AN ATMOSPHERE-ORIENTED ECOSYSTEM SIMULATION MODEL

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A human urban-rural ecosystem has been modeled numerically and run on the National Center for Atmospheric Research CDC 6600 computer system. A decision-making executive routine coordinates the interactions between five submodels. These second level subroutines comprise a statistical atmospheric model, a hydrology model, a city model, a biology, and a botany model. The present paper will give a brief description of the scheme and show specifically the manner in which the people in the city move in response to air pollution.

The development of this model was begun both for teaching and for research purposes. Pedagogically, it is important to relate both the atmosphere and the atmospheric scientist to the ecosystem of which they are a part. As the scientist comes increasingly close to being capable of effecting significant modifications to the atmosphere, it is vital that he have some mechanism through which to make an objective assessment of the long-term consequences of his tinkering. The research involves the development of such a mechanism through the use of computers which can analyze the observations obtained from carefully designed field experiments.

In the first attempt by the University of Oklahoma meteorology group to make such a computer model (1), a simple rain-grass-grasshopper ecosystem served to whet the appetites of both students and research workers. Since that time, seminars and contact with other groups in the field have led to the more comprehensive model presented in this report. While the new model is admittedly still naive, it contains the flexibility and logistics necessary to permit its growth into a useful diagnostic tool.

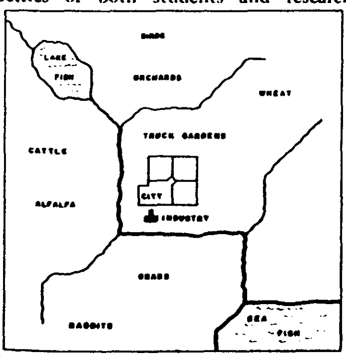

Figure 1. An urban rural ecosystem. The total ea shown is 256 miles square.

SCOPE OF THE MODEL

Figure 1 shows the main characteristics and physical dimensions of the system which has been simulated. Man plays two roles: firstly, as a portion of the zoology and, secondly, as a manipulator of the entire system. The manipulator can control the way the resources are allocated to the several components with which man is zoologically a competitor. He must compete for air, water, food, and space. If he takes for his own narrow use an improper quantity of any of these, he will destroy himself.

Since much is to be learned from the study of a closed system, our first work is being done with such a constraint. We have designed our program to permit an eventual flux through the boundary of the whole spectrum of components. Clearly, both the sea and air cannot be constrained to such a small closed system.

The time scale which occupies our interest in initial stages is that of a quarter century. This will permit us to have the city build to about two million people and to have realistically serious droughts, floods, and air and water pollution problems. Diseases can be developed in man over this time scale and genetic responses of various components of the zoological and botanical subsystems can be studied as man invents and uses new pesticides, fertilizers, and medicines.

Emphasis has been placed on the provision for adaptibility of the various subsystems at the present time. The input of real data will follow in a succeeding phase.

