APPLICATION OF REMOTE SENSING TO SOLUTION OF ECOLOGICAL PROBLEMS

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General

When a region of the world is still virgin, such as the U.S. was 400 years ago, people are few, the land is vast, and the resources are large. We enter an era known as the era of exploration free of ecological problems. As time goes on, population grows, but resources remain constant. We find that the human groups attempt to exploit the resources of the region, agriculture resources, mining, rivers, etc., to the maximum. This we call the era of exploitation, which began for the U.S. in the early 19th century. As these resources are increasingly exploited, and as the population continues to grow, we begin to notice a phenomenon of coupling between human activities, well known in physical systems. One can consider a human enterprise as occupying a certain span of resources, such as water, land, air, and exploiting these resources to a certain degree of intensity. The problem arises when there is overlap between the various resources' span-intensity domains. It is the areas of overlap which causes the ecological problem.

Experience shows that the effects of coupling between diverse human endeavors are by and large deleterious. Is this necessarily so, or is it caused by our ignorance of the underlying mechanisms? Can the technology which has caused the problem also show the way to the cure? The answer is, very probably, yes. Theoretical and applied research and measurement systems of all types are already being focused upon the problem. Among these, the techniques of remote sensing of the environment promise significant contributions.

The significant economic consequences appear to be that increasing portions of the gross national product (GNP) will be devoted to evading the ill effects of coupling. Unfortunately, these particular portions of GNP are nonproductive. A $100 000 SO_2 filter in an electric coal-burning plant produces nothing in return except cleaner air. To be productive in the conventional sense, the $100 000 should be spent in more furnaces or in improving the efficiency of the process.

In addition, a growing network of management superstructure will unavoidably increase buildup Net results of inspections, studies, permits, restrictions and data gathering will be the production of the same number of automobiles, kilowatt-hours, or pairs of shoes, and will require more expenditure of time, effort, and capital, than was required during the earlier Era of Exploitation.

As a consequence, the economic standard of living will be reduced. Whether such reduction will be manifested through increased prices, more taxation, or inflation, is immaterial. The fundamental point is that more effort will have to be expended to produce the same quantity of goods as in the past. The overall net effect is to reduce the measured GNP to the lesser real GNP. Yet, if careful management of the coupling problem were not to be undertaken soon, a rather catastrophic reduction in GNP may well occur.

The era of ecology, which affects the developed nations first, may well place a natural brake upon their real expansion; whereas the developing nations, as yet free from such a brake, can continue to grow along the policies of the Era of Exploitation and, thus, catch up more rapidly with the developed nations until such time as continued exploitation eventually will also lead them into the era of ecology. This reverse lag may well become a powerful force for closing the economic gap between developed and developing nations.

The overall problem of environmental ecological management consists of three phases: (1) the establishment of the goals—namely, the determination of how much to reduce the impact on the environment, and at what burden to the different interested parties; (2) determination of who shares the costs —

not only the obvious economic costs, but also the costs in terms of limitation of other human costs; and (3) the solution of the technical problem.

We have a good grip upon the technical problem and are making progress toward reasonable solutions of equitable cost sharing. We still have problems in properly establishing the planning goals, because in large part to the lack of a theory of collective human wants. One could, however, speculate that the efforts of the next few decades may well usher in an era of deep insight into collective desires. Hopefully, such social self-knowledge can bring major, worldwide changes for the better.

It is clear now that there are two fundamental differences between the discovery and exploitation of natural resources, and their ecological management. In the former, economic return is the paramount criterion. In the later, economic payoffs vie with other, less tangible criteria as measures of success. Sometimes economic returns are of lesser priority than, for example, aesthetic motivations. In the former, the discovery and location of resources is of paramount importance. In the latter, we are much more concerned with resource exploitation and conservation dynamics as a function of time.

Hydrological Models - Objectives

Water resources represent a major environmental problem. The current consumption of water is 6 tons per capita per day in the U.S.; less, but still quite high, elsewhere. The reason why we need so much water in industrial countries is that industrial products need many tons of water per ton of product. This would still not be too bad if the industries were to limit themselves to use of the water and return it clean. When they pollute it, the additional quantity of water required as a solvent increases the tons of water required anywhere from 7 to perhaps 20 times.

