A Computer Simulation Model For Flood Plain Development

Part 1: Land Use Planning and Benefit Evaluation

IWR

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Director

A COMPUTER SIMULATION MODEL FOR FLOOD PLAIN DEVELOPMENT IWR 72-1

A COMPUTER SIMULATION MODEL FOR FLOOD PLAIN DEVELOPMENT
Part 1: Land Use Planning and Benefit Evaluation

A Report Submitted to the

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In the course of the project we have worked closely with Mr. Ed Cohn of the Economic and Evaluation Branch, Planning Division, Civil Works Directorate. Mr. Cohn provided us with a better insight in the practical problems involved in the evaluation of flood control projects, and his continuous and constructive review of our progress reports made it possible for us to proceed in the correct direction. His active participation in numerous discussions during the project contributed to the quicker delenia-tions of issues that, otherwise, would have taken considerable time and effort. Mr. Robert M. Gidez, Assistant Chief, Planning Division, Civil Works Directorate, provided the guidance and direction in defining the scope of the simulation model and has been most helpful in the formulation of the conceptual framework used for project evaluation.

We express our appreciation to both Messrs. Gidez and Cohn for their active participation and assistance throughout the project.

FOREWORD

A. PURPOSE.

This research by INTASA, a private consulting firm specializing in systems analysis, is directed toward improving the conceptual framework and practical methods for flood control evaluation with a view toward ultimate development of a computer simulation model as an aid in the analysis of flood control plans, programs and projects. This report addresses the first priority problems of developing the conceptual structure for the model; defining the area to be studied; accounting for all activities which can influence flood control plans and decisions; and developing practical means for (1) establishing land use demand; (2) determining available land with emphasis on flood plain land use for different levels of flood protection; (3) identifying and measuring benefits resulting from project induced shifts in land use; (4) measuring equilibrium land rents; and (5) estimating the components making up economic rent differences (locational advantages) for different activities. Throughout the report, emphasis is placed upon minimizing data requirements and evaluation time by maximizing use of computer facilities and upon studying the sensitivity of results to basic assumptions, data uncertainty and specific measurement techniques.

B. FINDINGS.

This research, following the conceptual model developed by INTASA in IWR 70-3, concludes that micro economic theory of decision making can be applied to public investment analysis and that several major problems associated with flood control evaluation can be overcome. The report concludes that maximal land rent of alternative and flood plain sites can be safely utilized in the determination of optimal land use patterns, in spite of the problem that equilibrium rents may not be unique (a single value). IWR 70-3 suggests the use of a general benefit formulae for determining the value of flood protection to activities induced by a project to locate on the flood plain. This report presents a procedure for adapting the general benefit formulae to specific cases of shifts in land use by introduction of the concept of cycles of relocation.

The thrust of this report (and IWR 70-3) is that there should be four major steps undertaken in the analysis of flood control benefits: determination of land use plans with and without protection; choice of applicable benefit formula, measurement of maximal land rents and economic rent differences (locational advantages); and measurement of flood damages. The report addresses practical issues with regard to each step, except flood damages. With respect to land use, a two-level assignment of activities with and without protection is proposed. For this purpose the study area and land use demands are defined; the subareas are divided into groups and the development and sequencing of these groups is specified; and a representative (dummy) location is introducted to account for impacts outside the study area. With respect to the choice of an appropriate benefit formula, emphasis is placed upon cycles of relocation. A choice among alternative formulas is made depending upon the geographical extent of the cycles and upon the type and number of activities involved. With respect to the measurement of economic rent differences, the report reviews existing literature, discusses data and conceptual problems and establishes a flexible framework within which specific situations and activities can be evaluated.

C. ASSESSMENT.

This report represents a major step in resolving problems heretofore associated with a computer simulation model for flood control evaluation. Specifically, a practical definition of the study area is presented in conjunction with a representative location; outside the flood plain, an orderly procedure of benefit measurement based upon land use changes is established through the use of cycles of relocation; the difficult problem of measuring economic rent is ameliorated through the use of economic rent differences (locational advantages) in conjunction with equilibrium land rents is circumvented through the use of maximal land rent; and the problem of fixed costs associated with the development of groups of subareas is handled by specifying the development sequence of these groups.

The report emphasizes the significance of available land and land use demand, and of land use with and without a given protection level. This emphasis is particularly appropriate at this time because of the large number of land use plans being generated as a result of the HUD 701 program and the increasing number of Federal programs, including the flood insurance program, which require local land use plans as a prerequisite for Federal assistance.

It is anticipated that the findings of this research will significantly aid the Corps of Engineers in evaluating the range of programs available in the flood plain management field, including flood plain zoning, flood plain regulation, flood insurance and structural measures.

The report is related to IWR studies on the relation between income, land rent and flood risk in occupying flood plains.*

D. STATUS.

The results of this research are being utilized as the basis for the subsequent development of a computer simulation model by INTASA which has proceded to the point where testing of this model has begun on the Connecticut River Basin in cooperation with the Corps' New England Division.

This research represents the findings, conclusion and independent judgement of the researchers. In light of the interim nature of the report, the conclusions are not to be construed to represent necessarily the views of the Corps of Engineers.

*See IWR Report Nos. 69-4
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Chapter I

PROJECT SUMMARY

A. Background

In April 1970, INTASA submitted to the Corps of Engineers a final report on "Preliminary Review and Analysis of Flood Control Project Evaluation Procedures" under Contract No. DACW07-70-C0050 (Ref. 1). The report described the results of a preliminary study dealing with important analytical issues related to the planning and evaluation of flood control projects. The study emphasized the use of analytical methods for evaluating flood protection benefits and recommended the development of a systematic and computerized framework for their evaluation. Specifically, the recommended simulation model should be capable of performing sensitivity studies with respect to crucial problem parameters and assumptions, should expedite the benefit evaluation part of project analysis, and should, to the extent possible, limit the data required for benefit estimation. In June 1970, a proposal was submitted to Mr. Robert M. Gidez, Assistant Chief, Planning Division, Civil Works Directorate, Office of Chief of Engineers, U. S. Army Corps of Engineers, to develop the model, and, in addition to the above, it also proposed to investigate several other issues related to the problem of planning and evaluation. On September 16, 1970, the Corps contracted INTASA to start the development of the simulation model. On April 1, 1971, the contract was extended to include analysis of several issues related to land use planning that would expedite the development of the computer program. This Final Report describes the work completed by INTASA under Contract No. DACW07-71-C-0026 with particular emphasis on the tasks covered in the contract extension.

B. Scope

The contract calls for INTASA to develop a systematic and computerized procedure that can be used in carrying out planning and evaluation studies for specific flood control projects. In particular, the procedure should be capable of performing sensitivity studies with respect to problem parameters and assumptions, which can be used to establish bounds on the kind of data that should be gathered and limits on the significant ranges of the problem variables. Specifically, the following tasks were agreed upon as constituting the first part of the development of the simulator ending in June 1971.

(1) Development of the basic logic for benefit evaluation of flood control projects together with the FORTRAN IV prototype computer program.

(2) Analysis of alternative measurement procedures for evaluating benefits from flood control projects. In particular, the measurement of benefits due to relocation of economic activities through damages reduced.

(3) Identification and analysis of basic input data requirements for the planning and evaluation of flood control projects and the development of methods for checking consistency of data.

(4) Development of relationships between assumptions, parameters and problem variables dealing with key engineering, economic and hydrological issues.

The following additional problems were to be investigated in the modified contract:

(5) Sensitivity of the allocation of activities to economic rents and its implications for the allocation procedure to be used in the simulator. Development of allocation methods that account for interdependencies of economic rents and for future development of the study area.

(6) Nonuniqueness of equilibrium land rents associated with the optimal assignment of activities to parcels and determination of conditions under which these land rents are unique. Use of alternative methods for measuring benefits using equilibrium land rents in a variety of practical situations.

(7) Feasibility of developing computerized procedures for the estimation of economic rent differences for various activity-location combinations.

C. Summary of Work Performed

The work performed deals with the development of a model for flood control benefit simulation. First, we describe concepts that were introduced in the course of this analysis. Second, we summarize the analytical studies related to the simulation model that were previously reported through a number of Interim Memoranda submitted to OCE during the contract period. Next, we summarize the chapters of the final report, and finally, we briefly report on the status of the computer program.

1. Concepts Introduced

We define economic rent, net economic rent, and equilibrium land rent by considering an economic activity that locates on a particular site.

The economic rent associated with this activity-site combination is defined as the total net earnings of the activity and land owner without subtracting the flood damages. Or in other words, economic rents are defined assuming that land is free and flood damages do not occur. The reason for the choice of this definition is that first we are interested in total benefits to both the activities and the land owners and not in the division between these two, and second, since flood damages are central to a flood control project, we want to consider these damages separately. Thus the economic rent of an activity i on site ℓ is given by

$$S_{i\ell} = G_{i\ell} - C_{i\ell} \tag{1.1}$$

where $S_{i\ell} \triangleq$ economic rent to activity i on site ℓ

$G_{i\ell} \triangleq$ gross income of activity i on site ℓ

$C_{i\ell} \triangleq$ all costs incurred by activity i on site ℓ except for land rent and flood damage.

In general the economic rent will depend on the level of protection. For instance the level of protection may change the desirability of residences on or off the flood plain as a result of the interdependency effects between activities. This dependency on protection level is indicated by making the economic rent a function of the protection level p, or $S_{i\ell}(p)$.

The net economic rent is defined as the economic rent net of flood damages, or

$$\hat{S}_{i\ell}(p) = S_{i\ell}(p) - r_{i\ell}(p) \tag{1.2}$$

where $\hat{S}_{i\ell}(p)$ is the net economic rent of activity i on site ℓ assuming level of protection p,

$r_{i\ell}(p)$ is the flood damage of activity i on site ℓ with level of protection p.

Land rents are the payments made by the activity to the land owner. Equilibrium land rents are useful in reducing data requirements and are defined as a set of land rents under which no activity can increase its profits by moving to a different location. Since the allocation of activities will in general change with and without protection, the equilibrium land rent will also differ. We define therefore $q_\ell(p)$ as an equilibrium land rent of site ℓ with level of protection p.

2. Summary of Interim Memoranda

The analytical developments reported in the six Interim Memoranda mentioned above are discussed in the following summaries.

Interim Memorandum I (Ref. 2), "Measurement of Benefits from Flood Control and Land Use Forecasting." This memorandum derives basic equations for representing net benefits due to flood protection as net income changes to the activities and land owners, while keeping the data requirements to a minimum. Two important classifications are discussed; one involves a shift in land use as a result of flood protection and the other land-use intensification. Measurement of benefits in the latter case requires economic rent differences. In the case of shifts in land use, differences in land rents associated with locations on and off the flood plain are also needed. In this way economic rent differences outside the flood plain as a result of shifts in land use need not be evaluated directly. The resulting flood control benefit formula in this case is given by

$$B(p) = \{\hat{S}_x^f(p) - q^f(0)\} - \{\hat{S}_x^o(0) - q^o(0)\}, \qquad (1.3)$$

where $B(p)$ is the flood control benefit from a level of protection p,

$\hat{S}_x^f(p)$ and $\hat{S}_x^o(0)$ are the net economic rents for activity x in the flood plain with protection and outside the flood plain without protection, respectively,

$q^f(0)$ and $q^o(0)$ are the equilibrium land rents without protection in the flood plain and outside the flood plain, respectively.

Procedures for deriving the economic equilibrium conditions for given land values outside the flood plain are outlined and the formulation of this problem as one of optimally allocating activities on flood plain parcels is indicated. Finally, a benefit measurement through damage reduction is discussed using activity-threshold levels. Threshold levels are defined in terms of net income changes to activities and preliminary method for determining flood plain development using threshold levels are explored.

Interim Memorandum II (Ref. 3), "Simulation of Flood Damages." The flood features and property characteristics that determine the expected flood damages in the flood plain are the subject of this memorandum. First, the level of protection is defined in hydrologically meaningful terms, a characterization of floods is presented that can be used in evaluating flood plain damages through computer simulation, and parameters needed to describe the flood characteristics of each parcel of the flood plain are identified. Next, two possible characterizations of property are presented. One characterization is based on detailed description of property values and existing relationships for assessing the damageable property, and the other uses indices that can be used to correlate damages with flood levels using past data sources. The use of indices in estimating flood damages provides a meaningful manner for reducing the data requirements and for avoiding interview methods in evaluation.

Interim Memorandum III (Ref. 4), "Clarification of the Benefit Measure Derived in Interim Memorandum I." The benefit formula derived in Interim Memorandum I involving a shift in land use assumes that land rents outside the flood plain are the same with and without protection. This memorandum describes and illustrates the adjustment that is required if the above assumption is not warranted. It requires the replacement of $q^o(o)$ in Equation (1.3) by $q^o(p)$, or

$$B(p) = \{\hat{S}_x^f(p) - q^f(o)\} - \{\hat{S}_x^o(o) - q^o(p)\} \qquad (1.4)$$

Interim Memorandum IV (Ref. 5), "Conceptual and Computerized Structure of the Simulator." In this memorandum the complete conceptual outline of the simulation model is presented and is divided into five main parts: (a) Population and Economic Activity Model; (b) Acitivity Location Model; (c) Flood Damage Assessment Model; (d) Public Policies and Plans; and (e) Benefit Model. Each one of these parts is presented in detail warranted not only by its importance within the overall scheme, but also by considerations regarding its importance for the development of the simulator (see Figure 1.1). Throughout the conceptual flow-chart emphasis is placed on blocks that would constitute the interface between the simulation program and the sub-programs that will provide the necessary information. The blocks that are marked by small triangular flags are of most significance for two reasons: (1) because they require substantial effort for the complete development, and (2) because their development is essential in interfacing current Corps practices with the simulation program. The computerized logical structure related to the above conceptual outline is also presented in this memorandum.

Interim Memorandum V (Ref. 6), "Benefit Measurement, Activity Location and Land Use Forecasting." Additional results are presented on problems dealing with alternate methods of benefit measurement and with the assignment problem as it is applied to land use forecasting. First, a general statement of the assignment problem and detailed discussion of the difficulties associated with obtaining results in practical situations is given. The main problems discussed are the non-uniqueness of equilibrium land prices, the difficulty in obtaining the required data to perform a complete assignment, and the relationship between the solution of the assignment problem and formula (1.4) for the measurement of benefits. Second, the use of equilibrium land prices is discussed when considering cycles of relocation of activities in the immediate vicinity of the flood plain. Finally, it is proposed to investigate a practical approach that uses limited data requirements for solving the assignment problem and more detailed data for the measurement of benefits.

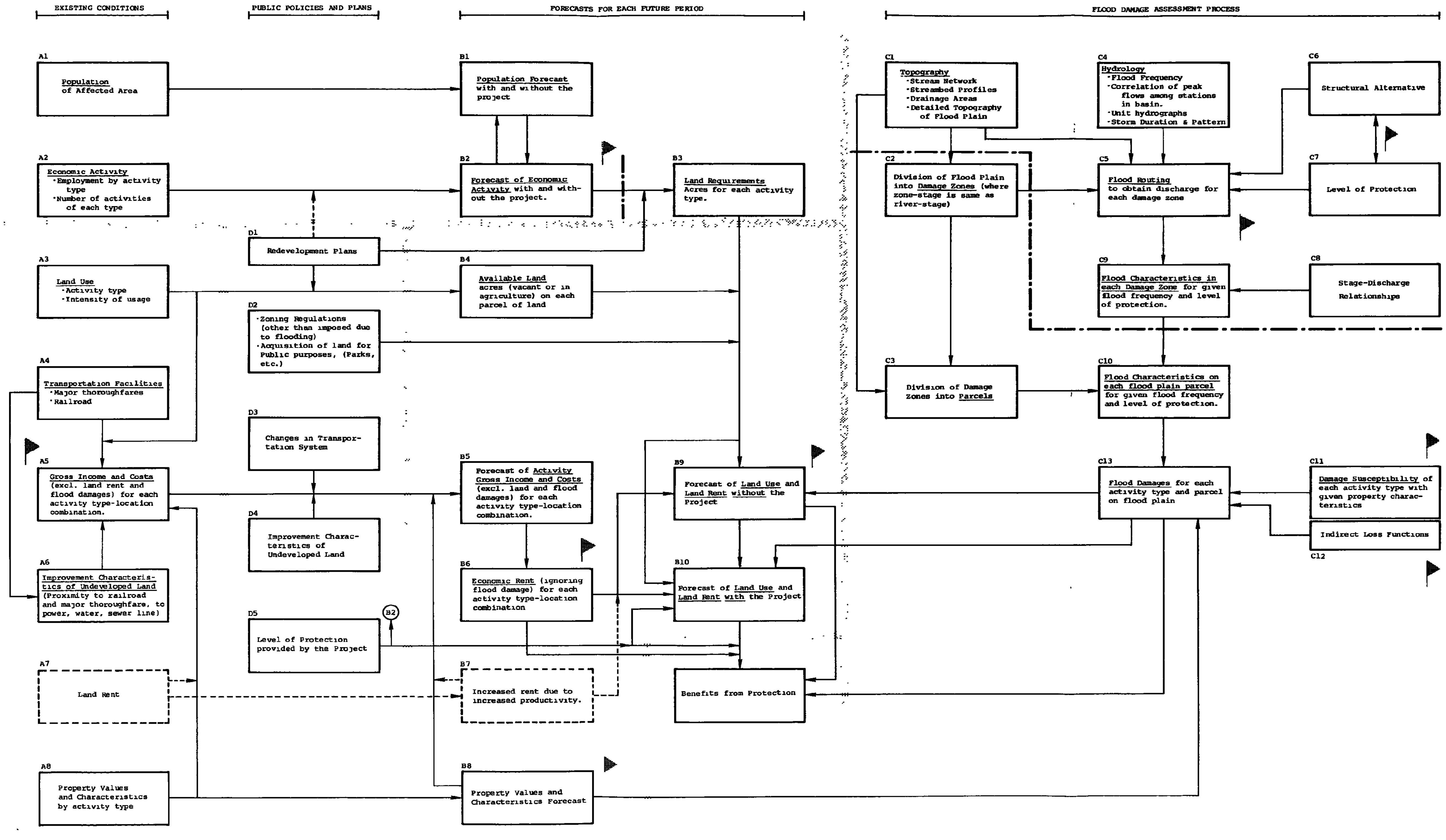

Figure 1.1 CONCEPTUAL STRUCTURE OF THE SIMULATION PROCESS

Interim Memorandum VI (Ref. 7), "Estimation of Economic Rents and Property Damages." This memorandum sets forth some of the anticipated difficulties in obtaining the required data for the simulation model and, whenever possible, suggests feasible approaches to the data problem. In particular, it discusses the problem of obtaining the economic rents as needed for the solution to the assignment problem and also addresses the question of using equilibrium land rents as a proxy measure to economic rents in specific cases. Furthermore, the data problem is related to the different procedures that can be followed for the measurement of benefits. The main purpose is to lay out a preliminary plan for data acquisition.

3. Summary of Final Report

From the summary of the Interim Memoranda it is clear that four major analytical steps must be undertaken to properly measure flood control benefits. First, land use plans with and without protection must be determined. Second, economic rent differences must be estimated in order to evaluate the locational advantage resulting from flood protection. Third, flood damages must be determined both with and without protection. And finally, formulas for evaluating the flood control benefits must be chosen. Analytical developments related to each of these topics, except flood damage estimation, are presented in the final report and will be summarized below. Results and conclusions will be presented in Section D of this chapter.

Flood damages are determined by combining hydrologic input data and flood damage characteristics. The hydrologic input necessary for the simulator is depth of flooding on each damage zone in the flood plain (e.g., 0-10 year zone; 10-25 year zone) and the frequency of these floods. This data must be provided to the simulator by Corps field offices. In this regard, the Corps Hydrologic Engineering Center at Davis, California has developed computer programs which could possibly be interfaced with the simulator to provide a complete hydrologic-economic package for benefit analysis. This possibility will be explored during Phase II of this research effort. The flood damage characteristics necessary for the simulator are the damage curves that give flood damage as a percentage of property value for different depth of flooding. Once hydrologic inputs and flood damage characteristics are given, flood damages become a function of the type of activities, the number of activities and the property value associated with these activities. Damages can also be compared to locational advantage and thus provide a decision-making tool for efficient flood plain use.

