International Institute for
Applied Systems Analysis
IIASA www.iiasa.ac.at

A Survey of Economic-Ecological Models

Braat, L.C. and Lierop, W.F.J. van

IIASA Collaborative Paper
November 1985

A SURVEY OF ECONOMIC-ECOLOGICAL MODELS

Leon C. Braat
Wal F.J. van Lierop

November 1985
CP-85-46

This project was jointly sponsored by the Dutch National Research Programme for Environmental Health (Lasom) and the International Institute for Applied Systems Analysis (IIASA), Austria.

INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
2361 Laxenburg, Austria

AUTHORS

Leon C. Braat and Wal F.J. van Lierop from the Free University, Amsterdam, carried out this survey while working as part time Associate Scholars at IIASA (1983-1984) in a joint effort between the Free University and IIASA's Adaptive Resource Policies Project.

Leon C. Braat is a systems ecologist, and has carried out most of his past research in environmental policy analysis, energy analysis, and simulation modeling. He is currently with the Institute for Environmental Studies at the Free University. Wal F.J. van Lierop is an economist. He is with the Economic and Social Research Institute of the Free University as project leader for research on environmental, regional and urban, traffic and transportation, and labour market economics. Both authors have a strong modeling background.

FOREWORD

I am pleased to have played a very small part in facilitating the publication of this survey of economic-ecological models by Leon C. Braat and Wal F.J. van Lierop. In fact, the manuscript was largely completed before I arrived at IIASA, and thanks should go especially to Carl Walters and Dennis Meadows, who were the main IIASA contacts during the study.

This report includes information on the current state of economic-ecological models in a variety of countries and applications. As a result, it will be a valuable reference over many years to come.

R.E. Munn
Chairman
Environment Program
International Institute for
Applied Systems Analysis

PREFACE

This paper reports on a survey of economic-ecological models conducted by a research team from the Institute for Environmental Studies, Free University, Amsterdam (IvM) in cooperation with and supported by the International Institute for Applied Systems Analysis (IIASA), Laxenburg Austria.

The paper attempts to describe the state-of-the-art in economic-ecological modeling as derived from this survey. Various classifications have been used to this end. These are:

- Classification of economic-ecological policy issues
- Classification of phases in economic-ecological policy analysis
- Classification of mathematical models used in the interface between economics and ecology
- Classification concerning the internal structure of mathematical models
- Classification concerning the relationships between economic and ecological models.

A combination of these classifications provides a framework for evaluating economic-ecological modeling. Special attention is paid to problems that economic-ecological modeling is still facing today, and some remarks are made on the perspectives of economic-ecological modeling.

In an extensive Appendix a catalogue of model summaries is presented. These summaries give a non-mathematical description of the model structure, model properties and the policy issue for each of the documented survey models. References to the model documentation are included.

The essence of this report will appear shortly in a state of the art book*, edited by the authors of this paper. In addition, it will include introductions to economic, ecological and environmental modeling and analysis of integration techniques between economic and ecological submodels. The book will further contain a number of chapters presenting evaluations of models considered representative for those used in various fields of policy and management. The book has been designed to present a coherent picture of the origins, state and future of economic-ecological modeling.

*Braat, L.C. & W.F.J. van Lierop (eds.) (1986) *Economic-Ecological Modeling for Environmental and Resource Management*, North-Holland Publishing Company, Amstedam (in press).

ACKNOWLEDGEMENTS

We would like to express our gratitude to the Dutch National Committee for Environmental Health Research and the International Institute for Applied Systems Analysis (IIASA) for funding this research project.

Acknowledgements are due to S.W.F. van der Ploeg for his contributions in starting the project and to L. Hordijk, D. Meadows, P. Nijkamp, and C. Walters for their comments and suggestions. An advisory group of scientists and policy advisers helped us in setting the course of the project. This group included J. Kindler, T.R. Lakshmanan, H.T. Odum, P. Pearse, and the above-mentioned scholars.

The extensive administrative work involved in this project was conducted with great competence by S. Wilson of IIASA. At IvM, we should like to thank K. George-Couvret for typing earlier manuscripts during this project, and the many secretaries at IIASA involved in typing this paper, in particular S. Jandl.