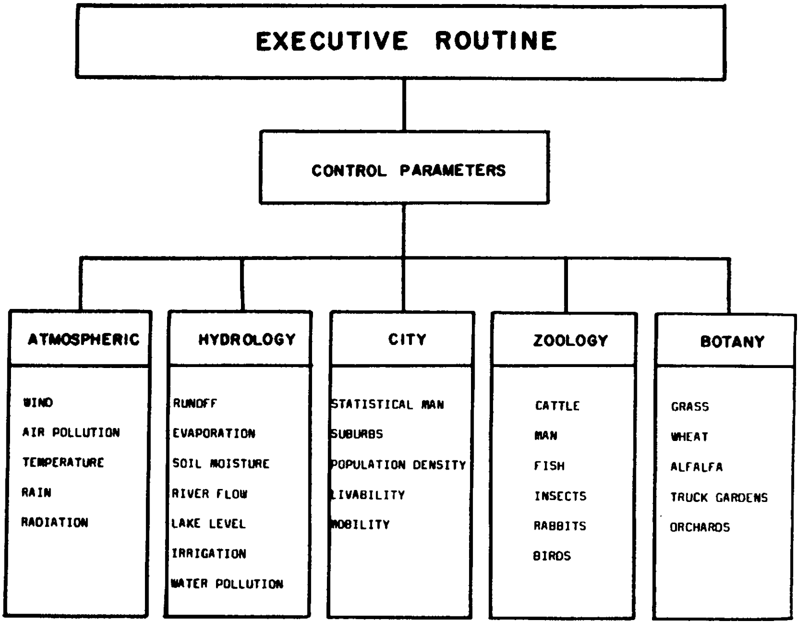

FIGURE 2. The subroutine organization of the computer model.

COMPONENTS

Reference to Figure 2 will show the manner in which the model has partitioned the ecosystem components.

Atmospheric subsystem

Our model is stochastic with known deterministic cycles, such as the annual and diurnal, incorporated where necessary to allow for realistic trends. Variables which have been provided for at this time are wind speed, wind direction, temperature, humidity, radiation, rain, and air pollution. With this set, we are able to show perturbations in the weather patterns which have been introduced through the urban activities of man. Such changes feed back effects to their instigators through, for example, the increase in disease incidence at the city center encouraged by the lower humidity found in that location. Rain clearly interfaces with the hydrology subsystem and also temperature and wind affect the evaporation. Radiation, rain, and temperature affect the botany subsystem, and anomalies in any of the atmospheric variables affect the growth characteristics and dispositions of the zoological components.

Hydrology subsystem

Here the variables are runoff, evaporation, soil moisture, lake level, river flow, irrigation, and water pollution. The supply of water for consumption by crops, animals, and people provides the regular interaction with these subsystems. In cases of drought, the water level sinks, competition for it increases, and water pollution increases as the usual amount of pollutants are distributed through less water. As a consequence, either the disease rate goes up or the wealth of the community goes down as more money is used for purification of the water. Flooding has related effects on the ecosystem.

Urban subsystem

Our current effort in this subsection has concerned population dynamics on a simplified level. We wish to consider both individuals and groups of individuals. However, when keeping track of two million individuals, each of which is defined by means of a few characteristics, one runs into programming problems. Our solution has been to define a city, its suburbs, and a "statistical" man. Figures 3 and 4 illustrate the scheme. Our city is divided, in this example, into four suburbs. Each suburb is assigned a set of five attributes as initial conditions: health, education, wealth, age, and race. Each attribute is subdivided into twenty classes and a log is kept of the number of people in each class at a given time. The suburb is divided into city blocks and the number of people in each city block is recorded.

To provide for movement of city boundaries, suburb boundaries, and individuals, the first two were moved in response to the latter. The individual must have a reason, an ability, and a manner in which to move. One reason to move could be to reach cleaner air. Figure 3 shows the gradient of pollution in suburb 5 which could tend to drive an individual in the north-eastern section of the suburb toward the east. Ability

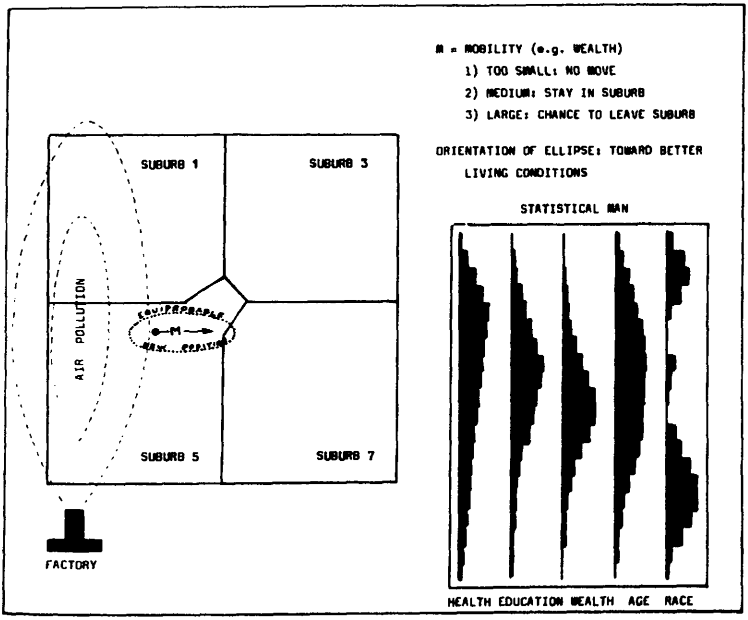

FIGURE 3. City suburbs, pollution and the statistical man. The heavy dot in suburb 5 shows the location of a person and the surrounding dotted ellipse represents his "intelligence."