Chapter II, "Two-Level Assignment of Activities With and Without Protection," deals with the first major analytical step to be undertaken, that of land use with and without protection. Several basic concepts are introduced such as study area, dummy location, and land use demands; definitions of these concepts are presented in Section D of this chapter under 1 and 2. Methods for determining the study area and land use demands are indicated, and subsequently a practical approach to the dynamic assignment of activities is presented. This approach is based on decomposition where, first, the future area development is determined by allocating aggregate activities to subareas; aggregate activities are defined by combining activities that will locate together and subareas are defined by areas that are expected to develop as a unit. This aggregate assignment then forms the basis for a more detailed allocation of activities to economic rent zones. Furthermore, the different needs for analysis with and without protection that lead to improved land use forecasting and better benefit evaluation are identified. Finally, a schematic outline of the allocation procedure at the two levels of aggregation is included.

Chapter III, "Nonuniqueness of Equilibrium Land Rents," discusses in theoretical terms the problem of nonunique equilibrium land rents and the proper choice of land rents in the benefit formula. Equation (1.4) uses equilibrium land rent differences in order to reduce the total data requirements in estimating economic rent differences outside the flood plain that are the result of relocating activities. The problem is that equilibrium land rents are in general not unique and thus the set of equilibrium land rents to be used in the simplified formula (1.4) must be chosen. First, formulating the allocation of activities as an assignment problem, conditions are derived under which equilibrium activity profits and land rents are unique to within a constant for both the simple and the multiple assignment problem. These conditions are closely related to the existence and characteristics of alternative optimal assignments which in practice are not expected to be satisfied. As a result equilibrium land rents will, in general, be nonunique. It is then shown that in such cases maximal land rents form the proper choice of land rents to be used in the simplified benefit formula. When many activities are located in the flood plain as a result of protection this formula will not always be exact but will provide in practice a good approximation.

Chapter IV, "Practical Methods for Measurement of Benefits from Shifts in Land Use," presents methods for estimating maximal equilibrium land rents that are suited for various situations. First, the concept of cycles of relocation as a result of shifts in land use with and without protection is introduced in the context of measuring benefits. Three basic measures of benefits from a cycle of relocation are presented, two involving only economic rent differences (or locational advantages) within the study area and the other also involving maximal land rents. In the latter case approximations to the maximal land rents are required and for several alternative conditions such approximations are derived. Finally, the appropriate measures for benefit evaluation are given in cases representative of actual flood plain development.

Chapter V, "Estimation of Economic Rent Differences," reviews the appraisal literature related to estimating economic rent differences and discusses its usefulness with respect to methods used, relevant variables and data availability. The components associated with gross income and cost that make up the locational advantages are identified for the different activity types and methods for estimating these components are presented.

4. Status of the Simulation Program

The main body of the program consists of the following parts: Flood Damage Assessment Routine, Economic Rent Estimation Routine, Activity Location Routine, and Benefit Evaluation Routine. Population and economic activity forecasts and the information required for flood damage assessment and economic rent estimation are assumed to be given exogenously as inputs to the program. The first and third of these routines have been programmed and work is in progress on the Activity Location Routine, and the Economic Rent Estimation Routine.

The Flood Damage Assessment Routine consists of (a) subprograms that accept information on flood characteristics in each damage zone for given flood frequencies and protection levels, on damage susceptibility and indirect losses of each activity type, and on property values and characteristics; (b) a subprogram that calculates flood damages for any given combination of activity type and flood damage zone; and (c) a subprogram that converts flood damage corresponding to damage zones to flood damages corresponding to subareas or economic rent zones.

The Activity Location Routine forecasts the land use with and without protection. The assignment of activities to economic rent zones is performed at two levels. The first level uses aggregate activity types and subareas and determines the future area development based on aggregate assignment. The second level uses individual activity types and economic rent zones and determines the detailed annual allocation of activities over zones. Constraints on future developments are included and a comparison between the resulting land use plans and existing plans will be provided.

The Benefit Evaluation Routine estimates the benefits during a given year of the planning period. The computations are controlled by an executive subprogram that calls other subprograms to perform the required benefit evaluation. These include the evaluation of benefits from damage reduction and activity intensification; and the evaluation of benefits from shifts in land use either through net income changes using alternative benefit formulas, or through damage reduction using threshold levels. In addition, lower and upper bounds on location benefits are determined and used to check the validity of the resulting benefit measurement.

D. Results and Conclusions

The following results and conclusions will form the basis for the continuation of the work to complete the simulation program:

1. The study area is defined such that it includes some or all of the following:

    a) all flood plain lands;

    b) immediate areas around the flood plain where changes in economic rent can reasonably be expected as a result of protection or provide alternatives to flood plain land use;

    c) alternative locations in the general region that may constitute reasonable alternatives to the flood plain development and for which data can be made available.

In addition, a dummy location is defined representing parts of the area affected by protection but not included in the above study area.

2. Land use demands are defined as the total land required by the activities that would like to locate in the study area, given that flood protection is provided.

3. Forecasting future land uses with and without protection, given the study area and the annual land use demands, is best achieved by decomposing the allocation problem into two levels: the first level determines future area development on the basis of aggregate assignments; and the second level determines the more detailed assignment during the planning period.

4. Analytical emphasis for the without protection condition should be on properly assigning activities outside the flood plain. Flood plain assignments are in this case only important if zoning regulations are lifted in which case they should aid in determining the economic justification of existing zoning regulations. Emphasis for the with protection condition should be on locating activities in the flood plain. The reason for this is that the major part of the flood control benefits due to relocation will be associated with changes in economic rents of activities that would locate in the flood plain with protection but outside otherwise.

5. To optimally assign activities to economic rent zones, only differences in economic rents are needed. As a result a reference location can be chosen for each activity type with respect to which the economic rent differences are measured.

6. Equilibrium land rents and activity profits are in general non-unique. Conditions for uniqueness to within a constant require special situations that are closely related to the existence and characteristics of alternative optimal assignments of activities to economic rent zones.

7. Assuming non-negative land rents and activity profits, the non-unique equilibrium land rents are bounded from above and from below while these upper and lower bounds themselves form a set of equilibrium land rents and are referred to as the maximal and minimal land rents. The maximal land rent of an economic rent zone measures the decrease in total

economic rent to the existing activities when these activities have to relocate with that particular zone being kept vacant, or alternatively, it measures the increase in total economic rent to the existing activities that resulted when that particular zone becomes available.

8. The use of maximal land rents in the simplified benefit formula (1.4) provides a good approximation to the actual benefits obtained.

9. The identification of changes in land use with and without protection through cycles of relocation allows for an orderly analysis of the benefit measurement. The set of cycles of relocation associated with the land use with and without protection is, in general, not unique. At the same time, it is advantageous to use short cycles in the benefit evaluation procedure. The procedure for determining cycles of relocation therefore first searches for all cycles involving two locations, then all cycles involving three locations, etc.

10. There are three basic methods for measuring the benefits associated with a cycle of relocation. First, if the cycle of relocation is within the study area the benefits can be measured by the sum of the differences in economic rents with and without protection. Second, if part of the cycle of relocation is outside the study area the benefits can be approximated by the sum of all economic rent differences within the study area. Third, benefits can be approximately measured by the sum of the economic rent differences of activities that will locate in the flood plain as a result of protection and the differences in maximal land rents that accounts for the change in economic rent to the remaining activities that relocate as indicated in formula (1.4).

11. An approximation to the maximal land rent is desirable because its exact determination will require, in general, all economic rents in the area and as such would defeat the purpose of a simplified but approximate measure of the benefits. For a location with a non-urban activity the maximal land rent may be assumed equal to the economic rent of the activity and can thus be easily obtained. In the case of an urban activity a reference location with a non-urban activity is chosen, or if this is not possible a reference

location with the least intensive urban activity is chosen for which the economic rent can be estimated. The approximate maximal land rent of the location is then equal to the sum of the economic rent difference between that location and the reference location and the maximal land rent of the reference location.

12. Appropriate benefit measures for most representative cases can be obtained based on the above results. The selection of the measure depends on the length of the relocation cycle, the existence of non-urban activities in the cycle, and whether the alternative location of activity induced by protection is within or outside the study area.

13. Appraisal literature can contribute to the development of estimating procedures for economic rent differences through the identification of workable methodologies, relevant problem variables, and data availability. The main difficulty is that appraisal techniques estimate market land values and not annual economic rent differences, while the relationship between market value and annual income is quite complex. Furthermore, existing models are not generally applicable and also do not account for important location attributes such as aesthetic amenities.

14. Economic rent differences can be obtained as the sum of gross income differences and cost differences. For agricultural and residential activities and for some types of institutional activities such as recreation both gross income and cost difference are important, while for commercial and industrial activities only cost differences are needed. The components that measure gross income differences for residential activities include natural and related amenities, and social environment factors. Components that measure cost differences for residential activities include site development cost, construction cost, and commuting cost. For commercial and industrial activities the cost differences are measured by the site development cost, construction cost and transportation cost excluding commuting.

Chapter II

TWO-LEVEL ASSIGNMENT OF ACTIVITIES WITH AND WITHOUT PROTECTION

A. Introduction

This chapter presents a practical approach to land use planning. It deals with the problem of assigning economic activities to zones of uniform economic rent throughout the planning period. This type of planning is required when land uses with and without flood protection are different so that benefits from flood protection result due to locational advantages. It is concluded that without protection emphasis should be placed on analytically determining the location of activities outside the flood plain, while with protection analysis should be used to properly locate activities inside the flood plain. Furthermore, the problem of alternative locations outside the study area is addressed and it is proposed that the concept of a representative location, or dummy location, be used for activities locating outside the study area.

Section B describes the basic concepts used in the assignment problem and discusses terms such as affected area, study area and associated land uses and land use demands. An approach to forecasting the location of activities with and without protection based on performing a two-level assignment and taking into account sensitivity, interdependence and dynamics of economic rents is described in Section C. Section D discusses the different needs for analysis with and without protection, while Section E outlines the total assignment procedure.

B. Basic Concepts in the Assignment Process

Flood control benefits are given by the difference in total net economic rent with and without protection throughout the area in which net economic rents are affected by protection. To determine this difference in net economic rents forecast of land use with and without protection is needed. When considering interdependencies between activity types, dynamics of land uses, and fixed cost associated with area developments, land use forecasting can become quite complicated (Refs. 8-12). This may not only result in computer storage and programming problems, but can also make it difficult to interpret the results and check them with existing land use plans. Therefore, in practice the size of the study area considered and the number of economic land uses included in the analysis should be limited. In obtaining insight as to the manner in which the scope of the evaluation process can best be reduced, the ideal situation based on complete knowledge of future economic development with and without protection is first discussed, and then practical approximations to this are presented.

1. Affected Area and Associated Annual Land Uses

Given that the future economic development with and without protection is known, the following concepts are introduced:

- Activity Type: Defined so as to allow grouping of similar land uses while its precise characteristics depend on the level of aggregation desired. Examples of activity types include: different types of housing (high, middle, or low income as well as single-family versus multiple family), retail commercial, industrial (manufacturing, ware-housing, etc.), non-urban (agricultural, vacant), etc.

- Affected Area: The locations for which the net economic rent during the planning period is not the same with and without protection. This difference may be the result of a change in an activity's net economic rent through reduction in flood damages, through interdependency effects of different activities in the surrounding area, or through effects due to relocation of activities that locate differently with and without protection.

- Activity Requirement: The required acres per unit of each activity type.

- Annual Land Uses: The total additional number of acres in the affected area used by each activity type for a particular year.

The second definition suggests the affected area can be obtained by comparing the net economic rents over the length of the planning period and by deleting those locations for which the net economic rents do not differ with and without protection. The annual land uses are determined by adding together the total annual acreages for each activity type in the affected area. These land uses will be the same with or without protection if the availability of the flood plain with protection will not influence the intensity of land use; that is, if the flood plain is small compared to the available land. The benefits of protection are now obtained by comparing the total net economic rents with and without protection for the affected area.

There are several practical problems associated with implementing a procedure for measuring benefits based on the above definitions for the affected area and annual land uses. First the affected area and associated land uses cannot be known prior to solving the assignment problem and therefore must be estimated. Second, the size of the estimated affected area may be very large or otherwise widely dispersed. Third, obtaining data on the economic rents for the entire estimated affected area may be extremely difficult. Therefore approximations to the affected area and annual land uses are necessary.

2. The Study Area

A practical approximation to the affected area, referred to as the study area, can be obtained by including those areas in the region surrounding the flood plain that are expected to provide alternative locations to activities competing for flood plain land with protection. We thus may exclude detailed representation of areas that are either far away, widely dispersed, difficult to identify, or for which data is not readily available. This leads to the following description of the study area, dummy location, and associated annual land use demands.

- Study Area: The study area is made up of all or some of the following areas:
  - a) the flood plain land which should always be included in the study area;
  - b) the immediate area around the flood plain where changes in economic rent can reasonably be expected as a result of protection or which provides alternatives to flood plain land use;

c) alternative locations in the general region that may constitute reasonable alternatives to the flood plain development and for which data can be made available.

- Dummy Location: The dummy location represents parts of the affected area not included in the above study area.
- Annual Land Use Demands: The annual land use demands per activity type are specified by considering the additional activities that wish to locate in the study area given that flood protection is provided. This definition, to a large extent, limits the use of the dummy location to activities that must locate in the unidentified part of the affected area without protection.

The study area may be chosen based on initial knowledge concerning potential developments of the area with and without protection. Thus, certain areas will be included on the basis of information obtained from regional and local plans or from surveys of feasible alternative areas for future development that are presently in lower uses. Areas outside the flood plain that are expected to develop in exactly the same manner with and without protection can be safely excluded. Within the constraints of incomplete knowledge concerning the affected area, allowable problem size and data availability, it is expected that the study area will take into account the parts of the affected area that are of significance.

The annual land use demands for the study area may be different with and without protection because of the manner in which the study area is defined. For purposes of benefit evaluation annual land use demands will be based on the assumption that the flood plain will be protected. In that case comparing total net economic rent associated with locating the activities with and without protection leads to an appropriate measure of the flood control benefits. The annual land use demand for the study area may be on the high side in order to allow for inaccuracies in determining in advance which activities will locate inside and which will locate outside the study area. At the same time they should not be above the economic projection for the area or otherwise excessively high and thus lead to computational inefficiencies without improving the accuracy of the land use forecasts.

Several methods may be followed to determine the annual land use demands of the study area depending on the particular case being considered. Possible sources for determining a forecast of the development of the study area are:

- national and local projections and allocations made by public and private entities;
- regional and local land use plans and support data;
- location of valuable natural resources such as water, minerals, climate, forests and oceans;
- historical trends in land use;
- socioeconomic projections affecting land use, such as population, income, employment, social services, health facilities, education facilities, and recreation;
- existing zoning regulations and anticipated changes.

Given the forecasted development of the study area the annual land use demands are obtained by grouping the land uses corresponding to the particular activity types and by calculating the associated acreage requirements. On the other hand, if the list of annual land use demands is given, the above data sources should provide a consistency check between these demands and other plans and projections made concerning the region.

Based on the definition of the study area and on the list of annual land use demands, forecasts must be made of the location of activities with and without protection for each year of the planning period.

C. Practical Approach to Forecasting Activity Locations

Dynamic assignment of activities over the planning period is complex and a straightforward formulation of the problem results in approaches that are infeasible from the point of view of computation and data handling. Simplifications are therefore needed that will, at the same time, assure the validity of the result in practical situations. The approach proposed in this section is based on dividing the problem into two parts. First, the future area development is determined on the basis of aggregate assignments, which in turn forms the basis for a more detailed or second level allocation. The latter assignment is then used as the basis for the benefit evaluation procedure. This reduces the problem of dynamic assignment to manageable proportions.

1. Assignment at Level 1

This allocation accounts for first order influences of the regional infrastructure, interdependencies of activity types and future land use potentials. The results of this allocation provide aggregate land use plans for the study area in cases where such plans are not available or for parts of the study area that are not already committed to specific land uses. The procedure will in general allow for review and consistency checks of plans provided by regional and local agencies. As the aggregate land use plan is not expected to be sensitive to small changes in economic rents, activity-location combinations will be represented in a manner mainly accounting for the regional infrastructure, and spatial and time dynamics.

Following the determination of the study area, allocation at level 1 requires that aggregate activity types be defined by group-activities which are expected to locate together in the same vicinity. For example, various types of housing may be combined with retail commercial, but separated from industrial activities. Subsequently, a list of annual land use demands will be constructed based on the definition of the aggregate activity types. Next, the study area is divided into several subareas for which the net economic rent of the aggregate activities is approximately the same. The subareas are chosen such that they reflect important differences related to the infrastructure of the area. Finally, the entire planning period is divided into several periods during which competition between activities that locate in subsequent years is taken into account.

Assignment at level 1 starts with the introduction of activities that will locate during the first period. As explained in the next chapter, for the purpose of assigning activities only differences in economic rents reflecting locational advantages are required. The activities are therefore assigned to the subareas so that the total discounted net economic rent differences is maximized. The value of the locational advantage used in the assignment routine is obtained by discounting all future annual economic rent differences to the beginning of the first period. Thus, if an activity is introduced toward the end of the first period its discounted net economic rent difference will be lower than when it is introduced at the beginning. The location of activities during the first period will set the pattern of development for the area as can be expected to be the case in practice. Next, the activities that will be introduced during the second period are located in a similar manner subject to constraints imposed due to the location in the first period, and so on for subsequent periods. The resulting assignment at level 1 is not used for benefit evaluation but only for specifying land use plans.

2. Assignment at Level 2

Allocation at level 2 is concerned with the more detailed assignment during each year of the planning period. The results of this allocation provide the basic input concerning the activity locations with and without protection used in the benefit evaluation routine. At this level, activity types are defined in a less aggregate manner, and a new list of annual land use demands based on these specifications is obtained. Furthermore, the study area is divided into zones each of which can be considered homogeneous so that the economic rent of each activity type, after subtraction of residual flood damages, is constant. Again only annual economic rent differences and its increase over time are needed for each activity-zone pair in order to allocate activities. It should be noted that economic rent differences for subareas where activities will not locate based on the analysis at level 1 are not needed. This may result in a reduction in the number of economic rent differences that need to be estimated. Finally, the planning period is divided in small periods during which the level of development is assumed to remain constant.

The allocation at level 2 can be divided into two main steps. First, the activities are assigned to one of the subareas, and then to one of the economic rent zones within the subarea. The first step is straightforward when there is only one subarea in which the activity will locate based on the results obtained at level 1, or, if a clear preference exists in the order of developing subareas based either on the present value of the net economic rent differences or on other considerations. If several subareas are expected to develop simultaneously, a rule for distributing the activities between them must be chosen. Since in this case the net economic rent differences are expected to be small, the influence of the particular choice of rules on the size of the benefits will be small. In the second step the activities are located in zones within the subarea so as to maximize the total present value of the net economic rent differences of activities located in the subarea.

In the above procedure, the allocation is performed each time period for the activities that are being introduced during the period and so that all competition between present and future activities is neglected. It is possible, however, to perform this per period allocation for activities that will be introduced over several periods so that time competition can be taken partly into account. In each case the present value of the net economic rent difference is then with respect to the period for which the allocation is made. This type of a refinement will only change the timing of the benefits and is therefore not expected to sufficiently improve the accuracy with which the benefits can be determined so as to justify the additional computational effort.

Thus, the dynamic assignment of activities over the planning period is resolved by decomposing the allocation in two parts. At level 1 the first order influences in the area's development are accounted for and at level 2 a detailed assignment completes the assignment of activities to zones. It should be noted that not all parts of the assignment are of equal importance for the evaluation of flood control benefits. In the next section we will discuss where emphasis in the allocation is expected to pay off in improved evaluation of flood control benefits.

D. Use of Analysis in Land Use Planning

Of major importance in determining the best procedure for assigning activities with and without protection is the question of where analysis is expected to contribute the most to improving land use planning and, in turn, to a more accurate measurement of the benefits due to flood protection.

A representative situation in which activities locate differently with and without protection is shown in Figure 2.1. The left side of the figure gives the land use without protection, and the right side the land use with protection. The areas above the dotted line are within the study area while the area below the dotted line is considered outside the study area. Typically the flood plain with protection is in urban use and without protection in non-urban use. The list of annual land use demands is therefore given by the urban activities indicated by a_1 through a_{10}. Activities b_1 and b_2 indicate non-urban activities that are located in the flood plain when no protection is provided.

1. Assignment Without Protection

In the typical situation presented the non-urban activities b_1 and b_2 occupy the flood plain. The urban activities a_1 through a_{10} compete for the land outside the flood plain with the result that activities a_1, a_2 and only part of a_3 locate in the study area while the remainder of the activities locate outside the study area.