TABLE OF CONTENTS

A SURVEY OF ECONOMIC-ECOLOGICAL MODELS

Leon C. Braat and Wal F.J. van Lierop

1. INTRODUCTION

1.1. The Economic-Ecological Modeling Project

In 1982, the Institute for Environmental Studies, Free University, Amsterdam (IvM) started a research project concerning the relevance of economic-ecological models for environmental policy. In August 1982, the International Institute for Applied Systems Analysis (IIASA) agreed to join IvM in this project.

The main aims of the project were defined as:

- an international survey of economic-ecological models, and
- an evaluation of these models.

Within these aims a distinction was made between:

- scientific aims, and
- policy aims.

The scientific purpose of the international survey was to make an inventory of:

- the types or classes of models in different problem fields,
- the kind of structure and specifications they have, and
- the frequency distribution of different types.

The scientific evaluation purpose concentrated on:

- the levels of sophistication the models have reached,
- comparison of the various models by field, in order to discover general and specific features,
- problems, and
- "hot" research items.

Policy related purposes of the survey were:

- the assessment of the actual (and potential) use of the models, and further
- to analyze who applied them,
- in which context, and
- with what kind of policy objectives.

The policy evaluation purpose concentrated on the evaluation of the effectiveness of the applied economic-ecological models. The method chosen to acquire the available information on economic-ecological models and their applications included a questionnaire, a survey literature study, communication with modelers and policy advisers, and a Workshop on Economic-Ecological Modeling (December 12-14, 1983), at IIASA.

A generally accepted definition and classification of economic-ecological models was not available at the start of the project. We therefore used a ***preliminary definition*** that was given as: ***a set of mathematical relationships describing any connections between economic and ecological systems.***[1] This definition was communicated to all the participants in the project. Models in environmental economics and environmental biology were not excluded, because we could not tell in advance whether they contained anything that could be described and would be accepted as ecological and economic, respectively. We shall come back to the definition problem in Section 3.

A description and evaluation of a set of models can only be rendered accessible and intelligible with an effective classification system used to aggregate the individual models. We have therefore developed a simple classification system, which we found effective in analyzing and evaluating the models. This classification is introduced in Section 2.

1.2. Survey Response and Representation

During October and November 1982, approximately 200 questionnaires (see Appendix II) with a background paper* were mailed to modelers thought to be involved in economic-ecological modeling. Additional questionnaires were sent out to people suggested by the initial respondents, the National Member Organizations of IIASA, and other people who expressed interest, bringing the total up to 350. Analysis of the response started after the final deadline of April 15, 1983. Additional information for the project was also received in the form of detailed model descriptions in research reports and published papers, which had been requested in the questionnaire.

Of the 354 scientists who received a questionnaire, 123 (almost 35%) responded; 16 of them (5%) reported that they were no longer involved in economic-ecological modeling, 19 others (5%) showed interest in the project but did not answer the questionnaire for various reasons (for instance, because of being a theoretician in the field or because they felt that their model was not a truly integrated model). A total of 109 questionnaires were completed by 88 scientists (25%). Many people reported not only for themselves but represented a team; as a result 30 modelers (11%) are indirectly involved in the survey. Consequently, 36% of the scientists originally contacted are represented, while the total response is 46%. The non-response rate is 189 (53%), which includes those who never responded and those that responded after the deadline. The remaining 1% includes respondents from IIASA and IvM.

Unfortunately, some questionnaires had to be excluded. This was due, among other reasons, to the fact that in these cases either theoretical model concepts only, or a monodisciplinary economic or ecological model were represented. This brought the survey sample back to exactly 100. The results represented in this report are based on this number of questionnaires. However, even within these 100 questionnaires, several had to be excluded in the analysis of some of the questions. Consequently, the total number of valid answers differs among questions.

The extent to which the results are representative for the entire area of economic-ecological modeling is not clear. The initial mailing list for the survey was derived from IIASA and IvM files. A second wave of questionnaires was mailed in early 1983 to people who were suggested by respondents of the first wave. In

*Braat, L.C. & W.F.J. van Lierop, (1982), Economic-Ecological Models: A background picture. Informal paper, IIASA, Laxenburg, Austria, October 1982.

our opinion, a fair representation of the area of economic-ecological modeling was obtained.

