# SYSTEMS ANALYSIS IN NATURAL RESOURCES MANAGEMENT

E. T. Bartlett[1]

## Biographical Sketch

Mr. Bartlett is a native of New Mexico, where he obtained his high school education. His undergraduate work included courses at Ft. Lewis College in Durango, Colorado and Utah State University at Logan, Utah, where he was awarded a Bachelor of Science Degree in Range Management in 1965. During his undergraduate training, Mr. Bartlett worked for the Bureau of Land Management. To continue his education, the University of Arizona awarded him an assistantship in the Department of Watershed Management. He completed his Masters work in 1967. Research during this time was concerned with herbicidal effects on creosotebush and the relationship to carbohydrate levels of the plant. Mr. Bartlett is currently completing the requirements for a Ph.D. in Watershed Management at Tucson. His course work and interests have been in statistics, economics and systems analysis. He is currently Associate Coordinator of the Tucson Site of the Desert Biome Study, a part of the International Biological Program, and also works under an Agency for International Development grant for studying Systems analysis in Watershed Management.

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Forest, range, wildlife and watershed managers have based their decisions on an impirical interpretation of basic inventory data. While this method of decision making is used widely and has essentially been the only one available, researchers are now in the position to develop allocation models for natural resources using systems analysis. Systems analysis evolved during World War II when it was used as an aid in logistic decisions. After the war systems analysis was applied in the business world for allocating resources, products, or personnel to meet demands. However, only within the last ten years has systems analysis, through allocation models, been used in natural resource management; and this use has been primarily in water allocation and

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[1] University of Arizona

reservoir operation (4, 6, 7, 9). Some allocation models have dealt with other natural resources such as range forage or timber. But these have either been extremely limited in the resource base considered (8), limited to a particular problem concerning one or more resources (1), or both.

Models are needed which will deal with a much broader range of resources and problems. Natural resource managers, faced with decisions concerning the allocation of funds in resource conservation and development efforts, must be able to predict specific benefits resulting from the investment or allocation of limited funds and manpower available to them from the basic data of resource condition and potential. Existing techniques can be adapted and new techniques developed to produce a meaningful transition from inventories to decisions which enable the manager to use past knowledge and experience, as well as economics, physical relationships of the natural system, and the ecological and social constraints. A resource allocation model would provide such a transition. A model can and should incorporate a larger number of alnatives than the typical manager would consider in the empirical process. It is not to be implied that such a resource allocation model would eliminate all empiricism from resource planning, but that the decisions will be based on a quantitative analysis. Because uncertainties will always be present and knowledge will never be perfect, final decisions will always be tempered by the manager's judgement.

In fact, such models will be linked to the manager's experience and expertise in three ways. First, the decision maker must specify his objectives and goals so that they can be incorporated in the systems analysis program. Second, the manager always has certain levels of production which he must meet, and these minimum levels of production can be incorporated into the model as constraints. Finally, after the management plan has been developed with the model, the manager must still make the decision of whether it should be implemented.

## A Desired Model

In developing a model that would serve as an effective tool in managing natural resources for multiple objectives, a factor common to all objectives is needed. Two possible factors are the fundamental inputs to the natural system, water and energy. Since water, once it enters the system, is more amenable to management, it provides this factor. It is also convenient that the watershed basin is a natural ecological area where in a balance can be struck between inputs and outputs of water and energy. As such it provides the logical management area. Even though water can be used to relate the components and products of the ecosystem, monetary and social values will still be used to evaluate and compare alternatives to the decision maker.

What should a resource allocation model include to be an effective management tool? Certainly it should include the following submodels as components:

1. A stochastic submodel of rainfall.
2. A hydrologic submodel that will synthesize the effects of land treatment and management practices on water yield.

3. An operational submodel which will actually serve as the tool for managers.

Of the above components, the first two provide information and linkages for the last and will be very briefly covered.

### Rainfall Submodel

Precipitation is a major input to the natural system, and one that the manager cannot control. Rainfall occurrence must be predicted in order for the model to predict future events. Stochastic models of rainfall such as the one developed by Fogel and Duckstein (3) are promising. Their model at present requires only two parameters, the mean number of storm events per year and the probability of having rain at a point given an event has occurred. It is necessary that this model or a similar one be expanded so that sequential events are generated over the long term.

### Hydrologic Submodel

Several hydrologic models are in existence (2, 5), and it should be possible to adapt these for the needs of the allocation model. The hydrologic submodel will provide not only the results of an alternative, but will also give feedback to the operational model which may in fact alter the result of that model.

### Operational Submodel

The operational submodel is actually the tool for the decision maker and incorporates the output from the other submodels of the system. This is where systems analysis methods will be used to guide resource managers. It combines technology and economics, subject to the constraints of the physical system, social patterns, politics, and money available. In the operational submodel, the wide range of treatments that can be imposed on a watershed are considered as alternatives to the manager. This does not mean that an unrealistic treatment would be considered for a particular management unit. The components of the area would be classified by some system and the model would only consider treatments amenable to a particular class. The resource allocation model is further explained in the following example.

### Example

This example represents an extremely simplified representation of an allocation model concerning natural resource development and is illustrated in Figure 1. The model considers only two products of a water basin: water and forage. Forage is considered only as an on-site product while water can be used both on the site and down stream. Because this model is simplified and is a prototype for future model development, only a very limited number of management alternatives are considered, and those are manipulative treatments which increase forage yield.