Based on this situation the following conclusions can be reached with respect to the need for analysis in case of no protection. First, it may be assumed that land use within the flood plain can be obtained by simple extrapolation of present conditions, unless it is desirable to lift any zoning regulation that may exist. In the latter case, the flood plain could develop due to pressure caused by land unavailability and may develop the same way with and without protection. In that case, the benefits are determined through flood damages reduction (Ref. 1, 3). The main flexibility provided is in locating activities outside the flood plain and this is where analysis can play an important role. The reason for this is that, given there is pressure for land, local and regional development plans will normally assume the existence of some form of flood protection. A major area of concern will therefore be the determination of alternative locations for the economic activities if flood control is not provided subject to the fact that local and regional plans may restrict analysis under such conditions. The location of the above activities is very important in determining net benefits due to flood protection because these benefits depend on economic rent differences with and without protection.

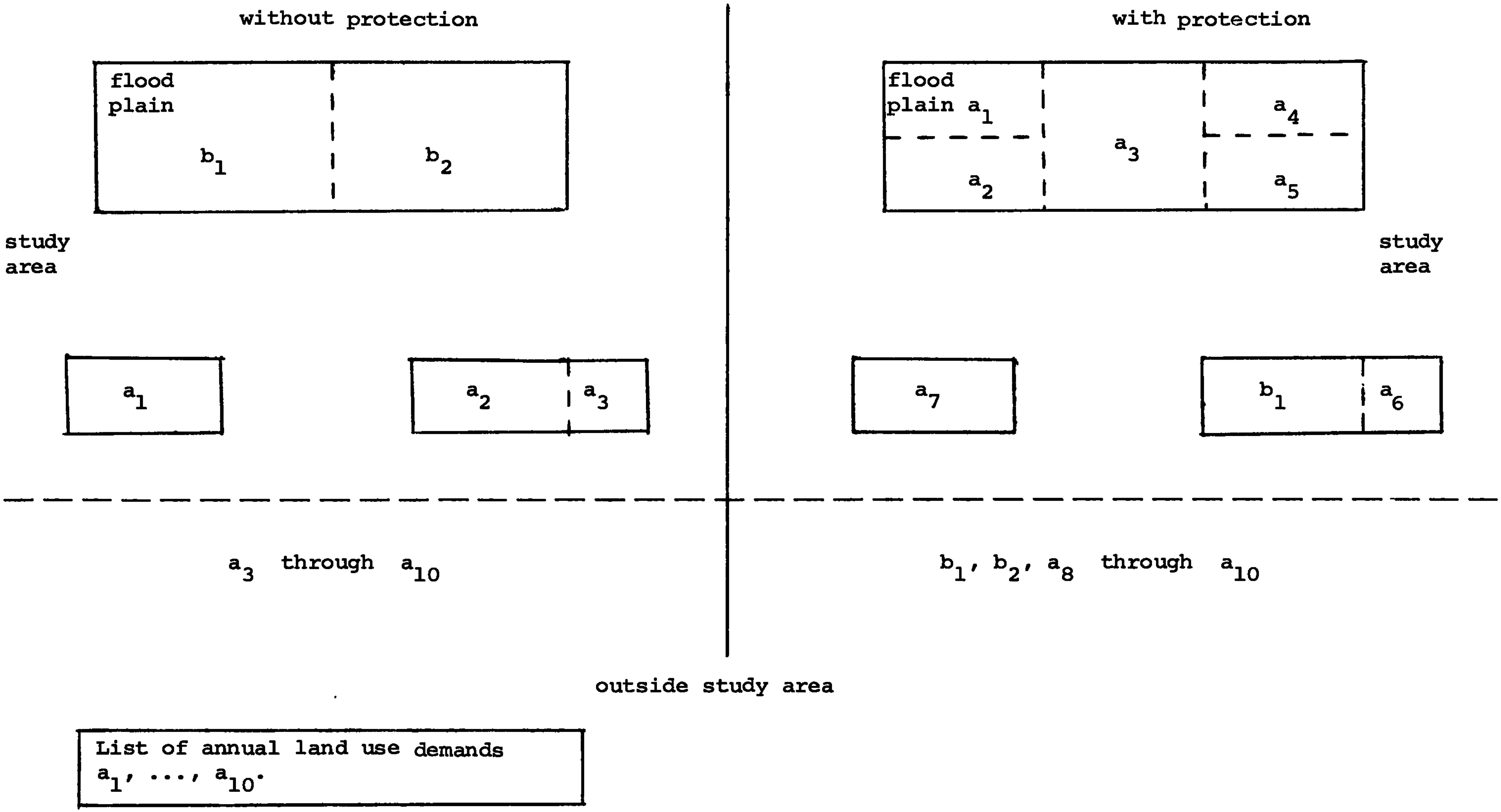

Figure 2.1 TYPICAL SITUATION WITH AND WITHOUT PROTECTION

Location outside the study area in the case of no protection deserves special attention. First, since the list of annual land use demands is based on conditions with protection, it may not be possible to locate all activities in the study area because of acreage limitations. The activities will therefore possibly compete for the available locations within the study area with some of them being forced to locate outside. Second, although all activities may be able to locate in the study area, some may prefer more attractive locations outside. It is for these reasons that a representative or dummy location outside the study area is needed.

Furthermore, allocation of activities without protection may take place either with no change in existing zoning regulations or under the assumption that existing zoning regulations can be removed. In the first case it may be assumed that the use of flood plain land will not change in the future so that all new urban activities have to locate outside the flood plain. In the second case where zoning regulations exist, it may be assumed that they can be lifted so that this situation can be analyzed to determine whether it can become profitable for some activities to locate in the flood plain. This case can be used to investigate the economic justification of existing zoning regulations and analysis can definitely play an important role.

2. <u>Assignment With Protection</u>

In the typical example with protection presented in Figure 2.1 urban activities a_1 through a_5 displace the non-urban activities b_1 and b_2 in the flood plain. Furthermore, part of b_1 will locate in the study area while the remainder of b_1 and b_2 locate outside the study area. In addition, activities a_6 and a_7 locate inside and a_8 and a_{10} outside the study area.

The analysis here should concentrate on which activities locate in the flood plain as well as where they locate within the flood plain. The reason for this is that the major part of the benefits will derive from the comparison of location of activities in the flood plain with protection with their location outside the flood plain without protection. Of somewhat lesser importance are activities that locate outside the flood plain either in or outside the study area because their exact location only has marginal effect on the overall benefits.

The method of allocating activities with protection is the same as without protection and without the zoning regulation, except that the economic rent differences involving subareas in the flood plain are now adjusted for flood damages with protection. In addition, similar to the with or without zoning case, the economic rent differences for a particular activity should be measured with respect to a subarea outside the flood plain on which that activity would locate without protection.

Resulting allocations of activities may be compared with land use plans prepared by regional and local planning agencies. Based on this comparison changes in the existing land use plans may be recommended, in particular when substantial improvements can be made either in forecasting the actual development of the area or in the proposed distribution of activities over the area. Also, inconsistencies in assumptions concerning economic rent differences may be identified through this comparison. In the end, however, the allocation of activities with protection can be made to be the same as the land use plan even if this would indicate a non-optimal assignment of activities to the area based on economic rent differences.

E. Outline of Allocation Procedures

The outline of the allocation procedure to be used in the simulator is presented in Fugures 2.2 and 2.3. Figure 2.2 shows the main elements of the allocation of the aggregate activities at level 1 as they were described in the earlier part of this chapter. The output of this procedure provides the ultimate use of each subarea by aggregate activity types. In case zoning regulations are in existence it will also give the use of each subarea with and without zoning regulations. Figure 2.3 shows the main elements in the allocation of individual activities over time at level 2. The output identifies the economic rent zones on which the individual activities will locate through time in the cases of no protection, protection, and with and without zoning regulations.

F. Summary

In this chapter, the study area and associated land use demands were defined and methods for their determination indicated. A practical approach

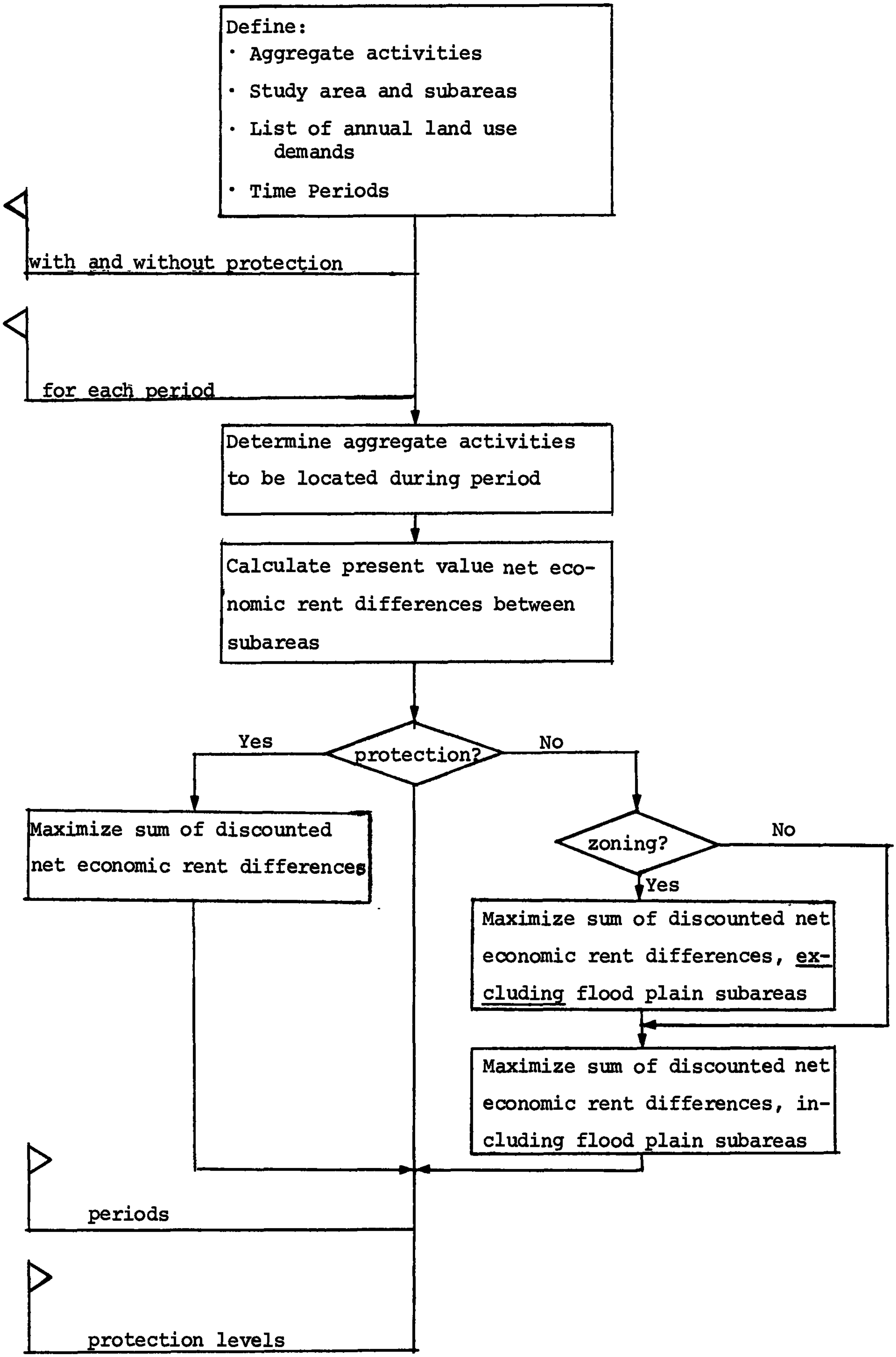

Figure 2.2 ASSIGNMENT OF AGGREGATE ACTIVITIES AT LEVEL 1

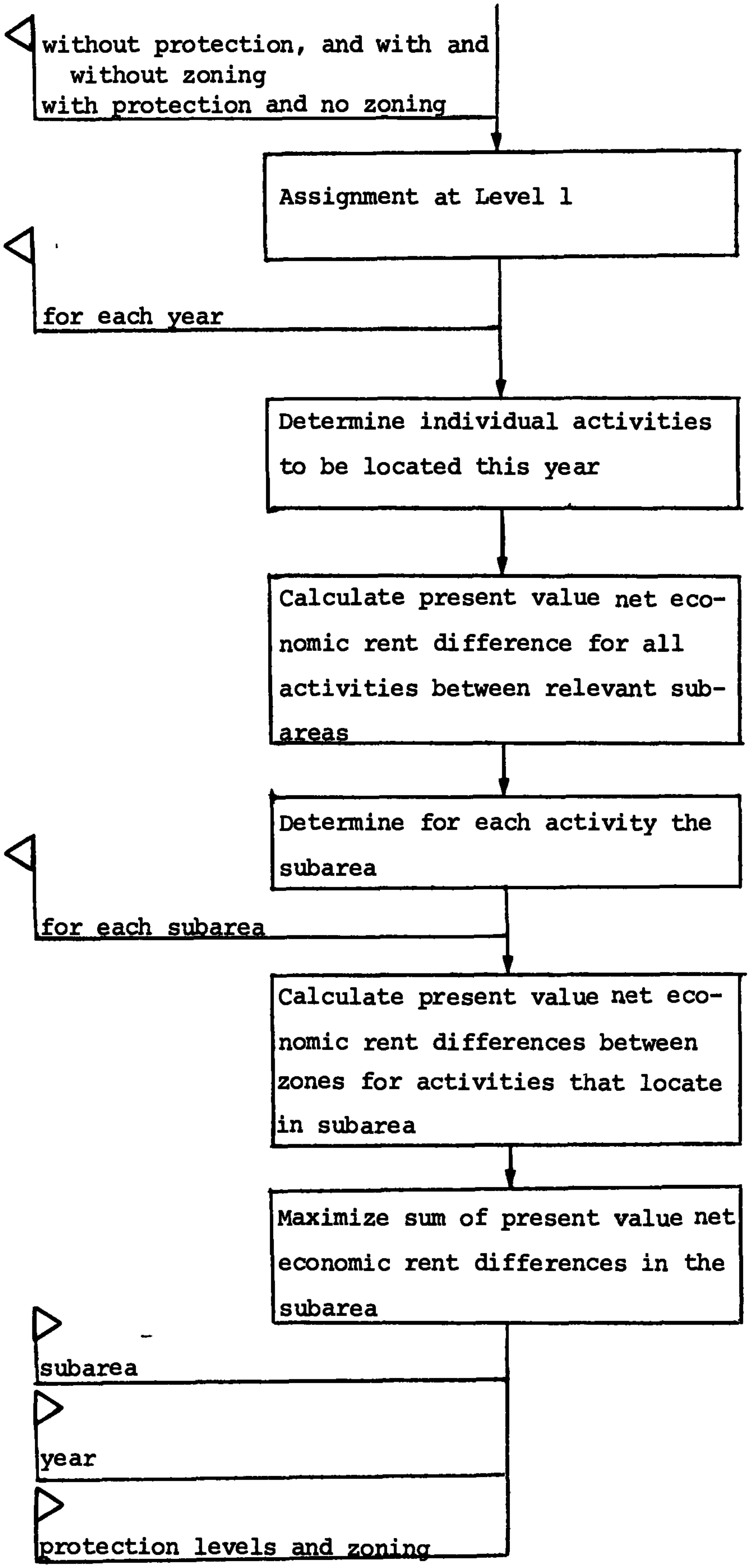

Figure 2.3 ASSIGNMENT OF INDIVIDUAL ACTIVITIES AT LEVEL 2

to the dynamic assignment of activities to economic rent zones was presented based on decomposition using two levels of allocation. First, the future area development is determined on the basis of aggregate assignments which, in turn, forms the basis for a more detailed allocation. The allocation at level 1 accounts for first order influences of regional infrastructure, interdependencies of activity types and future land use potential, while the allocation at the second level is concerned with the detailed assignment during each year of the planning period. The need for analysis with and without protection that could lead to improved land use forecasts and better benefit evaluation was identified. Finally, a schematic outline of the allocation procedure at the two levels of aggregation was presented.

Chapter III

NONUNIQUENESS OF EQUILIBRIUM LAND RENTS*

A. Introduction

The simplified benefit formula given by Equation (1.4) uses differences in net economic rents and equilibrium land rents and is discussed extensively in Interim Memoranda I, III and V and Reference 1. The purpose of this formula is to reduce the data requirements for economic rent calculations by replacing part of the economic rent differences by a difference in equilibrium land rents. As was pointed out, one of the major problems has been the choice and determination of the equilibrium land rents, because in general there will be more than one set of land rents that satisfies the equilibrium conditions under which total net economic rents are maximal. The objective of this chapter is to show that in case of nonuniqueness the proper choice in the benefit formula is to use maximal equilibrium land rents.

First, nonuniqueness is demonstrated for the simple assignment problem where each activity locates on a single parcel. Next, the problem is discussed for the case of multiple assignment where more than one activity may locate on a homogenous block of parcels. For both cases conditions are established under which equilibrium land rents are unique to within a constant. Since these conditions are quite restrictive, the equilibrium land rents will in general be nonunique. Next, it is shown that the maximal equilibrium land rent for a given parcel measures the change in the total economic rent resulting when only that parcel has remained vacated under new equilibrium conditions. This result is used to demonstrate that maximal equilibrium land rents can appropriately

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*This chapter does not provide in itself a practical method for measuring benefits. Rather, it offers the basic conceptual tools for establishing the theoretical foundations needed for arriving at a practical methodology. Readers primarily interested in practical implementation may wish to skip this chapter except for the summary section at the end.

be used in the simplified benefit formula. Because this chapter addresses the static assignment problem, economic rents, activity profits and land rents are assumed to be on an annual basis.

B. The Simple Assignment Problem

The simple assignment problem in the context of measuring land use benefits consists of matching on a one-to-one basis a set of activities with an equally large set of parcels. Suppose that n activities are to be matched with n locations. Let S_{ij} be the economic rent where activity i is assigned to location j. The optimal assignment problem is:

$$\max \sum_i \sum_j S_{ij} x_{ij}$$

subject to:

$$\sum_i x_{ij} = 1 \qquad (3.1)$$

$$\sum_j x_{ij} = 1$$

where

$$x_{ij} = \begin{cases} 1 & \text{if activity } i \text{ locates on location } j \\ 0 & \text{if activity } i \text{ does not locate on location } j \end{cases}$$

The above assignment problem is well known to be the special linear programming problem of Koopmans and Beckmann (Ref. 13). The result of fundamental importance is that the assignment problem formulated above in a combinatorial fashion can be solved by permitting the (0,1) variables x_{ij} to take on fractional values while solving the problem using a linear programming algorithm. This is because it can be shown that any basic solution to this seemingly more general linear program has integer variable-values. At the same time the imbedding in the framework of linear programming permits us to apply a wealth of existing theory to the assignment problem.

The primal and dual linear programs are then written as follows:

PRIMAL

$$\max \sum_i \sum_j S_{ij} x_{ij}$$

subject to:

$$\sum_i x_{ij} = 1, \ \sum_j x_{ij} = 1, \ x_{ij} \geq 0$$

$$\text{for } i,j = 1,2,\ldots,n$$

DUAL

$$\min \{\sum_i p_i + \sum_j q_j\}$$

subject to:

$$p_i + q_j \geq S_{ij}$$

$$\text{for } i,j = 1,2,\ldots,n \qquad (3.2)$$

where p_i is the dual variable associated with activity i and q_j is the dual variable associated with location j. For the optimal solution, where activity i is assigned to location j, p_i^* and q_j^* represent the equilibrium activity profit and land rent, respectively. The important aspects of this problem discussed here include the use of differences in economic rents for obtaining the optimal assignment and the nonuniqueness of the dual variables.

1. Use of Economic Rent Differences

The known values S_{ij} associated with each activity-location pair can be modified in certain ways without changing either the basic problem structure or the solution. In particular, for a given activity i an arbitrary constant c_i may be added to each S_{ij} for all j without changing the essential features of the problem. The optimal assignment will be the same since the value of all feasible assignments will be c_i units greater; this is because activity i must be assigned to some location j and every location now has a value c_i greater than before. Likewise for a given location j an arbitrary constant d_j may be added to each S_{ij} for all i without changing the problem structure or the optimal assignment.

It is convenient to think of the assignment problem in terms of an n x n array of the values S_{ij}, as shown in Figure 3.1. The assignment problem is then expressed as choosing n squares from this array by selecting precisely one square in every row and in every column so as to maximize the total sum of the selected values. In terms of this array structure, the flexibility of adding arbitrary constants c_i and d_j is equivalent to the statement that arbitrary constants can be added to all elements in given rows and given columns.