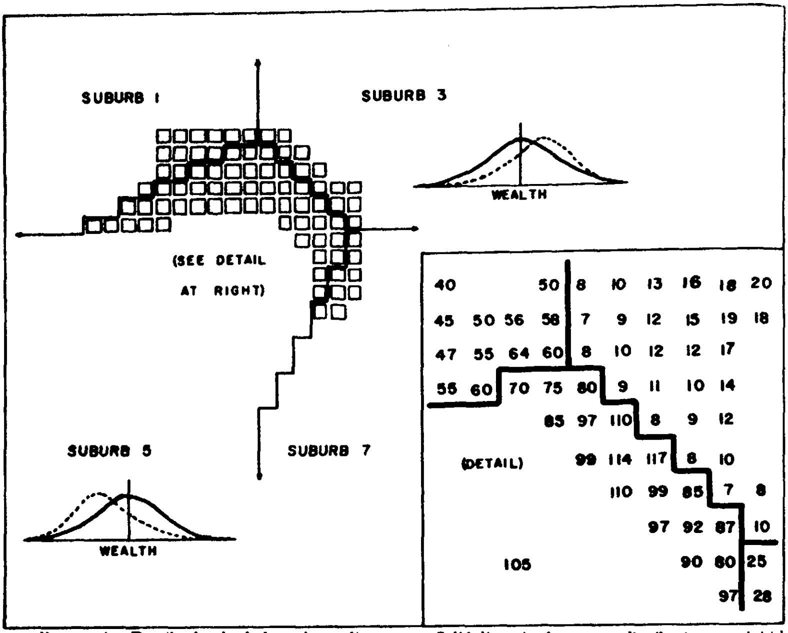

FIGURE 4. Detail of suburb boundary adjustments. Solid lines in frequency distribution are initial wealth. Dashed lines represent wealth after a period of evolution. Numbers in detail show population density per block after evolution.

to move can be correlated to the wealth of an individual. Once selected an individual is assigned wealth drawn at random from the current wealth distribution of his suburb. If this wealth lies below a certain value, we do not effect any movement and go to the next man. Should the selected wealth be greater than this minimum, but less than another higher critical value, the man can only move within his suburb.

His manner of moving is stochastic. One focus of an ellipse is placed over his position with the major axis oriented from polluted air toward clean air. The ellipticity can be adjusted, for example, by the assigned wealth. To allow for individuality, the ellipse is made to represent an equiprobable line of possible destinations. Movement is governed by these constraints through the selection of a random number.

If the wealth assigned lies above the higher critical value, the person may move from his suburb. If this occurs, the individual takes a complete set of attributes with him. His wealth is already assigned, so he draws one each of the other attributes in a fashion which is random, but permits constrained interrelationships between attributes. Thus it can be seen that an undesirable suburb will become poorer and a desirable one will become richer with time. This is indicated by the wealth distribution curves shown in suburb 3 and suburb 5 of Figure 4.

Middle income people tend to concentrate along the boundaries of the suburb. This leads to a population density gradient across the boundary and finally to the movement of the boundary to relieve this zone of stress. Details of such a stress zone are shown in Figure 4. City boundaries move in a similar manner.

Many variables, such as the variation in population growth from suburb to suburb, have not been discussed here. A complete description will be published later.

