper sequence of capital works programming could be determined. The greatest impact of the plan design model on metropolitan and regional plan making will probably be in establishing a standard, or norm, against which all proposed plans can be evaluated. A final important application of the model relates to the ready estimation of the cost of any suggested plan design constraints.

The land use plan design model in its present form and state of development has displayed only limited success in a "real world" application. Although the model has been proven to be conceptually valid and has produced a reasonably satisfactory solution when applied to a subarea of the Southeastern Wisconsin Region, several deficiencies in the model exist which seriously impair its wide application in land use planning. The major difficulties associated with the model are listed below:

1. The performance of the model is highly dependent on the specified design constraints in defining spatial relationships between modules. There is a direct payoff relationship between the distance constraints imposed and the computer time the model takes to generate the required number of feasible plans for given values of plan effectiveness parameters. As the distance constraints become more strict, the probability of arriving at a feasible solution becomes lower and therefore the algorithm has to search more experimental plans, which in turn requires longer computer run times. In some cases, this time can be so high that model application becomes impractical.

2. Although the holistic error inherent in the previous model algorithm based on set decomposition technique has been eliminated by the incorporation of the new random placement algorithm, the present algorithm is not completely free from operational difficulty. Since the algorithm is just a random procedure and the model only evaluates a small fraction of the feasible plans, the optimal plan given by the model is simply the least cost plan of the total of only 29 random plans generated (in case of $a = 0.10$, and $S = 0.95$). The nature of the present model operation is such that these 29 plans might not include a desirable plan, even though all of them satisfied the given constraints. This situation occurs because the present form of the constraint schedule does not include any specifications which would direct the development pattern. The present form of intermodule constraints represents only spatial relationships of individual module types without any regard to the overall pattern of module arrangement. Consequently, a feasible plan is produced which consists of wide scattering of the modules or clustering of several service modules of the same type in one area. Such a plan is a feasible plan in the sense that it satisfies all the intermodule distance constraints, but it is not a desirable plan since it would not realistically meet the planning requirements as related to the implementation of a plan.

3. Another major difficulty of the present algorithm lies in the manner in which it computes the linkage costs of a plan. The linkage costs are calculated for connecting each module to the closest module of the type to which it must be connected. Apart from being inefficient, this operation

involves double counting, since such connections, for some linkages at least, can be made through other modules. Furthermore, the values for unit linkage costs as used in the model to date appear to be such as to provide unrealistic results. Consequently, the model run yields somewhat ambiguous values for the total cost of linking the modules in a plan.

SUGGESTIONS FOR IMPROVING THE MODEL

Although the land use plan design model has been proved to be workable in a gross and limited application, further work with the model will be necessary in order to produce more reliable and effective results before the model can be used as an operational planning tool by land use planners.

As the model was run, at different levels of planning and with various design constraints, at the Commission as well as at Marquette University,[1] it was observed that several modifications could be readily made in the model algorithm as well as in the computation procedure of model input data which would greatly improve the model. Some of these suggestions are listed below:

1. A possible approach to modifying the model operation in order to obtain a more meaningful arrangement of modules would be to establish a priority ranking in the selection of the module types in the assignment process. Instead of choosing the sequence of module types for placement on a purely random basis, some of the module types should be allocated before other module types. The priority can be set to assign all the residential modules of different types before such modules as industrial, commercial, recreational, and institutional are allocated. The rationale for this approach is that the location of residential land use is perhaps the most important factor in the location of modules which represent the land uses performing the service functions to residential areas. In this approach, however, actual assignment of the first set of modules will follow random placement. For example, the sequence of assignment of low-, medium-, and high-density residential modules will be determined through a random process. This modification will considerably improve the desirability of the land use pattern that results from model application.

2. The service modules such as school and neighborhood centers may be assigned in such a way that they are accessible by at least 1/n of the total residential modules within a given distance, where n is the total number of service modules of the given type to be assigned. In addition, a restriction might be imposed that two units of a particular service module, such as elementary schools, must not be placed within at least a given minimum distance between each other. This type of restriction will eliminate clustering of schools, neighborhood centers, and other such module types within a small area. This arrangement will also provide more appropriate and desirable distribution of such modules throughout the planning area.

3. Another approach for placement of modules might follow a search procedure from a specified cell which contains a module that can be considered as a central facility, such as a water treatment plant or a sewage treatment plant. As the residential development would be expected to be located near and around the location of a central facility to limit the linkage costs, the resulting plan would be of a more coherent and orderly pattern than a scattered arrangement of modules. In this way the model operation would follow a logical process of locating modules to create a land use plan that would approximate more closely the conventional planning process. In connection with this approach, further attempts could be made to locate modules in cells falling within a given distance band from the cell containing the central or focal module. By assigning modules within bands, a proper direction can be provided in the model operation for the development of a pattern, a condition which is missing in the present form of the model algorithm.

4. The present form of the model algorithm does not take into account the locational characteristics of the planning area under consideration. The model includes the initial condition of the area by

[1] *Concurrent research is being conducted in the Department of Civil Engineering at Marquette University on land use design modeling under the sponsorship of the National Science Foundation.*

filling the appropriate cells with existing modules, and the algorithm assigns the additional modules required for the design year in the remaining cells. In the assignment process, however, no constraint is imposed in placing the new modules in relation to the existing modules. Apart from including the initial conditions of the planning area, the model should also consider the land use development of the surrounding areas. Such consideration can be incorporated into the model by establishing a weighting system that can be assigned to cells for the location of some given modules. If the model algorithm can be revised to include such constraints, the desirability of a land use plan design resulting from the model can be increased considerably.

5. The present procedure used in computing the linkage cost between modules in the model operation is not efficient and creates a certain amount of double counting. A major improvement in the model operation can be effected by improving the linkage cost computation part of the algorithm. A procedure similar to what is known as the "traveling salesman" algorithm can be used to determine the linkages between modules in an experimental plan.

6. To make the model algorithm more readily applicable to different levels of planning it is necessary to redefine both the cells and modules that are used as basic units in the plan design process. The cells may be further divided into smaller subcells so that gross division of the planning area into large areal units does not affect the spatial continuity of a land use plan.

7. The cost data used to run the model include both the site development and linkage costs. The unit linkage and site development cost figures that are currently used to run the model should be reexamined and updated. A critical review should be made of the procedure used to develop the unit linkage costs, since it appears that the unit linkage costs used in the model runs do not produce realistic designs.

8. The performance of the model is extremely sensitive to the type of constraints imposed in the plan preparation. The efficiency of the model operation in terms of the computer time as well as the quality of the model results as represented by the desirability of the land use plan design prepared by the model are directly dependent on the type of constraints used as input data. Accordingly, it is important that a careful review be made of the constraint schedule prescribed for the preparation of a plan design at different levels of planning.

9. The two primary parameters that affect the plan design developed by the model are constraints and costs. Constraints eliminate plans from consideration as feasible plans, while costs provide a measure of effectiveness in selecting the best plan. However, a desirable plan might be designated as that experimental plan whose cost is lowest while the degree of infeasibility is also the lowest. In other words, a plan which does not satisfy all the design constraints should not be condemned as an infeasible plan and taken out of consideration. Rather, the selection of the best plan should attempt to approach an optimal solution with respect to the cost and constraint schedule. In the model operation, a record can be maintained of the infeasibility of each plan in terms of the number of constraints not satisfied and the margin by which each of such constraints could not be fulfilled. Then, by means of a weighting procedure, each plan can be evaluated with respect to its rank order of feasibility along with the cost consideration.

10. The usefulness of the model can be greatly enhanced if the model results are provided in a graphic form directly from the computer run rather than in a tabular form as given by the present model algorithm. This improvement will aid the planner in his decision in plan preparation, since he will not have to wait for translation of the model results from tabular form to a spatial map. It should be noted that research work done on the land use plan design model at Marquette University under the sponsorship of the National Science Foundation has involved the development of a computer package which allows the model results to be given in the form of a map generated on-line.[2]

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[2] *K. C. Sinha and A. J. Hartmann, "An Application of Optimization Approach in Land Use Plan Design Problem," Paper prepared for presentation at the 5th International Conference on Optimization, Rome, Italy, May 1973.*

11. Finally, the computer program for the model algorithm can be rewritten to make the model operation more efficient. The present version of the model is written in FORTRAN IV, a programming language which is widely used and easy to understand. The computer run time, however, could be significantly reduced if the model were written in another machine-oriented programming language, such as assembler language. This change would allow evaluation of a large number of experimental plans within a reasonable computer running time and thus would make the model results more desirable than those obtained from the present version of the model. It should be noted, however, that such a change can only be made at the cost of flexibility in the use of the model algorithm, because the computer programs written in a machine-oriented language have severe limitations in their use since they cannot be run on any system other than that system for which they were written.

In conclusion, the research effort on land use plan design has produced a model which is conceptually sound and internally consistent. The model, however, requires further refinement before it can be successfully used as an operational planning tool. An outline of the possible refinements has been described above. It may be noted that the improvements or refinements needed do not alter the basic concept or structure of the model. In order to make the model a useful operational tool, it is necessary that the model be extensively applied to actual land use plan design at various levels of planning. The model is sufficiently developed and its potential use is significant enough to warrant further effort.

APPENDICES

Appendix A

SAMPLE PLAN DESIGN MODULES
(MODULE DEFINITIONS)

I. MODULE TYPE: RESIDENTIAL (low density)

DEFINITION: The module consists of a total area of 2,521.6 acres allocated to the primary and accessory land uses and facilities listed below.

A. Area: The allocation of land to the functional subcomponents of the module is:

Component	Acres
Gross area	2,521.6[1]
Building area	114.1[2]
Parking, service, access, internal vehicular, and pedestrian circulation areas	11.4[3]
Open space, side, rear, and front yards	1,922.5[4]
Arterial street right-of-way	31.7
Collector street right-of-way	19.4
Local street right-of-way	371.3
Neighborhood park and parkway	38.4
Elementary school	12.8

B. Land Use Characteristics: The primary land use of the module is single-family dwelling units and may include the following representative land use types: single-family homes on various lot sizes combined in such proportions as to average 1.2 dwelling units per net residential acre on lots averaging 185 by 200 feet, an elementary school, a neighborhood park, and facilities needed for day-to-day life.

PURPOSE: To provide, in a cellular unit, the area necessary to house the population served by one elementary school and neighborhood park, by an internal street system which discourages penetration of the unit by through traffic, and by all the community facilities necessary to meet day-to-day living requirements of the family within the immediate vicinity of its dwelling unit.

DESIGN STANDARDS: The following design standards are intended to ensure proper site development within the module, to provide requisite functional linkages with other modules, and to maintain a proper balance between the demands of the module and the supporting natural resource base.

1. Intramodule Standards
   a. The module shall include 10,560 lineal feet of arterial street right-of-way or full width equivalent constructed to rural cross section standards.[5]
   b. The module shall include 10,560 lineal feet of collector street right-of-way or full width equivalent constructed to rural cross section standards.[6]
   c. The module shall include 245,000 lineal feet of local street right-of-way or full width equivalent constructed to rural cross section standards.[7]
   d. An area of 114.4 acres shall be suitably graded for building sites.
   e. An area of 11.4 acres shall be suitably graded for off-street parking area.
   f. An area of 12.6 acres shall be suitably graded for playgrounds and playfields.
   g. An area of 100.6 acres of building foundation suitable for the appropriate structure types required shall be provided.
   h. There shall be 2,485 onsite sewage disposal units provided.
   i. Public sanitary sewage collection facilities shall be provided for the elementary school in accordance with established standards.
   j. Public water supply facilities shall be provided for the module in accordance with established standards.
   k. Gas transmission and service facilities shall be provided for the module in accordance with established standards.
   l. Electrical power transmission and service facilities shall be provided for the module in accordance with established standards.
   m. Telephone transmission and service facilities shall be provided for the module in accordance with established standards.
   n. Surface storm drainage facilities shall be provided for suitable surface drainage of 2,522 acres of land along 266,720 lineal feet of street full width equivalent.
2. Intermodule Standards
   a. Allocation Standards
      (1) One module shall be allocated in the design for each 8,200 persons residing in residential (low-density) modules.
   b. Spatial Accessibility and Compatibility Standards
      (1) The module shall be located no more than two miles from an arterial street linkage.
      (2) The location of the module relative to others shall be constrained only by the optimization of combined linkage costs, site development costs, accessibility costs, and compatibility costs.
   c. Resource Conservation Standards
      (1) The location of the module shall be constrained only by the optimization of combined site development costs, linkage costs, accessibility costs, and compatibility costs.
   d. Linkage Requirements Standards
      (1) The module shall be connected by a rural arterial street linkage.
      (2) The module shall be connected by a public water supply transmission.
      (3) The module shall be connected by a public sewage collection line linkage.