Locations

Activities		1	2	3	...	n
	1	S_{11}	S_{12}	S_{13}	. . .	S_{1n}
	2	S_{21}	S_{22}	S_{23}	. . .	S_{2n}
	3	S_{31}	S_{32}	S_{33}	. . .	S_{3n}
	⋮	⋮				⋮
	n	S_{n1}	S_{n2}	S_{n3}	. . .	S_{nn}

Figure 3.1 SIMPLE ASSIGNMENT PROBLEM ARRAY

The above observation has important consequences for the data requirements when solving an actual assignment problem. Specifically, for each activity a <u>reference location</u> can be chosen and only the economic rent differences are required between the various locations and the chosen reference (Ref. 7). This in effect means that only contributions to total economic rent that are due to locational advantages are needed and contributions that are independent of location can be totally ignored. The implications of this to data requirements for estimating economic rents are rather obvious.

The use of economic rent differences affects the dual problem but the transformation is straightforward. If for a particular activity i the economic rents S_{ij} for all locations j are reduced by $\hat{c}_i$, all feasible dual variables p_i associated with activity i including the optimal one, are reduced by the same amount. The corresponding dual variables q_j associated with the locations j are not affected.

2. Nonuniqueness of Dual Variables

The dual variables to the assignment problem will in general not be unique. This section demonstrates the reasons for this general nonuniqueness and derives specific conditions under which the dual variables are unique to within a constant. First, it is made clear that the equilibrium is not disturbed if for each activity-location pair the land rents are increased by a constant while at the same time the corresponding profits are decreased by the same constant. Furthermore, it is shown that it is, in general, possible to choose a different constant to change the values of the dual variables for groups of optimal activity-parcel pairs, thus demonstrating the nonuniqueness of equilibrium land rents and activity profits. Finally, conditions are derived under which land rents and profits for all activities and parcels are unique to within a constant.

Assume that an optimal assignment is given, and that for this assignment activities and parcels are numbered such that each activity is located on a parcel bearing the same number. A set of equilibrium profits and rents exists that satisfy

$$\begin{aligned} p_i^* + q_i^* &= S_{ii}, \qquad i = 1,\ldots,n \\ p_i^* + q_j^* &\geq S_{ij}, \qquad i,j = 1,\ldots,n \text{ and } i \neq j. \end{aligned} \tag{3.3}$$

In addition, it can be shown that if there exists a set of profits and rents that satisfies (3.3), then the associated assignment is optimal in that it maximizes total economic rent. Therefore, using (3.3), nonuniqueness is shown by adding a constant λ to all activity profits and subtracting the same λ from all land rents; the new dual variables

$$p_i^1 = p_i^* + \lambda, \quad q_i^1 = q_i^* - \lambda; \qquad i = 1,\ldots,n \tag{3.4}$$

trivially satisfy (3.3). The simple transformation (3.4) together with (3.3) clearly demonstrates that equilibrium profits and rents are always nonunique to within a scaling constant λ. Furthermore, other transformations than (3.4) are possible, demonstrating the more complicated nonuniqueness of the dual variables. It is, in general, feasible to choose a different constant for groups of activity-parcel pairs so that, in addition to trivially maintaining the equality constraints in (3.3), the inequality constraints are also satisfied. That is, choose constants λ_i so that

$$p_i^1 = p_i^* + \lambda_i, \quad q_i^1 = q_i^* - \lambda_i, \quad i = 1,\ldots,n$$

while (3.5)

$$p_i^* + \lambda_i + q_j^* - \lambda_j \geq s_{ij}, \quad i,j = 1,\ldots,n \text{ and } i \neq j$$

In demonstrating the range of choice for different λ_i's, we subsequently prove that uniqueness of the simple scaling type in (3.4) is subject to a certain condition. Therefore, not withstanding such a condition, different λ_i's exist that satisfy (3.5). In the following discussion, the trivial transformation of the (3.4) type is referred to as <u>uniqueness within a constant</u>, while that of (3.5) is referred to as nonuniqueness.

In arriving at conditions for which equilibrium land rents and profits are unique (within a constant), it is convenient to use the <u>cycle of relocation</u> concept. Given a set of parcels numbered 1 through n and a set of n activities where activity i is located on parcel i, a cycle of relocation is obtained if for a new assignment activity i relocates on parcel i+1, i = 1,2,...,n-1, while the n-th activity closes the cycle by locating on parcel 1. That is, if the relocation of activities are indicated by arcs, and the parcels indicated by nodes then the cycle of relocation forms a completely connected chain where no activity-parcel pair is the same as before. Cycles of relocation are said to be <u>disjoint</u> if they have no parcels in common, while cycles that have parcels in common are said to be joint. It follows that each new assignment of activities to parcels can be obtained from the old assignment either by a cycle of relocation or by a set of disjoint cycles but not through joint cycles. Having established the basic concepts, we now derive fundamental uniqueness results.

a. Basic Uniqueness Theorem for a Cycle of Relocation

If a new optimal assignment of activities and parcels can be obtained from the old through a single cycle of relocation involving all activities and parcels without changing the total economic rent then the equilibrium profits and rents are unique to within a constant.

Proof:

Consider a new assignment obtained from the old through a single cycle of relocation of all activities and parcels. In addition, assume that both assignments are optimal in the sense that the total economic rent remains unchanged following relocation. Using (3.3) as the sufficient and necessary conditions for both optimal assignments it follows that the dual variables p_i^* and q_i^* satisfy the following equilibrium conditions for the new assignment:

$$p_i^* + q_{i+1}^* = s_{ii+1}, \quad i = 1,n-1$$
$$p_n^* + q_1^* = s_{n1} \tag{3.6}$$

Using transformation (3.5) with (3.6) and the single cycle assumption, it follows that the constants λ_i have to satisfy the following equalities:

$$\lambda_i - \lambda_{i+1} = 0, \quad i = 1,2,\ldots,n-1, \text{ and}$$
$$\lambda_n - \lambda_1 = 0, \tag{3.7}$$

and as a result all λ_i's must be equal to the same constant λ.

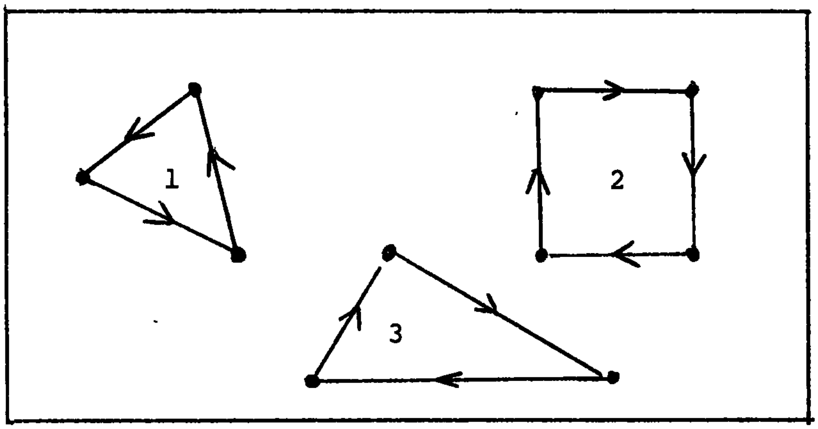
b. Uniqueness Theorem for Simple Assignment Problem

For the simple assignment problem, equilibrium land rents and profits are unique to within a constant if: (1) a set of optimal assignments exist so that all parcels can be included in cycles of relocation for which the total economic rent does not change; and (2) cycles of relocation resulting from the various assignments can be found that form a group of cycles that is fully connected through joint parcels.

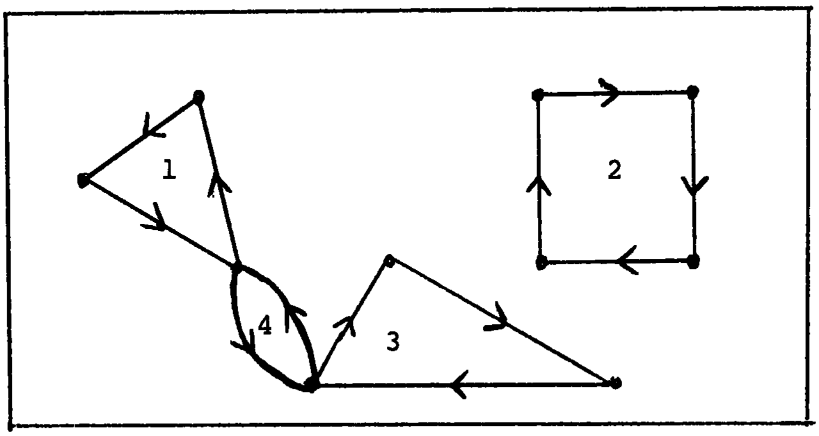
Proof:

Suppose that all possible cycles of relocation resulting in new optimal assignments are given and that they involve all parcels. Figure 3.2 depicts three alternative assignment problems. Figure 3.2a shows the situation where all possible cycles that may result from new optimal assignments are disjoint and no other optimal assignments exist that will result in a cycle connecting any of the groups. Because of the equilibrium condition it follows that for the total economic rent to remain unchanged for the optimal assignments, the same must be true for each single relocation cycle. Using the previous theorem it then follows that equilibrium profits and rents of the parcels involved in each of the cycles are unique to within a constant but that three such constants exist for the total assignment problem. The second case, Figure 3.2b depicts a problem including an additional cycle of relocation. It should be noted that cycles 1 and 4 cannot result from the same new optimal assignment since they are not disjoint. Using the previous theorem again, cycle 4 will require that the equilibrium land rents associated with its two parcels are unique to within a constant. This constant, however, is also associated with cycles 1,3 and as a result it will be the same throughout cycles 1,3 and 4. Since cycle 2 is not connected to any of the other cycles land rents are still not unique for the entire problem. The uniqueness case is presented in Figure 3.2c where cycle 5 assures that all cycles are connected and therefore all equilibrium land rents and activity profits are unique to within a constant λ.

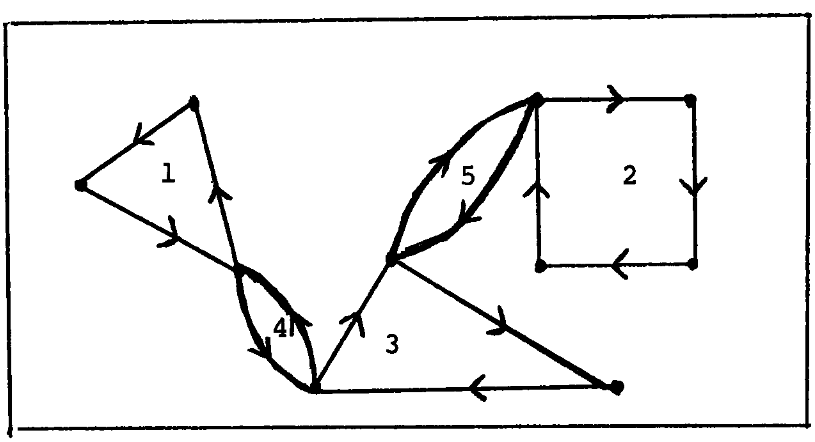
The nonuniqueness of the equilibrium dual variables is simply illustrated with a two activity-two parcel example as shown in Figure 3.3. The horizontal axis measures the economic rent associated with locating an activity on parcel i while the vertical axis measures the economic rent associated with locating an activity on parcel j. Thus when activity i locates on parcel i and activity j on parcel j, the corresponding economic rents are given by S_{ii} and S_{jj}, respectively. This assignment is indicated by the point A and the corresponding total economic rent by the intercept of the 45° line through that point. If activity i is located on parcel j and activity j on parcel i the assignment



(a)



(b)



(c)

Figure 3.2 ALTERNATIVE EQUILIBRIUM SITUATIONS

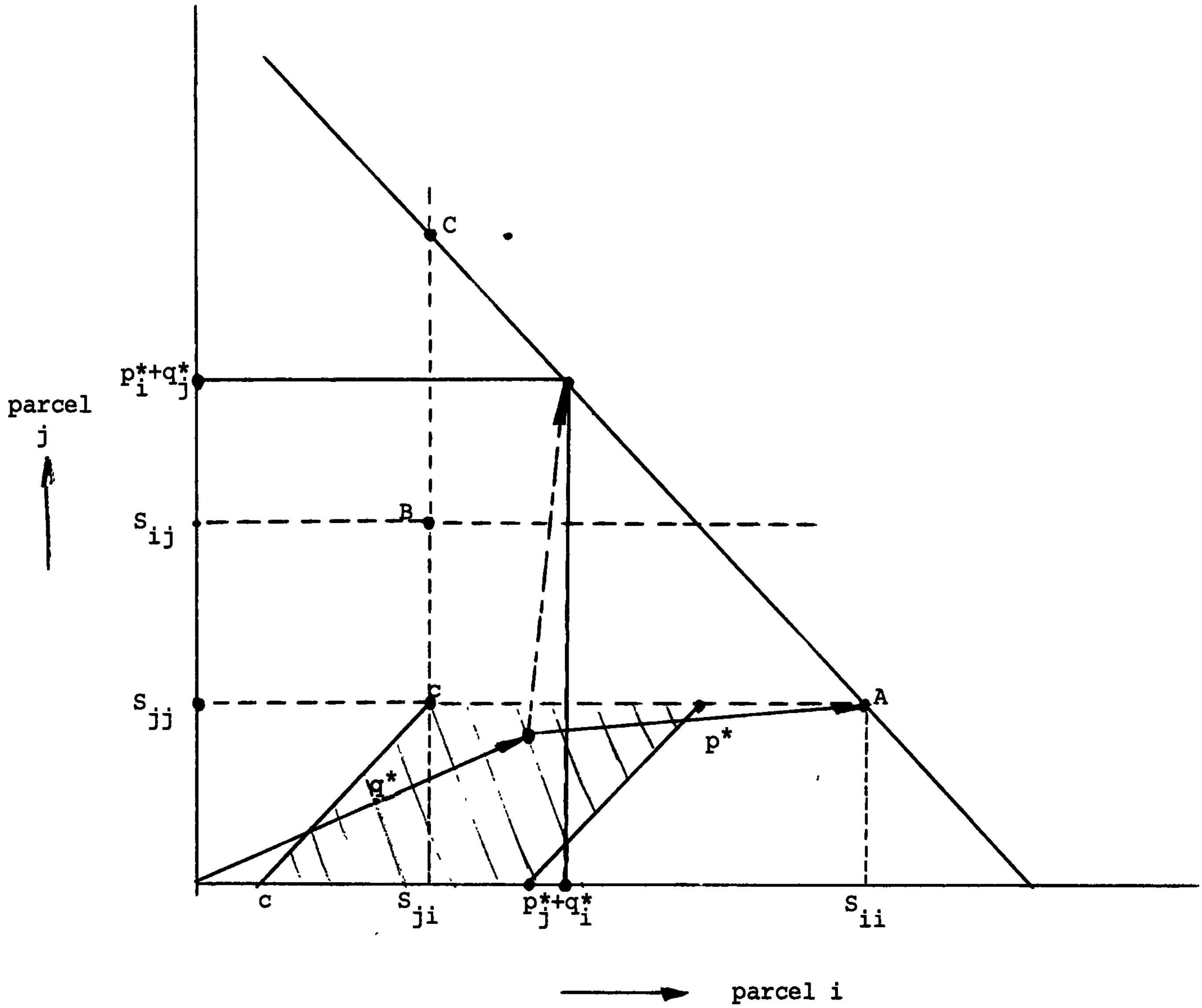


Figure 3.3 NONUNIQUENESS OF EQUILIBRIUM PROFITS AND LAND RENTS

can be indicated by point B. Since this point is below the 45° line through point A, it follows that $S_{ii} + S_{jj} > S_{ji} + S_{ij}$ and therefore the assignment (S_{ii}, S_{jj}) is optimal. A set of equilibrium dual variables that satisfy (3.3) are indicated by the vectors $q^* = (q_i^*, q_j^*)$ and $p^* = (p_i^*, p_j^*)$. Clearly, $p_i^* + q_i^* = S_{ii}$ and $p_j^* + q_j^* = S_{jj}$. Also, as can be seen from the dotted vector, $p_j^* + q_i^* > S_{ji}$ and $p_i^* + q_j^* > S_{ij}$. The locus of all end points of the vector q^* that will result in equilibrium dual variables is given by the striped area, where it is assumed that all dual variables have to be positive. Thus, for the given values of the economic rents the equilibrium dual variables are not unique, as could be expected since $S_{ii} + S_{jj} > S_{ji} + S_{ij}$. If however, S_{ij} is increased such that this inequality becomes an equality or point B moves to C, then the equilibrium dual variables will be unique to within a constant and will be given by the line cc.

C. The Multiple Assignment Problem

The simple assignment problem is mostly used to analyze and demonstrate the mathematical properties inherent in optimally assigning activities to parcels so as to maximize the total economic rent. In practice, individual activities and parcels are often indistinguishable and can be grouped in types or blocks where all activities of a particular type and all parcels within a block have identical economic properties. A positive integer can be associated with each activity type that indicates how many individual units are contained; e.g., number of housing units of a particular type. Further on, as it is assumed that each activity type requires the same number of acres, a positive integer can be associated with each homogeneous block of land that indicates the number of parcels available. The multiple assignment problem is then defined by associating with each type i of activities and each block j of land parcels the economic rent S_{ij} that will result from locating one unit of activity type i on a land parcel of block j.

The multiple assignment problem can also be visualized in terms of a rectangular array similar to that associated with the one-to-one assignment. If there are m activity types and n blocks of land the array will be as the one given by Figure 3.4. The problem is to assign a positive number to each box in such a way that the sum of any row i is equal to the total number of units A_i of activity type i and the sum of any column j is equal to the total number of parcels

B_j within block j. Subject to these conditions, the sum of these numbers weighted by the corresponding S_{ij} must be maximized. It is assumed that $\sum_i A_i = \sum_j B_j$ which can always be made to hold by adding slack variables in the original problem.

Land Blocks

Activity Types	S_{11}	S_{12}	. . .	S_{1n}	A_1
	S_{21}	S_{22}	. . .	S_{2n}	A_2
	⋮				⋮
	S_{m1}	S_{m2}	. . .	S_{mn}	A_m
	B_1	B_2	. . .	B_n	

Figure 3.4 MULTIPLE ASSIGNMENT PROBLEM ARRAY

The primal and dual linear program associated with the multiple assignment problem can be written as follows:

PRIMAL

$$\max \sum_i \sum_j S_{ij} x_{ij}$$

subject to:

$$\sum_j x_{ij} = A_i, \quad i = 1,\ldots,m$$

$$\sum_i x_{ij} = B_j, \quad j = 1,\ldots,n$$

$$x_{ij} \geq 0, \quad i = 1,\ldots,m \quad j = 1,\ldots,n$$

DUAL

$$\min \{\sum_i A_i p_i + \sum_j B_j q_j\}$$

subject to:

$$p_i + q_j \geq S_{ij}, \quad i = 1,\ldots,m \quad j = 1,\ldots,n$$

(3.8)

where p_i and q_j correspond to the dual variables per unit of activity type i and per land parcel of block j, respectively, and have identical interpretation as in the simple assignment problem. The same arguments as before can be made to show that only economic rent differences are required in order to solve the multiple assignment problem.

The nonuniqueness of the dual variables can best be explained by considering this multiple assignment problem as one for which the basic results on the cycles of relocation for the simple assignment are applicable. The conditions for uniqueness of land rents to within a constant are, therefore, derived by considering the example in Figure 3.5. In this example three blocks of parcels and three types of activities are considered. Furthermore, it is assumed that block 1 locates activities of type 1, block 2 locates activities of type 1 and 2, and block 3 locates activities of type 3. First, it is noted that all parcels within a block should be part of a single cycle of relocation for which the total economic rent does not change. This implies that the land rents for parcels within each block are unique to within a constant. Next, since activities of type 1 are located both in block 1 and 2 and since interchanging two activities of the same type does not change the total economic rent, a cycle of relocation exists involving parcels in block 1 and 2. To insure uniqueness, according to the uniqueness theorem of the simple assignment problem, a similar cycle of relocation involving parcels in block 2 and 3 will still be required. Such a relocation cycle is easily constructed if block 2 and 3 also have an activity of the same type in common. Otherwise, as is the case in Figure 3.5, a cycle involving different activities may exist. In both cases this will result in land rents for all parcels that are unique to within a constant that leads to the following result:

> The equilibrium land rents and profits in the multiple assignment problem are unique to within a constant if: (1) a set of optimal assignments exist so that in each block there is a parcel that is part of a relocation cycle, involving parcels in other blocks, for which the total economic rent does not change. This cycle may involve either one or more activity types; and (2) cycles of relocation as described under (1) can be found that form a group of cycles that is fully connected through joint blocks.

