Expect the Unexpected

An Adaptive Approach to Environmental Management

EXECUTIVE REPORT 1

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An Adaptive Approach to Environmental Management

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Executive Reports bring together the findings of research done at IIASA and elsewhere and summarize them for a wide readership. The views or opinions expressed in these reports do not necessarily reflect those of the National Member Organizations supporting the Institute or of the Institute itself.

This report is largely based on *Adaptive Environmental Assessment and Management,* edited by C.S. Holling, published by John Wiley & Sons, Chichester, England, 1978. The figures are reproduced with the permission of John Wiley & Sons.

PREFACE

This Executive Report is the first of a new series of publications designed to communicate the findings of research conducted at and in collaboration with IIASA to a wider readership, especially to those who can put the findings into effect, such as executives in government and industry. This is consistent with IIASA's goal not only to develop useful information on important international issues, but also to convey that information to those who can act on it. The Executive Reports parallel the Research Reports prepared by IIASA for the scientific community.

Most of the material in this report derives from *Adaptive Environmental Assessment and Management*, edited by C.S. Holling (John Wiley & Sons, Chichester, 1978). The book is based on the work of a group led by C.S. Holling, which drew upon an international network of scientists linked with IIASA and the Institute of Animal Resource Ecology of the University of British Columbia. Supplemental funding for the study and for preparation of the book was provided by the United Nations Environment Programme (UNEP). Some of the individuals who have contributed to the development of adaptive environmental assessment and management are listed on page 16.

Roger Levien
Director

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THE APPROACH IN BRIEF

So far, no one is very happy with environmental management. A strong statement, but one echoed by a growing number of environmental professionals – biologists, geologists, economists, architects, engineers, statistical analysts, and the administrators in public and private organizations who try to put the advice of scientists and other specialists into practice.

Despite all the disappointment and controversy, few of these environmental foot soldiers blame the higher-ups. They know that concern over what they call man's "impacts" on his environment has spread rapidly to people everywhere in recent years, so that those in charge have had to improvise environmental management under pressure without much experience to guide them.

Guidelines are hard to set because impact problems take so many forms, as the box below suggests. Simple solutions with arbitrary rules or laws often do unforeseen harm. Major projects may require what is called in the United States an "environmental impact statement" – a long catalog of possible impacts. But this approach is static and has come to be abused so often that it is now widely recognized as unsatisfactory.

A new approach, called adaptive environmental assessment and management, shows promise of helping with the problems of environmental impact – as it already has done with the problems listed below. In fact, some 30 experiments with this approach since 1974 prove that it can be

ENVIRONMENTAL PROBLEMS

Social and economic

- In the Austrian high-Alpine village of Obergurgl, resort development conflicts with farming and may damage the environment irreversibly.
- In the Georgia Strait of British Columbia, Canada, sport fishing conflicts with the commercial harvest of salmon.

Large-scale resource development

- In the Orinoco River basin of Venezuela, vegetation changes caused by hydroelectric power generation could jeopardize an extensive regional development.
- In the western United States, oil-shale exploration and mining conflict with wildlife preservation.

Population dynamics of species

- In the Canadian province of New Brunswick, spraying has saved forests from the spruce budworm while widening the area where the pest can occur.

useful in addressing environmental problems in a variety of settings. It has been applied effectively to *assessment* projects, which often get mired in attempts to measure everything, and also to *management* projects, where inflexibility tends to create new problems after environmental programs have begun. Much of the work to appraise the experiments was done at the International Institute for Applied Systems Analysis (IIASA) in Laxenburg, Austria.

What it is. The adaptive approach to environmental assessment and management is a carefully designed and scheduled series of alternating workshops and research periods. Participants continuously review and modify their own efforts to develop computer models used to provide environmental options for policymakers. The monitoring and adjusting process starts with the first planning session and continues after an option has been chosen and put into effect.

What it does. In essence, this approach provides a program of environmental assessment and management that responds to its effects as it proceeds. Knowledge gained in efforts to assess, regulate, manage, and monitor man's environmental impact is used to improve these efforts. This sets the stage for an ongoing, evolving program rather than a one-shot attack, and it also makes the most of programs that cause unforeseen problems. Environmental programs are not failures if the information provided by unexpected events is used to improve policies.

How it works. The adaptive approach starts with a meeting of a small group, usually led by someone from an environmental agency with a problem. The group includes at least one person who is familiar with adaptive techniques. This initial group roughly defines the problems to be addressed and selects people to help with the project.