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[1] *This module was adapted from a 2,560-acre residential planning unit used by SEWRPC and includes all elements of the unit except the necessary neighborhood commercial area and the necessary other public and quasi-public use areas which together total 28.4 acres and which were included in separate module types. See Appendix A, SEWRPC Planning Report No. 7, Volume 2, Forecasts and Alternative Plans--1990.*

[2] *Assuming 2,485 single-family dwelling units with an average building site of 2,000 square feet per dwelling unit.*

[3] *Assuming 200 square feet per dwelling unit.*

[4] *Assuming an average lot size of 185 by 200 feet.*

[5] *For detailed standards, see SEWRPC Planning Guide No. 1, Land Development Guide, November 1963.*

[6] *Ibid.*

[7] *Ibid.*

(4) The module shall be connected by a gas transmission line linkage.
(5) The module shall be connected by a telephone transmission line linkage.
(6) The module shall be connected by an electrical power transmission line linkage.

II. MODULE TYPE: RESIDENTIAL (medium density)

DEFINITION: The module consists of a total area of 627.2 acres allocated to primary and accessory land uses and facilities listed below.

A. Area: The allocation of land to the functional subcomponents of the module is:

Component	Acres
Gross area	627.2[8]
Building area	61.7[9]
Parking, service, access, internal vehicular, and pedestrian circulation areas	9.1[10]
Open space, side, rear, and front yards.	383.6[11]
Arterial street right-of-way	7.9
Collector street right-of-way	9.7
Local street right-of-way	129.6
Neighborhood park and parkway	16.0
Elementary school	9.6

B. Land Use Characteristics: The primary land use of the module is single and multi-family dwelling units and may include the following representative land use types: single-family and multi-family homes in such proportions as to average 4.3 dwelling units per net residential acre on lots averaging 85 by 125 feet, an elementary school, a neighborhood park, and facilities needed for day-to-day family life.

PURPOSE: To provide in a cellular unit the area necessary to house the population served by one elementary school and neighborhood park, served by an internal street system which discourages penetration of the unit by through traffic, and served by all the community facilities necessary to meet day-to-day living requirements of the family within the immediate vicinity of its dwelling unit.[12]

DESIGN STANDARDS: The following design standards are intended to ensure proper site development within the module, to provide requisite functional linkages with other modules, and to maintain a proper balance between the demands of the module and the supporting natural resource base.

1. Intramodule Standards
   a. The module shall include 2,640 lineal feet of arterial street right-of-way or full width equivalent constructed to urban cross section standards.
   b. The module shall include 5,280 lineal feet of collector street right-of-way or full width equivalent constructed to urban cross section standards.
   c. The module shall include 94,100 lineal feet of local street right-of-way or full width equivalent constructed to urban cross section standards.
   d. An area of 61.7 acres shall be suitably graded for building sites.
   e. An area of 9.1 acres shall be suitably graded for off-street parking area.
   f. An area of 61.7 acres of building foundation suitable for the appropriate structure types required shall be provided.
   g. Public sanitary sewage collection facilities shall be provided for the module in accordance with established standards.
   h. Public water supply facilities shall be provided for the module in accordance with established standards.
   i. Gas transmission and service facilities shall be provided for the module in accordance with established standards.
   j. Electrical power transmission and service facilities shall be provided for the module in accordance with established standards.
   k. Telephone transmission and service facilities shall be provided for the module in accordance with established standards.
   l. Storm drainage facilities shall be provided for suitable surface drainage of 627 acres of land along 102,020 lineal feet of street full width equivalent.
2. Intermodule Standards
   a. Allocation Standards
      (1) One module shall be allocated in the design for each 6,500 persons residing in the residential (medium-density) modules.
   b. Spatial Accessibility and Compatibility Standards
      (1) The module shall be located no more than one mile from an arterial street linkage.
      (2) The location of the module relative to others shall be constrained only by the optimization of combined linkage costs, site development costs, accessibility costs, and compatibility costs.
   c. Resource Conservation Standards
      (1) The module shall not be located on a major natural watershed boundary.
      (2) The location of the module shall be constrained only by the optimization of combined site development costs, linkage costs, accessibility costs, and compatibility costs.
   d. Linkage Requirements Standards
      (1) The module shall be connected by an urban arterial street linkage.
      (2) The module shall be connected by a public water supply transmission line linkage.
      (3) The module shall be connected by a public sewage collection line linkage.
      (4) The module shall be connected by storm sewer collection line linkage.
      (5) The module shall be connected by a gas transmission line linkage.
      (6) The module shall be connected by a telephone transmission line linkage.
      (7) The module shall be connected by an electric power transmission line linkage.

III. MODULE TYPE: NEIGHBORHOOD COMMERCIAL CENTER (low density)

DEFINITION: The module consists of a total area of 6.4 acres allocated to the primary and accessory land uses and facilities listed below.

[8] *This module was adapted from a 640-acre residential planning unit used by SEWRPC and includes all elements of the unit except the necessary neighborhood commercial area and the necessary other public and quasi-public use areas, which together total 12.8 acres and which were included in separate module types. See Table A-1 and A-2, SEWRPC Planning Report No. 7, Volume 2, Forecasts and Alternative Plans--1990, June 1966.*

[9] *Assuming 355 multi-family dwelling units with an average building size of 750 square feet per dwelling unit and 1,615 single-family units with an average building size of 1,500 square feet per dwelling unit.*

[10] *Assuming 200 square feet per dwelling unit.*

[11] *Assuming an average lot size of 85 by 125 feet.*

[12] *SEWRPC Planning Report No. 7, Volume 2, Forecasts and Alternative Plans--1990, June 1966.*

A. Area: The allocation of land to the functional subcomponents of the module is:

Component	Acres
Gross area	6.4[13,14]
Building area	1.1
Parking, service, access, internal Vehicular, and pedestrian circulation areas	2.9[15]
Open space, side, rear, and front yards	0.6
Arterial street right-of-way	0.9
Collector street right-of-way	0.4
Local street right-of-way	0.5

B. Land Use Characteristics: The primary land use of the module is neighborhood commercial and may include the following representative land use types: bakeries, barbershops, bars, beauty shops, business offices, clinics, clothing stores, cocktail lounges, confectioneries, delicatessens, drugstores, fish markets, florists, fraternities, fruit stores, gift stores, grocery stores, hardware stores, house occupations, hobby shops, lodges, meat markets, optical stores, packaged beverage stores, professional offices, restaurants, self-service and pickup laundry and dry cleaning establishments, soda fountains, sporting goods stores, supermarkets, tobacco stores, and vegetable stores.[16]

PURPOSE: To provide the area necessary to house convenience goods and service establishments needed for day-to-day living requirements of the family within the immediate vicinity of its dwelling unit.

DESIGN STANDARDS: The following design standards are intended to ensure proper site development within the module, to provide requisite functional linkages with other modules, and to maintain a proper balance between the demands of the module and the supporting natural resource base.

1. Intramodule Standards
   a. The module shall include 340 lineal feet of arterial street right-of-way or full width equivalent constructed to urban cross section standards.[17]
   b. The module shall include 150 lineal feet of collector street right-of-way or full width equivalent constructed to urban cross section standards.[18]
   c. The module shall include 340 lineal feet of local street right-of-way or full width equivalent constructed to urban cross section standards.[19]
   d. An area of 1.1 acres shall be suitably graded for building sites.
   e. An area of 2.9 acres shall be suitably graded for off-street parking area.
   f. An area of 1.1 acres of building foundation suitable for the appropriate structure types required shall be provided.
   g. Public sanitary sewage collection facilities shall be provided for the module in accordance with established standards.
   h. Public water supply facilities shall be provided for the module in accordance with established standards.
   i. Gas transmission and service facilities shall be provided for the module in accordance with established standards.
   j. Electrical power transmission and service facilities shall be provided for the module in accordance with established standards.
   k. Telephone transmission and service facilities shall be provided for the module in accordance with established standards.
   l. Surface storm drainage facilities shall be provided for suitable surface drainage of 6.4 acres of land along 830 lineal feet of street full width equivalent.
2. Intermodule Standards
   a. Allocation Standards
      (1) Two modules shall be allocated in the design for each residential (low-density) module in the design.
   b. Spatial Accessibility and Compatibility Standards
      (1) The module shall be located contiguously to a residential (low-density) module.
      (2) The location of the module relative to others shall be constrained only by the optimization of combined linkage costs, site development costs, accessibility costs, and compatibility costs.
   c. Resource Conservation Standards
      (1) The location of the module shall be constrained only by the optimization of combined site development costs, linkage costs, accessibility costs, and compatibility costs.
   d. Linkage Requirements Standards
      (1) The module shall be connected by an urban arterial street linkage.
      (2) The module shall be connected by a public water supply transmission line linkage.
      (3) The module shall be connected by a public sewage collection line linkage.
      (4) The module shall be connected by a gas transmission line linkage.
      (5) The module shall be connected by a telephone transmission line linkage.
      (6) The module shall be connected by an electrical power transmission line linkage.

IV. MODULE TYPE: COMMUNITY COMMERCIAL CENTER

DEFINITION: The module consists of a total area of 28.2 acres allocated to the primary and accessory land uses and facilities listed below.

A. Area: The allocation of land to the functional subcomponents of the module is:

Component	Acres
Gross area	28.2[20]
Building area	4.6
Parking, service, access, internal vehicular, and pedestrian circulation areas	18.3[21]

[13] *This module corresponds to the 12.8 acres allocated to neighborhood commercial uses in the 2,560-acre residential planning unit used by SEWRPC; therefore, the allocation is two (6.4-acre) modules per residential (low-density) module in the problem. Since 6.4 acres is considered a viable unit for neighborhood commercial centers, the use of two 6.4-acre modules, rather than one 12.8-acre module, allows greater flexibility in model application.*

[14] *See Appendix A, SEWRPC Planning Report No. 7, Volume 2, Forecasts and Alternative Plans--1990, June 1966.*

[15] *Assuming 300 square feet per 100 square feet of building area.*

[16] *These uses are listed as principal uses in the B-1 Neighborhood Business District in the Model Zoning Ordinance contained in SEWRPC Planning Guide No. 3, Zoning Guide, April 1964.*

[17] *For detailed standards, see SEWRPC Planning Guide No. 1, Land Development Guide, November 1963.*

[18] *Ibid.*

[19] *Ibid.*

[20] *The Community Builder's Handbook, Community Builder's Council of Urban Land Institute, Washington, D. C., 1960.*

[21] *Assuming 400 square feet per 100 square feet of building area.*

Open space, side, rear, and front yards. .	0.9
Arterial street right-of-way.	3.0[22]
Collector street right-of-way	0.0
Local street right-of-way.	1.4

B. Land Use Characteristics: The primary land use of the module is community commercial and may include the following representative land use types: All uses permitted in the neighborhood commercial centers and the following: appliance stores, caterers, clothing repair shops, crockery stores, electrical supply, financial institutions, food lockers, furniture stores, furniture upholstery shops, heating supply, hotels, laundry and dry cleaning establishments employing not over seven persons, liquor stores, music stores, newspaper offices and press rooms, night clubs, office supplies, pawn shops, personal service establishments, pet shops, photographic supplies, plumbing supplies, printing, private clubs, publishing, second-hand stores, signs, trade and contractor's office, upholsterer's shops, and variety stores.[23]

PURPOSE: To provide the area necessary to house convenience and shopper goods and service establishments which serve a larger tributary area than a residential module but a smaller tributary area than that required to support a regional commercial module.