Thus, both in the simple and the multiple assignment problem the conditions for uniqueness are closely related to the existence of alternative optimal assignments of activities to parcels. In addition these assignments have to satisfy specific conditions for the profits and rents to be unique. In practice, it is

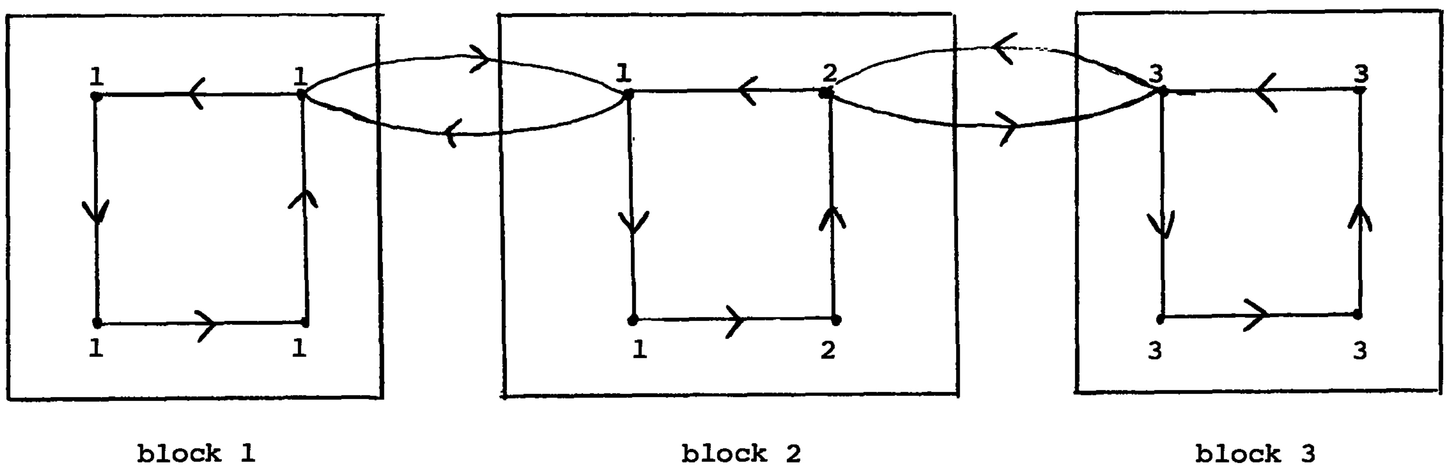


Figure 3.5 EQUILIBRIUM CONDITIONS IN THE MULTIPLE ASSIGNMENT CASE

not expected that such conditions will hold except in special cases and as a result equilibrium land rents will, in general, not be unique.

D. Maximal Equilibrium Land Rents

Because equilibrium land rents are in general not unique, the question arises as to which of the nonunique equilibrium land rents should be used in the benefit formula (1.4) or

$$B(p) = \{\hat{S}_x^f(p) - q^f(0)\} - \{\hat{S}_x^o(0) - q^o(p)\} \tag{3.9}$$

It was conjectured in Reference 1 that these rents should equal the maximal rent that the activities would be willing to pay for the respective locations. This result is presently made precise and it is conclusively shown that this choice of land rents is the correct one. First, the minimal and maximal land rents are defined, and then the maximal land rents are related to changes in the total economic rent when that location is vacated. This result is then used to show that maximal land rents should be used in the benefit formula.

For nonnegative land rents and activity profits the nonunique equilibrium land rents are bounded from above and from below, and the upper and lower bounds themselves form a set of equilibrium land rents (Ref. 14). Thus, if a set of equilibrium land rents are given by $q_1, q_2, \ldots, q_n$, then

$$\underline{q}_i \le q_i \le \bar{q}_i \qquad \text{for } i = 1,\ldots,n \tag{3.10}$$

The equilibrium land rents $\underline{q}_i$ and $\bar{q}_i$ are referred to as the minimal amd the maximal land rents, respectively.

1. Changes in Economic Rent Measured by Maximum Land Rent

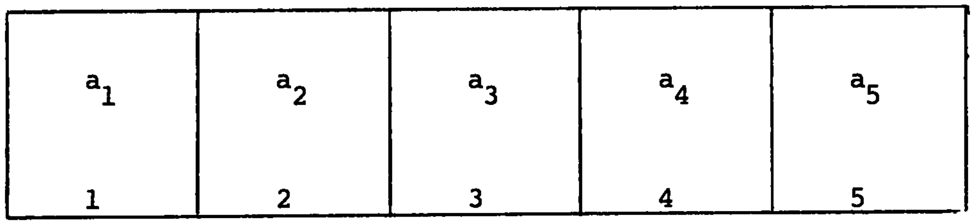
It is now shown that the maximal rent of a land parcel measured the net change in total economic rent to the existing activities when these activities have to relocate with that particular parcel being kept vacated. This is illustrated by a simple example while complete proof of this result can be found in Reference 15.

Consider a simple case where the available land is divided in five equal parcels numbered 1 through 5. There are also five activities a_1 through a_5 each of which will occupy a complete parcel. Assume that an initial equilibrium exists where activity a_i is located on parcel i as is indicated in Figure 3.6a. Suppose now that this equilibrium is disturbed by vacating parcel 1, so that activities a_1 through a_5 have to compete for the four remaining locations and thus one of them will go out of operation. Also assume that in the new equilibrium activity a_i is located on parcel $i+1$, while activity a_5 goes out of operation as in Figure 3.6b. The reduction in total economic rent between the old and new equilibrium can then be measured by the maximal land rent of parcel 1 in the initial equilibrium.

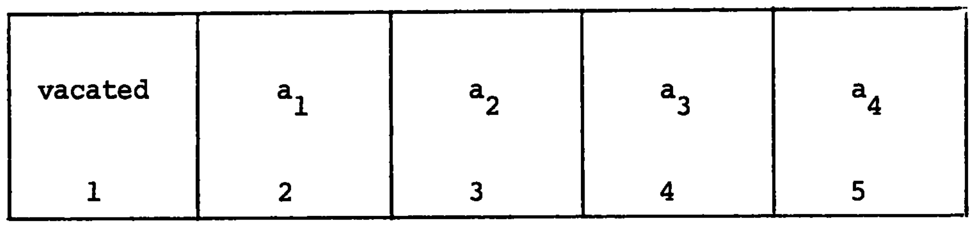
The maximal land rent on parcel 1, $\bar{q}_1$, can now be determined based on the observation that the maximum land rent that can be charged is that on the next best alternative location plus the difference in economic rents between these two locations. The rent $\bar{q}_1$ can therefore be reconstructed as shown in Figure 3.6c. Since the next best alternative for a_5 is going out of production the maximal land rent for location 5 is equal to the economic rent S_{55} and $\bar{q}_5 = S_{55}$. The economic rent to activity a_4 on parcel 4 is $(S_{44} - S_{45})$ larger than on parcel 5, its next best alternative. As a result the maximal land rent is given by $\bar{q}_4 = \bar{q}_5 + (S_{44} - S_{45})$. In a similar manner the maximal land rents are calculated for the remaining parcels as is indicated in Figure 3.6c. The resulting maximal land rent for parcel 1 is:

$$\bar{q}_1 = (S_{11} - S_{12}) + (S_{22} - S_{23}) + (S_{33} - S_{34}) + (S_{44} - S_{45}) + (S_{55} - 0) \tag{3.11}$$

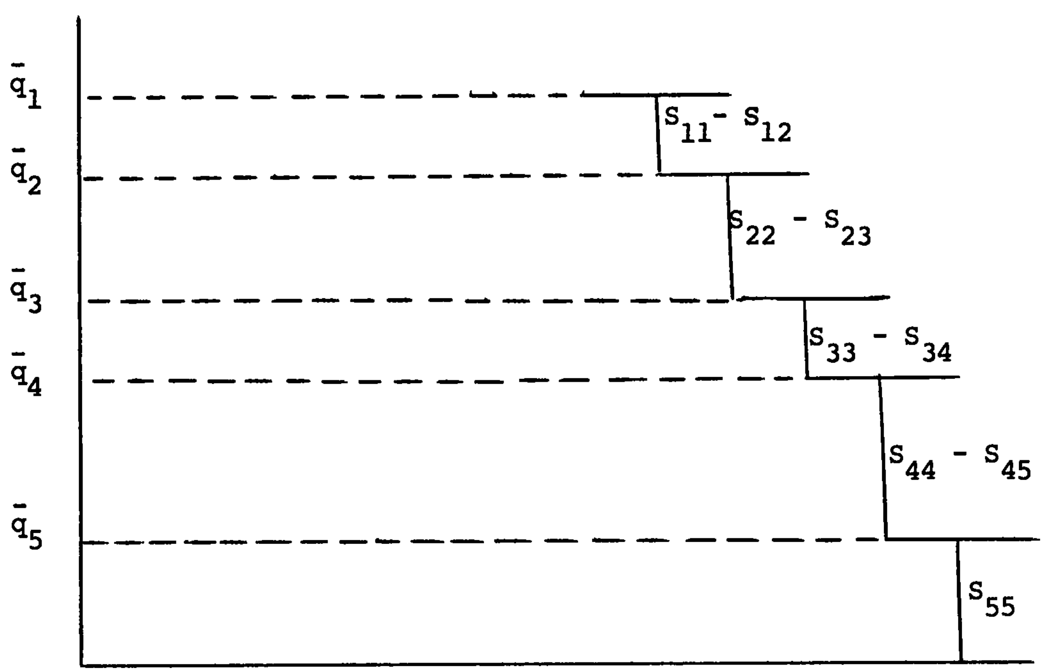
This is exactly the reduction in the total economic rent as a result of the relocation and although the result is only illustrated for a simple example its validity is more general and includes the multiple assignment case. In addition it is easy to show that if a parcel becomes available the increase in economic rent to the area is equal to the maximal land rent for that parcel under the new equilibrium.



(a) Initial Equilibrium



(b) New Equilibrium



(c) Maximal Land Rent

Figure 3.6 CHANGE IN ECONOMIC RENT RESULTING FROM VACATING PARCEL

2. The Use of Maximal Land Rents in the Flood Control Benefit Formula

The use of maximal land rents in the benefit formula (3.9) is first explained for a simple situation involving only one activity that moves in the flood plain as a result of protection. Subsequently, it is shown that the use of maximal rents provides a good approximation to the benefits for the more general case involving many activities.

Consider the situation as depicted in Figure 3.7 where activity x locates on parcel o outside the flood plain in case of no protection and on parcel f inside the flood plain in case of protection. Let parcel f without protection be occupied by activity y and parcel o with protection by activity z. Furthermore, we assume that in this simplified situation parcel f is the only parcel in the flood plain that will be put to productive use and that the economic rents outside the flood plain are independent of the flood control project.

The benefits that result from the relocation of activity x in the flood plain as a result of flood protection can be obtained by comparing the difference in economic rents with and without protection. First, we note that with protection activity x will make an economic rent $\hat{S}_x^f(p)$ on parcel f, while without protection it will make $\hat{S}_x^o(0)$ on parcel o. The benefit to activity x as a result of protection is therefore equal to the difference $\hat{S}_x^f(p) - \hat{S}_x^o(0)$. Second, to capture all the benefits resulting from protection, the increases in economic rent to the area associated with the availability of each of parcels f without protection and o with protection must still be included.

Before determining the above increases in economic rents, we demonstrate that their difference indeed measures the remaining benefits due to the project. For this purpose we first vacate the parcel f in the flood plain in the case of no protection and relocate activity y somewhere outside the flood plain other than parcel o. Similarly, vacate parcel o outside the flood plain in case of protection and relocate activity z somewhere outside the flood plain. In both cases all activities except x are located outside the flood plain while excluding location o. Since the economic rent outside the flood plain is assumed to be independent of the project and location o is excluded, the optimal assignment of these activities will result in the same economic rent with and without the project. It then follows that the difference of the increases in economic

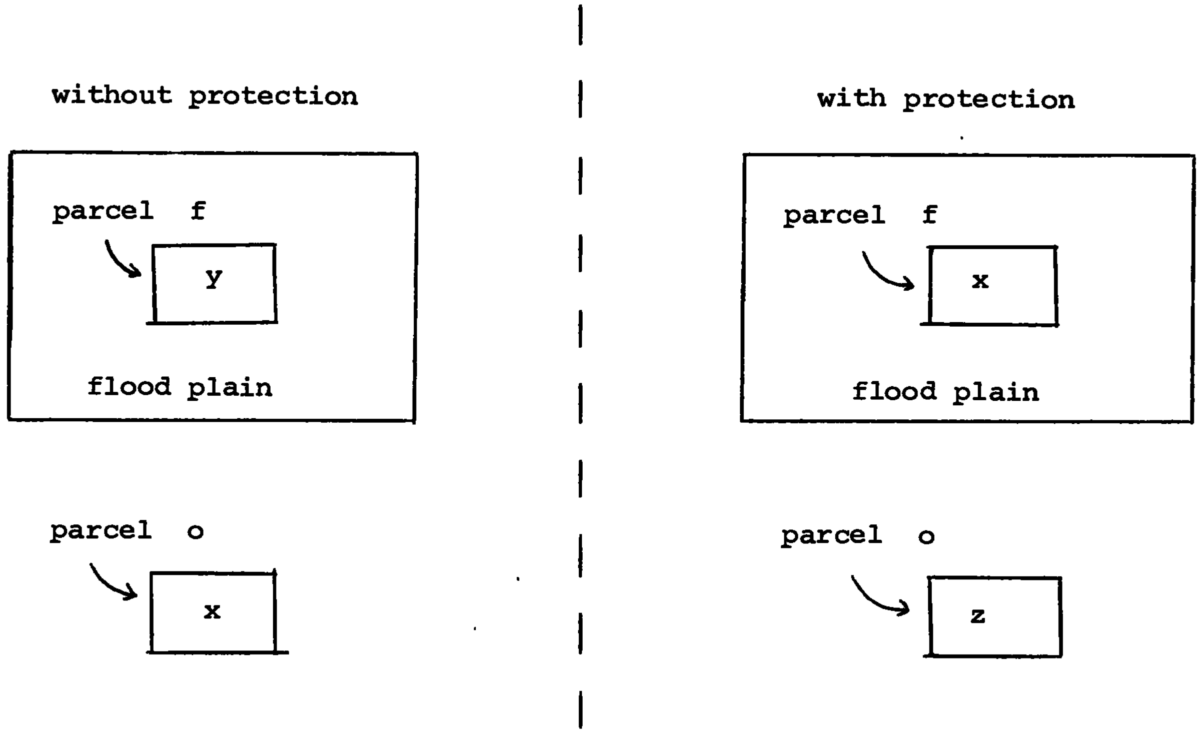


Figure 3.7 SIMPLE SITUATION WITH AND WITHOUT PROTECTION

rent that result either by making parcel o available with the project or parcel f without the project, will actually measure the benefits to all the activities other than x.

The increases in economic rent that result from the availability of parcel o with the project and parcel f without the project are determined by making use of the results obtained in the previous section concerning maximal rents. First, consider the situation where parcel o is vacated with the project, and where, as a result, activities other than x will relocate. The associated decrease in economic rent will be equal to the maximal land rent $\bar{q}^o(p)$ at parcel o obtained from the equilibrium with protection shown in Figure 3.7. Equivalently, the increase in economic rent resulting from the availability of parcel o with the project is $\bar{q}^o(p)$. Similarly, the increase in economic rent resulting from the availability of parcel f without protection is $\bar{q}^f(0)$. The difference between these two maximal land rents, $\bar{q}^o(p) - \bar{q}^f(0)$, will therefore properly measure the remaining benefits due to the project.

The total benefits due to the project are obtained as the sum of the difference in economic rent to activity x with and without the project, and the difference of the increases in economic rents associated with the availability of parcel o with the project and parcel f without the project. As a result,

$$B(p) = \{\hat{S}_x^f(p) - \hat{S}_x^o(0)\} + \{\bar{q}^o(p) - \bar{q}^f(0)\} \qquad (3.12)$$

This formula is the same as in (3.9) except that in this case maximal equilibrium land rents are used.

For the case where with the project more than one activity of type x is located in the flood plain the simplified benefit formula will not always provide an exact measure. The difference in economic rents of activities x with and without the project can again be obtained directly as before. However, to be exact the maximal land rents should be obtained for a sequence of equilibrium conditions. Consider for instance the process for determining the increase in economic rents associated with the parcels in the flood plain without protection. As more and more parcels are vacated the number of activities of type y that are located outside the flood plain will increase and as a result the maximal land rent may also increase. Therefore, the use of the maximal land rent associated with the initial equilibrium may underestimate the increase in economic rents associated with the availability of the parcels in the flood plain. This is not expected to be of practical significance as the total number of relocations is usually small when compared to the total study area.

E. Summary

In this chapter we derived conditions under which the equilibrium activity profits and land rents are unique to within a constant for both the simple and the multiple assignment problems. These conditions are closely related to the existence and the characteristics of alternative optimal assignments which in practice are not expected to be satisfied so that equilibrium land rents will, in general, be nonunique.

It was then shown that in such cases the maximal land rents of the initial equilibria with and without protection form the proper choice of land rents to be used in the simplified benefit formula. When many activities are located in the flood plain with protection this formula is not always exact but will provide in practice a good approximation. Maximal land rents were shown to be a conceptually useful tool. However, to be useful in actually determining flood control benefits a simple method for obtaining good estimates of maximal land rents is needed. Such methods will be discussed in the next chapter, where a variety of cases will be examined in detail.

Chapter IV

PRACTICAL METHODS FOR MEASUREMENT OF BENEFITS FROM SHIFTS IN LAND USE

A. Introduction

The general problem of measurement of benefits due to shifts in land use caused by a flood control project has been addressed in a number of our previous reports (Refs. 1, 2, 4, 6). Throughout this work we have placed emphasis on the benefit formula (1.4) and more recently on the assignment problem. Further on, Chapter III of this report was totally devoted to the properties of optimal assignment solutions, the nonuniqueness of equilibrium land rents and the use of maximal rents in the benefit formula. It has become progressively clearer that neither the optimal assignment approach nor the formula (1.4) provide practical benefit measures by themselves. Rather, they offer basic conceptual tools for establishing the theoretical foundations needed to arrive at a practical methodology. The purpose, therefore, of this chapter is to draw upon these basic concepts and use them in deriving measures that are appropriate for various practical situations.

In principle, given the assignment of economic activities with and without protection, the benefits are measured as the difference of the sums of economic rents (adjusted for flood damages). Thus, having obtained the two optimal assignments, one automatically obtains the total benefits. As a practical matter, however, there are many cases where much of the required information is not available, and even if it could be made available the resulting improvements in accuracy will not justify the prohibitive cost of data gathering. For example, in the case where activities would locate outside the study area defined in Chapter II, their locations cannot be identified unless the study area is made quite large. Extending the study area to cover most of the possible activity relocations substantially extends information requirements. Furthermore, the nature of the problem is such that estimation of present and future economic rents cannot be very accurate and therefore limited but carefully selected information may provide as good a degree of accuracy as is feasible. For these reasons, an approach based on obtaining the economic rents for all affected activity-zone combinations is abandoned as impractical.

Similarly, the approximate benefit formula uses maximal land rents to account for changes in productivity of other activities as a result of the movement of a given activity into the flood plain. However, determination of maximal land rents would require the use of all economic rents and thus defeat the purpose of using a simplified but approximate measure. It is seen in this chapter that contingent on the existence of non-urban activities within the study area or the availability of the economic rent for low-use activities, maximal land rents can be approximated and therefore the formula (1.4) can be applied.

As in the previous chapter, the concept of cycles of relocation proves very useful in dealing with the measurement problem. It provides the vehicle for applying the assignment concepts and the benefit formula to practical situations. In particular, it permits:

(1) recognition of the fact that some shifts in land use outside the flood plain do not contribute to the benefits and, therefore, can be ignored;

(2) identification of, and, subsequently, concentration on the most important shifts in land use;

(3) dealing with the cases when some of the activity locations are outside the study area and, therefore, cannot be identified; and

(4) classification of shifts in land use according to the extent to which they affect the use of other locations, and thus selection of the appropriate benefit measure for each case.