Once the objectives of the project have been sketched out, the initial group must choose a project leader, a core group, and prospective participants in a series of workshops. The core group is essentially a technical workshop staff. Its members attend all the workshops to provide continuity. Outside experts join the workshops occasionally to offer

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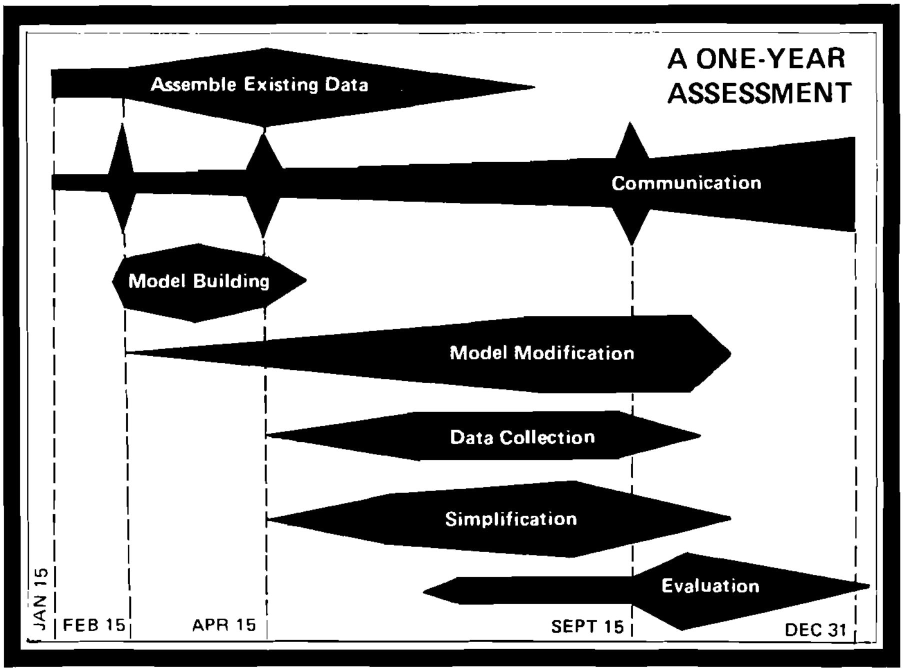
fresh views. The workshop participants can be experts in various subjects, advocates from various constituencies, managers, planners, policymakers, and others. They must reflect a wide range of opinion. Since the adaptive approach is meant to resolve conflicts, the project leader does not seek a consensus at the outset. Free discussion among individuals representing conflicting factions promotes the development of programs that are both workable and flexible.

Flexibility is also encouraged by keeping the accumulation of data to an essential minimum. Quantified information must bear directly on the specific problems that have been singled out for solution. This information is converted into one or more computer models. Then, as key links



between factors are identified, needs for new data to define these relations more precisely are likely to emerge. A research phase preceding the next workshop introduces the new information as it becomes available and is needed. When the model is built, alternatives can be tested and recommendations made.

The main tasks of the project overlap; several go on at any one time (see box above). The process involves continuing interaction among managers, experts, and analysts. The expert needs the policy person to tell him which issues are not relevant. But the expert may have to tell the policy person about certain variables that must be included if program goals are to be reached.

Upon completion of the process, the managers receive well-articulated management plans. Then monitoring begins. Subsequent workshops can be made part of a continuing evaluation process.

The process from the first, small meeting until management plans are presented may take a year, but shorter schedules can be effective. A successful application of the adaptive approach resulted from an intensive five-day workshop at Obergurgl, Austria, in 1974.

For more information. The adaptive approach is described in brief above. Chapter 2 describes the procedures of a one-year assessment project in greater detail. Chapter 3 suggests the part played by computer models, and Chapter 4 summarizes the Obergurgl project, which serves to illustrate the approach because of its simplicity and readily identifiable components. Considerably more detail on all aspects of the approach, including four case studies, are available in what now stands as the seminal work on the adaptive approach: *Adaptive Environmental Assessment and Management*, edited by C.S. Holling (John Wiley & Sons, Chichester, 1978). ●

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THE APPROACH IN THEORY

Ecosystems, the natural ecological systems of the environment, have long been subjected to severe shocks imposed by flood, fire, drought, and geological change. The systems that have emerged can adapt to such traumas. While these systems are not necessarily fragile, neither are they infinitely resilient. Knowing how they respond to disturbances is the key to their management.