DESIGN STANDARDS: The following design standards are intended to ensure proper site development within the module, to provide requisite functional linkages with other modules, and to maintain a proper balance between the demands of the module and the supporting natural resource base.

1. Intramodule Standards
   a. The module shall include 990 lineal feet of arterial street right-of-way or full width equivalent constructed to urban cross section standards.[24]
   b. The module shall include 990 lineal feet of local street right-of-way or full width equivalent constructed to urban cross section standards.[25]
   c. An area of 4.6 acres shall be suitably graded for building sites.
   d. An area of 18.3 acres shall be suitably graded for off-street parking area.
   e. An area of 4.6 acres of building foundation suitable for the appropriate structure types required shall be provided.
   f. Public sanitary sewage collection facilities shall be provided for the module in accordance with established standards.
   g. Public water supply facilities shall be provided for the module in accordance with established standards.
   h. Gas transmission and service facilities shall be provided for the module in accordance with established standards.
   i. Electrical power transmission and service facilities shall be provided for the module in accordance with established standards.
   j. Telephone transmission and service facilities shall be provided for the module in accordance with established standards.
   k. Storm drainage facilities shall be provided for suitable surface drainage of 28.2 acres of land along 1,980 lineal feet of street full width equivalent.
2. Intermodule Standards
   a. Allocation Standards
      (1) One module shall be allocated in the design for each 71,500 persons residing in the area for which a plan design is being prepared.
   b. Spatial Accessibility and Compatibility Standards
      (1) The location of the module relative to others shall be constrained only by the optimization of combined linkage costs, site development costs, accessibility costs, and compatibility costs.
   c. Resource Conservation Standards
      (1) The location of the module shall be constrained only by the optimization of combined site development costs, linkage costs, accessibility costs, and compatibility costs.
   d. Linkage Requirements Standards
      (1) The module shall be connected by an urban arterial street linkage.
      (2) The module shall be connected by a public water supply transmission line linkage.
      (3) The module shall be connected by a public sewage collection line linkage.
      (4) The module shall be connected by a storm sewer collection line linkage.
      (5) The module shall be connected by a gas transmission line linkage.
      (6) The module shall be connected by a telephone transmission line linkage.
      (7) The module shall be connected by an electrical power transmission line linkage.

V. MODULE TYPE: SENIOR HIGH SCHOOL (public)

DEFINITION: The module consists of a total area of 45.0 acres allocated to the primary and accessory land uses and facilities listed below:

A. Area: The allocation of land to the functional subcomponents of the module is:

Component	Acres
Gross area	45.0[26]
Building area	3.6
Parking, service, access, internal vehicular, and pedestrian circulation areas	5.1
Open space, side, rear, and front yards. .	11.0
Arterial street right-of-way.	2.1
Collector street right-of-way	1.3
Local street right-of-way.	1.9
Playfields	20.0

B. Land Use Characteristics: The primary land use of the module is senior high school and may include the following representative land use types: the school classrooms and administrative building, auxiliary structures, playfield and apparatus.

PURPOSE: To provide the area necessary to house the high school facilities and related community activities, such as sports events and adult education.

DESIGN STANDARDS: The following design standards are intended to ensure proper site development within the module, to provide requisite functional linkages with other

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[22] *Assuming the module has access to two arterial streets.*

[23] *These uses are listed as principal uses in the B-2 Community Business District in the Model Zoning Ordinance contained in SEWRPC Planning Guide No. 3, Zoning Guide, April 1964.*

[24] *For detailed standards, see SEWRPC Planning Guide No. 1, Land Development Guide, November 1963.*

[25] *Ibid.*

[26] *Assuming an optimal enrollment of 1,500 pupils and an allocation of 30 acres plus one additional acre per each 100 pupils.*

modules, and to maintain a proper balance between the demands of the module and the supporting natural resource base.

1. Intramodule Standards
   a. The module shall include 700 lineal feet of arterial street right-of-way or full width equivalent constructed to urban cross section standards.[27]
   b. The module shall include 700 lineal feet of collector street right-of-way or full width equivalent constructed to urban cross section standards.[28]
   c. The module shall include 1,400 lineal feet of local street right-of-way or full width equivalent constructed to urban cross section standards.[29]
   d. An area of 3.6 acres shall be suitably graded for building sites.
   e. An area of 5.1 acres shall be suitably graded for an off-street parking area.
   f. An area of 20.0 acres shall be suitably graded for a playfield.
   g. An area of 3.6 acres of building foundation suitable for the appropriate structure types required shall be provided.
   h. Public sanitary sewage collection facilities shall be provided for the module in accordance with established standards.
   i. Public water supply facilities shall be provided for the module in accordance with established standards.
   j. Gas transmission and service facilities shall be provided for the module in accordance with established standards.
   k. Electrical power transmission and service facilities shall be provided for the module in accordance with established standards.
   l. Telephone transmission and service facilities shall be provided for the module in accordance with established standards.
   m. Storm drainage facilities shall be provided for suitable surface drainage of 45 acres of land along 2,800 lineal feet of street full width equivalent.
2. Intermodule Standards
   a. Allocation Standards
      (1) One module shall be allocated in the design for each 63,000 persons residing in the area for which a plan design is being prepared.[30]
   b. Spatial Accessibility and Compatibility Standards
      (1) The location of the module relative to others shall be constrained only by the optimization of combined linkage costs, site development costs, accessibility costs, and compatibility costs.
   c. Resource Conservation Standards
      (1) The location of the module shall be constrained only by the optimization of combined site development costs, linkage costs, accessibility costs, and compatibility costs.
   d. Linkage Requirements Standards
      (1) The module shall be connected by an urban arterial street linkage.
      (2) The module shall be connected by a public water supply transmission line linkage.
      (3) The module shall be connected by a public sewage collection line linkage.
      (4) The module shall be connected by a storm sewer collection line linkage.
      (5) The module shall be connected by a gas transmission line linkage.
      (6) The module shall be connected by a telephone transmission line linkage.
      (7) The module shall be connected by an electrical power transmission line linkage.

VI. MODULE TYPE: PLANNED INDUSTRIAL DISTRICT (light)

DEFINITION: The module consists of a total area of 640 acres allocated to the primary and accessory land uses and facilities listed below.

A. Area: The allocation of land to the functional subcomponents of the module is:

Component	Acres
Gross area	640.0[31]
Building area	157.4[32]
Parking, service, access, internal vehicular, and pedestrian circulation areas	114.6
Open space, side, rear, and front yards.	157.5
Arterial street right-of-way.	7.9
Collector street right-of-way	4.8
Rail spur right-of-way	78.1[33,34]
Truck docks and apron	18.6[35]
Internal circulation ways and cul-de-sacs.	101.1[36,37]

B. Land Use Characteristics: The primary land use of the module is light industrial and may include the following representative land use types: automotive body repair; automotive upholstery; cleaning, pressing, and dyeing establishments; commercial bakeries; commercial greenhouses; distributors; farm machinery food locker plants; laboratories; machine shops; manufacture and bottling of nonalcoholic beverages; painting; printing; publishing; storage and sale of machinery and equipment; trade and contractors' offices; warehousing and wholesaling; manufacture, fabrication, packing, packaging, and assembly of products from furs, glass, leather, metals, paper, plaster, plastics, textiles, and wood; manufacture, fabrication, processing, packaging, and packing of confections, cosmetics, electrical appliances, electronic devices, food except cabbage, fish and fish products, meat and meat products, and pea vining, instruments, jewelry, pharmaceuticals, tobacco, and toiletries.[38]

[27] *For detailed standards, see SEWRPC Planning Guide No. 1, Land Development Guide, November 1963.*

[28] *Ibid.*

[29] *Ibid.*

[30] *Assuming 3.96 percent of the total population attends a senior high school and that 60 percent of attendants (or 2.38 percent of total population) are pupils of a public facility.*

[31] *See SEWRPC Planning Report No. 7, Volume 2, Forecasts and Alternative Plans--1990.*

[32] *See Local Planning Administration, The International City Managers Association, (Chicago, 1959).*

[33] *Ibid.*

[34] *Assuming a railway spur right-of-way of 52 feet.*

[35] *For detailed standards, see SEWRPC Planning Guide No. 1, Land Development Guide, November 1963.*

[36] *Ibid.*

[37] *Assuming the internal circulation ways and cul-de-sacs have a right-of-way width of 50 feet.*

[38] *These uses are listed as principal uses of the M-1 Industrial District in the Model Zoning Ordinance contained in SEWRPC Planning Guide No. 3, Zoning Guide, April 1964. Quarrying and other mineral extraction and related uses are not included in either the planned industrial (light) or the planned industrial (heavy) modules. It is reasoned that, because of the resource orientation of extractive industries, they shall be conditional uses and subject to the established review procedure at the time of initiation of zoning appeal.*

PURPOSE: To provide the area necessary to house industrial uses in an exclusive zoning district and with the economies afforded by joint use of facilities and utilities.

DESIGN STANDARDS: The following design standards are intended to ensure proper site development within the module, to provide requisite functional linkages with other modules, and to maintain a proper balance between the demands of the module and the supporting natural resource base.

1. Intramodule Standards
   a. The module shall include 2, 640 lineal feet of arterial street right-of-way or full width equivalent constructed to urban cross section standards.[39]
   b. The module shall include 7, 920 lineal feet of collector street right-of-way or full width equivalent constructed to urban cross section standards.[40]
   c. The module shall include 88, 100 lineal feet of internal circulation street right-of-way or full width equivalent constructed in accordance with established standards.[41]
   d. An area of 157. 4 acres shall be suitably graded for building sites.
   e. An area of 114. 6 acres shall be suitably graded for off-street parking area.
   f. An area of 18. 6 acres shall be suitably graded for truck docks and apron.
   g. An area of 157. 4 acres of building foundation suitable for the appropriate structure types required shall be provided.
   h. Public sanitary sewage collection facilities shall be provided for the module in accordance with established standards.
   i. Public water supply facilities shall be provided for the module in accordance with established standards.
   j. Gas transmission and service facilities shall be provided for the module in accordance with established standards.
   k. Electrical power transmission and service facilities shall be provided for the module in accordance with established standards.
   l. Telephone transmission and service facilities shall be provided for the module in accordance with established standards.
   m. Storm drainage facilities shall be provided for suitable surface drainage of 640 acres of land along 113. 8 lineal feet of street full width equivalent.
   n. The module shall include 66,400 lineal feet of railway spur right-of-way or full width equivalent constructed in accordance with established standards.
2. Intermodule Standards
   a. Allocation Standards
      (1) One module shall be allocated in the design for each 9, 100 persons employed in the area for which a plan is being prepared.[42]
   b. Spatial Accessibility and Compatibility Standards
      (1) The location of the module relative to others shall be constrained only by the optimization of combined linkage costs, site development costs, accessibility costs,. and compatibility costs.
   c. Resource Conservation Standards
      (1) The location of the module shall be constrained only by the optimization of combined site development costs, linkage costs, accessibility costs, and compatibility costs.
   d. Linkage Requirements Standards
      (1) The module shall be connected by an urban arterial street linkage.
      (2) The module shall be connected by an urban collector street linkage.
      (3) The module shall be connected by a public water supply transmission line linkage.
      (4) The module shall be connected by a public sewage collection line linkage.
      (5) The module shall be connected by a storm sewer collection line linkage.
      (6) The module shall be connected by a gas transmission line linkage.
      (7) The module shall be connected by a telephone transmission line linkage.
      (8) The module shall be connected by a railroad main line linkage.
      (9) The module shall be connected by an electrical power transmission line linkage.