The following section discusses the concept of a relocation cycle as it applies for comparing conditions with and without protection and describes a procedure for establishing such cycles. The remaining sections deal with deriving measurement methods as they will apply to specific situations.

B. Relocation Cycles in With and Without Project Analysis

Practical difficulties encountered in using the conceptually correct benefit measure are minimized when we recognize patterns of land use change by observing how a particular shift affects the use of other locations. This procedure is facilitated by using relocation cycles which allow for the orderly analysis of relocation movements in the study area. We thus discuss the basic concept of relocation cycles as applied to with and without project analysis and then we give a procedure for establishing relocation cycles when the land use with and without the project is specified.

1. Definition of a Relocation Cycle

Let us assume activity x that locates at a particular site with the project is different from activity y that would locate at the same site without the project. We then say that activity x displaces activity y, although what is actually "observed" is that with the project one activity takes the place that would be taken by the other without the project. This is quite different from the displacement that takes place when moving from one "observed" equilibrium to another as in the previous chapter. Let us further assume that activity y displaces another activity z. Activity y is then said to move or relocate from one site to the other although what is again "observed" is that activity y locates at one site with protection whereas it would locate at another site without protection. By tracing "movements" of the above type over the affected area we say we have established a cycle of relocation when we encounter the location from which the original activity x had moved.

In practice, we often encounter cases for which when an activity is displaced from one site there is no alternative site for it to relocate. In such cases we say that the displaced activity goes out of production and we artificially establish a relocation cycle by introducing a ficticious site with zero economic rent. This mechanism allows us to analyze all differences in land use with and without the project in terms of relocation cycles. An additional practical consideration is that many economic activities are indistinguishable so that their movements cannot be "observed". The cycles of relocation may then be based on activity types rather than on individual activities and as a result will be non-unique. However, their choice will not influence the value of the benefits, and thus given the assignment with and without protection, the cycles most suited for benefit measurement can be chosen.

2. Procedure for Establishing Relocation Cycles

The following discussion shows that there is not necessarily a unique set of relocation cycles but there are a number of possible choices. It also shows that there is significant advantage in forming short cycles so that one should first attempt to establish the simplest possible cycles involving only two locations, then proceed to form three-location cycles and continue until all necessary movements are exhausted. The discussion uses a simple example to illustrate the procedure.

Let us consider a five-site example shown in Figure 4.1 where the land use with and without the project is indicated by the numbers in parenthesis. The first number indicates the activity type that locates at the site without the project and the second with the project. Links between any two locations indicate activity "movement" and they are numbered with the index of the activity type that relocates because of the project. Thus the link between sites (1,3) and (2,1) indicates that an activity of type 1 moves from the first location to the second. This is also the only possible link from location (1,3) since there is no other location where an activity of type 1 locates with the project. The case with location (2,1), however, is different in that activity type 2 can either be considered to move to location (3,2) as in Figure 4.1a, or to location (4,2) as in Figure 4.1b. Having established a link for activity type 2, the remaining links are as shown in the two parts of the figure. It should be observed that the two types of movement are equivalent as we have no way to distinguish the "actual" relocation.

There is an advantage in working with the two short cycles in Figure 4.1a as opposed to the longer cycle in Figure 4.1b. To see this, suppose that location (2,1) is in the flood plain whereas all other locations in the figure are outside. If in addition we assume that the economic rent for a given activity at a site outside the flood plain is not affected by the project, then there is no benefit from the interchange of locations between activity types 2 and 4; otherwise the land use without the project would not have been an optimal one. It is therefore clear that the benefit is associated only with the shifts in land use represented by the three-location cycle in Figure 4.1a which requires less information than the longer cycle in Figure 4.1b. It should be noticed that the longer cycle can be avoided by first establishing the two-location cycle. For the case in which the assumption that economic rents outside the flood plain are not affected by protection is not valid because the social environment changes, neglecting the cycle outside the flood plain may still be considered a good approximation. It follows from this discussion that for minimizing information requirements we should attempt to form all possible two-location cycles first, three-location cycles next, and so on.

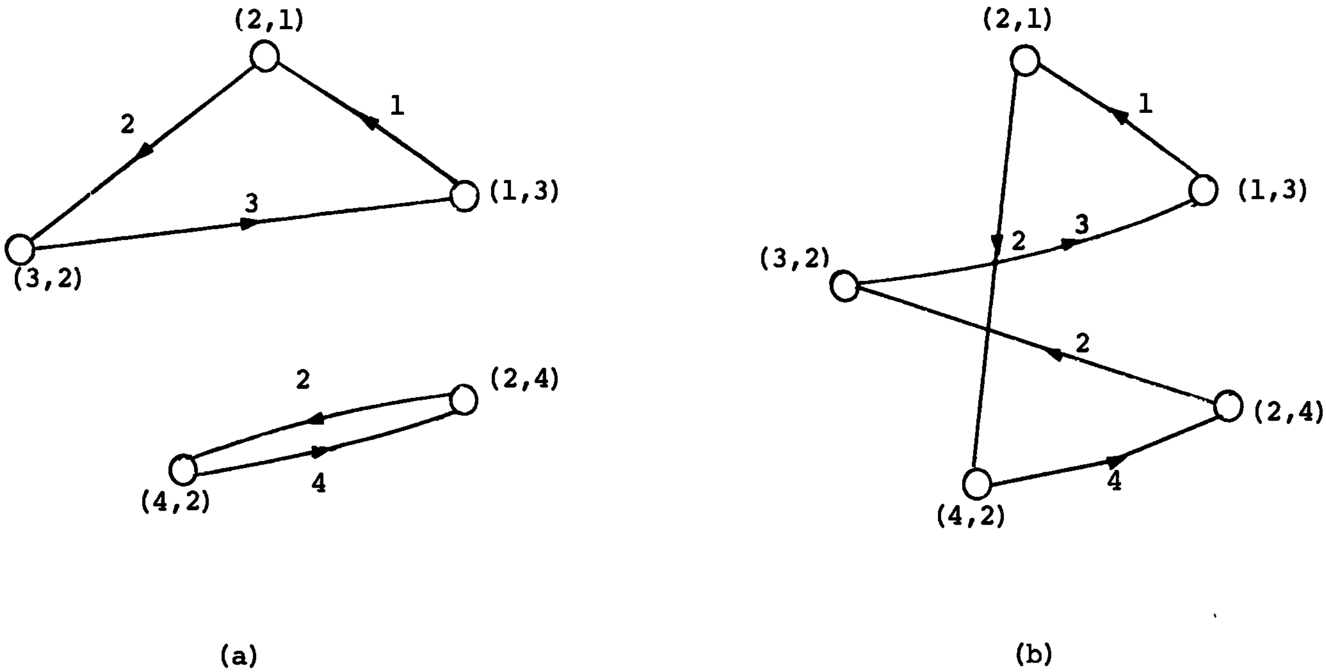


Figure 4.1 ALTERNATIVE RELOCATION CYCLES FOR THE SAME CHANGES IN LAND USE

Let us now illustrate how we would apply the above rule in the case of the five-location example. Suppose we start with location (1,3) and since there is no location indicated by (3,1) it follows that it is not possible to form a two-location cycle including location (1,3). Similarly, it is impossible to form such a cycle with either location (2,1) or (3,2) for the same reason and we are only able to form a two-location cycle when we encounter either location (4,2) or location (2,4). Having exhausted all possibilities of two-location cycles, we may then proceed to form three-location cycles. Starting again with location (1,3) we search for a location with first index 3, such as (3,2), or with second index 1, such as (2,1). If we first encounter (3,2) we have the link 3 and we have to look for a location (2,1). If such a location did not exist we would have to abandon link 3 and attempt to form a new cycle not including (1,3).

After all three-location cycles have been formed, we may then proceed to form longer cycles. The procedure becomes more complicated but the principles are the same. Subsequent sections illustrate that as long as the study area is not fully developed we will not be interested in establishing cycles involving more than three locations because for such study areas we will make use of approximate benefit measures for which three-location cycles are sufficient.

C. Basic Measures of Benefits from Cycles of Relocation

We have three basic methods for measuring benefits associated with cycles of relocation. Using the full measure of the benefits over a cycle requires all changes in economic rent of the activities involved. This can be obtained only in cases where all locations of the cycles are included in the study area and the respective economic rent differences are known. An alternative measure is obtained when not all relocations are included in the study area; this requires additional information about activities that locate outside. The third basic benefit measure is the approximate measure that concentrates on the activity induced in the flood plain by protection and uses maximal land rents for the total change in productivity associated with the movement of the remaining activities involved in the relocation cycle.

1. The Full Measure of the Benefit

The benefit over a given cycle of relocation equals the sum of the differences in economic rents with and without protection adjusted for flood damages. Each difference is normally expressed in terms of the locational advantage offered to each activity by its location with protection over its location without protection. Thus, considering a cycle involving locations 1, 2,...,n as in Figure 4.2, where activity i $(i = 1,2,\ldots,n-1)$ locates at site i without the project but locates at $i+1$ with the project and activity n locates at 1, we define:

$S_{ij}(p) \triangleq$ economic rent of activity i at location j with level of protection p;

$r_{ij}(p) \triangleq$ flood damage of activity i at location j with level of protection p; and

$$\hat{S}_{ij}(p) \triangleq S_{ij}(p) - r_{ij}(p)$$

The benefit from the shifts in land use represented by the relocation cycle is

$$B(p) = \sum_{i=1}^{n} \delta\hat{S}_i$$

where (4.1)

$$\delta\hat{S}_i \triangleq \begin{cases} \hat{S}_{i,i+1}(p) - \hat{S}_{ii}(0) & \text{for } i = 1,2,\ldots,n-1 \\ \hat{S}_{n1}(p) - \hat{S}_{nn}(0) & \text{for } i = n \end{cases}$$

Thus, only location advantages and flood damages for locations in the flood plain are required for the full measure of the benefits as expressed by Equation (4.1).

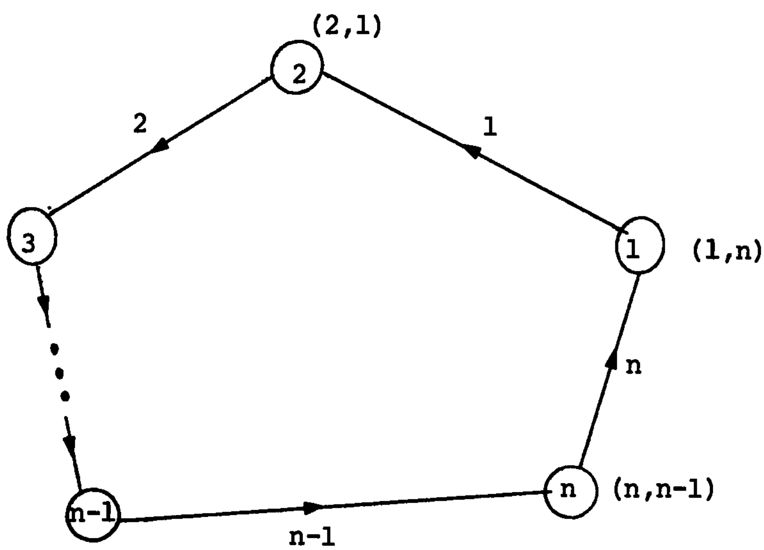


Figure 4.2 A CYCLE OF RELOCATION

2. <u>Benefit Measure When Not All Locations Are Included in the Study Area</u>

It has been mentioned that a fundamental difficulty with measuring all changes in economic rents over the affected area is that some locations may be outside the study area and therefore cannot be identified. In terms of relocation cycles, this means that only part of the cycle may be within the study area. This sort of difficulty cannot be eliminated, but can be greatly diminished by the introduction of equilibrium land rents and by making use of assumptions about the conditions outside the study area.

A basic assumption is that economic rents and land rents outside the study area are not affected by the project which implies that the marginal use for these locations will be the same with and without the project. Thus for any location i outside the study area we may assume that the land rent q_i is independent of the protection level, or

$$q_i = q_i(p) = q_i(0) \tag{4.2}$$

Using (4.2), it can be shown that for an activity which locates outside the study area both with and without the project, either at a different location or at the same location, the change in economic rent equals the change in the corresponding land rents. This is seen by considering activity i locating at i without the project and at $i+1$ with the project where locations i and $i+1$ lie outside the study area. Under conditions of economic equilibrium and without the project, location $i+1$ cannot be more profitable than location i or

$$S_{i,i+1} - q_{i+1} \leq S_{ii} - q_i.$$

Similarly, with the project

$$S_{ii} - q_i \leq S_{i,i+1} - q_{i+1}.$$

From these two inequalities it follows that

$$S_{i,i+1} - q_{i+1} = S_{ii} - q_i$$

or (4.3)

$$\delta S_i \triangleq S_{i,i+1} - S_{ii} = q_{i+1} - q_i.$$

Suppose then that we have a cycle with n links as shown in Figure 4.3, and that locations $1,2,\ldots,m$ lie within the study area, whereas locations $m+1,\ldots,n$ lie outside it. Using the above result, Equation (4.1) becomes

$$B(p) = \sum_{i=1}^{m} \delta S_i + \sum_{i=m+1}^{n-1} (q_{i+1} - q_i) + \delta S_n$$

or

$$B(p) = \delta S_n + \sum_{i=1}^{m} \delta S_i + (q_n - q_{m+1}) \tag{4.4}$$

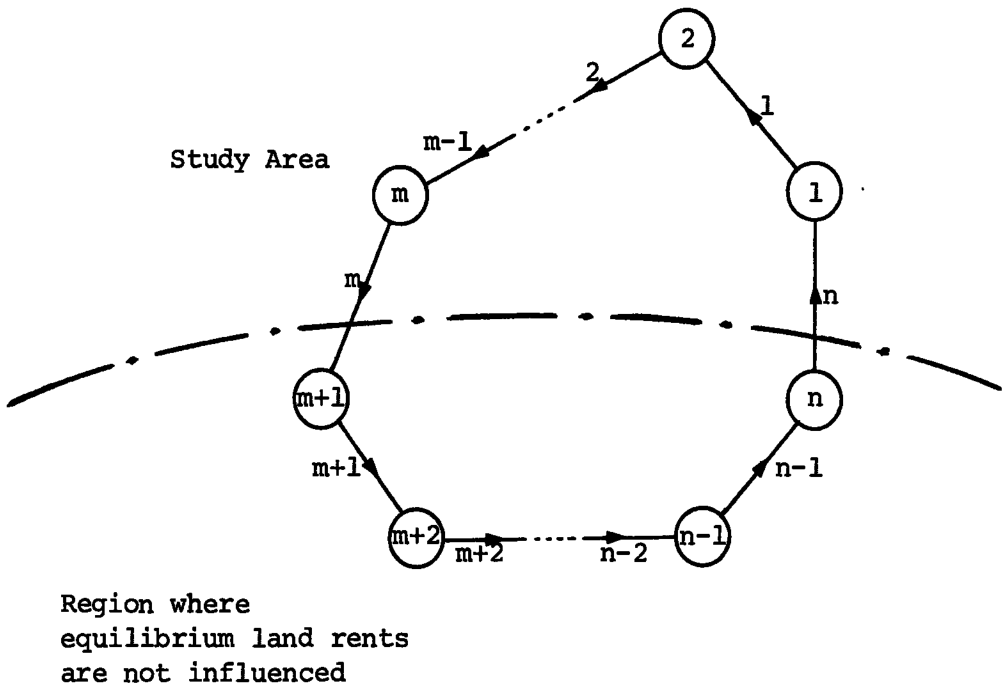


Figure 4.3 A CYCLE OF RELOCATION WHICH LIES IN PART OUTSIDE THE STUDY AREA

We observe that the sum of differences in economic rents over the links that lie outside the study area is measured by the difference in equilibrium land rents $q_n - q_{m+1}$, where location n is the location of activity n without the project and m+1 is the location of activity m with the project. Activity n moves in the study area with the project, whereas activity m is within that area without the project but moves outside if protection is provided.

It will be possible to obtain only very rough estimates of δS_n and δS_m, whereas for the land rents we need to make some assumption. Since the locations outside the study area are not identifiable, we can make no assumption about which q is larger, and when we sum up all the benefits, differences like

$q_n - q_{m+1}$ would tend to cancel each other. Thus it may be the best course of action is to neglect such differences and therefore measure the benefit as

$$B(p) = \delta S_n + \sum_{i=1}^{m} \delta S_i \qquad (4,5)$$

3. <u>The Approximate Measure Using Maximal Land Rents</u>

The approximate benefit formula (4.1) emphasizes the activity that is induced by the project to locate in the flood plain and uses land rents to account for changes in productivity of other activities that also relocate. The formula has been discussed in Chapter III where it was shown that the appropriate land rents to be used are the maximal ones. In addition, it was demonstrated in Interim Memorandum III that this formula gives an accurate measure when the activity that locates in the flood plain with protection displaces a non-urban activity in the flood plain, while the site it would have occupied without protection outside the flood plain remains non-urban with protection.

The use of the approximate measure depends on finding a way to obtain or approximate maximal land rents. Therefore before we apply all three measures to specific situations in Section E, we must first deal with the problem of maximal land rent estimation.

D. <u>Approximation of Maximal Land Rents</u>

In general, it will be possible to obtain only approximate values of maximal rents. Exact values can be obtained for non-urban activities, since for such activities the maximal land rent is equal to the economic rent adjusted for flood damages, which in turn can be estimated. Similarly, whenever both urban and non-urban activities exist in the same economic rent zone, the maximal rent is determined by the lowest use in that zone and therefore is again equal to the economic rent of the non-urban activity. Thus, the present problem is restricted to the estimation of maximal rents in the case when only urban activities occupy a given zone.

The procedure presented requires knowledge of the maximal rent at some reference location and therefore it is contingent upon the existence of non-urban activities somewhere in the study area or on knowing the economic rent of some urban activity instead of its economic rent differences. Accordingly, estimation of the maximal land rent in the flood plain without protection,

$\bar{q}^f(0)$, will not, in general, present a problem whereas this is not the case with the maximal land rent outside the flood plain with protection, $\bar{q}^o(p)$. This is because the flood plain will, normally, not fully develop in urban use without protection but the area outside may attain full urban development with the project.

1. Approximation of Maximal Rents when Study Area Is Not Fully Urbanized

We proceed to describe a procedure for approximating maximal rents when non-urban activities exist in the study area. The discussion does not depend on whether we are considering the conditions with the project or the conditions without it and therefore we will use the symbol $\bar{q}$ to indicate maximal land rents for both conditions.

Suppose we want to obtain the maximal land rent $\bar{q}_\ell$ when an urban activity i locates in zone ℓ. We now assume that a non-urban activity j exists in some other zone k within the study area. Activity j being non-urban, the maximal land rent $\bar{q}_k$ is equal to the economic rent of the activity in that location, $\hat{S}_{jk}$. Because activity i prefers to locate on ℓ, the location must offer an advantage at least as great as the difference in land rents; i.e.,

$$\hat{S}_{i\ell} - \hat{S}_{ik} \geq \bar{q}_\ell - \bar{q}_k$$

from which it follows that

$$\bar{q}_\ell \leq \bar{q}_k + (\hat{S}_{i\ell} - \hat{S}_{ik}).$$

The last inequality states that the correct value $\bar{q}_\ell$ can be obtained if the right-hand expression is calculated for all non-urban activities in the study area and we then choose the minimum among them. The process must, of course, be repeated for all other types of urban activities that are also located in the same zone ℓ and the smallest of the minimum values will then correspond to $\bar{q}_\ell$. This lengthy process can be avoided by first assuming that the economic rent of non-urban activities in the same general area does not widely vary, and, second, by selecting zones ℓ and k as close as possible so that the difference $\hat{S}_{i\ell} - \hat{S}_{ik}$ is smallest. Under these conditions, the maximal rent for zone ℓ occupied by activity type i may be approximated by

$$\bar{q}_\ell \approx \bar{q}_k + (\hat{S}_{i\ell} - \hat{S}_{ik}) \qquad (4.6)$$

A consequence of using (4.6) is that if more than one activity type locates in a different location of the same zone, the maximal land rent for that zone will not be unique. That is, given that activity h of a different type than i locates in the same zone, the maximal land rent for the zone ℓ could also be given by $\bar{q}_k + (\hat{S}_{h\ell} - \hat{S}_{hk})$. As a result, (4.6) does not provide a unique maximal land rent for a given zone unless we search over all urban activities in the zone and choose the minimum. Using different maximal land rents for locations occupied by different activity types in a zone is, however, a preferable approximation for measuring changes in economic rents along cycles of relocation than using the minimum land rent for each cycle going through the same zone. The reason for this is that the unique maximal land rent per zone corresponds to marginal equilibrium changes and as discussed at the end of the previous chapter it only provides a lower bound to the benefits when many activities simultaneously relocate. As a result, the heuristic approach based on measuring the benefits along cycles of relocation allows us to better capture the actual changes in economic rents than when using the unique maximal land rent based on marginal changes in equilibrium conditions.