Certain characteristics of ecosystems have influenced the development of an adaptive approach to environmental assessment and management:

- The components of ecosystems are connected in a selective way. Everything is not closely tied to everything else.
- The impact of ecological events is not uniform. Different areas react in different ways.
- Dramatic changes in behavior are natural to many ecosystems, and many of these changes are beyond man's means to predict. It is always necessary to expect the unexpected.
- Variability – not consistency – is the characteristic of ecosystems that enables them to adjust and therefore to persist.

In the light of these ecosystem characteristics, our failures to manage our environment successfully are more easily understood. We have based our response to environmental problems on assumptions about ecosystems that are invalid (see box, opposite page). Then, when acting on those assumptions has led to new problems, we have been unable to revise our actions.

Since ecosystems are adaptive, it is clear that, to be effective, environmental management must also be adaptive. Accordingly, any sound

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program must meet several requirements. Environmental factors should be introduced at the very beginning of the policy design process. Environmental, social, and economic aspects of the project should be weighed. All significant constituencies should be involved, right from the start when problems are identified. Also, an adaptive program should stress the interaction of people, rather than the accumulation of facts. Participants should make a particular effort not to accumulate nonessential material.

On the other hand, information should be gathered not just at the start, but indefinitely – some of it becoming part of an ongoing management program. Managers, as well as participants in the development of the program, should observe change, evaluate it, and act on it. Monitoring and remedial mechanisms are essential.

ENVIRONMENTAL MYTHS

Workshops conducted at IIASA over the last six years have considered applications of the adaptive approach by various governmental agencies and departments of industrial corporations in eight countries. People in these organizations often cite mistaken assumptions as the reasons for failures of environmental programs. These assumptions have proved to be remarkably similar in all types of management systems. These are some of the myths of traditional assessment and management:

Myths of assessment

● *"Assessment should include all conceivable results of a proposed program."* In fact, it is impossible to foresee all — or even most — results of any environmental program.

● *"Each new assessment is unique."* In fact, all ecological systems face some common problems, and the ecological literature can throw some light on them.

● *"Comprehensive surveys are necessary to assessment."* In fact, such studies frequently produce nothing but uninterpreted data that give no clues to natural changes about to occur.

● *"Any good scientific study relating to the problem helps to solve it."* In fact, the scientist's interests are often too narrow to answer management's questions.

● *"Systems analysis will choose the best alternative."* In fact, systems models do not always make reliable predictions, and where they do, someone has to place values on the results of each alternative.

Myths of management

● *"Effective environmental management produces or maintains stable social, economic, and environmental conditions."* In fact, control of the environment invariably produces change, and an ability to adapt to change should be part of the management program.

● *"Development programs will not need to be modified."* In fact, successful programs often depend on continuous monitoring and frequent adjustments.

● *"Policies should serve economic and social goals, with environmental goals considered merely as constraints."* In fact, unless all three of these goals are considered from the beginning, none of them is likely to be met.

From the start, everyone associated with the project should bear in mind that unexpected developments can be even costlier than the problems at hand (see box below). The costs of monitoring and remedial programs must be considered as part of the overall design, and like every other aspect of the project, monitoring and remedial programs must be adaptive – flexible enough to alter at any time.

Steps in the process. The developers of adaptive environmental assessment and management have organized a program that makes the kind of flexibility described above possible. It consists, basically, of creative periods followed by periods of consolidation when innovations are built into the program and more information is gathered as needed.

The approach depends on careful sequencing. The timetable summarized in the remainder of this chapter shows how a major assessment project can be organized in a year's time (if the participants can come on short notice). To be ideal, the program should combine assessment and management, but many environmental agency structures do not allow both jobs to be done together. However, description of an assessment alone provides an example of how an adaptive project works.

January 1. The program manager is assigned to evaluate the environmental, economic, and social consequences of a major development proposal. First, he must choose his technical staff. Some will have analytic skills, such as computer programming and statistical analysis. Some will be subject specialists – biologists, geologists, and others. Some advisers will come from his own organization; others will be outside experts in various fields of interest.

The analysts and one or two of the specialists form a core group.

HOW ENVIRONMENTAL PROJECTS GO WRONG

When attempts to manage the environment fail, it is often because unanticipated results create greater problems than those addressed. Environmental management frequently reacts to an obvious, pressing problem in a narrow environmental, social, and economic context. The choice among several alternative programs is guided by inadequate information about the present and future states of the ecosystem.

