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An Allocation Model for Catchment Land Use Planning

"SUMMARY" A quadratic programming model, previously used in city planning problems is being used to develop optimal land use plans for the catchment of the Murray River in Western Australia. Land use activities considered include natural and plantation forestry, three types of agriculture, mining followed by production or protection forestry or agriculture, national park and water storage. Benefits evaluated cover the primary products, water and its salt and sediment load, recreation and conservation.

INTRODUCTION

Control over land use in catchments varies from nil to absolute, depending on the history, size and characteristics of the catchment and the use made of the land and water. How much control should be exercised? The objective could be to maximise the merit or utility of the catchment to the community. This involves selecting an optimal set of activities for each zone of a catchment. It is unlikely that this optimal set will be achieved under a *laissez-faire* policy because some of the costs and benefits do not accrue to the landowners. Catchments yield, among other things, water, salt, sediment and aquarian fauna in the river system; timber, crop, animal and mineral products from the land, industrial sites, transport links, recreation and living areas for man's activities, as well as containing biological populations and scenic beauty which may justify conservation. Landowners are not paid for many of these products, and therefore legislative control of catchments is often required.

Organizations, interested in performing research into questions of catchment management, need to justify the importance of their activities. This requires some formalised structure of catchment management decisions, which can then be used to identify the sensitivity of catchment management to the process or parameters being measured, and so dictate the accuracy necessary in the studies. (Currently CSIRO has two research projects relating to catchment land use in Western Australia, i.e., salinity and vegetation hydrology, while the State Forests Department is concerned, not only with these areas, but many aspects of forest management which govern water yield and quality.)

The problem of catchment management can be subdivided into two parts: determining the optimal set of activities to maximise the utility to the community, and implementing controls to achieve that optimal set. This paper is solely concerned with the first part.

MODEL

The model being used to represent catchment management decisions is a modified version of the quadratic programming model developed by Brotchie and others (Ref. 1, 2, 3, and 4) to optimally allocate activities to zones over a set of time periods.

The problem is to select an optimal set of activities A, with elements $\{a_{ijm}, a_{kln}, \ldots\}$ to maximize a measure of merit U(A) such that:

$$U(A) = \sum_{ijm} b_{ijm}\, a_{ijm} + \sum_{ijk\ell mn} b_{ijk\ell mn}\, a_{ijm}\, a_{k\ell n} \qquad (1)$$

subject to the constraints that

(i) all zones must be filled during all time periods

$$\sum_i a_{ijm} = Z_{jm} \qquad (2)$$

and (ii) activity allocations must be non-negative

$$a_{ijm} \geq 0 \qquad (3)$$

in which a_{ijm} (a_{kln}) = amount of activity i(k) allocated to zone j(l) in time period m(n).

b_{ijm} = total benefit less cost of establishing and operating activity i in zone j during time period m.

$b_{ijk\ell mn}$ = total benefit less cost of interaction between activity i in zone j in time period m, and activity k in zone ℓ in time period n.

Z_{jm} = capacity of zone j in time period m.

Additional constraints of the following form are useful:

(iii) The amount of an activity in a time period to be less than, equal, or greater than a given value:

$$\sum_j a_{ijm} \; (<, =, \text{ or } >) \; Y_{im} \qquad (4)$$

(iv) The amount of an activity in a particular zone in a given time period to be a fixed value:

$$a_{ijm} = X_{ijm} \qquad (5)$$

(v) The level for a component of merit function to be less than, equal, or greater than a given value:

$$\sum_{ij} b_{ijm} a_{ijm} \; (<, =, \text{ or } >) W_m \qquad (6a)$$

$$\sum_{ij} b_{ijk\ell mn} a_{ijm} a_{k\ell n} \; (<, =, \text{ or } >) T_m \qquad (6b)$$

The above formulation is a quadratic programming problem with IJM elements, where I, J and M are the numbers of activities, zones, and time periods, respectively. The formulation may be solved by iterative linear programming techniques.

A computerized version of the model called TOPAZ-WA (Technique for the Optimum Placement of Activities into Zones - WAter catchment and land use version) has been programmed in FORTRAN for the CDC 6600 and Cyber 7000 series computers.

