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A REGIONAL PLANNING APPROACH TO THE FLOODPLAIN MANAGEMENT PROBLEM*

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1. INTRODUCTION

The research reported here deals with the problem of planning land use and engineering alternatives for floodplain management. An analytical and decision making methodology has been developed in this study.

The methodology can consider <u>land use regulations</u> such as zoning ordinances, subdivision regulations, and building and housing codes; <u>development policies</u> such as direction of services and utilities, acquisition or open space uses, redevelopment and renewal, and permanent evacuation; <u>engineering measures</u> such as dams, reservoirs, levees, floodwalls and channel alterations. The objective of the floodplain management system model is to select the most economically efficient combination of land use and engineering alternatives. A computer-based mathematical optimization approach is used to select the combination of management alternatives that will maximize the aggregate economic productivity of all land resources within a study area subject to an appropriate set of planning constraints.

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*The research presented in this paper is extracted from a Ph.D. dissertation recently completed at the University of Arizona which should be published this spring by the National Technical Information Service as a U.S. Army Corps of Engineers Institute for Water Resources report. Electronic data processing experiments were conducted at the University of Arizona Computer Center.

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2. PROBLEM

In the American past, flood damage control planning has been usually limited to the economic evaluation and implementation of engineering works designed to regulate streamflow. While federal agencies have concentrated on this means of attaining floodplain management objectives, local governmental planning has often sought better solutions to the problem by encouraging intelligent use and development of floodprone land.

A coordinated planning effort by local and federal agencies could result in a synergistic effect on the overall ability of planners to meet many objectives, including economic efficiency. The reason that a comprehensive planning approach (considering all relevant means including land use and engineering alternatives) has rarely if ever occurred is suggested by the U.S. Water Resources Council [8]:

> Perhaps the root of the institutional problem is the lack of a <u>conceptual framework</u> and incentives such as planning grants that permit a unified and unbiased approach by all concerned (emphasis added).

The floodplain management system model (FMS) developed and tested in this research project provides a conceptual framework for facilitating interagency interaction by integrating land use and engineering means of attaining floodplain management objectives.

3. ECONOMIC RENT

The unifying principle in this study is the concept of economic rent. A body of economic literature pertinent to the floodplain management problem (including Renshaw [5], Pendleton [4], Day [2], Boxley [1], and Struyk [6]) is devoted to a theoretical analysis of the impact of floodplain management alternatives on the income potential of land resources. Rent is commonly defined as the net gains associated with a resource, and as such is synonymous with economic efficiency returns.

The economic rent of a parcel of land may be computed as the sum of the annual net returns discounted to their present value. This relationship can be expressed in the following way:

$$(1) \quad SR = \sum_{n=0}^{N} \frac{A_n}{(1+d)^n}$$

where:

SR = site rent to a parcel of land

N = total number of years in the planning horizon

n = index denoting a particular year

A_n = annual net return in year n

d = discount rate.

The net annual return to a parcel of land in time period n is defined as the gross annual return minus the annual total non-land cost. Economic rent can be used as an efficiency index to evaluate the combined effectiveness of alternative means of attaining floodplain management objectives.

Management Impacts on an Individual Site

The following relationship can be used to evaluate the impact of a floodplain management system on the economic productivity of an individual parcel of land that is subject to land use regulations.

$$(2) \quad SR_{ijfpts} = LV_{ijt} - CF_{ijft} - CP_{ijpt} - SD_{ijfpts} - OD_{ijfpts}$$

where:

i = index denoting a specific land use,

j = index denoting a specific location,

f = index denoting a specific level of fill,

p = index denoting a specific level of floodproofing,

t = index denoting a specific time period during which development for land use i may begin to occur at a site at location j,

s = index denoting specific development policy and/or engineering measures considered,

SR_{ijfpts} = site rent to the ijfpt activity given public investment in s,

LV_{ijt} = "land value which would be expected in the absence of a flood hazard" to the ijt activity,

CF_{ijft} = cost of fill to the level f for the ijt activity,

CP_{ijpt} = cost of floodproofing to the level p for the ijt activity,

SD_{ijfpts} = residual site damages to the ijt activity after private investment in fill to level f and floodproofing to level p, and after public investment in s,

OD_{ijfpts} = residual off-site damages associated with the ijt activity after private investment in fill to level f and floodproofing to level p and after public investment in s,

where all terms in the site rent equation are stated in terms of present value.[1]

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1. A few items of interest should be stated. Equation (2) may be taken as an illustration of how a site rent equation can be defined. Minor modifications of this equation may be desirable from one application of the methodology to another.

For example, for the purpose of illustration in this study, floodproofing is defined to include all means of modifying the susceptibility to flooding (of a building and contents) other than the employment of dirt fill. Hence, the costs of fill and floodproofing are indicated as two separate terms in the site rent equation. However, floodproofing may also be defined so as to include the concept of site elevation through fill; where this is done the costs of fill and other means of floodproofing may be lumped together in one term. A joint cost of fill and floodproofing may also be appropriate if their costs are independent.