1.3. Structure of the Paper

In Section 2, the distribution and frequency of the answers per question of the questionnaire (see Appendix II) are shown. Twelve types of economic-ecological models have been distinguished by combining questions 5.1 and 5.2. The characteristics and fields of application of each of these twelve types are presented and discussed in Section 3. In Section 4, a classification of policy issues for which models may be developed is introduced. This classification is subsequently used to analyze tendencies in properties and fields of application of the survey models developed for particular types of questions and policy issues.

In Section 5, we describe the model structure of the survey models by policy issue class and present a tentative framework for the selection of appropriate model structures for particular policy issues. Section 6 discusses problems and perspectives in economic-ecological modeling. A general review and conclusions are given in Section 7.

2. GENERAL DISTRIBUTION OF ANSWERS

2.1. Geographical Distribution of the Models

The geographical distribution of the survey sample is presented in Table 1; 23 models came from Western Europe, 6 from Scandinavia, 15 from Eastern Europe, 40 from North America, 2 from South America, 9 from Australia, 3 from Japan, and 2 from Israel.

2.2. Purpose of the Economic-Ecological Models

Models in general have the purpose of documenting and understanding systems of the real world, solving problems, and predicting consequences of human activities. This, of course, is also true for models in which both economic and ecological components, processes, and activities are represented. Three alternative purposes have been distinguished:

1. *Analytical Interest*: The model has been developed for academic purposes. It may, of course, have potential for application in a policy context;

2. *Specific Policy Problems*: The model has been developed for small-scale short-term policy problems;

3. *General Policy Issues*: Here larger systems and long-term policy and planning are characteristics. The output will most likely be indications of trends, ranges in predictions, guidelines, and standards.

Question 2 dealt with these alternative purposes. The distribution of the answers is presented in Table 2.

Table 1. Country of Origin of Models Included in the Survey

Country	Number of Models
Argentina	1
Australia	9
Belgium	1
Brazil	1
West Germany	6
Canada	10
Czechoslovakia	6
East Germany	1
France	3
Great Britain	4
Hungary	5
Israel	2
Italy	1
Japan	3
The Netherlands	6
Norway	2
Austria	2
Finland	1
Sweden	3
USA	30
USSR	3
(21 countries participated)	Total 100

Table 2. Purpose of Economic-Ecological Models

	Types of Answers							Σ
a. Application to a general policy issue	X			X	X		X	35
b. Application to a specific (policy) case		X		X		X	X	46
c. Analytical interest (only potential relevance for policy)			X		X	X	X	35
Distribution:	23	38	24	4	7	3	1	

Total valid cases: 100

2.3. Fields and Extent of Application

Fields of actual or potential application can be identified. Twenty-five models from the survey were designed for a specific field, the 75 other models are more general and are used in various fields. The fields listed in Question 3.1 (see Table 3) represent fields of planning and decision making in which economic and environmental issues have traditionally been dealt with. The list was not exhaustive, nor fully consistent as to the level of detail. The option of defining additional fields of application appropriate to the modeling effort has been used 16 times.

Other fields mentioned were:

a. economic development and physical planning
b. water pollution
c. industry (especially food industry)
d. drinking water
e. response to stress
f. balance of payments
g. transportation
h. housing
i. economic and environmental policy in general
j. human ecology.

Within a field of application, models may, for instance, be used for identification and description, analysis of complex processes, and prediction of consequences of policies, control, or management. Since various models have multiple-use capability in this respect, and because these distinctions are sometimes hard to make, these aspects have not been included in the survey. The questionnaire concentrated on the fields as such. Table 3 gives an overview of the frequency distribution of the survey models over the various fields of application. The diagonal numbers represent the number of models built for one field of application only. For example, the first diagonal element, 2, indicates that only 2 models focus exclusively on agriculture, whereas a total of 48 focus on agriculture in combination with other fields. The "row" total gives the number of models dealing with a specific field. For agriculture this number is 50. The various other elements of Table 3 indicate relationships between the fields of application. For instance, 17 models are applied (or applicable) both in land use and nature conservation. It is possible that many of these 17 models include more fields of application. Several combinations between fields of application are quite obvious and consequently occur quite regularly. For example, agriculture with land use, fisheries with water, etc. This