VII. MODULE TYPE: MUNICIPAL HALL (community)

DEFINITION: The module consists of a total of two acres allocated to the primary and accessory land uses and facilities listed below.

A. Area: The allocation of land to the functional subcomponents of the module is:

Components	Acres
Gross area	2. 0[43]
Building area	0. 5[44]
Parking, service, access, internal vehicular, and pedestrian circulation areas	0. 5
Open space, side, rear, and front yards. .	0. 4
Arterial street right-of-way.	0. 3
Collector street right-of-way	0. 2
Local street right-of-way.	0. 1

B. Land Use Characteristics: The primary land use of the module is generally municipal hall and may include the following representative land use types: city or village administrative offices and auxiliary structures.

PURPOSE: To provide the area necessary to house municipal services and administrative offices, and to centralize municipal offices where practical.

DESIGN STANDARDS: The following design standards are intended to ensure proper site development within the module, to provide requisite functional linkages with other modules, and to maintain a proper balance between the demands of the module and the supporting natural resource base.

1. Intramodule Standards
   a. The module shall include 100 lineal feet of arterial street right-of-way or full width equivalent constructed to urban cross section standards.[45]
   b. The module shall include 140 lineal feet of collector street right-of-way or full width equivalent constructed to urban cross section standards.[46]

[39]*For detailed standards, see SEWRPC Planning Guide No. 1, Land Development Guide, November 1963.*

[40]*Ibid.*

[41]*Ibid.*

[42]*Assuming an allocation of seven acres per 100 employees.*

[43]*Assuming a minimum of two acres is required for a viable unit.*

[44]*Assuming a need for 200 square feet of building area per employee.*

[45]*For detailed standards, see SEWRPC Planning Guide No. 1, Land Development Guide, November 1963.*

[46]*Ibid.*

c. The module shall include 100 lineal feet of local street right-of-way or full width equivalent constructed to urban cross section standards.[47]
d. An area of 0.5 acre shall be suitably graded for building sites.
e. An area of 0.5 acre shall be suitably graded for an off-street parking area.
f. An area of 0.5 acre of building foundation suitable for the appropriate structure types required shall be provided.
g. Public sanitary sewage collection facilities shall be provided for the module in accordance with established standards.
h. Public water supply facilities shall be provided for the module in accordance with established standards.
i. Gas transmission and service facilities shall be provided for the module in accordance with established standards.
j. Electrical power transmission and service facilities shall be provided for the module in accordance with established standards.
k. Telephone transmission and service facilities shall be provided for the module in accordance with established standards.
l. Storm drainage facilities shall be provided for suitable surface drainage of two acres of land along 340 lineal feet of street full width equivalent.

2. Intermodule Standards
   a. Allocation Standards
      (1) One module shall be allocated in the design for each 14,000 persons residing in each municipality of the area for which a plan design is being prepared.[48]
   b. Spatial Accessibility and Compatibility Standards
      (1) The location of the module relative to others shall be constrained only by the optimization of combined linkage costs, site development costs, accessibility costs, and compatibility costs.
   c. Resource Conservation Standards
      (1) The location of the module shall be constrained only by the optimization of combined site development costs, linkage costs, accessibility costs, and compatibility costs.
   d. Linkage Requirements Standards
      (1) The module shall be connected by an urban arterial street linkage.
      (2) The module shall be connected by a public water supply transmission line linkage.
      (3) The module shall be connected by a public sewage collection line linkage.
      (4) The module shall be connected by a storm sewer collection line linkage.
      (5) The module shall be connected by a gas transmission line linkage.
      (6) The module shall be connected by a telephone transmission line linkage.
      (7) The module shall be connected by an electrical power transmission line linkage.

[47] *Ibid.*

[48] *Assuming a need to house seven municipal employees per 1,000 population.*

Appendix B

LAND USE PLAN DESIGN MODEL COMPUTER PROGRAMS

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C       VARIABLE NAME LIST ALL PROGRAMS
C
C       A - - - - - - - PLAN ACCURACY
C       S - - - - - - - SUCCESS PROBABILITY
C       MRSC  - - - - - RANDOM NUMBER RESIDULE
C       NMT - - - - - - NO. OF MODULE TYPES
C       NC  - - - - - - NO. OF CELLS
C       N   - - - - - - PLAN NO.
C       NR  - - - - - - NO. OF PLANS REQUIRED
C       TPC - - - - - - TOTAL PLAN COST
C       TLC - - - - - - TOTAL LINKAGE COST
C       TSC - - - - - - TOTAL SITE COST
C       NFP(10) - - - - FEASIBLE PLAN NO. (ONE OF 10 BEST)
C       NIP(10) - - - - INFEASIBLE PLAN NO. (ONE OF 10 BEST)
C       TPCF(10)  - - - PLAN COSTS (10 BEST FEASIBLE)
C       TPCI(10)  - - - PLAN COSTS (10 BEST INFEASIBLE)
C       PF  - - - - - - PROBABILITY OF A FEASIBLE PLAN
C       NFEAS - - - - - 0-PLAN FEASIBLE  2-PLAN INFEASIBLE
C       AM(50)  - - - - MODULE TYPE AREA
C       MN(50)  - - - - MODULE TYPE NO.  (NO. OF MODULES OF THE TYPE)
C       CA(400) - - - - CELL AREA
C       CNSC(400) - - - CELL NORTH SOUTH COORDINATES
C       CEWC(400) - - - CELL EAST WEST COORDINATE
C       CMM(50) - - - - MODULE - MODULE DISTANCE CONSTRAINT
C       CML(50) - - - - MODULE LINKAGE COST
C       IMODV - - - - - READING VARIABLE -- MODULE MATRIX ROW
C       IMODE   - - - - READING VARIABLE -- MODULE MATRIX COLUMN
C       IV11  - - - - - DEFINE FILE VARIABLE -- REQUIRED BUT NOT USED
C       CAR   - - - - - CELL AREA REMAINING
C       MPC(50) - - - - MODULE PLACEMENT COUNT (NO. OF TYPE PLACED IN CELL)
C       MC(50)  - - - - MODULE CONSTRAINT (LIMIT ON NO. OF TYPE PLACE CELL)
C       SC(50)  - - - - SITE COST (SITE COST TO PLACE ONE MODULE OF TYPE)
C       CLE(50) - - - - LINKAGE COST EXTENSION (THAT MODULE TYPE THAT CELL)
C       ICELL - - - - - READING VARIABLE -- CELL NO.
C       IMOD  - - - - - READING VARIABLE -- MODULE NO.
C       IV12  - - - - - DEFINE FILE VARIABLE -- REQUIRED BUT NOT USED
C       DATA SET  1 - CARD READER
C       DATA SET  2 - CARD PUNCH
C       DATA SET  3 - PRINTER
C       DATA SET  4 - TAPE NOT USED
C       DATA SET  5 - TAPE NOT USED
C       DATA SET  6 - TAPE NOT USED
C       DATA SET  7 - TAPE NOT USED
C       DATA SET  8 - DISK SCALLAR VALUES
C       DATA SET  9 - DISK MODULE AREA AND NO. VECTORS
C       DATA SET 10 - DISK CELL AREA VECTOR
C       DATA SET 11 - DISK MODULE - MODULE MATRIX
C       DATA SET 12 - DISK CELL - MODULE MATRIX
C       DATA SET 13 - DISK CELL DISTANCE VECTORS
C       DATA SET 14 - DISK CELL COORDINATE VECTORS
C       CD(400) - - - - CELL - CELL ORDERED DISTANCE VECTOR   (ONE PER CELL)
C       NCD(400)  - - - CELL NUMBERS FOR ORDERED CELL DISTANCE VECTOR
C       DNS - - - - - - NORTH SOUTH DISTANCE
C       DEW - - - - - - EAST WEST DISTANCE
C       DNS2  - - - - - NORTH SOUTH DISTANCE SQUARED
C       DEW2  - - - - - EAST WEST DISTANCE SQUARED
C       DIST  - - - - - SQUARE ROOT OF SUM OF SQUARES
C       IPLACE  - - - - TO HARD TO EXPLAIN ON ONE LINE
C       IPUSH - - - - - PUSH DOWN INDEX
C       IPUSH2  - - - - PUSH DOWN INDEX
C       CDIP2 - - - - - CELL DISTANCE  TEMPORY PUSH DOWN STORAGE
C       NCDIP2  - - - - CELL NO.       TEMPORY PUSH DOWN STORAGE
C       IPCD  - - - - - OUTPUT INDEX
C       IV13  - - - - - DEFINE FILE VARIABLE -- REQUIRED BUT NOT USED
C       MULT  - - - - - RANDOM NUMBER MULTIPLIER
C       IELCD - - - - - RANDOM NO. WITH LOW ORDER DIGIT ELIMINATED
C       IEHOD - - - - - RANDOM NO. WITH 4 HIGH ORDER DIGITS ELIMINATED
C       MRNDLT  - - - - RANDOM NO. LIMIT (NO. OF MODULE TYPES OR CELLS)
C       MODCEL  - - - - GO TO INDEX  (MODULE OR CELL)
C       NOM   - - - - - NO. OF MODULES
C       MOD - - - - - - MODULE TYPE NO. (RANDOM NO.)
C       NCN - - - - - - CELL NO.        (RANDOM NO.)
C       CSC - - - - - - CELL SITE COST  TOTAL SITE COST THAT CELL
C       CLC - - - - - - CELL LINKAGE COST   TOTAL LINKAGE COST THAT CELL
C       LS(50)  - - - - LINKAGE SATISFACTION VECTOR
C       LSC - - - - - - LINKAGE SATISFACTION VECTOR SUM
C       NCD980  - - - - CELL NO.
C       CAR980  - - - - CELL AREA REMAINING
C       MPC980  - - - - MODULE PLACEMENT VECTOR
C       CL  - - - - - - LINKAGE COST
C       A1  - - - - - - A PRIME
C       FN  - - - - - - FLOATING POINT  N
C       FNOFP - - - - - FLOATING POINT  NOFP
C       TCV(10) - - - - SUBROUTINE PUSH DOWN  TOTAL PLAN COST
C       NCV(10) - - - - SUBROUTINE PUSH DOWN  PLAN NO.