Zoology subsystem

This subsystem permits the introduction of the food chain and provides competition for physical resources. These elements affect the health characteristics of the people. We distinguish between man, cattle, fish, rabbits, birds, insects, and microorganisms because they serve different purposes and represent different time scales when interacting with the rest of the ecosystem. Fish may concentrate water pollutants and bring them back to man. Birds can distribute various physical quantities (some toxic) in a manner not open to the other life forms. Rabbits can be pests (competitors) with respect to some crops and, in this case, man becomes a predator. Cattle consume crops but provide meat and dairy products (toxic on occasion) for people. Clearly, a carefully balanced zoology is not yet attained, but the flexibility to do this exists in the model.

Botany subsystem

The variety of crops at this stage comprises grass, wheat, alfalfa, orchards, and truck gardens. This not only provides food for the animal population, but also enables us to introduce pesticides and to effect evapotranspiration and competition for space and water. Food supplies are seasonal and are subject to the random influence of floods and droughts.

Executive routine

Man, the manipulator, influences the evolution of the ecosystem through the executive routine. Figure 2 shows a rectangle labelled "control parameters" situated as an interface between the five subsystems described above and the decision-making executive program. Initial conditions which various subsystems use as their point of departure are to be found among these control parameters. Each time one of the five subsystems is called upon to re-evaluate and update its field of variables, it begins by looking at the current status of its control parameters.

At regular intervals, the executive routine looks over the status of the ecosystem and determines whether sufficient deviation from normal has occurred to require changes in control parameters.

Thus, the evolutionary path of the ecosystem can be influenced by adjusting elements in the strategy-cost matrices of the decision-making executive routine.

Three simple examples of this kind of influence are shown in Figure 5. The health-

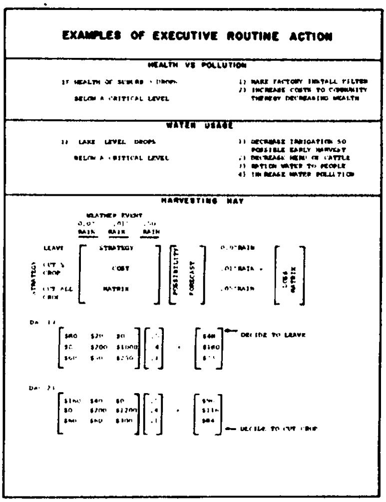

FIGURE 5. Examples of decision making by the executive routine.

pollution and water usage decisions are self-explanatory. The harvesting example contains dollar values invented solely to illustrate the procedure. Here, the costs of the three actions (cutting all the hay, cutting one-fourth of the crop, or leaving the crop) under these weather conditions are a function of the time of year and maturity of the crop. The same probability forecast at two different times separated by nine time steps will result in different actions in the botany subroutine. Since the weather variables change in a stochastic fashion, there is no *a priori* way to know exactly how and when the harvesting will take place. All we insure is that it will be done in an optimum manner according to the cost functions we have imposed.

FUTURE DEVELOPMENT

The feature occupying our attention in the immediate future is the design of a balanced system which will run for a quarter of a century without producing a plague of rabbits, a barren landscape, or herds of 4,000 pound cattle. Once this has been accomplished and we have examined several case histories, small variations will be introduced into each of the processes to test the stability of the model.

The second step will involve the introduction of realistic perturbations in some ecologically relevant variables. These perturbations will include droughts, floods, air pollution, water pollution, rain making, and land pollution.

The third step will concern an attempt to alleviate disaster problems by importing and exporting material through boundaries of the system.

While these problems are being explored, we shall begin collecting and introducing real data into the model. At first, we shall use the data which has been published and modify our subroutines according to ideas currently held by workers in the appropriate fields. Later the model will be used to decide where more precise information is needed.

This model-directed scheme will involve the deploying of field equipment in a manner which will produce information critical to the better definition of the ecosystem. The uses to which such a model can be put are manifold. Clearly, one of the main uses will be to enable people to consider possible long-term ecological consequences of present actions. We shall publish more along these lines as our model evolves and produces realistic results.

ACKNOWLEDGMENT

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REFERENCE

1. A. Eddy, Trans. N. Y. Acad. Sci., Ser. II, 31: 618-628 (1969).