Table 3. Fields of Application

	Agriculture	Forestry	Fisheries	Land Use	Outdoor recreation	Energy	Nonrenewable res.	Nature conservation	Diseases	Pests	Water	Soil	Air	Other	TOTAL
1. Agriculture	(2)	8	8	30	11	11	10	17	3	11	29	21	7	7	50
2. Forestry		(1)	5	8	3	8	5	10	0	2	7	5	4	4	12
3. Fisheries			(11)	8	7	6	5	8	0	3	12	5	4	3	25
4. Land Use				(2)	15	14	10	17	0	5	27	17	8	10	45
5. Outdoor recreation					(0)	3	3	12	0	1	15	4	4	6	19
6. Energy						(2)	13	9	1	1	8	7	10	5	25
7. Nonrenewable resources							(0)	8	1	2	6	6	6	4	18
8. Nature conservation								(0)	1	3	21	11	6	5	28
9. Diseases									(0)	2	1	2	0	0	4
10. Pests										(0)	6	6	2	2	11
11. Water											(6)	19	8	9	50
12. Soil												(0)	6	4	23
13. Air													(0)	4	14
14. Other														1	16

might imply that the number of models designed for specific fields of application is higher than 25.

Some models have been designed for many fields of application. Consequently the sum of models in a row in Table 3 will usually differ from the row total for a field given in the last column. None of the models applied in or applicable for outdoor recreation, nonrenewable resources, nature, conservation, diseases, pests, soil and water were built exclusively for these fields of application.

In general, models are developed from some *conceptual* framework, often described in the form of a set of boxes and arrows (diagrams), which have no strict definitions or constraints.

These diagrams, sometimes also called conceptual models, often form the basis for the next stage of model development, in which system components, processes, and relationships are described in a mathematical format. The resulting structure is less ambiguous. These models in mathematical format, called *theoretical* by some modelers, are *operational* in that with the addition of fictional or real world data, some form of quantitative analysis can be made. When these operational models are subsequently used, they may be called *applied* models. Two categories have been distinguished in the questionnaire in relation to the purpose of the model: models which have been *applied in a research context* (e.g., methodological) only, and those *applied in actual policy formulation or decision making*.

Question 3.2 dealt with the extent of application. The distribution of answers is represented in Table 4. From this table we can see that models applied in an actual policy context and models applied in a research context are equally high in representation in the sample (both 36 times). The combination a-c, in which only one score is made, is probably a mistake. It should be mentioned that the total number of questionnaires represented in Table 4 is only 91. This is due to incomplete answers.

2.4. Model Testing

The degree to which a model or its output represents the structure or behavior of the system it was meant to represent, can be evaluated in various ways. The relative performance of a model can be tested by comparing its results with the results of other models calibrated with the same data input. Statistical and econometrical testing techniques can be of help in this respect. A model can also be evaluated by comparing calculated (predicted) values with values measured in the real world. Of course, the measured values that have been used for calibration cannot be used as valid test data. Statistical methods (tests) may be used in deciding the significance of the difference between predicted values and measured values.

Dynamic simulation models can be regarded as tested when repeated success in prediction is observed. This may be done by starting the simulation at some point in history with adequate (initial) historical conditions and subsequent assessment of the deviation of the present values, or by monitoring the real world systems for continuous testing.

Question 4 dealt with the issue of model testing. Table 5 gives the distribution of the answers. Apparently testing against the data, other than used for calibration of the model, is the most common way of testing economic-ecological models. The combination b-d scores twice, most likely by mistake or due to misunderstanding.

Table 4. Extent of Application

	Type of Answers							Σ
a. Applied in an actual policy context	X			X		X	X	37
b. Applied in a research context		X		X	X		X	50
c. Not yet applied but operational			X		X	X	X	24
Distribution:	22	31	18	14	5	1	0	

Total valid cases: 91

Table 5. The Reported Testing of the Survey Models

	Types of Answers								Σ
a. Tested by comparison of performance, with other models in relation to the same set of historical data	X				X			X	17
b. Tested against data, other than used for calibration of the world		X			X	X	X	X	54
c. Tested by repeated success in prediction			X			X		X	16
d. Not yet tested				X			X		32
Distribution:	5	32	3	30	7	8	2	5	

Total valid cases: 92

2.5. Types of Economical-Ecological Models

Economic-ecological models are considered to consist of at least one economic and one ecological submodel. It is, however, also possible to have several economic submodels connected to one or several ecological ones. The internal *structure* of the submodels can be defined by the form of the internal relationships between the variables. Only two types have been distinguished in Question 5.1:

1. a submodel consisting of separate, isolated variables only ('s', simple submodel), and
2. a submodel containing a set of variables which are fully, or partially, interrelated ('c', complex submodel).