The alternative chosen typically requires a considerable investment, which fosters commitment to the program in many ways. This commitment snowballs, making changes in the program extremely difficult later on. At the same time, the program chosen often forecloses various future options. These are a few among many examples of the pattern:

- Insecticides have successfully suppressed spruce budworms in Canada, preserving the forest industry and many jobs. But

They will run workshops during the year, do computer modeling, and analyze alternative policies when they have been developed. Specialists who are not part of the core group are called in to join the workshops as their expertise is needed.

January 15. The core group meets to plan the first workshop. They outline the problem, identifying objectives, options, and conflicting interests. Then they make the first rough attempt to determine the boundaries of the problem and the amount of detail to be considered.

The first meeting of the core group also produces a list of participants for the first workshop and assigns them responsibilities. Finally, the core group begins to assemble the computer software and hardware for the modeling activities, and the specialists review the available data considered relevant to the problem.

Later, when the first workshop is held, the core group's preliminary decisions defining the problem are not introduced. These decisions (or similar ones suitably revised) are made again, this time in the light of the broader experience of the participants. This technique serves to introduce flexibility from the start. It also gives the workshop participants identification as creators of the model, which tends to heighten their commitment to the project. If the workshop falters, the core group's original definitions can be introduced to provide direction.

February 15. The first workshop is held for two or three days. The core group and all the specialists attend, and high-level decision makers are involved as much as possible, even if they only sit in for short times.

The main task of the first workshop is to define the problem and determine where its limits should be. If the core group is especially ex-

longtime spraying has left the forest more vulnerable to outbreaks of the pest. In addition, newly suspected health hazards and public opposition have developed, and yet ways to solve the problem are few and costly.

- Diverting the Santee River into Charleston Harbor on the eastern seaboard of the United States not only failed to improve the natural flushing of silt and other pollutants, it also produced a stagnant saltwater pool under the surface that traps these materials and increases dredging costs. The project also generates electric power, which makes it politically impractical to return the river to its natural course.
- Thick bark protects large coniferous trees from the natural cycle of forest fires. But in many areas of North America and Europe, forest management has stressed fire prevention for decades. This lets deciduous brush and trees grow – so any fires that do start get hot enough to destroy the conifers. Fire prevention has become progressively more costly, and large conifers can now be destroyed over large areas, making natural regeneration much slower.

perienced, a rough computer model can be running by the end of the gathering. In any case, all materials needed to write the computer program are identified to provide the core group with a crude outline of a model. To the extent possible, the group notes its needs for additional information, and its specialists outline their preliminary research plans.

April 15. A three-day workshop is held. The core group now has a version of the model running on the computer, and it has even developed various alternatives so that comparisons can be made. The specialists have gathered information from the available literature and formed their final research plans.

On the first day of this second workshop, the core group puts the specialists' data in the model and makes any changes needed in the programming. Then the workshop explores alternatives using the model. By the end of this second workshop, the specialists have research plans to carry out and the core group has options to test. After the workshop, the core group simplifies the model and awaits results of fieldwork by the specialists, which may demand major changes in the model.

September 15. Participants devote the first two days of a five-day workshop to adjusting the model to reflect the past five months of research. The core group has already begun this effort as new data have become available from the specialists. The last three days of this third workshop are devoted to using the model to evaluate alternative policies. A top-level policy authority participates in these final sessions to observe the types of results being generated. This gives him a preview of the final report.

For the rest of the year, everyone connected with the project contributes to communication. The core group completes evaluation runs, produces information packages, and describes to people in the management organization the likely outcomes of various options. The group stages numerous demonstrations of the model for the benefit of administrators at several levels.

The entire team (core group and workshop participants) is involved in presenting the results of its work to interested groups and individuals. The purpose of the adaptive approach is not merely to provide sound options, but also to exert compelling influence on decision makers. The final report, then, is merely a part of the complete assessment.

December 31. The appropriate representative of the decision-making agency receives the final report. But the work of the core group may not be complete. Some or all of its members may be involved in monitoring activities of a management program resulting from the assessment. At some time in the future, the workshop participants reconvene to review progress of the assessment and subsequent actions.

This year-long assessment project has been ambitious, demanding considerable effort by about four core group members and fifteen specialists. But full-time commitments would be required from these people only for a major project, such as a regional development based on a power generating station. For a modest project, the specialists might contribute half or less of their time. The core group can have three or four such projects under way at once. ●

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TOOLS OF THE APPROACH

A computer model can be designed to mimic changes in an ecosystem, including environmental, social, and economic changes. The adaptive approach applies adaptive modeling. As the analysis proceeds, the team learns more, so techniques and models are made to shift and expand. Flexibility, which is built into a series of workshops followed by periods of consolidation and research (as outlined in the preceding chapter), allows the team to draw on alternative analytical and predictive techniques as needed.