The water basin is divided into subwatersheds or management areas. The subwatershed is then divided into management units. The management unit is an area which is sufficiently homogeneous to permit the decision maker to assume

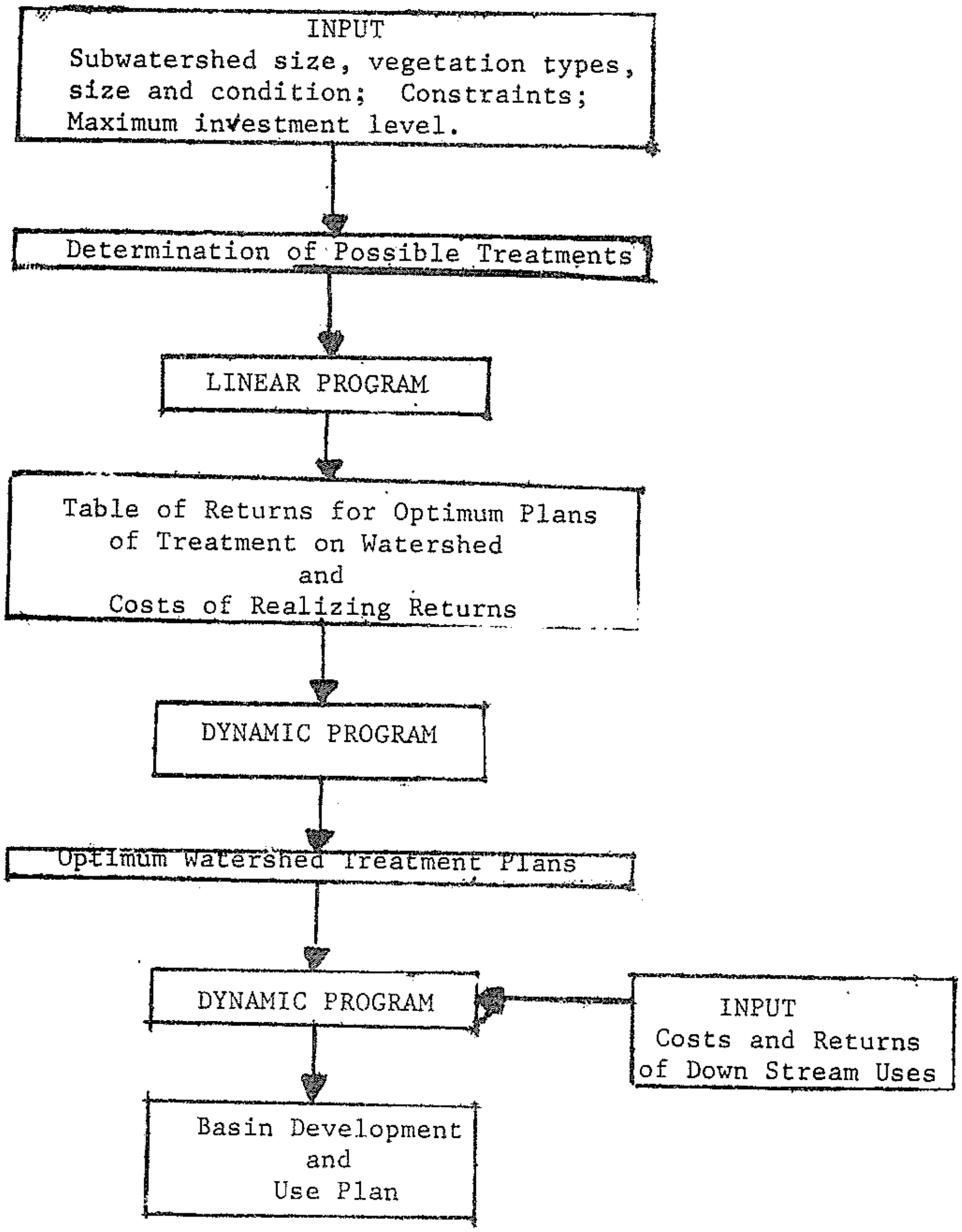

Figure 1: Simplified flow chart of the resource allocation model.

that each acre of that area will respond to treatment the same as every other acre. This assumption never completely holds in the real world, but is necessary because of the continuous manner in which the parameters governing treatment response occur. In this example the management unit was assumed to be a general vegetation type. However, this could be refined further to a more specific vegetation classification or even a vegetation-soil classification.

The model utilizes two techniques of systems analysis: linear programming and dynamic programming. From basic inventory data, constraints and the maximum level of investment, linear programming is used for each subwatershed to determine the optimal treatment or development plan for an array of investment levels. Both the costs and returns of the treatments are compared over a common planning horizon by discounting to present values. The results are then used for the dynamic program in which the subwatersheds are stages and the level of investment is the state variable.

By using the dynamic program, the manager is given a guide in allocating his investment among the subwatersheds for the investment levels. An additional cost to the alternatives is the requirement for water by livestock if the increased forage production is to be utilized, and the cost of supplying that water using small reservoirs. This is a realistic constraint within the model because the increase in income from increased forage is not realized unless that forage is utilized.

After an investment is made on the watershed, a basin decision must be made concerning the use of the water produced when the plan is implemented. Such a decision can again use dynamic programming as a tool. In this case, water may be used for agricultural purposes, by municipalities, or possibly for recreation. The different uses are the stages of the program while the state variable is the amount of water used by a stage. The basin benefits include on-site benefits and the down stream benefits of water use. Finally by combining the results of the two dynamic programs the manager is given a guide to watershed development and use of the water that would be produced.

It is hoped, through the development of this model as well as the development of other resource allocation models, managers will be provided a tool that will guide them in their decision making process. It is good to reiterate the idea that good common sense is the final step in decision making and that man has the last say. However, it is useful to note that even though the source of knowledge in computer models is man, the computer has the advantage of total recall and an unfailing memory.

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