Consider the three-activity cycle shown in Figure 4.4 where non-urban activity y is displaced by urban activity x when protection is provided. The correct benefit measure is then given by the sum of the differences in economic rents with and without the project. That is,

$$B(p) = \{\hat{S}_x^f(p) - S_x^o(0)\} + \{S_y^a(p) - \hat{S}_y^f(0)\} + \{S_z^o(p) - S_z^a(0)\}.$$

Since y is non-urban, we have

$$\bar{q}^f(0) = \hat{S}_y^f(0) \quad \text{and} \quad \bar{q}^a(p) = S_y^a(p).$$

With the above substitutions the benefit is

$$B(p) = \{\hat{S}_x^f(p) - S_x^o(0)\} - \bar{q}^f(0) + \{\bar{q}^a(p) + S_z^o(p) - S_z^a(0)\}.$$

It can then be seen from the above expression that using (4.6) for $\bar{q}^o(p)$ would have given the exact benefit along the cycle, whereas if the unique maximal rent for zone o were used it would not necessarily give the exact benefit.

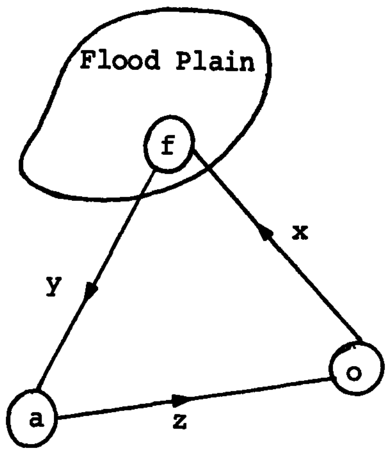


Figure 4.4 THREE-ACTIVITY CYCLE

The simple case above is only an example for demonstrating that using equation (4.6) for estimation of location maximal land rent will generally provide a better measure for the benefits than when using the maximal land rent for the zone. Further evidence can be provided by using longer cycles.

2. Approximation of Maximal Rents when Study Area Is Fully Urbanized

When the study area is fully developed it is not possible to find a non-urban location that can be used as a reference for obtaining maximal rents. As mentioned earlier, this situation is expected usually to occur only under the with the project conditions, since without the project the flood plain is not expected to attain full development. In addition, it should be noted that full development of the study area will not be attained until after several years from the completion of a project where both predictions are less accurate and the benefits are more heavily discounted.

When the study area is fully developed it may be assumed that requirements for land in the region are such that for the less intensive urban uses, such as single-family housing, the maximal land rent at the least desirable location equals the economic rent minus normal activity profits. Provided an estimate can be obtained, this land rent can then be used as a reference to obtain maximal land rents for other locations in a similar manner as before. Otherwise, the formula cannot be applied and we would have to resort to using either of the two other basic measures discussed in the previous section, depending on whether the relocation cycle lies wholly or in part within the study area.

E. Benefit Measures for Representative Cases in Flood Plain Development

This section discusses appropriate measures for benefit evaluation in cases representative of alternative development with and without protection. The main criteria for selection of a measure are: (a) length of the relocation cycle, (b) existence of non-urban activities in the cycle, and (c) whether the alternative location of the activity induced by the project is within or outside the study area.

1. Two-Location Cycles

Consider the situation illustrated in Figure 4.5 where, without flood protection, location f in the flood plain is occupied by activity y, whereas location o outside the flood plain is occupied by activity x; with protection, the use of the two locations is the reverse. This is a representative situation, in particular, where activity y is non-urban or of lower economic use than activity x.

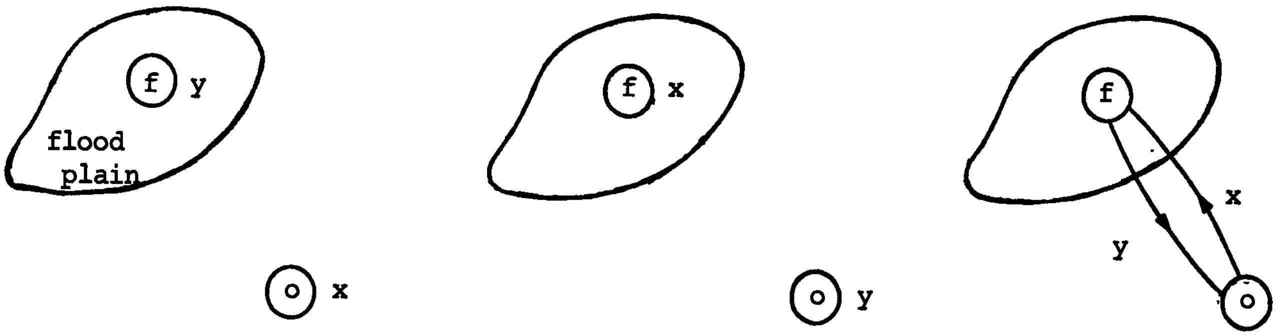
In terms of relocation cycles, activity x moves from location o to location f from where it displaces activity y; in turn, activity y moves to occupy location o. In this case there is no need for an approximate measure of the benefits, since only two locations are involved. Applying (4.1) we obtain the exact measure of the benefit:

$$B(p) = \{\hat{S}_x^f(p) - S_x^o(0)\} - \{\hat{S}_y^f(0) - S_y^o(p)\} \tag{4.7}$$

Depending on the type of activities involved in the relocation, we must estimate either the differences in economic rents above, or if activity y is non-urban this estimate is also given by the respective land rents.

2. Three-Location Cycles With a Dummy

This is the case where the activity displaced from the flood plain and the activity that replaces the one moving into the flood plain are both non-urban but not of the same type: e.g., the displaced use may be agricultural, whereas the



(a) Without Protection (b) With Protection (c) Two-location cycle formed by comparing land use with and without protection

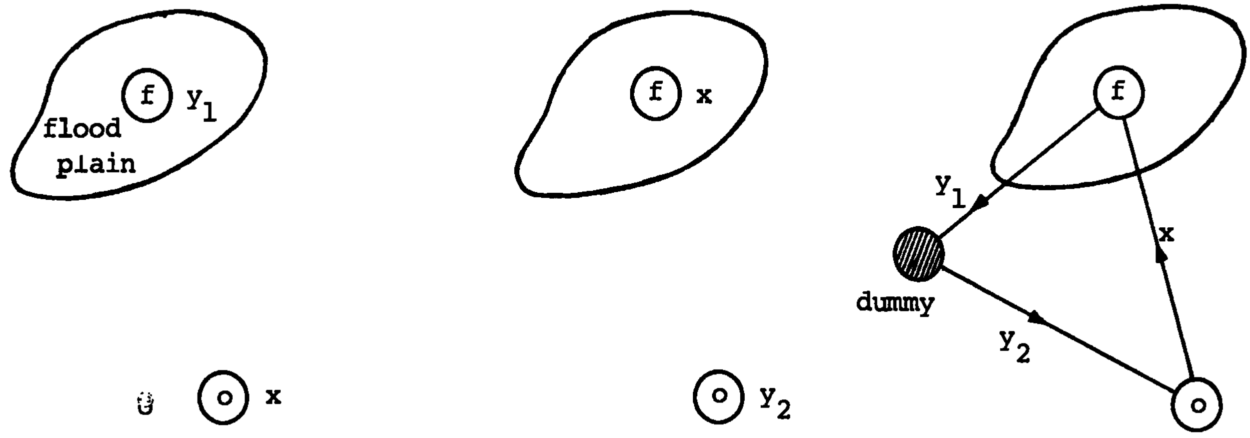
Figure 4.5 EXAMPLE OF TWO-LOCATION CYCLE

other one may be grazing land or vacant. The usual case is that the displaced non-urban activity would go out of production and the activity outside the flood plain with protection would not exist without the project. This situation is illustrated in Figure 4.6 and the exact benefit measure is

$$B(p) = \{\hat{S}_x^f(p) - S_x^o(0)\} + \bar{q}^o(p) - \bar{q}^f(0) \tag{4.8}$$

where $\bar{q}^o(p)$ and $\bar{q}^f(0)$ are maximal land rents measuring marginal productivity. For non-urban activities we assume that $\bar{q}$ equals the economic rent of the activity minus flood damages and for vacant land we have $\bar{q} = 0$.

In the usual case above, (4.8) gives again an exact measure of the benefit. When more activities are involved, the use of the above formula corresponds to aggregating all non-urban activities into a single activity type. Since urban activity types are also aggregates of different urban activities, and since the error in aggregating non-urban activities is not expected to be larger than the error in aggregating urban activities, this approximation is expected to be sufficiently accurate.



y_1 is non-urban

(a) Without protection activity y_2 does not exist

y_2 is non-urban

(b) With protection activity y_1 does not exist

(c) Relocation cycle including a dummy location

Figure 4.6 CASE WHEN THE ACTIVITY DISPLACED FROM THE FLOOD PLAIN AND THE ACTIVITY THAT REPLACES THE ONE MOVING INTO THE FLOOD PLAIN ARE BOTH NON-URBAN

3. Three-Location Cycles Within the Study Area

According to the discussion in the previous section, the determination of the maximal land rent in a zone requires the estimation of a difference in economic rents, unless the zone in question contains a non-urban activity. Thus, whenever the marginal use in either of the two zones under consideration is urban and we have a three-location cycle, there is no advantage in using the formula

$$B(p) = \{\hat{S}_x^f(p) - S_x^o(0)\} + \bar{q}^o(p) - \bar{q}^f(0).$$

Instead we can sum up the three changes in economic rent over the cycle which gives the exact measure of the benefit; that is,

$$B(p) = \sum_{i=1}^{3} \delta\hat{S}_i \tag{4.9}$$

In case locations 1 and 3 (see Figure 4.7) lie within the same subarea, so that it can be assumed that δS_3 is negligible, then the benefit is approximated by

$$B(p) \approx \{\hat{s}_{12}(p) - s_{11}(0)\} + \{s_{23}(p) - \hat{s}_{22}(0)\}$$

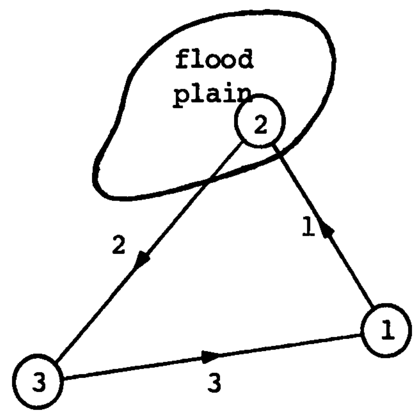


Figure 4.7 A THREE-LOCATION CYCLE

4. <u>All Other Cases When Activities that Move Into the Flood Plain With Protection Would Locate Within the Study Area Without Protection</u>

In all cases other than those previously covered and where the location of activities x without protection is within the study area, we may use the formula (4.8),

$$B(p) = \{\hat{s}_x^f(p) - s_x^o(0)\} + \bar{q}^o(p) - \bar{q}^f(0)$$

to obtain an approximate measure. In particular, there are two categories of relocation cycles which fall in this category. First, cycles which lie within the study area and involve more than three locations. Such cycles are not expected to occur frequently; therefore the significance of the error over such cycles for the total benefit is expected to be small. The second category includes cycles which are not wholly within the study area. In such cases and, in view of the difficulties of estimating differences in economic rents referring to locations outside the study area, it appears preferable to use (4.8) instead of attempting to estimate the benefits according to (4.5).

5. Case When the Activity that Moves Into the Flood Plain With Protection Would Locate Outside the Study Area Without Protection

a. The Activity Displaced from the Flood Plain Locates Within the Study Area

This case is illustrated in Figure 4.8. The benefit estimate can be obtained by using the approximate measure, which for this particular case gives the expression

$$B(p) = \{\hat{S}_x^f(p) - S_x^w\} + \bar{q}^w - \bar{q}^f(0)$$

where the superscript w denotes an unidentified location outside the study area.

Since the difference in economic rent can only be roughly estimated, there is no particular advantage in estimating $\bar{q}^w$ very accurately. On the other hand $\bar{q}^f(0)$ will usually be low since there will be non-urban activities in the flood plain without protection. If it can also be assumed that activity x can earn the estimated S_x^w by locating on land of low-intensity use, then the difference $\bar{q}^w - \bar{q}^f(0)$ may be neglected and

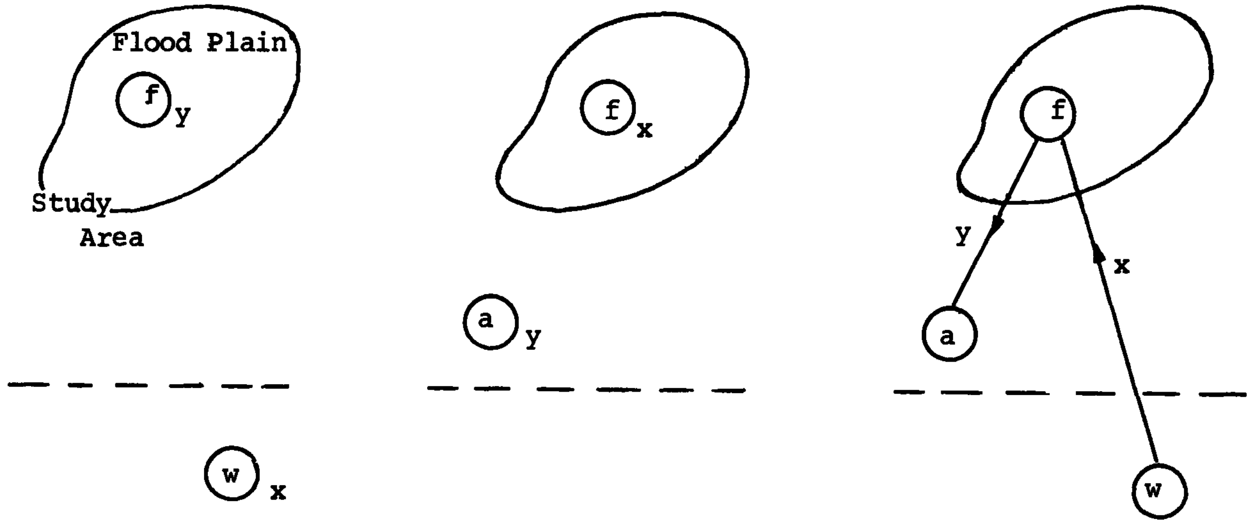
$$B(p) = \hat{S}_x^f(p) - S_x^w. \tag{4.10}$$

b. The Displaced Activity Moves Out of the Study Area

Figure 4.9 illustrates this case. Without protection activity x is at w_x outside the study area, and activity y is at f in the flood plain. With protection activity x occupies location f whereas activity y moves outside the study area at w_y. Locations w_x and w_y cannot be identified, since they are outside the study area. Applying the benefit measure given by Equation (4.5) we obtain

$$B(p) = \{\hat{S}_x^f(p) - S_x^{w_x}\} + \{S_y^{w_y} - \hat{S}_y^f(0)\} \tag{4.11}$$

The problem with the measures presented in Equations (4.10) and (4.11) is the estimation of economic rent differences for locations outside the study area. For this purpose we need to characterize the dummy location by the average economic rents that an activity can be expected to achieve outside the study area. These average economic rents may be obtained by identifying locations within the study area that are representative of average conditions outside the study area or by specifying the characteristics of average locations outside the study area.



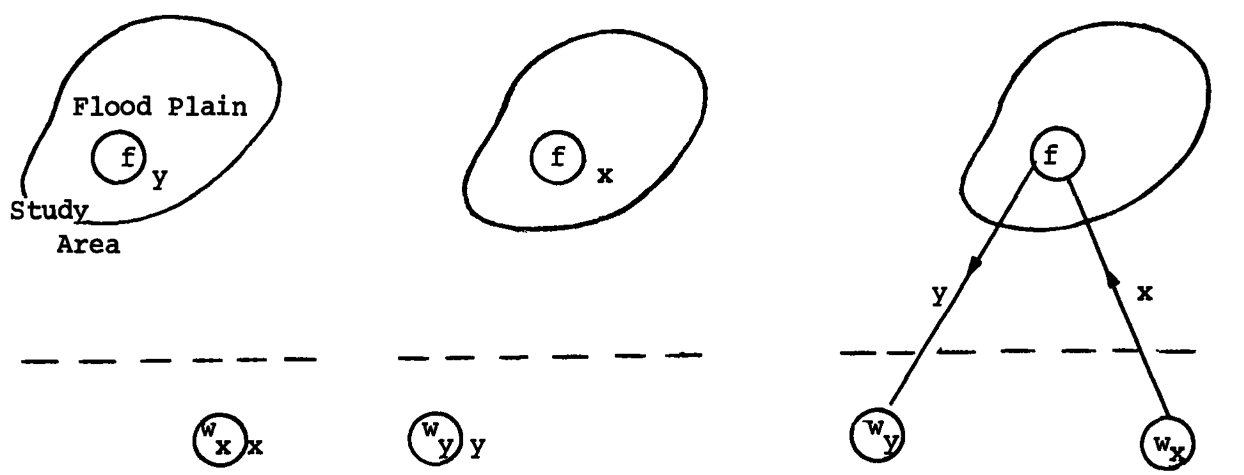
(a) Without protection

(b) With protection

(c) Relocation of activities x and y due to protection

(Location w is outside the study area)

Figure 4.8 WITHOUT PROTECTION ACTIVITY x WOULD LOCATE OUTSIDE THE STUDY AREA; DISPLACED ACTIVITY y RELOCATES WITHIN THE STUDY AREA.



(a) Without protection

(b) With protection

(c) Relocation of activities x and y due to protection

(Locations w_x and w_y are outside the study area)

Figure 4.9 WITHOUT PROTECTION ACTIVITY x WOULD LOCATE OUTSIDE THE STUDY AREA; DISPLACED ACTIVITY y RELOCATES OUTSIDE THE STUDY AREA

F. Summary

This chapter addressed the problem of developing practical methods for the measurement of benefits from shifts in land use due to a flood control project. It was seen that the concept of relocation cycles is very useful in dealing with the measurement problem, as it allows for the orderly analysis of relocation movements in the study area. A section was devoted to the definition of this concept and the development of a procedure for establishing relocation cycles given the land use with and without the project. It was shown that there is not necessarily a unique set of relocation cycles and also that there is significant advantage in forming short cycles, so that one should first form the simplest possible cycles including only two locations, then proceed to form three location cycles and continue until all relocations are exhausted.

The three basic measures available for estimating benefits associated with cycles of relocation were reviewed, including the approximate measure using maximal land rents. A procedure was then developed for approximately constructing maximal land rents with limited information and it was seen that the approximation, based on measuring the benefits along cycles of relocation, allowed us to better capture the actual changes in economic rents than when using the correct value of the maximal rent based on marginal changes in equilibrium conditions. The procedure presented requires knowledge of the maximal rent at some reference location and therefore is contingent upon the existence of non-urban activities somewhere in the study area or on knowing the economic rent of some urban activity instead of its economic rent differences.

The foregoing analysis guided the choice of the appropriate benefit measure for cases representative of alternative developments with and without protection. The selection of a measure mainly depends on (a) the length of the relocation cycle, (b) the existnce of non-urban activities in the cycle, and (c) whether the alternative location of the activity induced by the project is within or outside the study area.

Chapter V

ESTIMATION OF ECONOMIC RENT DIFFERENCES

A. Introduction

Economic rent differences have been used throughout the analysis presented in this report. It is the objective of the present chapter to address the problem of estimating these economic rent differences, to highlight the crucial difficulties in obtaining good estimates and to establish preliminary procedures for arriving at practical results. The most relevant parts of the existing literature is reviewed in Section B together with two examples of multiple regression for estimating residential values and certain conclusions that resulted from the literature search are presented. Section C discusses locational advantage as it applies to different activity types, while Section D presents an approach to estimating the locational advantage for residential activities. The same issue for other activity types is addressed in Section E.