The nature of the problem must be examined and categorized before analytical techniques are considered. The problem's particular mix of three elements determines the approach to analysis:

- The complexity of the problem
- The amount of data available
- The degree to which the ecological system is understood

It is possible to get good results even when all three elements are adverse – when little information is available about a complex problem that is not well understood. But, in any case, the elements dictate the approach. It is important to define the problem roughly and sketch in boundaries before choosing computer techniques. At this point, team members must put aside their preconceptions about computer analysis and their pet modeling techniques until the problem has been characterized.

Modeling techniques are being developed and refined all the time, so that this report can summarize only some that have been tried, not

"It is important to define the problem roughly and sketch in boundaries before choosing computer techniques."

those that may be ideal for any given environmental assessment or management. Techniques available for the adaptive approach include qualitative as well as quantitative procedures. The qualitative techniques arrange information into interaction matrices and rely on the expert's intuition and understanding of the problem to assign values and make projections. When a problem is complex, the matrices cannot manage all the variables.

Quantitative techniques, such as simulation models and optimization procedures, can process great amounts of data. But for these techniques to work, the relevant variables and their relationships must be identified. These models can fail by growing to a complexity that sometimes appears to exceed that of the real world. On the other hand, if the model is built without enough data, it can lead to false conclusions.

To determine what sort of modeling techniques might serve the adaptive approach, several of them were tested in a two-year experiment involving about 50 people of varying scientific backgrounds in three countries – Argentina, Canada, and Venezuela. Experiments applied each of four techniques to each of three environmental problems with varying amounts of data provided. Three of the techniques were used only for qualitative modeling, while the fourth was numerical simulation modeling, a quantitative technique.

Gallopin simulation impact model. GSIM is simple. The user merely specifies relevant system variables and then notes whether the relationships between them are positive (an increase in A increases B), negative (an increase in A decreases B), or zero (an increase in A does not directly affect B). Little information is required, and the technique can be implemented readily on a computer. Its main advantage is that it allows a view of a system's dynamics and interactions when information is too sparse for a standard simulation model. It is also fast, and it needs little computer hardware. But GSIM can reveal only qualitative trends.

Kane simulation impact model. KSIM starts with the same information as GSIM and adds data on the relative magnitudes of the interaction effects. It allows some factors to be more important than others and provides greater variation in other ways. KSIM is fast and simple, but like GSIM, it has only a limited ability to mimic reality.

Leopold matrix. Designed as a guide for preparing and evaluating environmental impact reports, this technique forms a matrix with possible actions listed down one side (water diversions, road construction) and potentially affected environmental features listed across the top (water quality, wildlife populations). The assessment team fills in the boxes with their impressions of the strength and also of the importance of each impact on a scale from one to ten.

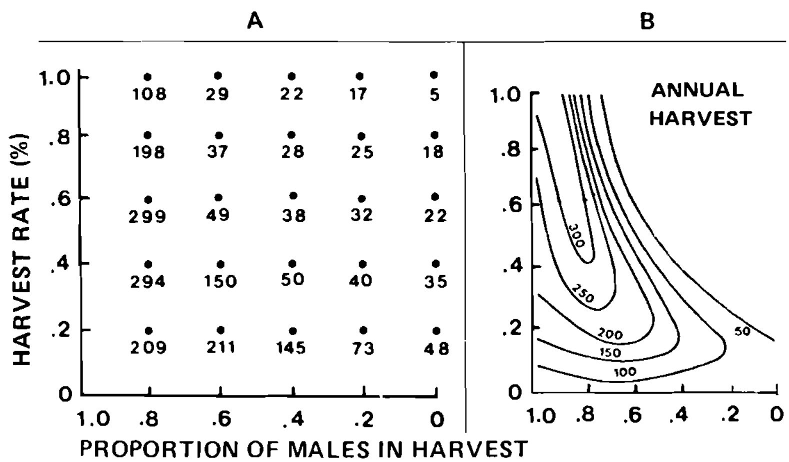
The result is a massive table. (The Leopold matrix used for North American environmental impact statements lists the effects of 100 actions along the horizontal axis on 88 environmental conditions along the vertical.) The predictions are based only on the users' intuition, and the effort is large in relation to value. But the Leopold matrix is easy to use, it needs little hard information, and, when used with other techniques, it serves as a check to make sure that nothing important has been omitted.