The letter "t" is used as an index to denote a time period that is relevant for land use planning. It does not necessarily denote a particular month, day, or year within a planning horizon; different lengths of time may be associated with different values of t. For example, there may be three time periods, t = 1, 2, and 3, in a fifty year time horizon that are relevant for land use planning; the first two time periods may each be five years in length and the third time period, t = 3, may be forty years in length.

Aggregate Impact on all Regulated Sites

The following relationship can be used to evaluate the impact of a floodplain management system on the total economic productivity of all parcels of land within the planning area that are subject to land use regulations:

$$(3)\quad ASR_s = \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{t=1}^{T} R_{ijfpts} \cdot X_{ijfpts}$$

$$= \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{t=1}^{T} (SR_{ijfpts} \div L_i) \cdot X_{ijfpts}$$

where:

I = total number of land uses,

J = total number of locations,

T = total number of time periods within the planning horizon,

ASR_s = aggregate site rent of all parcels of land within the planning area that are subject to land use regulations given public investment in s,

SR_{ijfpts} = site rent to the ijfpt activity given public investment in s,

R_{ijfpts} = rent per acre to the ijfpt activity given public investment in s,

L_i = lot size, in acres, associated with land use i,

X_{ijfpts} = acres of land assigned to the ijfpt activity given public investment in s; and

where all other items are defined as before. This equation indicates that the present value of the total sum of the net annual returns of all parcels of land subject to land use regulations is a function of the pattern, mode, and timing of regulated land use activities inside and outside the floodplain that are "planned around" development policy and engineering alternatives.

Aggregate Impact on the Entire Planning Area

The planning area consists of all land resources whose productivity is affected by a floodplain management system. The following equation may be used to evaluate the aggregate economic productivity of all land resources within the planning area:

(4) $AER_s = ASR_s - RDED_s - C_s + OB_s - OC_s$

where:

s = index denoting a particular development policy and/or engineering measure considered,

AER_s = aggregate economic rent of the planning area given public investment in s,

ASR_s = aggregate site rent to activities affected by land use regulations given public investment in s,

$RDED_s$ = residual damages to existing development given public investment in s,

C_s = cost of the engineering measures associated with s,

OB_s = other benefits associated with s but not accounted for in the first three terms of the aggregate economic rent equation,

OC_s = other costs associated with s but not accounted for in the first three terms of the aggregate economic rent equation; and

where all of the terms in the above equation are stated in terms of present value. The aggregate economic rent of a floodplain management system measures the combined economic efficiency of land use and engineering alternatives. The aggregate economic rent equation accounts for the total economic productivity of all regulated land resources, the residual flood damages to existing development, the costs of the engineering measures, and other benefits and costs related to the particular development policy and/or engineering measure considered.

There is a strong theoretical foundation for using aggregate economic rent as a basis for planning. For example, quoting Gaffney [3]:

> . . . government represents landholders collectively, and it is the medium through which they must act to supply their parcels with certain kinds of collective improvements . . . The true latent potential rent of lands is that which would be obtained if local government as well as individual landholders behave optimally.

Although Gaffney's remarks were in relation to the role of local government, the sentiment holds in a broader context as well.

4. THE FMS (FLOODPLAIN MANAGEMENT SYSTEM) MODEL

The aggregate economic rent equation developed in the preceding section forms the basis of the FMS model. The general economic problem the planner must solve is to determine that combination of land use regulations, development policies, and engineering measures that will maximize the overall economic efficiency objective subject to various physical and institutional constraints. This problem is expressed by the general form of the floodplain management system model:

$$(5)\quad \text{Maximize } AER_s = ASR_s - RDED_s - C_s + OB_s - OC_s$$

subject to the appropriate set of constraints where all of the terms in the objective function are defined as earlier; see equation (4) in the preceding section for definitions. The specific formulation of the appropriate set of constraints will vary from one application of the FMS model to the next.

5. THE LAND USE REGULATION MODEL WITHIN THE FMS MODEL

Within the overall floodplain management problem is an urban land use planning subproblem. The approach adopted in this study views a local community as a single entrepreneur who is seeking the most economically efficient way of combining scarce land resources with a development policy and engineering measure that is being tentatively considered. The approach has been placed within the framework of a general maximization problem that seeks to select values for a set of decision variables such that the economic objective function is maximized subject to the appropriate set of constraints. In the case of the land use regulation planning problem, the decision variable, X_{ijfpts}, indicates the acres of land assigned to the ijfpt activity given public investment in s. The value of the objective function, aggregate site rent, is one indicator of the general economic welfare of the community. The constraint set can define a number of limitations on the ability of a land use regulation plan to maximize the economic productivity goal; this may describe the community's land resources endowment and population growth potential for example.