Economic-ecological models that have only one elaborately developed submodel linked to a single index (or set of independent indices) representing the other system, or a submodel that is driven by one, or several, exogenous, independent variables from the other system, can be considered as a group in which these two types are mixed. Among the 81 valid cases there are:

16	simple economic submodels
9	simple ecological submodels
65	complex economic submodels
72	complex ecological submodels

and the following combinations:

simple economic	+	simple ecological submodel	:	4
simple economic	+	complex ecological submodel	:	12
complex economic	+	simple ecological submodel	:	5
complex economic	+	complex ecological submodel	:	60

Apart from being classified by the relative complexity of the internal structure of the submodels, economic-ecological models can be classified further by the types of *relationships* between the submodels. Three types are distinguished, based on the direction of the relationships (Question 5.2):

1. a one-way relationship in which the economic submodel drives the ecological submodel (10 models);
2. a one-way relationship in which the ecological submodel drives the economic submodel (19 models);

3. a two-way relationship, i.e. interdependent submodels (52 models).

In Table 6 questions 5.1 and 5.2 have been combined to produce 12 types of economic-ecological models.

Table 6. Types of Economic-Ecological Models

	Econ. Ecol.	Econ. Ecol.	Econ. Ecol.	Total
simple models	S → S 1	S ⇄ S 2	S ← S 1	4
simple economic complex ecological models	S → C 2	S ⇄ C 3	S ← C 7	12
complex economic simple ecological models	C → S 2	C ⇄ S 0	C ← S 3	5
complex models	C → C 5	C ⇄ C 47	C ← C 8	60
Total	10	52	19	81

2.6. Model Characteristics

Models can be described by many characteristics, their time and space dimensions, their size, and their function. Where time is concerned, the first distinction made is whether a model has time as a variable. If so, the model is referred to as dynamic. In Question 6.1 dynamic explicitly refers to temporal dynamics. If time is not a variable, models are called static. One class of models which does consider time, but not as a variable, is separately indicated: comparative static models. These models deal only with time in as far as they take into account the beginning and the end of the period for which they have been developed. Table 7 presents the distribution of answers to Question 6.1, the time dimension of models; "En" stands for economic submodel, "El" stands for ecological submodel. Dynamic models dominate the field; both completely dynamic models and models with a dynamic ecological submodel linked to a static or comparative static economic submodel are numerous.

Table 7. Dynamics of Economic-Ecological Models

		En/El		En/El		En/El		En/El		En/El		En/El		En/El		En/El	
a.	Static	X	X					X					X				
b.	Comparative static			X	X					X					X	X	X
c.	Dynamic					X	X		X		X	X		X			X
	Distribution:	12		6		48		12		6		1		3		1	

Total valid cases: 89

Another way of looking at the answers is presented in Table 8.

Four geographical *scales* have been distinguished in the survey: local, regional, national and global. Global and national scales were considered to present no problems in delineation. Regional models can range from very large to rather small areas. However, it was explained in the background paper that accompanied the questionnaire, that they should cover only part of a nation and include more than just a city or an ecosystem (the latter considered to be the local scale).

Table 8. Total Number of Economic and Ecological Submodels from Various Time Categories.

		Economic Submodels	Ecological Submodels
a.	Static	24	13
b.	Comparative static	13	10
c.	Dynamic	52	67
		--	--
	Total valid cases:	89	90*

*One double-count, due to the combination represented by the extreme right column in Table 7.

Table 9 gives a distribution of the various geographical scales in the models.