C       LAND USE  PLAN DESIGN  MODEL
C
C       PROGRAM 1 VERSION 2  9/20/71       BOEHLEN
C
C
C       FORMATS
  100 FORMAT(E14.8)
  101 FORMAT(I5)
  102 FORMAT('1' T40,'LAND USE PLAN DESIGN MODEL'/
     X  '0' T48, 'RUN VARIABLES'////)
  103 FORMAT( ' PLAN ACCURACY '          T25,  F8.4  )
  104 FORMAT( ' SUCCESS PROBABILITY '    T25,  F8.4  )
  105 FORMAT( ' PLAN RUNS REQUIRED '     T25,  I5    )
  106 FORMAT( ' NO. OF MODULE TYPES '    T25,  I5    )
  107 FORMAT( ' NO. OF CELLS '           T25,  I5    )
  108 FORMAT( ' RANDOM NO. RESIDULE '    T25,  I5    )
  109 FORMAT( '0' / '0MODULE TYPE' T15,'MODULE AREA' T30,'NUMBER' //)
  110 FORMAT(I3,2X,F11.2,2X,I3)
  111 FORMAT(' 'T6,I5, T15,F11.2, T31, I5)
  112 FORMAT('0' / '0CELL NUMBER' T15,'CELL AREA'  T30,'NORTH-SOUTH'T50,
     X'EAST-WEST '//)
  113 FORMAT(I3,3X,F10.2,2(2X,F11.2))
  114 FORMAT(' ' T5,I5, T12,F11.2, T30,F11.2,  T48,F11.2)
  115 FORMAT('0'/'0MODULE' T10,'MODULE' T20,'DISTANCE CONSTRAINT'T45,
     X 'LINKAGE COST'/)
  116 FORMAT(2(I3,2X),2(F11.2,2X))
  117 FORMAT(' 'T2,I5,T11,I6,T28,F11.2,T46,F11.2)
  118 FORMAT('0'/'0 CELL' T12,'MOD' T20,'PLACED'T30,'LIMIT' T40,
     X  'SITE COST'/)
  119 FORMAT(4(I3,2X),F11.2)
  120 FORMAT(' 'I5, T10,I5, T21,I5, T30,I5, T39,F12.2)
C
C       DIMENSION1
        DIMENSION NFP(10),NIP(10),TPCF(10),TPCI(10),AM(50),MN(50),CA(400),
     XCNSC(400),CEWC(400),CML(50),DMM(50),MPC(50),MC(50),SC(50),CLE(50)
        DIMENSION INIT(50)
        DEFINE FILE 7(400,50,U,IV7)
        DEFINE FILE 11(50,100,U,IV11),12(400,203,U,IV12)
C
C       READ INITIALIZE AND STORE SCALARS
C
        READ(1,100) A,S
        READ(1,101) MRSD, NMT, NC
        PF=0.0
        N=0
        NR=10
        NFEAS=0
        TPC=0.0
        TLC=0.0
        TSC=0.0
        DO 200 I200=1,10
        NFP(I200)=0
        NIP(I200)=0
        TPCF(I200)=10.0E+70
  200   TPCI(I200)=10.0E+70
        WRITE(3,102)
        WRITE(3,103) A
        WRITE(3,104) S
        WRITE(3,105) NR
        WRITE(3,106) NMT
        WRITE(3,107) NC
        WRITE(3,108) MRSD
        WRITE(8) NC,A,S,PF,NR,N,MRSD,NOFP,NOIFP,NFEAS,NMT,TPC,TLC,TSC,NFP,
     XNIP,TPCF,TPCI
C
C
C       READ INITIALIZE AND STORE MODULE VECTORS
C
        DO 300 I300=1,50
        AM(I300)=0.0
        MN(I300)=0
  300   CONTINUE
        WRITE (3,109)
  301   CONTINUE
        READ(1,110) I, AM(I), MN(I)
        WRITE(3,111) I, AM(I),MN(I)
        IF(I-50) 301,302,302
  302   CONTINUE
        WRITE(9) AM,MN
C
C
C       READ INITIALIZE AND STORE CELL VECTORS
C
        DO 400 I400=1,400
        CA(I400)=0.0
        CNSC(I400)=0.0
        CEWC(I400)=0.0
  400   CONTINUE
        WRITE(3,112)
  401   READ(1,113) I, CA(I), CNSC(I), CEWC(I)
        WRITE(3,114) I, CA(I), CNSC(I), CEWC(I)
        IF(I-400)401,402,402
  402   CONTINUE
        WRITE(14) CNSC,CEWC
C
C       READ INITIALIZE AND STORE MODULE-MODULE MATRIX
C                   INPUT SHOULD BE SORTED IMODE W/I IMODV
C                   EACH ROW ENDS IN IMODE=50
        WRITE(3,115)
  500   CONTINUE
        DO 501 I501=1,50
        DMM(I501)=0.0
        CML(I501)=0.0
  501   CONTINUE
  502   CONTINUE
        READ(1,116) IMODV, IMODE, DMM(IMODE), CML(IMODE)
        WRITE(3,117) IMODV, IMODE, DMM(IMODE), CML(IMODE)
        IF(IMODE-50) 502,503,503
  503   CONTINUE
        WRITE(11'IMODV)DMM,CML
        IF(IMODV-50)500,504,504
  504   CONTINUE
C
C
C       READ INITIALIZE AND STORE CELL-MODULE MATRIX
C           INPUT SORTED MODULE W/I CELL -- NEED LAST MODULE 50
C                                        -- NEED LAST CELL 400
        WRITE(3,118)
  600   CONTINUE
        CAR=0.0
        DO 601 I601=1,50
        INIT(I601)=0
        MPC(I601)=0
        MC(I601)=0
        SC(I601)=0.0
        CLE(I601)=0.0
  601   CONTINUE
        CSC=0.0
        CLC=0.0
  602   CONTINUE
        READ(1,119) ICELL, IMOD, INIT(IMOD), MC(IMOD), SC(IMOD)
        WRITE(3,120)ICELL, IMOD, INIT(IMOD), MC(IMOD), SC(IMOD)
        CA(ICELL)=CA(ICELL)-AM(IMOD)*INIT(IMOD)
        IF(CA(ICELL))6021,6022,6022
 6021   CA(ICELL)=0
 6022   CONTINUE
        IF(IMOD-50)602,603,603
  603   CONTINUE
        WRITE(7'ICELL)INIT
        WRITE(12'ICELL) CAR,MPC,SC,MC,CLE,CSC,CLC
        IF(ICELL-400)600,604,604
  604   CONTINUE
        WRITE(10) CA
        RETURN
        END
```

```
C     LAND USE PLAN DESIGN MODEL
C
C     PROGRAM 2 VERSION 2  9/2/71 BOEHLEN
C
C     CELL COORDINATES ARE READ FROM DISK
C     CELL TO CELL DISTANCES ARE COMPUTED
C     CREATES A VECTOR OF CELL DISTANCES FOR EACH CELL
C     SORTS THE VECTOR FOR THE SHORTEST DISTANCE FIRST
C     WRITES THE VECTOR(S) CN DISK
C
C     FORMATS
  100 FORMAT('0'/'0CELL DISTANCE VECTOR FOR CELL' T33,I5 //)
  102 FORMAT(5(I5,2X,F11.2))
C     DEMINSIONS
      DIMENSION CNSC(400),CEWC(400),CD(400),NCD(400)
      DEFINE FILE  13(800,400,U,IV13)
C
C
C     READ THE NUMBER OF CELLS
      READ(8) NC
C
C
C     READ THE CELL COORDINATES
      READ (14) CNSC,CEWC
C
C
C     COMPUTE, SORT AND WRITE A CELL DISTANCE VECTOR FOR EACH CELL
      DO 900 I900=1,NC
C
C     INITIALIZE THE CELL DISTANCE VECTOR AND THE CELL DISTANCE NUMBER
C     VECTOR
      DO 200 I200=1,400
      CD(I200)=10E74
      NCD(I200)=9999
  200 CONTINUE
      ND=0
C
C     COMPUTE DISTANCES AND STORE IN CELL DISTANCE VECTOR IN ORDER
C     WITH THE SMALLEST DISTANCE FIRST
      DO 300 I300=1,NC
C
C     COMPUTE A DISTANCE
      DNS=CNSC(I900)-CNSC(I300)
      DEW=CEWC(I900)-CEWC(I300)
      DNS2=DNS*DNS
      DEW2=DEW*DEW
      DIST=SQRT(DNS2+DEW2)
      ND=ND+1
C
C     PLACE THE CELL DISTANCE AT THE TOP OF THE CELL DISTANCE VECTOR
C     BUT NEVER LOWER THEN 5TH PLACE
      IPLACE=ND
      IF(IPLACE-5) 202,203,203
  202 CONTINUE
      IPLACE=5
  203 CONTINUE
      CD(IPLACE)=DIST
      NCD(IPLACE)=I300
C
C     DO A PUSH DOWN OPERATION UNTIL DIST IS IN ITS PROPER PLACE IN
C     THE CELL VECTOR
      IPUSH=IPLACE+1
      IPUSH1=IPLACE
  204 CONTINUE
      IPUSH=IPUSH-1
      IPUSH1=IPUSH-1
      IF(IPUSH1) 300,300,206
C
C     SHOULD THE DISTANCE IN CD(IPUSH) BE PUSHED DOWN
  206 IF(CD(IPUSH)-CD(IPUSH1)) 205,300,300
C
C     PUSH CD(IPUSH) DOWN
  205 CONTINUE
      CDIP1=CD(IPUSH1)
      NCDIP1=NCD(IPUSH1)
      CD(IPUSH1)=CD(IPUSH)
      NCD(IPUSH1)=NCD(IPUSH)
      CD(IPUSH)=CDIP1
      NCD(IPUSH)=NCDIP1
      GO TO 204
  300 CONTINUE
C
C     WRITE THE CELL DISTANCE VECTOR ON THE PRINTER AND DISK
      WRITE(3,100) I900
      WRITE(3,102) (NCD(IPCD),CD(IPCD),IPCD=1,NC)
      ID13=I900*2
      WRITE(13'ID13-1) NCD
      WRITE(13'ID13) CD
  900 CONTINUE
      RETURN
      END
```

```
      COMMON NC,A,S,PF,NR,N,MRSD,NOFP,NOIFP,NFEAS,NMT,TPC,TLC,TSC,
     X       NFP(10),NIP(10),TPCF(10),TPCI(10)
      COMMON IV11,IV12,IV13
      COMMON INIT(50)
      DEFINE FILE 7(400,50,U,IV7)
      DEFINE FILE 11(50,100,U,IV11)
      DEFINE FILE 12(400,203,U,IV12)
      DEFINE FILE 13(800,400,U,IV13)
      DOUBLE PRECISION PNL3,PNL4,PNL5
      WRITE(4,101)
  101 FORMAT('PHL3    PHL4    PHL5    ')
      BACKSPACE 4
      READ (4,102) PNL3,PNL4,PNL5
  102 FORMAT(3A8)
C READ VARIABLES 1ST TIME ONLY
      READ(8)NC,A,S,PF,NR,N,MRSD,NOFP,NOIFP,NFEAS,NMT,TPC,TLC,TSC,NFP,
     XNIP,TPCF,TPCI
  150 CALL FETCH(PNL3)
      CALL L3
      CALL FETCH(PNL4)
      CALL L4
      CALL FETCH(PNL5)
      CALL L5
      IF(N-NR)201,199,199
  199 STOP
  201 REWIND 8
      REWIND 9
      REWIND 10
      WRITE(8) NC,A,S,PF,NR,N,MRSD,NOFP,NOIFP,NFEAS,NMT,TPC,TLC,TSC,NFP,
     XNIP,TPCF,TPCI
      GO TO 150
      END
```