The linear programming constraints are numbered and briefly explained as follows: Constraint 1 indicates the quantity of land that can be regulated in each location j; Constraint 2 (a) indicates the level of population growth associated with each type of land use that must be accommodated by the model within each time period; Constraints 2 (b), 2 (c), 2 (d), and 2 (e) define the relationship between the location of business and commercial land uses and the location of residential land uses; Constraint 3 (a) is the non-negativity constraint.

Constraints 3 (b), 4, and 5 are additional requirements that must be satisfied outside of the LP computational algorithm, but within the land use regulation model. Constraints 3 (b) and 4 reduce the number of activities that must be considered by the LP model. Constraint 5 determines the value of the right-hand-side element in Constraint 1, i.e., the quantity of land that can be regulated in each location j. The output of this last set of constraints serves as input to the LP model.

The following statement defines the land use regulation model:

$$\text{(6)} \quad \text{Maximize } ASR_s = \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{t=1}^{T} R_{ijfpts} \cdot X_{ijfpts}$$

subject to:

Constraint 1:

$$\sum_{t=1}^{T} \sum_{i=1}^{I-1} X_{ijfpts} + X_{Ijfpts} = A_{js} \quad j = 1 \ldots J$$

Constraint 2(a):

$$\sum_{j=1}^{J} d_i \cdot X_{ijfpts} = P_{it} \quad \begin{matrix} i = 1 \ldots I-2 \\ t = 1 \ldots T \end{matrix}$$

Constraint 2(b):

$$PPBA \cdot X_{I-1,jfpts} - \sum_{i=1}^{I-2} d_i \cdot X_{ijfpts} = 0 \quad \begin{matrix} j = 1 \ldots D \\ t = 1 \ldots T \end{matrix}$$

Constraint 2(c):

$$\sum_{j=D+1}^{D+12} PPBA \cdot X_{I-1,jfpts} - \sum_{i=1}^{I-2} \sum_{j=D+1}^{D+12} d_i \cdot X_{ijfpts} = 0 \quad t = 1 \ldots T$$

Constraint 2(d):

$$\sum_{j=D+13}^{D+16} PPBA \cdot X_{I-1,jfpts} - \sum_{i=1}^{I-2} \sum_{j=D+13}^{D+16} d_i \cdot X_{ijfpts} = 0 \quad t = 1 \ldots T$$

Constraint 2(e):

$$\sum_{j=D+17}^{D+20} PPBA \cdot X_{I-1,jfpts} - \sum_{i=1}^{I-2} \sum_{j=D+17}^{D+20} d_i \cdot X_{ijfpts} = 0 \quad t = 1 \ldots T$$

Constraint 3(a): $X_{ijfpts} \geq 0$ for all i, j, f, p, t, s.

Constraint 3(b): $X_{Ijfpts} = 0$ for all $t > 1$

Constraint 4: Choose $X_{\underline{ijfpts}}$ s.t. $R_{\underline{ijfpts}} \geq R_{\underline{ij}fp\underline{ts}}$ for all $fp \neq \underline{fp}$

Constraint 5: $A_{js} = A_j - EXOG_{js}$ $j = 1 \ldots J$

where:

D = number of locations (j=1...D) that are outside the floodplain,

A_{js} = acres of land in location j available for assignment by the model to regulated land use activities given public investment in s,

P_{it} = population growth forecast associated with land use i in time period t,

d_i = population per acre of residential land use i,

PPBA = population per business acre coefficient,

A_j = total acres of land presently suitable for site development in location j, and

$EXOG_{js}$ = total acres of land in location j which will be publicly acquired by public investment in s, and

where all other terms are defined as before.[2]

6. TESTS AND EXPERIMENTS WITH THE FMS MODEL

A test application of the methodology by Wesiz and Day [7] in Pima County, Arizona specifically examines economic rationale and decision rules for determining the most economically efficient combination of:

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2. Just as equation (2) may be taken as an illustration of how a site rent equation can be defined, the above set of equations should be considered an example of how the land use regulation problem can be structured as a linear activity analysis problem.

Modifications of this model may be desirable from one application of the methodology to the next. For example, a more complete set of constraint equations may be necessary.

(a) spatial[3] and temporal distribution of urban land uses,

(b) site elevation through dirt fill,

(c) floodproofing,

(d) public acquisition of undeveloped land for open space uses,

(e) public acquisition and removal of existing improvements from the floodplain,

(f) dams, and

(g) channel improvements.

There is not enough space available in this report to describe the results and conclusions of the tests and experiments with the FMS model. However, the demonstration study has illustrated how the methodology can be used to:

(a) formulate floodplain management system plans,

(b) evaluate the economic impact of floodplain management system plus,

(c) perform "with and without" analysis,

(d) perform incremental analysis of development policy and engineering alternatives, and

(e) perform sensitivity analysis.

Hopefully, the model developed in this study can aid planners in achieving a unified, unbiased approach to floodplain management.

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3. Site alternatives consist of floodplain and upland locations.

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