An alternative way of looking at time in models, different from the approach followed in Tables 7 and 8, is from the point of view of ***time periods covered*** by the model, either in analysis or in prediction (time horizon). Additional features then, are the time intervals. Since time is often treated differently in economic and ecological models, a distinction was indicated in the questionnaire (Question 6.3). Regrettably the survey did not supply unambiguous information on this point. Question 6.3 caused much confusion and has a low response score. This should be taken into account when interpreting the results that are presented in Table 10. Because of the problems with this question, we give the scores for each time aspect for the economic and ecological submodels separately. Combinations are not taken into consideration here. A similarity in economic and ecological submodels is evident in using a "1" year period in their analysis as well as for their time interval. Economic submodels seem to have slightly longer time intervals than ecological ones. The horizon of prediction varies between 20 and 30 years. It looks as though many models from the survey aim to give a forecast for the year 2000.

A distinction between optimization models (which contain an objective function), simulation models, and other models which have no internalized objectives was the basis for Question 6.4. Table 11 presents the distribution of the combinations. The other models that have been mentioned in the questionnaire are:

Table 9. The Geographical Scale of Economic-Ecological Models

	En/El	En/El	En/El	En/El	En/El	En/El	En/El	En/El	En/El	En/El	En/El	En/El	En/El
a. Local	X X				X X	X X		X X		X	X X	X	X
b. Regional		X X			X X	X X	X	X	X X	X X	X	X	X X
c. National			X X			X X	X		X		X		X
D. Global				X X									
Distribution:	22	28	8	6	6	2	3	2	2	3	1	2	1

Total valid cases: 86

Table 10. Analyzed Time Periods, Time Intervals, and Predicted Horizons of Economic and Ecological Submodels

	Covered time period		Time interval		Horizon of Prediction	
	En	El	En	El	En	El
1 day	1	2	4	16	1	1
1 wk	1	1	1	4	-	-
2 wks	-	-	1	1	-	-
6 wks	-	-	1	-	-	-
1 mth	-	1	5	5	-	1
2 mths	-	-	-	-	-	1
3 mths	-	-	3	5	2	3
5 mths	-	1	-	-	-	-
6 mths	1	2	-	-	1	2
1 yr	17	17	37	29	5	6
2 yrs	2	1	-	-	-	-
3 yrs	3	3	-	-	2	2
4 yrs	-	1	-	1	-	1
5 yrs	2	4	6	6	4	2
6 yrs	-	-	-	-	-	1
7 yrs	-	-	-	-	-	1
8 yrs	-	-	-	-	1	2
9 yrs	1	1	-	-	1	-
10 yrs	8	5	-	1	4	3
15 yrs	2	1	-	-	1	1
20 yrs	3	3	-	-	7	8
25 yrs	3	3	-	-	3	3
30 yrs	4	4	-	-	5	6
40 yrs	-	-	-	-	2	2
50 yrs	7	9	-	-	1	2
100 yrs	5	5	-	-	2	2
200 yrs	-	-	-	-	1	1
250 yrs	-	-	-	-	1	-
Indefinite	2	3	2	2	6	7
Total valid cases:	62	67	60	70	50	58

a. input-output models;
b. scenario;
c. analytical;
d. statistical functions;
e. decision models.

Because they scored only a few times, they have not been included in Table 11. It should be mentioned that the models in this listing are not absolutely exclusive.

Table 11. Optimization and Simulation of Economic-Ecological Models

	En/El	En/El	En/El	En/El	En/El	En/El	En/El	Total En	Total El
a. Optimization	X X		X	X X	X	X X	X	44	24
b. Simulation		X X	X	X X	X X	X	X X	27	47
Distribution:	23	25	12	10	3	6	1	71*	71*
Total valid cases:	80								

*Due to double-counting

Economic submodels often use optimization techniques, whereas ecological submodels are applied with simulation techniques to a greater extent. The combination of an economic simulation submodel with a single ecological optimization model does not exist. The other combination, however, is quite popular.

One way to indicate the *size* of a model, relevant in both ecological and economic models is the number of endogenous (state) variables. Question 6.5 focused on this model characteristic. The results are presented in Table 12.

There appears to be a greater tendency towards small- and medium-sized models rather than towards larger models. However, one should note that the number of variables per submodel is indicated. Two submodels of type b may imply close to 200 variables!