B. Review of the Literature

Practical methods for directly estimating either economic rents or economic rent differences as defined in this report are virtually non-existent. Most of the existing methodologies deal with the problem of appraising market values of land and/or structures using standard appraisal techniques such as Cost, Income and Market Data Approaches (Ref. 16). Because the relationship between market values and annual economic rents is in general not well defined and quite complex, appraisal techniques are of little value for benefit evaluation outside of providing background information as to data availability and significance of certain parameters (Ref. 7, 17). They are more useful in cases where forecasted market values are of interest rather than for the actual measurement of flood control benefits, such as in land use planning where market values determine the allocation of activities.

In the case of residential activities where most of the existing work has been done, market values, such as house sales prices, rents to be paid or residential land prices, can be used in an attempt to isolate value-components paid for differences in locational attributes. However, a search of existing literature has shown that existing models have two important limitations: first, attributes such as aesthetic amenities have not been included, and, second, they are tailored to specific situations without arriving at a general body of knowledge that would be applicable to a variety of situations. Both these limitations are significant for the purpose of this study. In the following we present two examples of residential value appraisals using multiple regression and market data. Their usefulness is that they provide a guide with respect to the significance of variables included in the analysis.

1. Multiple Regression Models in Determining Residential Values

Multivariate statistical analysis on market sales of land was applied by P. B. Downing to estimate residential land values in the metropolitan area of Milwaukee (Ref. 18). He used quite a large number of variables but those of most concern to us can be grouped under three general categories:

- Accessibility included three measures: distance to CBD, distance to the nearest regional shopping center, and distance to the nearest public grade school or junior high school. Among these only the distance to CBD was found significant.

- Land Uses considered only sites zones for residential use. These were classified into zones, distinguished by the maximum density allowed. The zones were as follows:

ZONE	MAXIMUM NUMBER OF DWELLING UNITS/ACRE	TYPE OF RESIDENCE ALLOWED
B	2049	High-rise apartments
C	36	Multi-family low-rise units and duplexes
D	18	Single-family units in one-quarter acre lots or smaller
E	9	Single-family units on larger lots
F	7	Single-family units on larger lots

  Land values in Zone C were found significantly higher than for Zone D whereas the values for Zones E and F were approximately the same as in Zone D.

- Amenities can be divided into social and aesthetic. Aesthetic amenities have been neglected, because no measure of such attributes was available, and six measures of social amenities were used: (1) the percentage of dwelling units in each block which were deteriorating or dilapidated; (2) crowding, as measured by the percentage of dwelling units in the block occupied by more than one person per room; (3) the percentage of the dwelling units in the block in which the head of the household was non-white; (4) median education in census tract; (5) median income ($/year) in census tract; and (6) location on either the north or the south of the city to test the significance of existing cultural differences. Only the first, fourth, and fifth of the above variables were found statistically significant.

The predictive power of the model was found poor. Reasons for the low quality performance included the inability to quantify many of the variables thought to influence residential land value and the neglect of dynamic factors in the analysis. Additional reasons may involve the fact that many of the variables were strongly correlated and as a result the estimates of the regression coefficients were noisy; also without having identified the significant variables it became difficult to detect inconsistencies in the data.

W. C. Pendleton conducted another multiple regression study whose purpose was to estimate the value that residents of the Washington, D. C., metropolitan area place on highway accessibility to job opportunities and to the central business district (Ref. 19). The approach consisted of analyzing a cross-section of sales prices of residential properties. As measures of accessibility he used linear distance to CBD, driving time to CBD, and an index for job accessibility which measures for any point within the metropolitan area the access to job opportunities. He also used median family income of the census tract to measure the effect of the quality of residential neighborhoods on the sales price. Houses were distinguished as single-story, one-and-a-half story, two-story, and semi-detached houses. Other variables accounted for characteristics of the residence such as size, construction material, number of bathrooms, age, etc.

The regression equations provided a very good fit ($R^2 \approx 0.90$) and among the three measures of accessibility, job accessibility was slightly better but driving time and distance were also adequate measures. The author concludes that each additional minute of driving time to the CBD reduced selling prices by about $64 and each additional thousand dollars of neighborhood median income added $350 to the price.

One might be interested in comparing the results of the two models but because the objectives of the two studies and the sets of variables used were so different a meaningful comparison does not appear possible. Neither study, however, used step-wise regression to evaluate the explanatory power of each variable and thereby establish a more meaningful and general model.

2. Conclusions from Literature Search

It follows from our discussion that it is not presently feasible to construct a general regression model that would estimate annual residential land values for any location and project area. Neither can it be expected that such a model could be constructed for each particular area where a flood-control project is contemplated without an amount of effort that would seem to be in excess of the gain in accuracy that might be derived. It is therefore our objective to first concentrate on identifying and quantifying the various factors that make up the advantage of one location over another for each type of residence and later on attempt to use these factors in model building.

From the Pendleton study we observe that only two variables remain if we compare two locations for the same house: the accessibility measure, and the median family income of the census tract. Using Downing's model and discarding variables statistically non-significant we may consider two more variables: the percentage of deteriorating or dilapidated structures and the median education. Both these measures, together with the median family income, belong to the category of social amenities or neighborhood factors.

The significance of these factors in our case is somewhat different. Since we are interested in projecting development of groups of residences on currently non-urban land rather than in building within an existing neighborhood, it is mainly the nature of nearby neighborhoods that may be of interest. Its significance will be smaller as developments get larger which has been to an increasing extent the case in recent years. Large scale projects allow a greater degree of control over the quality of the residential community in question so that the influence of the adjacent neighborhood is minimized.

Accessibility to the central business district is important for more than one reason. Not only does CBD provide employment opportunities, but it is also a cultural and entertainment center. However, such opportunities are not offered by the CBD alone, so that accessibility measures should take account of the distribution of various opportunities over a wider region. Such an approach is logically related to the origin and destination techniques used in transportation planning. We would thus distinguish between trips to and from work and trips made for entertainment, recreation, etc. This distinction implies the use of two accessibility measures: one for job accessibility and another for accessibility to other locations in the region. Narrowing the scope of the second measure down to what we deem important for our purposes, we may consider only trips for recreation. Finally, the difference in value between two locations with respect to accessibility can be taken to be equal to the difference in transportation costs.

C. Characterization of Location Advantage

Because our need has been limited to estimating only economic rent differences rather than total economic rents, we have identified the concept of locational advantage as the single component contributing to the difference in economic rent for the same activity in two alternative locations. The economic rent of an activity i on site ℓ is given by

$$S_{i\ell} = G_{i\ell} - C_{i\ell} \tag{5.1}$$

where

$G_{i\ell} \triangleq$ gross income of activity i on site ℓ

$C_{i\ell} \triangleq$ all costs incurred by activity i on site ℓ except for land rent and flood damages.

Given any two locations ℓ and k, the difference in economic rent or locational advantage for activity i is

$$\delta S_i = \delta G_i - \delta C_i$$

where

$$\delta G_i = G_{i\ell} - G_{ik} \tag{5.2}$$

and

$$\delta C_i = C_{i\ell} - C_{ik}$$

We now explore for which activity types the difference in gross income due to a locational difference is either negligible or is easily estimated and therefore locational advantage can be mainly characterized by the difference in costs. The implications of this in terms of data requirements and expected accuracy in benefit estimation are obvious.

Agricultural yield of land depends, among other factors, on the quality of the soil which in turn implies that activity gross income depends on the location. Therefore, for agricultural activities we must estimate locational advantage on the basis of differences in costs and gross income which, however, is not expected to be difficult. The same estimate provides the differences in equilibrium land rents that we have found quite useful throughout the benefit evaluation procedures.

Industrial activities do not depend, for their gross sales, on the particular site within the study area and consequently gross income differences for such activities can be considered zero.

Institutional activities such as schools and other public services usually serve the local community and therefore their location depends upon the location of that community while their value of service does not depend on it. There are facilities though, such as parks serving a wider area, where the value of the facility depends on its location. Such cases must be treated separately, and therefore activities of this type should be disaggregated accordingly.

Commercial activities can be classified in three broad categories:

a. Wholesale,

b. Region-serving retail,

c. Local business.

For wholesale and region-serving retail activities, gross income depends in general on location. But, as higher or lower sales of such activities will be compensated by decreased or increased sales of similar firms elsewhere, differences in gross income between various locations will not correspond to benefits or losses from the public viewpoint; that is, if all activities within a large enough area were considered, such differences cancel out. At the same time, costs of operation and commuting costs will be influenced by the level of sales; but for relatively small differences in sales these are clearly second-order effects as compared to cost differences obtained assuming no change in gross income and therefore can be ignored in the analysis. The location of local businesses depends upon the location of the community they serve. Thus their gross income depends on the nature of the community, but not on its specific location within the area. Therefore, gross income differences are not needed in estimating the locational advantage of commercial activities.

Residential activities' locational advantages depend greatly on amenity characteristics of the location and therefore the difference in gross income is important for estimating benefits. For residential activities gross income may be thought of as the value in dollars that residents assign to living in a particular house and location; or in other terms as their willingness to pay for living there. It is inclusive of any other outlays associated with the location, such as transportation costs, and therefore it is not equivalent to the maximum amount they would be willing to pay as rent for the residence. Thus, the maximum amount the residents would be willing to pay for rent, $V_{i\ell}$, is equal to $G_{i\ell} - C^t_{i\ell}$ where $C^t_{i\ell}$ is the commuting cost associated with that location. If the value of $V_{i\ell}$ could be estimated, then the advantage of location ℓ over location k could be obtained as

$$\delta S_i = \delta V_i - (\delta C^s_i + \delta C^c_i)$$

where $\delta V_i \triangleq (G_{i\ell} - G_{ik}) - (C^t_{i\ell} - C^t_{ik})$ = difference in willingness to pay (5.3)

$\delta C^s_i \triangleq C^s_{i\ell} - C^s_{ik}$ = difference in site development cost,

$\delta C^c_i \triangleq C^c_{i\ell} - C^c_{ik}$ = difference in construction cost.

Information obtained from market transactions reveals the willingness to pay of the marginal consumer. Such values underestimate the aggregate value by an amount equal to the consumer surplus. However, since we only need the difference δV_i and the consumer surpluses tend to cancel out, we could use market values to estimate it.

The conclusion of the foregoing discussion is that differences in gross income are important for estimating benefits only for agricultural and residential activities and for some types of institutional activities such as recreation serving an area wider than the local community. For residential activities differences in gross income can be captured by differences in market values provided that commuting costs are excluded from the cost difference.

D. Estimating Locational Advantage for Residential Activities

As we have seen, residential activities present, among urban activities, the case where differences in gross income between alternative locations within the study area have a bearing on the estimation of benefits. In this section we further explore methods for estimating the difference in value of residences plus location as previously defined.

The studies reviewed have not included the influence of natural and related amenities of locations. Such amenities must be considered in addition to the social amenities. The difference in value of the residence can then be expressed as the sum of differences related to the factors identified above, and

$$\delta V_i = \delta V_i^a + \delta V_i^s - \delta C_i^t \tag{5.4}$$

where

$$\delta V_i^a \triangleq \delta(\text{value of natural and related amenities})$$

$$\delta V_i^s \triangleq \delta(\text{influence of social environment})$$

and

$$\delta C_i^t \triangleq \delta(\text{commuting cost}).$$

The locational advantage can now be expressed as

$$\delta S_i = \delta V_i^a + \delta V_i^s - (\delta C_i^t + \delta C_i^s + \delta C_i^c) \tag{5.5}$$

where all the symbols have been previously defined. The factors included in (5.5) are now described in more detail.

1. Natural and Related Amenities

This type of amenities includes factors associated with the natural environment surrounding a specific site as well as the physical characteristics of the site itself. Examples include the view from the residence (over a lake, a parkway, etc.), proximity to recreational facilities, hillside location versus location in the plain, etc. Adverse effects include the smell of a brewery, a tanning operation, an oil refinery, heavy smog, noise, through-traffic, etc.

It may be possible to obtain at least rough measures of the value assigned to natural amenities by comparing market values of existing residences when other things are equal. The difficulty normally lies in finding a sufficiently representative sample so that the value of these amenities can be roughly estimated. In case such a task proves either impossible or costly, subjective estimates can be used and the sensitivity of the benefits determined. Given that the benefits are sensitive to the value assigned to natural amenities, more effort can be devoted to better assessing their value.

2. Social Environment Factors

A single criterion may be used such as the average income of adjacent communities. Because it appears difficult to quantify the impact of such factors, they should be considered only in cases where there is a big difference in income levels such as when there is a socioeconomically depressed area nearby the new housing development project. Thus, residential values near depressed areas can be studied to obtain a rough measure of their impact. Even though such a measure will be used only in particular cases, it is desirable to allow for this kind of flexibility in an automated evaluation procedure.

3. Site Development Costs

These costs include clearing, grading, and all other costs necessary to provide public improvements at particular sites, such as water, sewers, power, and transportation facilities. Since we are interested only in differences between alternative sites we can ignore those portions of the costs that are essentially the same for all sites. Thus, as a first approximation, we need only the number of lineal miles of transportation facilities, water mains and sewer interceptors, together with unit cost estimates for each. Clearing costs will depend on the amount of work involved and can be characterized as light, medium or heavy, while unit values ($/acre) can be estimated using a representative sample. The cost of grading will depend on whether rough or fine grading is required and on the steepness of the terrain.

4. Construction Costs

Construction costs that may differ from site to site include foundation cost which depends on the type of soil, and transportation costs for personnel, equipment and materials during construction. Foundations costs can be roughly estimated based on the type of structure and type of soil, such as: rock, common soil, sand, clay. Transportation costs during construction may significantly differ only between sites at a significant distance from one another in which case they will be calculated outside the simulator.

5. Commuting Costs

To compute the commuting costs for a given residential area we need estimates of: (a) the number of commuting trips, (b) the cost per round trip to each employment zone and (c) the distribution to employment zones of trips originating from the given residential area. A more sophisticated formulation would distinguish between use of private and public transportation.

(a) Number of Commuting Trips. The number of commuting trips will depend on the number of commuters, the number of working days, and car pooling arrangements. Thus, a simple formula would be

$$t = n_w p_e P/f \tag{5.6}$$

where

t = number of commuting trips

f = factor for car pooling (persons/car)

n_w = number of working days per year

p_e = percent active population

P = number of people in the given residential area

(b) The Cost Per Round Trip to an Employment Zone consists of the monetary cost and the value of travel time. Thus, the cost per trip to employment zone j is

$$c_j = c_j^r + c_j^t \qquad (5.7)$$

where c_j^r and c_j^t denote running cost and value of time, respectively. Given the distance to zone j, d_j, and the average running cost per mile, c^r, the running cost is equal to

$$c_j^r = 2c^r d_j \qquad (5.8)$$

To estimate the value of travel time, we need its unit value, u_t, the distance to zone j as above, the average speed of travel to zone j, $\bar{v}_j$, and the factor for car pooling mentioned earlier:

$$c_j^t = 2fu_t d_j/\bar{v}_j \qquad (5.9)$$

(c) Distribution of Work Trips to Employment Zones. A gravity model, as has been used in transportation studies, can be used to estimate the distribution of work trips to employment zones. Such trips are attracted to a different degree by each zone. The strength of this attraction is assumed to be directly related to the number of jobs in the employment zone and inversely related to some power of the travel time between the given residential area and the employment zone:

$$a_j = E_j/T_j^b \qquad (5.10)$$

where

a_j = index of attraction of employment zone j

E_j = number of jobs in zone j

T_j = travel time from the residential area to employment zone j

and

b = an empirically-determined constant related to the willingness of people to travel to work.

The percent of trips to employment zone j is then obtained by normalizing the indices so that the sum adds up to unity; i.e.,

$$p_j = \frac{a_j}{\sum_j a_j} \tag{5.11}$$

Consequently, given the total number of work trips from the residential area t, the number of trips to employment zone j is

$$t_j = p_j t = \frac{a_j}{\sum_j a_j} t \tag{5.12}$$

As mentioned above, the exponent b is empirically determined; it can be computed through an iterative procedure so that it can best predict the observed interchange of trips between employment zones within a given urban area.

E. Estimating Locational Advantage of Nonresidential Urban Activities

The locational advantage for urban activities other than residential can be measured by the difference in all costs incurred by the activity except land rent and flood damages (see Section C). This difference in costs is normally made up of three components: (a) the difference in site development cost, δC_i^s, (b) the difference in construction cost, δC_i^c, and (c) the difference in transport costs related to the operation of the activity, δC_i^t; i.e.,

$$\delta C_i = \delta C_i^s + \delta C_i^c + \delta C_i^t \tag{5.13}$$

Not all factors that influence locational choices, especially for industrial and commercial activities, are included in (5.13), e.g., nearness to markets, available labor supply, existence of water supply, etc. These factors may not be critical when relatively small study areas are being considered. However, larger areas may have to be considered in the future and therefore the possibility of expanding Equation (5.13) will be kept open. The method and detail of measurement will be reviewed in future efforts.

Costs for site development and construction do not differ conceptually from corresponding costs incurred for residential development; therefore, their estimation would require the same kind of information as for residential activities. Transport costs, however, are different and require different kinds of information.

The first point that needs to be made about transport costs for other than residential activities is that they do not include commuting costs to and from work, since those are considered in relation to residential activities and their inclusion here would involve double counting. Only costs incurred by the activity itself should be included, e.g., costs of business trips and for transportation of activity inputs, such as raw materials, and activity outputs, such as finished products. The number of such trips generated by each activity type has to be further differentiated in the case of non-residential activities to account for the diversity of vehicle types used, such as automobiles and light, medium and heavy trucks, since the running cost per mile differs accordingly. Furthermore, activity types would have to be properly disaggregated to account for the fact that the amount of traffic generated by different activities of the same general category may vary widely among them; e.g., food industry may require transport of a very different volume of goods than furniture industry.

Once we have the number of trips per vehicle type for each type of activity, the additional information required in order to estimate transportation costs is similar to that for commuting trips. However, the trip distribution needed to estimate trip lengths seems more difficult to obtain in this case and probably one would have to rely on assumptions based on informed judgment rather than on a derivation from a model.

F. Summary

This chapter addressed the problem of estimating differences in economic rents. It started by reviewing existing literature, in particular for the case of residential activities where most of the work on market values of land or residential property has been done. It was seen that existing models have serious limitations; they provide, however, a guide with respect to the significance of variables included in the analysis. The conclusion was that it is not presently feasible to construct a general regression model that would estimate residential values for any location and project area under consideration, whereas the effort required to construct such a model for each particular project area is not warranted. We thus concentrated on identifying and quantifying the various factors that make up the advantage of a location over an alternative one.

The problem of estimating locational advantage reduces to estimating differences in costs for activities whose differences in gross income are either negligible or easily estimated. Each activity type was examined from this viewpoint, and it was concluded that gross income differences are important for estimating benefits only for agricultural and residential activities and for some types of institutional activities such as recreation serving an area wider than the local community. Obtaining estimates concerning agricultural activities is not expected to be difficult because extensive studies on productivity have been performed in this area. Thus, the main problem is presented by residential activities and a section was devoted to the problem of estimating the locational advantage for such activities. The components identified as making up locational advantage include the differences in value placed on natural and related amenities and on the social environment, and the differences in activity costs such as commuting costs, site development cost, and construction cost. These components were then examined in turn with the objective to identify the factors entering their determination and to lay the conceptual base for their quantification. Because of the many factors entering the commuting costs we presented a rather detailed model for their estimation, although it is not clear at this time whether the effort required to include such a model in the simulation program is warranted or if something much simpler can be used.

The problem of estimating locational advantage for urban activities other than residential was dealt with briefly for the purpose of evaluating benefits. The differences in gross income were felt to be insignificant for estimating benefits, and costs for site development and construction do not differ conceptually from corresponding costs incurred for residential development. Transportation costs, however, presented a different case; the differences were pointed out and it was concluded that estimates of these costs are more difficult to obtain than cost estimates of commuting trips, and therefore one would probably have to rely on assumptions based on informed judgment rather than on derivation from a model. Since the main emphasis was on benefit evaluation not all factors related to the location of commercial and industrial activities were included in the above.

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13. ABSTRACT

This publication presents analytical progress in the development of a computer simulation model for flood plain development. A conceptual model was developed which includes the following five major parts: forecasting population and economic activities; allocating activities to available land; integrating public policies restricting land use; measuring and projecting flood damages; and evaluating benefits based on appropriate formulas using flood damages reduce, land rents, and economic rent differences (locational advantages). Several concepts are introduced to solve probelms associated with development of a simulation model including; a practical definition of the study area in conjuction with a dummy location; a two level allocation for land use planning; the use of economic rent differences and equilibrium land rents in benefit measurement instead of only economic rents; and the use of cycles of relocations as an aid to orderly evaluation of benefits.

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