Numerical simulation models. Ecological simulation is so new that no generally accepted synthesis of its principles and limitations has been published. In broadest terms, the technique uses sets of equations to approximate relations among a system's variables. The resulting models may require extensive computer facilities, time, and expertise, but when constructed well, these models are more accurate than what can be achieved with the qualitative techniques described above. Numerical simulation models are also more flexible, and they offer a better glimpse of the future.

Experiments conducted with various data suggest that both kinds of techniques can be used in adaptive assessment and management. Qualitative simulation models like GSIM and KSIM provide an easy way to formulate trial dynamic models and to experiment with alternative policies, but they do not provide detailed predictions. The Leopold matrix (and its various descendents) is useful for screening but not for

HOW NOMOGRAMS HELP

Nomograms, or isopleth diagrams, are one of many graphic techniques used in adaptive environmental assessment and management. They help the decision maker evaluate alternatives. In several runs of a simulation model, two management options are varied over some range. In the deer management model illustrated below, the decision options are percentage of population to be harvested and the ratio of males in the harvest. Each simulation run calculates the value of several variables; the variable shown here is annual harvest. The result of each run is plotted on a graph with the two management options as axes (*A*). Contour values are then drawn through the values on a grid (*B*). Nomograms of several runs are reduced to fit on a single page or are printed on plastic overlays. This summarizes some of the data needed for decision making, and it shows the limits of the system at a glance. By manipulating the overlays, the user can experiment with alternatives without using the computer.



predicting. Numerical simulation models offer good predictions when the data are good, and they can help guide research even when the data are poor. When an adaptive approach is used, combinations of these or other techniques can often be put to good use by the project team.

In their book describing the adaptive approach, C.S. Holling and his colleagues show how models can be simplified, divided into useful parts, tested for accuracy, and made more easily understood by nonexperts and specialists in various environment-related subjects. The book also describes ways to evaluate alternative policies and ways to communicate findings to decision makers (see box above). At least as much effort must go into communication, they note, as into the computer analysis.

4

THE APPROACH IN PRACTICE

The village of Obergurgl in the Tyrolean Alps of Austria has enjoyed nearly three decades of economic growth. Its hotels, despite a steady increase in number since about 1950, are completely booked during most skiing seasons, and they often fill up in the summer as well.

But the good times can't last. The community's fragile ecosystem has been deteriorating. Since hotels are easiest to build on bottomland, which is also best for grazing, farming is being lost as a major economic option. And places to attach a hotel to the craggy mountainside have just about run out.

Obergurgl became the subject of an adaptive environmental project in 1974 that illustrates the approach in simple terms. The actors are few and their interests easily identified. Land ownership is tightly controlled at Obergurgl by a few families. Economic development is limited by population growth – the number of people willing to invest in new hotels.

The project was intensive. A five-day workshop resulted in a simulation model and a policy analysis. At the meeting were Obergurgl hotel owners, a representative of the Tyrolean government, ecologists from UNESCO's Man and the Biosphere program, systems modelers from the University of British Columbia representing IIASA, and a few scientists in pertinent specialties. A team of three spent a month on the analysis of information gathered at the workshop.