Table 12. Number of Endogenous Variables in Economic-Ecological Models

	En/El		En/El		En/El		En/El		En/El		En/El		En/El		En/El		En/El	
a. 1-10	X	X					X					X				X	X	
b. 10-100			X	X				X	X		X			X				
c. > 100					X	X				X			X		X			X
Distribution:	34		19		4		17		2		5		5		1		2	

Total valid cases: 89

3. ECONOMIC-ECOLOGICAL MODELS

3.1. Introduction and Definitions

In this section, twelve types of economic-ecological models (see Table 6) are characterized and discussed. These types have been defined based on the structure and relationships of the submodels. Together they give a more precise description of the preliminary definition of economic-ecological models as given in Section 1.1 of this paper.

Based on the results of this survey a more elaborate definition of economic-ecological models has been developed. It was assumed that wherever mentioned in the questionnaire the submodels (economic and ecological) were recognized by the respondents as describing the respective systems. It was, however, not clear, whether the submodels denoted as "simple" would be recognized as real ecological or economic models by any of the ecologists or economists, respectively.

It appears that many modelers consider an economic model with an emission variable as economic-ecological, possibly equating the terms "environmental" and "ecological". In the same fashion ecological models with a pollutant as input are sometimes called economic-ecological, apparently on the grounds that the pollutant comes from the economic production or consumption process.

As the IvM-IIASA project progressed, the different meanings attached to the term economic-ecological became more transparent and easier to distinguish from each other. It became obvious through the study of the model documentation that a "simple" ecological submodel could contain either a single (or several independent) pollution indicator(s) or biotic variables such as animal population or vegetation biomass. Depending on the definition of "ecological", the submodel would be considered as such. If "ecological" implies a related set of variables, then none of the simple submodels should carry that name. If it implies that next to some physico-chemical variables (abiotic) at least one biotic variable should be included, then some of the 'simple' ecological submodels are not ecological but physicochemical only. Furthermore, even some 'complex' ecological submodels may not be truly ecological if the latter meaning is followed. These considerations for the ecological submodels have their counterpart on the economic side.

In summary, not all the models in the model structure classes where a simple and a complex submodel are combined, can be called integrated economic-ecological models.

In our definition, ***complex, integrated economic-ecological models*** consist of submodels which are accepted as adequately describing the structure (and behavior) of economic and ecological systems respectively, as well as the structure and functioning of the interrelationships between the two systems. Models in which one of the two kinds of submodels consists of an internally unrelated set of variables (combinations of simple and complex submodels) could still be called ***economic-ecological*** if this loose set of variables is accepted as a clear characterization of key-elements of the pertinent scientific discipline.

Models in which the latter condition is not met should, however, not be called economic-ecological. The various models in this group may still be recognized to fit in the realm of environmental economics, environmental biology, resource economics, or resource ecology. Although these kinds of models were not excluded in the survey (i.e., as was stated explicitly in the paper accompanying the questionnaire for environmental economic, and environmental biological models) only relatively few questionnaires could clearly be identified as representing any one of them.

The twelve types of economic-ecological models (see section 2.5) have been combined into four classes of models on the basis of the complexity of the submodels and each with three types of relations between economics and ecology. The ***first*** class, simple models, is only represented by 4 models. This does not provide enough information for unambiguous conclusions. The same is true for the ***third*** class, complex economic plus simple ecological submodels; here only 5 models are available to characterize the class. In the ***second*** class (complex ecological with simple economic submodels) and the ***fourth*** class (complex economic-ecological models) 12 and 60 models are included respectively. The discussion will mostly refer to these two classes of models. For each of the twelve types we have summarized the scores on model properties such as application, testing, dynamics, technical purpose (intended use, i.e., optimization or simulation), model size, and geographical scale of the system modeled.

3.2. Characteristics by Type of Economic-Ecological Models

In Table 13, the distribution of properties over the twelve types of economic-ecological models is presented. Scores are indicated per model type and aggregated per class of models. The majority of the types and classes of models represented in the survey have been applied in a general or specific policy case. The majority of the models in classes 2 and 4 have also been tested in one way or another (see Table 5), 91% in class 2 and 68.5% in class 4.