APPLICATION

It is difficult to test the value of a plan before implementation. One can however ask whether the solutions appear to satisfy the goals of planners and their clients or, at a lower level, whether the solutions appear feasible, or even sensible. One could also ask whether all the factors which bear on the problem have been adequately represented in the model.

To provide a test for the model, it is presently being applied to the catchment of the Western Australian Murray River, an area of 708,400 ha. This is one of the most extensive catchments in the Darling Range. Most of the catchments to the north, up to, but not including the Swan-Avon, are already or will soon be used for Perth's water supply. Land use in these catchments is restricted almost entirely to commercial forestry. Many of the catchments to the south have been dammed for irrigation supplies. Within the Murray catchment there are a variety of existing and competing land uses.

The activities considered within the catchment are national park, natural and plantation forestry, orchards, grazing alone and in combination with cropping, bauxite mining followed by protection or production forestry or farming, and water storage. The catchment has recently been mapped (McArthur and Churchward pers. comm.) into geomorphologic units (ref. 5) and these provide suitable homogeneous zones for the model. Land use studies by the participating organizations provide a link between geomorphology, vegetation and land use. Interactions between activities within zones take the form of costs of fire control, harbours for pests, dispersion of operation, etc.

Precipitation across the catchment varies from 500 mm in the headwaters in the agricultural areas of the Narrogin region to 1300 mm on top of the Darling Range around Dwellingup. Approximately 45 per cent of the catchment is already cleared, causing severe salinity problems (the present average is 1200 p.p.m. total dissolved salts). Hillman (ref. 6) states that the river or its tributaries will almost certainly be used for metropolitan water supply in the second half of the 1980's. If this is so, then a carefully formulated catchment land use plan is urgently required.

The benefits and costs have been divided up into a number of separate matrices in order to differentially weight them and constrain them for different solutions. The matrices developed in this study are: net present value of the land use activity (royalties, taxes and other transfers are not included in the costs), water, salt and sediment yields of each zone under each land use activity, conservation and recreational values.

It has been found necessary to use all the additional constraints to adequately represent the problem. Constraints of type (iii) are required to restrict the allocation of land to mining activities in any time period, to be less than the planned refinery capacity within the same period. Also, due to inadequate representation of market supply and demand, and the current poor prospects for orchard fruit sales overseas, orchards are constrained to their existing area. The type (iv) constraint is required to zone an area for water storage, when evaluating different dam proposals. Constraints of type (v) can be used to ensure the value of conservation or recreation is maintained or increased over time.

There are three additional problems in describing conservation values. Firstly, aggregation of a number of species with differing habitat requirements to produce one conservation value may result in solutions where many of one species are conserved, while several of the others become extinct. This can be overcome by having individual matrices for each, since relatively few species require special conservation in this catchment. Scarcity also dictates value (1000 numbats are worth preserving, 1,000,000 numbats would probably be considered a plague). The model is being adjusted to allow value (b_{ij}) to be a function of the size of the activity (a_{ij}) in these situations. Finally conservation values may well depend on activities in other catchments or other states. These boundary problems can only be studied by sensitivity studies of the solution to different conservation values.

By changing the weightings (b_{ij}) of the objective function the viewpoints of the different parties concerned with land use can be represented. Table 1 represents the sign of the weighting coefficients for possible groups. It is unlikely that the parties are as single-minded in real life as they are represented in the Table, but conflicts in viewpoint and plan can be explored by sensitivity tests of these weightings.

The present formulation of the problem allows for changes in both the weightings and the data specifying the catchment; so that, as values change with time, new solutions can be generated, and reformulated plans obtained.

I

Possible weightings of the benefit/cost matrices
by parties interested in catchment management

Matrix	"Land owner"	"Water supply agency"	"Average citizen"	"Land use agency"
Primary production	+	0	0	+
Interactions between users	+	0	0	+
Water yield	0	+	0	+
Salt yield	0	–	0	–
Sediment yield	0	–	0	–
Recreation	0	0	+	+
Conservation	0	0	+	+

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