How much water is available? Because of economic reasons, only the water that falls from the sky by precipitation, which is on the average of 850 mm per year, is available. If one multiplies 850 mm times the total dry area of the earth (125 million square kilometers), one gets so many cubic meters of water. Of that, an average of 0.75 evaporates before it is utilized, so that the theoretical efficiency is approximately 25 percent although not all of that 25 percent is used. As a gross figure for the U.S., the coefficient of utilization of rainwater is only about 7.5 percent.

Extrapolating the growth of water demands to the year 2000 and multiplying by the earth's estimated population — approximately 6 to 7 billion — one computes a total demand. If this were matched to the total availability of precipitation water, and a global efficiency of utilization of 4 percent in A.D. 2000 was assumed, it is easy to determine that we will not have enough water. The available water will have to be recirculated on the average every 2000 hours; in highly developed regions, approximately every 500 hours.

There is a lot of work going on to find sources of water. Of the world's water, 97 percent is saline. Of the remaining 3 percent water, approximately 95 percent is locked in ice, mostly in polar caps. The best price today at which large quantities of water can be desalinated practically is approximately $1 per 1000 gal. The price at which a city is willing to buy is perhaps half of this. The price for agricultural water is 5 cents per 1000 gal, and the price for industrial water ranges from 10 to 20 cents. The question of desalinization is a very interesting one. It is difficult to predict when practical installations will become economical.

Studies to determine the economics of transporting Arctic ice via supertankers found that the transportation rates are too high; it cannot, as yet, be done economically. Since much of the remaining 0.15 percent of the world's stored water is located deep below the surface, the cost of drilling and of the electricity to pump is still beyond the price levels mentioned before. Therefore, at the moment, and until a technological breakthrough is effected, we are confined to utilizing only the rainwater, also known as surface fresh water, which is about 0.1000 of 1 percent of the total water available on earth. At least for the near future, the question is what can be done to utilize it more efficiently?

The problem boils down to watershed management. The watershed is a system in which the input (rainfall) is stochastic, but the output requirements are deterministic. The watershed has to provide consumers with power, based upon certain schedules. Municipalities with water, also against schedules, have to supply irrigation water, and perhaps even recreation water. The consumption schedules are relatively fixed, but the input is stochastic. The problem is how to match the two?

To do this, the Environmental Science Services Administration (ESSA) is helping to solve this problem by the development of a model to predict how much water will be available in a watershed as a function of rainfall. This model is considered the best available in practice. Let us see briefly how it works, and what improvements can be added via remote sensing.

The ESSA model does three things. First it tries to correlate how much rain falls with how much water will flow out of the watershed — that is the utilization coefficient, which is roughly 25 percent on the average but which varies with season and region. The second thing it tries to predict is the time behavior of the flow. If all the water falls very rapidly, there will be a high crest and, therefore, floods. If it comes slowly then we have a smoother curve and no floods. The flow time behavior is called a hydrograph. The third thing the model does is to combine the first two parts in the channel flow to give the overall prediction. ESSA has built 11 modifications of this basic model, which run on IBM 1130 computers for 11 watersheds.

The first piece of the model, "correlation between rainfall and runoff," is based upon four inputs. The first input is the quantity of rain that comes down at any given time. The duration of the rainfall is the second input. The third one is the season of the year. The assumption is that history will roughly repeat itself (not always true, of course). The fourth input is related to the humidity; i.e., dry soil absorbs water faster and therefore yields less runoff from a given rain, whereas wet soil tends to become impermeable and, therefore, a given amount of rain yields more runoff. It is not possible to actually go into the field and measure how wet it is; it takes too many people and too much money. The model computes something called the Antecedent Precipitation Index which is based upon the rainfall of the preceding several weeks. With this Index, the model roughly calculates the soil humidity.

The gathering of these data requires costly instrumentation. As of a few years ago, ESSA had an agreement, whereby for $3 a season, farmers would phone in some of this information. This gives an idea of what are the real-world constraints upon the system.

The second piece of the model is the construction of the time-flow curve, the hydrograph. After painstaking, laborious, and lengthy measurements, one constructs the so-called Unit Hydrograph, which is the ideal response of the watershed system to a runoff of 1 in., assumed constant over the whole watershed area. Once this Unit Hydrograph is available, then by well-known mathematical techniques, one can multiply this, by convolution, by the actual time and duration of rainfall and obtain the flow-time output. This assumes, of course, that the watershed's parameters are linear and invariant.