```
      SUBROUTINE L3
C
C
C
C     LAND USE PLAN DESIGN MODEL
C
C     PROGRAM 3  VERSION 2   BOEHLEN  9/22/71
C
C     A MODULE (ALL MODULES)  IS SELECTED USING A RANDOM NUMBER
C         GENERATOR
C     A CELL IS SELECTED USING A RANDOM NUMBER GENERATOR
C     MODULE CELL COMPATIBILITY IS TESTED
C     CELL LAND CAPACITY IS TESTED
C     THE MODULE(S) IS ASSIGNED TO THE CELL(S)
C
C
      COMMON NC,A,S,PF,NR,N,MRSD,NCFP,NOIFP,NFEAS,NMT,TPC,TLC,TSC,
     X       NFP(10),NIP(10),TPCF(10),TPCI(10)
      COMMON IV11,IV12,IV13
      COMMON INIT(50)
C     FORMATS
  100 FORMAT (' ',F11.2,2X,I5,2X,F11.2, 4(2X,I5))
C
      DIMENSION  AM(50), MN(50), MPC(50), MC(50), SC(50), CLE(50),
     X CA(400)
      DIMENSION MPCX(50),DMM(50),CD(400),NCD(400)
C
C
C     GENERATE A RANDOM NUMBER
      MULT=12345
      GO TO 300
  200 CONTINUE
      MRSD=MRSD*MULT
C     ISOLATE THE UPPER 3 OF THE LOWER 4 DIGITS FOR THE RANDOM NUMBER
C     ELIMINATE THE LOWER ORDER DIGIT
      IELOD=MRSD/10
C     ELIMINATE THE 4 HIGH ORDER DIGITS
      IEHOD=(IELOD/1000)*1000
      MRAND=IELOD-IEHOD
C     IF MRAND IS ZERO TRY AGAIN
  205 IF(MRAND) 200,200,201
  201 CONTINUE
C     IF MRAND IS TO BIG (GREATER THEN THE NUMBER OF CELLS OR THE NUMBER
C        OF MODULE TYPES)REDUCE ITS SIZE
      IF(MRAND-MRNDLT) 204,204,203
  203 CONTINUE
      MRAND=MRAND/10
      GO TO 205
C     RETURN TO THE PROGRAM
  204 GO TO (401,426),MODCEL
C
C     READ THE MODULE AREA AND NUMBER VECTORS
  300 READ(9) AM,MN
C
C     READ THE CELL AREA VECTOR AND INITIALIZE THE CELL-MODULE
C     MATRIX FOR CELL AREA REMAINING
      READ(10) CA
C     READ THE CELL-MODULE MATRIX ONE CELL ROW AT A TIME
      DO 350 I350=1,NC
      READ(12'I350) CAR,MPC,SC,MC,CLE,CSC,CLC
      READ(7'I350)INIT
C     INITIALIZE THE CELL ROW
      DO 325 I325=1,50
      MPC(I325)=INIT(I325)
      CLE(I325)=0.0
  325 CONTINUE
      CAR=CA(I350)
C     WRITE THE CELL ROW BACK
      WRITE(12'I350) CAR,MPC,SC,MC,CLE,CSC,CLC
  350 CONTINUE
C
C     COMPUTE THE NUMBER OF MODULES
      NOM=0
      DO 360 I360=1,NMT
      NOM=NOM+MN(I360)
  360 CONTINUE
C
C
C     SELECT A MODULE TYPE USING THE RANDOM NUMBER GENERATOR
  400 CONTINUE
      MODCEL=1
      MRNDLT=NMT
      GO TO 200
C
C     ARE THERE ANY MODULES OF THE TYPE CHOSEN  IF NOT MAKE A NEW SELECT
  401 CONTINUE
      IF(MN(MRAND)) 200,200,402
C
C     REMBER THE RANDOM NUMBER
  402 MOD=MRAND
C
C
C     SELECT A CELL USING THE RANDOM NUMBER GENERATOR
      ITRY=NC**2
  425 CONTINUE
      ITRY=ITRY-1
      IF(ITRY)4255,4255,4259
 4255 ITRY=NC**2
      WRITE(3,4256)ITRY
 4256 FORMAT(' UNABLE TO PLACE A MODULE AFTER ',I5,' TRYS')
      STOP
 4259 CONTINUE
      MODCEL=2
      MRNDLT=NC
      GO TO 200
C
C     REMBER THE RANDOM NUMBER
  426 NCN=MRAND
C
C
C     TEST FOR MODULE CELL COMPATABILITY, LIMIT AND AREA
C
C     GET THE CELL ROW
      READ(12'NCN) CAR,MPC,SC,MC,CLE,CSC,CLC
C
C     COMPATIBILITY TEST   (NOT COMPATABLE PICK ANOTHER CELL)
      IF(MC(MOD)) 425,425,450
C
C     CELL MODULE LIMIT TEST  (FAIL PICK ANOTHER CELL)
  450 CONTINUE
      IF(MPC(MOD)-MC(MOD)) 451,425,425
C
C     LAND CAPACITY TEST   (FAIL PICK ANOTHER CELL)
  451 CONTINUE
      IF(CAR-AM(MOD)) 425, 452, 452
  452 CONTINUE
C
C     MODULE MODULE DISTANCE TEST  (FAIL PICK ANOTHER CELL)
C
```

```
C     TEST DISTANCE ONLY FOR THE FIRST OF A TYPE WITHIN A CELL
      IF(MPC(MOD))453,453,458
  453 CONTINUE
C     READ DISTANCE CONSTRAINT
      READ(11'MOD)DMM
      DO 457 I457=1,NMT
C     TEST IF MOD MUST BE SETERATED FROM TYPE I456
      IF (DMM(I457))454,457,457
  454 CONTINUE
C     READ THE CELL DISTANCE VECTOR
      ID13=NCN*2
      READ(13'ID13)CD
      READ(13'ID13-1)NCD
      DO 456 I456=1,NC
C     TEST ONLY CELLS CLOSE ENOUGH TO VIOLATE DISTANCE CONSTRAINT
      IF (CD(I456)+DMM(I457))455,457,457
  455 CONTINUE
      I12=NCD(I456)
      READ(12'I12)CARX,MPCX
      IF(MPCX(I457))456,456,425
  456 CONTINUE
  457 CONTINUE
C
C     RECORD THIS PLACEMENT
  458 CONTINUE
      CAR=CAR-AM(MOD)
      MPC(MOD)=MPC(MOD)+1
      MN(MOD)=MN(MOC)-1
      NOM=NOM-1
C
C     WRITE THE CELL ROW BACK ON DISK
      WRITE(12'NCN) CAR, MPC, SC, MC, CLE,CSC,CLC
C
C     HAVE ALL THE MODULES BEEN PLACED  IF NOT SELECT ANOTHER MODULE
      IF(NOM)470,470,400
  470 CONTINUE
C
C     DESIGNATE THE PLAN FEASIBLE
      NFEAS=0
      RETURN
      END


C     LAND USE PLAN DESIGN MODEL
C
C     PROGRAM 4  VERSION 2  BOEHLEN  9/22/71
C
C
C     TOTAL LINKAGE AND SITE COST ARE ZEROED
C     GETS CELL DISTANCE AND MODULE PLACEMENT VECTORS AND SUMS THE
C         SITE COSTS  (EACH CELL)
C     GETS THE MODULE LINKAGE VECTOR, ZEROS THE LINKAGE SATISFACTION
C         VECTOR AND UPDATES THE LINKAGE SATISFACTION VECTOR FOR
C         INTRA CELL LINKAGES  (MODULE TYPE WITHIN CELL)
C     GETS THE MODULE PLACEMENT VECTOR, SUMS THE LINKAGE COSTS AND
C         PRINTS THE LINKAGE DISTANCE VIOLATIONS
C         (CELL WITHIN MODULE TYPE WITHIN CELL)
C
C
      COMMON NC,A,S,PF,NR,N,MRSD,NOFP,NOIFP,NFEAS,NMT,TPC,TLC,TSC,
     X       NFP(10),NIP(10),TPCF(10),TPCI(10)
      COMMON IV11,IV12,IV13
      COMMON INIT(50)
C     FORMATS
  100 FORMAT(' CELL'I5,T15,'MOD'I5,T28,'CDPOS'I5,T43,'MOD'I5,T56,'DIST'
     XF11.2,T78,'DIST ALOW'F11.2,T100,'CELL'I5)
      DIMENSION CD(400),NCD(400),MPC(50),MC(50),SC(50),CLE(50),LS(50),
     X  DMM(50),CML(50),MPC980(50)
C
C
C     ZERO TOTAL LINKAGE AND TOTAL SIGHT COST
      TLC=0.0
      TSC=0.0
      TPC=0.0
C
C     DO THE FOLLOWING STEPS FOR EACH CELL
      DO 999 I999=1,NC
C
C     GET THE CELL DISTANCE VECTOR
      ID13=I999*2
      READ(13'ID13-1) NCD
      READ(13'ID13) CD
C
C     GET THE MODULE PLACEMENT VECTOR
      READ(12'I999) CAR, MPC, SC, MC, CLE, CSC, CLC
      READ(7'I999)INIT
C
C     SUM THE SITE COST FOR THIS CELL AND ADD TO TOTAL SITE COST
      CLC=0.0
      CSC=0.0
      DO 200 I200=1,NMT
      CSC=CSC+(MPC(I200)-INIT(I200)) * SC(I200)
  200 CONTINUE
      TSC=TSC+CSC
C
C     DO THE FOLLOWING STEPS FOR EACH MODULE TYPE WITH MODULES PLACED
C     IN CELL I999
      DO 990 I990=1,NMT
C
C     DOES MODULE TYPE I990 HAVE MODULE1 IN CELL I999  (IF NOT END OF L)
      IF (MPC(I990)-INIT(I990)) 990,990,201
  201 CONTINUE
C
C     ZERO THE LINKAGE SATISFACTION VECTOR
      DO 202 I202=1,50
      LS(I202)=0
  202 CONTINUE
C
C     GET THE MODULE LINKAGE VECTOR FOR MODULE TYPE I990
      READ(11'I990) DMM,CML
C
C     UPDATE THE LINKAGE SATISFACTION VECTOR FOR THOSE LINKAGES THAT CAN
C     BE SATISFIED WITHIN THE CELL OR ARE NOT REQUIRED AT ALL
      DO 205 I205=1,NMT
C     IS THE MODULE LINKAGE COST FOR MODULE TYPE I205 ZERO
      IF(CML(I205)) 204, 204, 203
C     ARE THERE ANY MODULES OF TYPE I205 IN CELL I999
  203 CONTINUE
      IF(MPC(I205)) 205, 205, 204
C     THE LINKAGE REQUIREMENT FOR MODULE I205 IS SATISFIED
  204 LS(I205)=1
  205 CONTINUE
C
C
C     DO THE FOLLOWING STEPS FOR EVERY CELL IN ORDER BY DISTANCE FROM
C     CELL I999 UNTIL THE LINKAGE SATISFACTION VECTOR IS SATISFIED
      DO 980 I980=1,NC
C
C     IS THE LINKAGE SATISFACTION VECTOR SATISFIED
      LSC=0
      DO 210 I210=1,NMT
      LSC=LSC+LS(I210)
  210 CONTINUE
      IF(LSC-NMT) 211, 980, 980
  211 CONTINUE
C
C     GET THE MODULE PLACEMENT VECTOR FOR CELL I980 IN THE CELL DISTANCE
C     VECTOR
      NCD980=NCD(I980)
      READ(12'NCD980) CAR980,MPC980
C
C
C     DO THE FOLLOWING STEPS FOR MODULE TYPES WITH MODULES IN CELL
C     NCD980
      DO 970 I970=1,NMT
C
C     IF NO MODULES OF TYPE I970 IN CELL NCD980 JUMP TO END OF DO LOOP
      IF(MPC980(I970)) 970, 970, 212
  212 CONTINUE
C
C     IF THE LINKAGE REQUIREMENT TO MODULE TYPE I970 FROM MODULE TYPE
C     I990 IS SATISFIED GO TO END OF LOOP
      IF(LS(I970)) 213,213,970
  213 CONTINUE
C
C     COMPUTE LINKAGE COST BETWEEN MODULE TYPE I990 IN CELL I999 AND
C     MODULE TYPE I970 IN CELL NCD980
      CL=CML(I970)*CD(I980)*(MPC(I990)+MPC980(I970)-1)
      TLC=TLC+CL
      CLC=CLC+CL
      CLE(I990)=CLE(I990)+CL
C
C     UPDATE THE LINKAGE SATISFACTION VECTOR
      IF(CL) 970, 970, 214
  214 CONTINUE
      LS(I970)=1
C
C     DETERMINE LINKAGE CONSTRAINT VIOLATIONS
C
      IF(DMM(I970))970,970,216
C     MUST BE WITHIN DMM
  216 IF(CD(I980)-DMM(I970))970,970,220
  220 CONTINUE
      WRITE(3,100) I999, I990, I980, I970, CD(I980), DMM(I970), NCD980
C
C     MARK THE PLAN INFEASIBLE
      NFEAS=1
  970 CONTINUE
  980 CONTINUE
  990 CONTINUE
C
C     WRITE THE MODULE CELL MATRIX ROWBACK WITH COST EXTENSIONS
      WRITE(12'I999) CAR, MPC, SC, MC, CLE, CSC, CLC
      TPC=TLC+TSC
  999 CONTINUE
      RETURN
      END