The public was involved throughout the project, and after the work-

COMPONENTS OF THE OBERGURGL MODEL

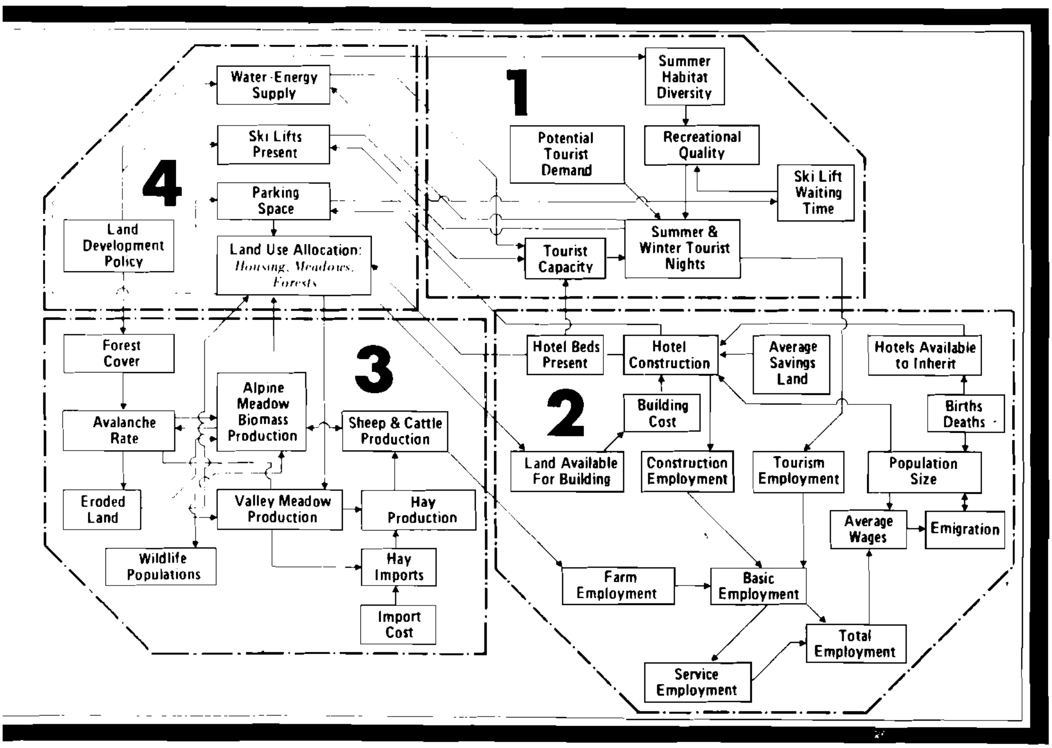
Interaction diagrams can get too complex to be of any use to people, but the one at the right serves to show what participants in the Obergurgl workshop considered to be the minimum set of components and interactions needed to make useful predictions. Their four classes of components are (1) recreational demand, (2) population and economic development, (3) farming and ecological change, and (4) land use and development control. Each class was the responsibility of a workshop subgroup of four to six people, including one computer modeler. These groups developed sections of the model, which were organized into an overall simulation framework by the modeling team. By the third day of the five-day workshop the model was working, and by the last day some thirty scenarios had been produced.

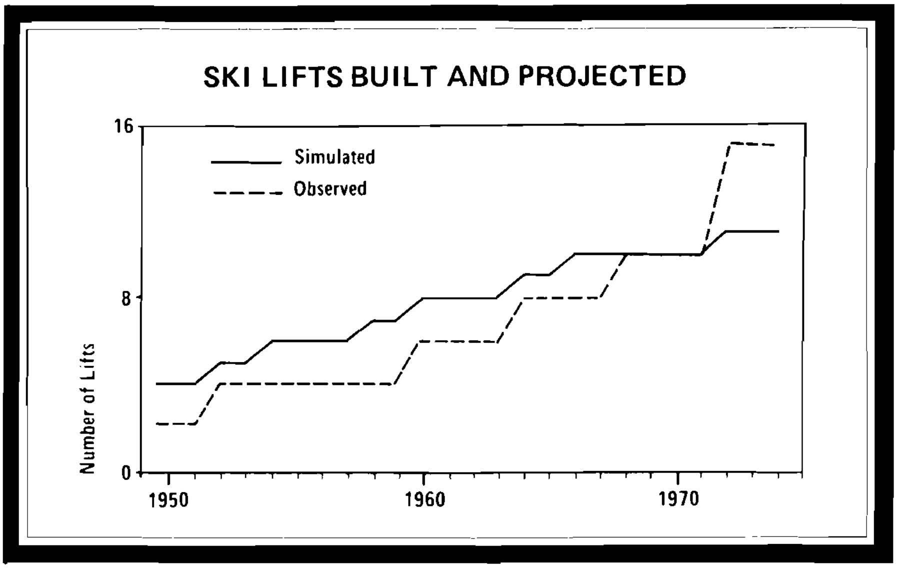
shop ended, project participants took pains to communicate the results to the local residents. The residents have taken the policy analysis to heart in the five years since the workshop took place, and steps have been taken toward preventing further deterioration of the ecosystem and toward averting social and economic crisis in the years to come.

Modest expectations. The workshop developed a preliminary model of human impact on the alpine ecosystem. Developing and validating a detailed descriptive model and producing a convincing analysis in five days was not the aim. Participants hoped merely that the model would identify potential areas of conflict and critical missing information. Then they could refine the model, which eventually could help identify better policy options for future development of the community. However, as well as throwing light on the problems, the model provided predictions of the next 20 to 40 years that were of use in establishing community priorities.