These are collected by three basic types of tools. The river gage measures the height of the river. The more simple ones are just sticks with numbers painted upon them, which a field worker reads periodically. At least in the U.S. and Europe, field workers are fairly expensive: $2.00 to $3.50 an hour, plus 8 cents per mile for their car, plus supplies. Thus the manual method is becoming rather expensive to use.

In addition, one would like to make this measurement frequently, at least once a day or more often during river activity periods. The trend is, therefore, to install automatic stations. Many use analog reporting, in which they write continuously on a strip of paper. The field worker now can come every 10 days or so, tear the paper chart off, and bring it back to the central data-collection facility for analysis. These towers vary from about 8 ft to 15 ft in height; some can even be higher. The cost of such an instrumentation unit can be as large as $30 000. Several are needed in a river, depending upon its length, uniformity and other characteristics.

The second tool is the rain gage. The manual version costs about $300. The field workers have the problem of reading, as was discussed before. The trend is to automate the gages by attaching them to telephone lines or providing them with radio transmitters.

The third tool measures the speed of the water. To compute the flow, one has to measure the area of the channel, or river, find the average velocity, and multiply the two. Because it is a channel flow, the speed is not the same throughout all sections; at the bottom it is low, it grows as we near the surface, then it slows down at the surface. The speed is measured at different points at various sections of the river. The measurements are then correlated and an average speed is calculated. Of course, if the river changes, this has to be done all over again. The cost, labor, and time consumption which these instruments entail call for improved systems of data collection.

How do we accomplish this? First, the ESSA model assumes the watershed to be substantially a "black box." It does not care what is inside the box. If one understands what is inside the "black box," one can get better insight and better predictions. Second, much laboratory work has been performed in hydrology. Many empirical and theoretical results are available. The problem is to extrapolate results from laboratory to the field. The reason is: economics. It is too costly to send large amounts of people into the great outdoors to gather data and to install permanent, remote measuring instrumentation.

Remote sensing appears to hold the potential for a major step forward in cost performance. From imagery, for example, we can divide the watershed into areas of homogeneity. For parking lots which have runoff coefficients of 0.9-0.95, practically all the rain runs off. Forests can have runoff coefficients very close to zero. One could, therefore, label an area which is all forest as type one; an area which is all parking lot as type two, and so forth. For each such homogeneous area one can create a kind of micromodel whose coefficients are already fairly well known from laboratory tests, then tie them all together and come up with a prediction which can be far more refined than the simple "black box" model used today.

Three things, for example, which are ignored in the present models are easily recognizable in even the poorest aerial pictures. The first one is the phenomenon of interception. When rain falls, anywhere from 0.10-0.2 in. remains attached to the plants, depending on the type of plant. Now 0.2 in. over a 100-by-100-mile watershed — which is a very tiny one — amounts to 2 weeks' flow of the Potomac. What we have to do is to recognize how much area is covered by forest and the type of forest. If we cannot tell the type of forest from the picture, we can at least send people there to obtain samples that will enable a relative determination of the type. In a large number of cases we can tell the type from observations — not necessarily photographic observations, but observations of the radiant spectrum — infrared, for example. The second thing is the very important phenomenon of evapotranspiration, which is simply the sweating of the plants. This again is a function of the area coverage and of the type of plant. We can also measure this from remote sensing. The third is infiltration. Every soil has different characteristics of water absorption. In parking lots, almost all the water will run off, but in sandy soil little water will run off. Experimental methods are being studied to measure the type of soil by remote sensing. We can also measure its vegetation cover, which has been shown by Holtan and others to be connected to the absorption coefficient, because certain plants grow better or grow only in certain kinds of soil. The coefficients are not 100 percent accurate, but they are already much better than having no information at all.

Additional parameters (such as soil type, basin area, stream slope, land cover, etc.) whose knowledge, for a particular watershed, could still further improve its model. All of these parameters are eminently amenable to aerial remote sensing. They are, by the way, difficult, if not impossible, to gather from maps because many of the significant features are edited out.

The point of applying remote sensing techniques to the determination of the hydrologic regime of watersheds is twofold: the improvement in predictive accuracy of already instrumented and modeled watersheds and the determination of the hydrologic regimes of as yet unknown watersheds, with potentially significant reductions in time, labor, and cost over present methods. Such a determination is an essential prerequisite for the planning of flood control and water resource utilization works within the watershed.