C     LAND USE PLAN DESIGN MODEL
C
C     PROGRAM 5 VERSION 2 BOEHLENN  9/24/71
C
C
C     PLANS COMPLETED IS UPDATED
C     FEASIBLE AND INFEASIBLE PLANS COMPLETED ARE UPDATED
C     THE PROBABILITY OF A FEASIBLE PLAN IS UPDATED
C     NUMBER OF PLAN REQUIRED IS UPDATED
C     UPDATES THE LOW COST 10 FEASIBLE AND 10 INFEASIBLE VECTORS
C     PRINTS THE PLAN IF IT IS BETTER THEN ANY OF THE 10 BEST FEASIBLE
C     OR INFEASIBLE PLANS
C
C
      COMMON NC,A,S,PF,NR,N,MRSD,NOFP,NOIFP,NFEAS,NMT,TPC,TLC,TSC,
     X       NFP(10),NIP(10),TPCF(10),TPCI(10)
      COMMON IV11,IV12,IV13
      COMMON INIT(50)
C     FORMAT
  100 FORMAT('0'/'0 PLAN',1X,I5,1X,'OF',1X,I5,5X,'COST',1X,E14.8,/)
  101 FORMAT(' NO PLANS WERE REPLACED'//)
  102 FORMAT('0 TOTAL LINKAGE COST'T22,E14.8,T40,'TOTAL SITE COST'T60,
     X E14.8)
  103 FORMAT('0FEASIBLE PLANS',T18,5(I5,13X),/,' ',T18,5(2X,E14.8),/,
     X' ',T18,5(I5,13X),/,' ',T18,5(2X,E14.8))
  104 FORMAT('0INFEASIBLE',T18,5(I5,13X),/,' ',T18,5(2X,E14.8),/,
     X' ',T18,5(I5,13X),/,' ',T18,5(2X,E14.8))
  105 FORMAT('0PLAN'T5,I5,T15,'CELL'T19,I5,T30,'AREA REMAINING'T45,E14.8
     X, /' CELL SITE COST' T18, E14.8, T40,'CELL LINKAGE COST'T60,E14.8)
  106 FORMAT('0 CELL    MOD   INIT PLACED  LIMIT',T41,'SITE COST',T54,
     *'LINKAGE COST')
  107 FORMAT(' ',4(I5,2X),2(E14.8,2X))
C     DEMINSIONS
      DIMENSION MPC(50),MC(50),SC(50),CLE(50)
C     UPDATE THE PLANS COMPLETED
      N=N+1
C
C     UPDATE THE FEASIBLE AND INFEASIBLE PLANS COMPLETED
      IF(NFEAS) 200,200,201
  200 NOFP=NOFP+1
      GO TO 202
  201 CONTINUE
      NOIFP=NOIFP+1
  202 CONTINUE
C
C     UPDATE THE PROBABILITY OF A FEASIBLE PLAN
C     11TH PLAN AND HIGHER
      PF=0.5
      NR=100
      IF(N-11) 205,203,203
  203 CONTINUE
C
C     UPDATE THE PROBABILITY OF A FEASIBLE PLAN
      FNOFP=NOFP
      FN=N
      PF=FNOFP/FN
      IF(PF)  204, 204, 206
  204 PF=0.5
  206 CONTINUE
      A1=A*PF
      NR=ALOG(1.0-S)/ALOG(1.0-A1)
  205 CONTINUE
C
C     IF REQUIRED REPLACE ONE OF THE 10 BEST FEASIBLE OR INFEASIBLE  PLN
      IF(NFEAS) 210,210,230
C
C     SHOULD A FEASIBLE PLAN BE REPLACED
```

```
  210 IF(TPC-TPCF(10))211,260,260
  211 CONTINUE
C
C     REPLACE A FEASIBLE PLAN
      CALL REPLAC(TPC,N,TPCF,NFP)
      GO TO 300
C
C     SHOULD AN INFEASIBLE PLAN BE REPLACED
  230 CONTINUE
      IF(TPC-TPCI(10)) 231,260,260
C
C     REPLACE AN INFEASIBLE PLAN
  231 CONTINUE
      CALL REPLAC (TPC,N,TPCI,NIP)
      GO TO 300
C
C
C     NO PLAN WAS REPLACED  PRINT MESSAGE
  260 CONTINUE
      WRITE(3,100)N,NR,TPC
      WRITE(3,101)
      GO TO 505
C
C
C     PLANS WERE REPLACED PRINT OUT NEW PLAN
  300 CONTINUE
      WRITE(3,100)N,NR,TPC
      WRITE (3,102)  TLC,TSC
      WRITE (3,103) (NFP(I),I=1,5),(TPCF(I),I=1,5),(NFP(I),I=6,10),
     X              (TPCF(I),I=6,10)
      WRITE(3,104) (NIP(I),I=1,5),(TPCI(I),I=1,5),  (NIP(I),I=6,10),
     *             (TPCI(I),I=6,10)
C
C     PRINT THE PLAN
      WRITE(3,106)
      DO 400 I400=1,NC
C     READ THE CELL ROW (MODULE PLACEMENT VECTOR)
      READ(12'I400)CAR,MPC,SC,MC,CLE,CSC,CLC
C     READ THE INITIAL CONDITIONS
      READ(7'I400)INIT
      DO 375 I375=1,NMT
      IF(MPC(I375)) 375,375,370
  370 IPLACD = MPC(I375)-INIT(I375)
      WRITE(3,107)I400,I375,INIT(I375),IPLACD,SC(I375),CLE(I375)
  375 CONTINUE
  400 CONTINUE
  505 RETURN
      END