Such progress was achieved by dividing the workshop into four subgroups (see box below). The scenarios produced for each subgroup classification provided useful information for Obergurgl's long-range planners in addition to what they learned from the model as a whole.

Recreational demand. Subgroup participants assumed that demand, as measured by tourist nights, is determined by general potential based on conditions outside the area, tourist capacity of the village, and recreational quality of the area. In their simulation, potential summer and winter occupancy demands were calculated to grow 2 percent a year from a 1950 base. As ski lifts become more crowded, winter demand declines, according to information derived from the impressions of the hotel





owners. Similarly, the model reduces summer demand as meadowland is eroded or used for housing.

The model mimicked the actual pattern of ski-lift construction from 1950 through 1974 (see box above). Knowing that ski-lift waiting time affects demand sharply, village people have been quick to build lifts. The simulation built a new lift whenever waiting time exceeded five minutes.

Population and economic development. Assumptions made by this subgroup: a constant 0.15 annual birth rate to homeowners aged 30 to 60 (a zero rate for all others), an 0.05 death rate (for those aged 60 and older), and negligible immigration. Outsiders cannot buy houses; few emigrants return. In the group aged 30 to 60, 20 percent of those who have not been able to build hotels depart. Using such broad assumptions as these, a simple model starting with 1950 population made a good match with 1974.

Using employment man-years as a basic unit, and assuming one winter tourist night yields about 0.6 employment man-days and one summer tourist night about 0.2 man-days, the model calculated that about 900 outside workers would be needed by 1974. The number actually employed was 800.

Hotel investment stops when occupancy rates fall below 60 percent. Construction costs rose from roughly five years of a man's savings in 1950 to seven years' savings in 1974. With these and other assumptions, the model figured accurately that there would be about 60 hotels by 1974.

Farming and ecological change. Three broad groups of environmental phenomena were treated: animals and forage, the forest, and erosion. The model set stocking rates for cows, sheep, and horses based on forage, imported hay, and total feed needed. The fact that sheep grazing affects erosion to a small degree was considered in one version of the erosion submodel.

Land use and development control. This subgroup was asked to propose ways to control Obergurgl's growth with plans the other three submodels could accept. The control targets were room prices, number of ski lifts and trails, hotel sizes and lot requirements, number of new hotels per year, water and electricity supplies, zoning, building subsidies and taxes, reforestation, and farming subsidies.

The model then had many ways of affecting Obergurgl's future. Zoning controls were implemented merely by changing the amount of land available to construction. Subsidies and taxes lowered or raised the building-cost curve. Upper limits were programmed for the development of services. A set of indicator variables was chosen to measure the results of control: number of hotels, occupancy, village population, emigration rate, wages, farming potential, environmental diversity, ski-lift crowding, and meadow area.

The model provided various alternatives for long-range development and also made such useful predictions as these:

- The most likely limit on Obergurgl's continued economic growth is the amount of safe land (not exposed to possible avalanches) for building. That limit – about 90 hotels and a local population of 600 to 700 – could be reached within 15 to 20 years (of 1974) with continued government building subsidy or in 20 to 30 years without subsidy.
- The limits on building opportunities and population growth may soon force substantial emigration, which will cause social problems. Building subsidies would postpone the emigration problem, but ultimately the subsidies would make the problem more severe.
- Of the measures for limiting growth – subsidies or taxes, zoning, and controls on such services as water, energy, ski lifts, and road access – building taxes and zoning controls appear to be the best. Controls on services would lower recreational quality in the long run without slowing development in the short run.

Among ways to mitigate Obergurgl's problems also tested with the model: A government subsidy to young people improves short-term conditions, but causes safe land to be exhausted earlier; a tax on hotel construction has little effect in the first decades, but later eases the emigration problem.

Obergurgl today. Additional research – on sensitivity of tourists to environmental quality, ski development and soil erosion, pasture production, recreational demand and changing transportation, and other pertinent matters – has been done, thanks in large measure to the ongoing Man and the Biosphere program sponsored by UNESCO. By the summer of 1979, the village had reduced growth rates and found ways to maintain environmental and esthetic quality. For example, the travel industry now helps support the local farmers.

The model is now far more accurate and detailed than it was in 1974, and it continues to mature. But something possibly even more useful has resulted from Obergurgl's experience with the adaptive approach. The 1974 workshop has brought its people together. They now have a vehicle for continuing cooperation and for helping to address and resolve conflicts. ●

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