      SUBROUTINE REPLAC (TC,N,TCV,NCV)
      DIMENSION TCV(10), NCV(10)
      TCV(10)=TC
      NCV(10)=N
      IPUSH=11
      IPUSH1=10
  800 CONTINUE
      IPUSH=IPUSH-1
      IPUSH1=IPUSH1-1
      IF(TCV(IPUSH)-TCV(IPUSH1)) 801,802,802
C     PUSH DOWN
  801 TCVIP1=TCV(IPUSH1)
      NCVIP1=NCV(IPUSH1)
      TCV(IPUSH1)=TCV(IPUSH)
      NCV(IPUSH1)=NCV(IPUSH)
      TCV(IPUSH)=TCVIP1
      NCV(IPUSH)=NCVIP1
  802 IF(IPUSH1-1) 803, 803, 800
  803 CONTINUE
      RETURN
      END
```

Appendix C

COST DATA FOR LAND USE PLAN DESIGN APPLICATION
VILLAGE OF GERMANTOWN, WISCONSIN

MODULE	MODULE	DISTANCE CONSTRAINT	LINKAGE COST
1	1	0.0	1CCC000.00
1	2	3.00	1CCC000.CO
1	3	6.00	5CC000.CO
1	4	0.0	5C000.CO
1	5	5.00	25C000.CO
1	6	0.0	0.C
1	7	2.50	75C000.00
1	8	0.0	0.0
1	9	0.0	125C000.CO
1	10	0.0	0.C
1	11	0.0	0.0
2	2	0.0	0.0
2	3	0.0	0.C
2	4	0.0	0.0
2	5	0.0	0.0
2	6	0.0	0.0
2	7	0.0	0.C
2	8	0.0	0.C
2	9	0.0	5CC000.CO
2	10	0.0	25C000.CO
2	11	0.0	0.C
3	3	C.0	0.C
3	4	0.0	0.C
3	5	0.0	5C0C0.CO
3	6	0.0	0.0
3	7	0.0	0.0
3	8	0.0	0.0
3	9	0.0	125C000.CO
3	10	0.0	25C000.CO
3	11	0.0	0.0
4	4	0.0	10C000.00
4	5	0.0	0.0
4	6	0.0	0.C
4	7	0.0	0.C
4	8	0.0	C.C
4	9	0.0	10CC000.CO
4	10	0.0	1250000.CO
4	11	0.0	0.0
5	5	0.0	25C000.CO
5	6	3.00	0.C
5	7	0.0	0.0
5	8	0.0	0.0
5	9	0.0	50C000.CO
5	10	C.0	5CC0C0.C0
5	11	0.0	0.0
6	6	0.0	0.C
6	7	0.0	0.0
6	8	0.0	C.C
6	9	0.0	1000000.CO
6	10	0.0	50C0C0.C0
6	11	0.0	0.C
7	7	0.0	5C000.CO
7	8	0.0	0.C
7	9	0.0	10CC0C0.CO
7	10	0.0	5C000.00
7	11	0.0	0.0
8	8	0.0	0.0
8	9	0.0	0.0
8	10	0.0	0.C
8	11	0.0	0.0
9	9	0.0	0.0
9	10	0.0	0.0
9	11	0.0	0.0
1C	10	0.0	0.C
1C	11	C.0	0.C

CELL	MOD	PLACED	LIMIT	SITE COST
1	1	0	2	427896C0.CC
1	2	0	5	873536.CC
1	3	0	1	122841C0.CC
1	4	0	1	1883562.CC
1	5	0	2	427896C0.CC
1	6	0	2	427896C0.CC
1	7	0	1	3753475.CC
1	8	0	2	9C000.CC
1	9	0	C	1C00000.CC
1	10	0	1	750000.CC
1	11	1	4	25000.CC
2	1	0	2	55909584.CC
2	2	0	5	1141376.CC
2	3	0	1	16C50600.CC
2	4	0	1	2461092.CC
2	5	0	2	55909584.CC
2	6	0	2	55909584.CC
2	7	0	1	4904350.CC
2	8	0	2	12C000.CC
2	9	0	C	1CCC0C0.CC
2	10	0	1	75C000.CC
2	11	3	4	25000.CC
3	1	C	2	427896C0.CC
3	2	0	5	873536.CC
3	3	0	1	122841C0.CC
3	4	0	1	1883562.CC
3	5	0	2	427896C0.CC
3	6	0	2	42789600.CC
3	7	0	1	3753475.CC
3	8	0	2	9C000.CC
3	9	0	C	1C0CCC0.CC
3	10	0	1	75C000.CC
3	11	2	4	25CC0.CC
4	1	C	2	427896C0.CC
4	2	0	5	873536.CC
4	3	0	1	122841C0.CC
4	4	0	1	1883562.CC
4	5	0	2	42789600.CC
4	6	C	2	42789600.CC
4	7	0	1	3753475.CC
4	8	0	2	9C000.CC
4	9	0	C	1CCC0C0.CC
4	10	0	1	75C000.CC
4	11	2	4	25CC0.CC
5	1	0	2	427896C0.CC
5	2	0	5	873536.CC
5	3	0	1	12284100.CC
5	4	0	1	1883562.CC
5	5	0	2	427896C0.CC
5	6	0	2	427896C0.CC
5	7	0	1	3753475.CC
5	8	0	2	9C0C0.CC
5	9	0	0	1CC00C0.CC
5	10	1	1	75C000.CC
5	11	1	4	25000.CC
6	1	0	2	17897712.CC
6	2	0	5	365376.CC
6	3	0	1	513810C.CC
6	4	0	1	787542.CC
6	5	0	2	17897712.CC
6	6	0	2	17897712.CC
6	7	0	1	1569975.CC
6	8	0	2	9C000.CC
6	9	0	0	1CC0CC0.CC
6	10	0	1	75C0C0.CC
6	11	0	4	25C00.CC

CELL	MOD	PLACED	LIMIT	SITE COST
7	1	0	2	17897712.CC
7	2	0	5	365376.00
7	3	0	1	5138100.CC
7	4	0	1	787542.00
7	5	0	2	17897712.0C
7	6	0	2	17897712.CC
7	7	0	1	1569975.00
7	8	0	2	90000.CC
7	9	0	C	1000000.CC
7	10	1	1	750000.CC
7	11	0	4	25000.CC
8	1	0	2	17897712.CC
8	2	0	5	365376.CC
8	3	0	1	5138100.0C
8	4	0	1	787542.00
8	5	0	2	17897712.CC
8	6	0	2	17897712.CC
8	7	0	1	1569975.CC
8	8	0	2	9C000.CC
8	9	0	0	1000000.CC
8	10	1	1	75C0C0.CC
8	11	C	4	25000.00
9	1	0	2	17897712.CC
9	2	0	5	365376.0C
9	3	0	1	51381C0.CC
9	4	0	1	787542.CC
9	5	0	2	17897712.CC
9	6	0	2	17897712.CC
9	7	0	1	1569975.0C
9	8	0	2	9C0C0.CC
9	9	0	C	10CC0C0.CC
9	10	0	1	750000.CC
9	11	0	4	25000.CC
10	1	0	2	42789600.00
10	2	0	5	873536.0C
10	3	0	1	12284100.CC
10	4	0	1	1883562.0C
10	5	0	2	42789600.CC
1C	6	0	2	42789600.00
10	7	0	1	3753475.0C
1C	8	0	2	9CCC0.CC
10	9	0	C	1000000.0C
10	10	0	1	750000.CC
1C	11	1	4	25000.CC
11	1	0	2	42789600.C0
11	2	0	5	873536.0C
11	3	0	1	12284100.0C
11	4	0	1	1883562.0C
11	5	0	2	42789600.CC
11	6	0	2	42789600.0C
11	7	C	1	3753475.0C
11	8	0	2	9C000.CC
11	9	0	C	1CC0CC0.CC
11	10	0	1	75C000.CC
11	11	1	4	25000.CC
12	1	0	2	55909584.CC
12	2	0	5	1141376.0C
12	3	0	1	16050600.CC
12	4	0	1	2461092.CC
12	5	0	2	55909584.0C
12	6	0	2	55909584.CC
12	7	0	1	4904350.CC
12	8	0	2	120000.CC
12	9	0	0	1000000.0C
12	10	0	1	75C0C0.CC
12	11	4	4	25000.CC
13	1	0	2	42789600.CC
13	2	0	5	873536.CC
13	3	0	1	12284100.CC
13	4	0	1	1883562.0C
13	5	0	2	42789600.CC
13	6	0	2	42789600.0C
13	7	0	1	3753475.0C
13	8	0	2	9C0C0.0C
13	9	0	C	1CCC000.CC
13	10	0	1	750000.CC
13	11	2	4	25000.CC

CELL	MOD	PLACED	LIMIT	SITE COST
14	1	0	2	55909584.CC
14	2	0	5	1141376.0C
14	3	0	1	16050600.CC
14	4	0	1	2461092.CC
14	5	0	2	55909584.CC
14	6	0	2	55909584.CC
14	7	0	1	4904350.CC
14	8	0	2	120000.CC
14	9	0	0	1CC0C0.CC
14	1C	0	1	75C000.0C
14	11	3	4	25000.CC
15	1	0	2	55909584.CC
15	2	0	5	1141376.CC
15	3	0	1	16050600.0C
15	4	0	1	2461092.CC
15	5	0	2	55909584.CC
15	6	0	2	55909584.CC
15	7	0	1	4904350.CC
15	8	0	2	12C000.CC
15	9	0	0	1CC0C0.CC
15	10	0	1	750000.CC
15	11	3	4	250C0.CC
16	1	0	2	42789600.CC
16	2	0	5	873536.CC
16	3	0	1	12284100.CC
16	4	0	1	1883562.CC
16	5	0	2	42789600.CC
16	6	0	2	42789600.CC
16	7	0	1	3753475.0C
16	8	0	2	9C000.CC
16	9	0	C	1CC0CC0.CC
16	10	1	1	750000.CC
16	11	0	4	25000.00
17	1	0	2	17897712.CC
17	2	0	5	365376.CC
17	3	0	1	51381C0.CC
17	4	0	1	787542.CC
17	5	0	2	17897712.CC
17	6	0	2	17897712.0C
17	7	0	1	1569975.0C
17	8	0	2	9C0C0.CC
17	9	0	C	1CCC000.CC
17	10	0	1	75C000.CC
17	11	0	4	25C00.CC
18	1	0	2	17897712.CC
18	2	0	5	365376.CC
18	3	0	1	51381C0.CC
18	4	0	1	787542.CC
18	5	0	2	17897712.0C
18	6	0	2	17897712.CC
18	7	0	1	1569975.CC
18	8	0	2	9C000.CC
18	9	0	C	1CCC000.CC
18	10	1	1	75C0C0.CC
18	11	0	4	25C00.CC
19	1	0	2	17897712.CC
19	2	0	5	365376.CC
19	3	0	1	51381C0.CC
19	4	0	1	787542.CC
19	5	0	2	17897712.0C
19	6	0	2	17897712.CC
19	7	0	1	1569975.CC
19	8	0	2	90000.CC
19	9	0	C	1CCC000.CC
19	1C	1	1	75C0C0.CC
19	11	0	4	250C0.CC
2C	1	0	2	17897712.CC
2C	2	0	5	365376.0C
2C	3	0	1	51381C0.CC
2C	4	0	1	787542.CC
20	5	0	2	17897712.CC
20	6	0	2	17897712.CC
2C	7	0	1	1569975.0C
2C	8	0	2	9CC00.CC
2C	9	C	C	1C000C0.CC
20	1C	1	1	75C0C0.CC
2C	11	0	4	25C00.CC

CELL	MOD	PLACED	LIMIT	SITE COST
21	1	0	2	42789600.00
21	2	0	5	873536.00
21	3	0	1	12284100.00
21	4	0	1	1883562.00
21	5	0	2	42789600.00
21	6	1	2	42789600.00
21	7	0	1	3753475.00
21	8	0	2	90000.00
21	9	1	0	1000000.00
21	10	0	1	750000.00
21	11	0	4	25000.00
22	1	0	2	42789600.00
22	2	1	5	873536.00
22	3	0	1	12284100.00
22	4	1	1	1883562.00
22	5	0	2	42789600.00
22	6	0	2	42789600.00
22	7	1	1	3753475.00
22	8	0	2	90000.00
22	9	0	0	1000000.00
22	10	1	1	750000.00
22	11	0	4	25000.00
23	1	1	2	42789600.00
23	2	1	5	873536.00
23	3	0	1	12284100.00
23	4	0	1	1883562.00
23	5	0	2	42789600.00
23	6	0	2	42789600.00
23	7	0	1	3753475.00
23	8	0	2	90000.00
23	9	0	0	1000000.00
23	10	1	1	750000.00
23	11	0	4	25000.00
24	1	0	2	42789600.00
24	2	0	5	873536.00
24	3	0	1	12284100.00
24	4	0	1	1883562.00
24	5	0	2	42789600.00
24	6	0	2	42789600.00
24	7	0	1	3753475.00
24	8	0	2	90000.00
24	9	0	0	1000000.00
24	10	0	1	750000.00
24	11	1	4	25000.00
25	1	0	2	17897712.00
25	2	0	5	365376.00
25	3	0	1	5138100.00
25	4	0	1	787542.00
25	5	0	2	17897712.00
25	6	0	2	17897712.00
25	7	0	1	1569975.00
25	8	0	2	90000.00
25	9	0	0	1000000.00
25	10	0	1	750000.00
25	11	0	4	25000.00
26	1	0	2	17897712.00
26	2	0	5	365376.00
26	3	0	1	5138100.00
26	4	0	1	787542.00
26	5	0	2	17897712.00
26	6	0	2	17897712.00
26	7	0	1	1569975.00
26	8	0	2	90000.00
26	9	0	0	1000000.00
26	10	1	1	750000.00
26	11	0	4	25000.00
27	1	0	2	17897712.00
27	2	0	5	365376.00
27	3	0	1	5138100.00
27	4	0	1	787542.00
27	5	0	2	17897712.00
27	6	0	2	17897712.00
27	7	0	1	1569975.00
27	8	0	2	90000.00
27	9	0	0	1000000.00
27	10	0	1	750000.00
27	11	0	4	25000.00
28	1	0	2	42789600.00
28	2	0	5	873536.00
28	3	0	1	12284100.00
28	4	0	1	1883562.00
28	5	0	2	42789600.00
28	6	0	2	42789600.00
28	7	0	1	3753475.00
28	8	0	2	90000.00
28	9	0	0	1000000.00
28	10	0	1	750000.00
28	11	2	4	25000.00
29	1	0	2	42789600.00
29	2	0	5	873536.00
29	3	0	1	12284100.00
29	4	0	1	1883562.00
29	5	0	2	42789600.00
29	6	0	2	42789600.00
29	7	0	1	3753475.00
29	8	0	2	90000.00
29	9	0	0	1000000.00
29	10	1	1	750000.00
29	11	2	4	25000.00
30	1	0	2	17897712.00
30	2	0	5	365376.00
30	3	0	1	5138100.00
30	4	0	1	787542.00
30	5	0	2	17897712.00
30	6	0	2	17897712.00
30	7	0	1	1569975.00
30	8	0	2	90000.00
30	9	0	0	1000000.00
30	10	1	1	750000.00
30	11	0	4	25000.00
31	1	0	2	17897712.00
31	2	0	5	365376.00
31	3	0	1	5138100.00
31	4	0	1	787542.00
31	5	0	2	17897712.00
31	6	0	2	17897712.00
31	7	0	1	1569975.00
31	8	0	2	90000.00
31	9	0	0	1000000.00
31	10	0	1	750000.00
31	11	0	4	25000.00
32	1	0	2	17897712.00
32	2	0	5	365376.00
32	3	0	1	5138100.00
32	4	0	1	787542.00
32	5	0	2	17897712.00
32	6	0	2	17897712.00
32	7	0	1	1569975.00
32	8	0	2	90000.00
32	9	0	0	1000000.00
32	10	1	1	750000.00
32	11	0	4	25000.00
33	1	0	2	42789600.00
33	2	0	5	873536.00
33	3	0	1	12284100.00
33	4	0	1	1883562.00
33	5	0	2	42789600.00
33	6	0	2	42789600.00
33	7	0	1	3753475.00
33	8	0	2	90000.00
33	9	0	0	1000000.00
33	10	1	1	750000.00
33	11	2	4	25000.00
34	1	1	2	17897712.00
34	2	1	5	365376.00
34	3	0	1	5138100.00
34	4	0	1	787542.00
34	5	0	2	17897712.00
34	6	0	2	17897712.00
34	7	0	1	1569975.00
34	8	0	2	90000.00
34	9	0	0	1000000.00
34	10	0	1	750000.00
34	11	0	4	25000.00

CELL	MOD	PLACED	LIMIT	SITE COST
35	1	0	2	17897712.00
35	2	0	5	365376.00
35	3	0	1	5138100.00
35	4	0	1	787542.00
35	5	0	2	17897712.00
35	6	0	2	17897712.00
35	7	0	1	1569975.00
35	8	0	2	90000.00
35	9	0	0	1000000.00
35	10	1	1	750000.00
35	11	0	4	25000.00

CELL	MOD	PLACED	LIMIT	SITE COST
36	1	0	2	17897712.00
36	2	0	5	365376.00
36	3	0	1	5138100.00
36	4	0	1	787542.00
36	5	0	2	17897712.00
36	6	0	2	17897712.00
36	7	0	1	1569975.00
36	8	0	2	90000.00
36	9	0	0	1000000.00
36	10	1	1	750000.00
36	11	0	4	25000.00