Table 13. Properties of Economic-Ecological Models

Submodels	Applied?		Tested?		Dynamics				Purpose			Size			Geographical Scale				
Economic Ecological	Y	N	Y	N	ST	CS	DY	MI	OP	SI	MI	SM	ME	LA	LO	RE	NA	GL	MI
S → S	1		1		1						1	1							
S ⇄ S	2			2	1		1		1			1	1			1			1
S ← S	1		1					1		1		1			1				
Simple Models	4		2	2	2		1	1	1	1	1	3	1		1	1			1
S → C	2		2					2		1		2			1				1
S ⇄ C	2		2				1	2	1	1	1	1	2			3			
S ← C	5	2	6	1				5		2		1	5	1	3	1			3
Sim.Econ./Com.Ecol.	9	2	10	1			1	9	1	4	1	4	7	1	4	4			4
C → S	2		1	1			1			1		1		1					1
C ⇄ S																			
C ← S	2	1	2	1	1		1	1	1	1	1	1		2	1		1		1
Com.Econ./Sim.Ecol.	4	1	3	2	1		2	1	1	2	1	2		3	1		1		2
C → C	4		2	2	1	1	1	2	1	1	2	1		2	1	1	1		2
C ⇄ C	29	11	27	15	3	3	32	8	14	14	16	16	25	3	12	12	6	6	9
C ← C	4	1	8			2	4	2	1	3	4	2	4	2	2	4			2
Complex Models	37	12	37	17	4	6	37	12	16	18	22	19	29	7	15	17	7	6	13

Y = yes   ST = static   OP = optimization   ME = medium   RE = regional

N = no   CS = comparative static   SI = simulation   LA = large   NA = national

MI = mixed   DY = dynamic   SM = small   LO = local   GL = global

The distribution of dynamic models in class 2 may appear odd; 9 out of 10 are mixed dynamic/static or dynamic/comparative static. However, all ecological submodels in this class are dynamic, and all economic (simple) submodels but one are not dynamic. In class 4, completely dynamic models dominate (63%). More than 76% of the ecological submodels and 67% of the economic submodels are dynamic. Only 4 (out of 59) models in this class are completely static. Given that classes 1 and 3 do not offer a strong counter argument within this survey, it seems that ***the way to go in economic-ecological modeling is dynamic***, especially since the majority appears to be tested and is applied in some context.

As to (the distribution of) prescriptive (optimization) and descriptive/-predictive (simulation) models, there is ***only a slightly greater number of pure simulation models than pure optimization models, while mixed types are as common as simulation models***. The ecological submodels are, in most cases, simulation models (83% in class 2, 71% in class 4). The economic submodels use optimization techniques in only 33% of the cases in class 2, but 62.5% in class 4.

Large models, defined as having at least one submodel with more than 100 endogenous variables, are relatively seldom used (8.5% in class 2, 13% in class 4, 14.5% overall). Most modelers appear to use models of medium size, defined as having submodels with up to 100 endogenous variables, while the small models (i.e., submodels with less than 10 endogenous variables) also occur quite frequently.

The next model characteristic in Table 13 is the geographical scale of the system for which the models were developed. The survey did not produce many models for national and global systems. Given the problem of the representativeness of the sample, we feel that conclusions cannot be drawn yet about the lack of economic-ecological integration at the important national level.

It is obvious from the numbers in Table 13 that the ***most common geographical scales for modeling are regional and local***. The focus on local and regional systems is even stronger than can be concluded from Table 13, since 9 out of 13 (in class 4, and 2 out of 4 in class 2) "mixed scales" models are combinations of regional and local.

3.3. Fields of Application of Economic Ecological Models

In Table 14, the fields of application of economic-ecological model types are indicated. It should be noted that, as remarked in relation to Table 3, many modelers have indicated that their models are applicable or applied in more than one field. The survey sample of models evidently covers a broad range of application fields (see also section 2.3). From the survey, it has not become clear which types of models are strictly developed for specific fields. However, the following observations may clarify the situation shown in the Table.

"Simple" ecological submodels are not found in applications in agriculture, forestry, nature conservation, diseases, pests and soil. They are only rarely used in fisheries (1 out of 19), land use (2 out of 38), outdoor recreation (1 out of 15) and water problems (1 out of 43). "Simple" economic submodels appear not to be used in applications for problems of non-renewable resources, and only in 1 out of 20 cases for energy problems and 1 out of 14 cases for air problems. In the survey, the "simple" ecological submodels form only 11% of the ecological submodels, and the "simple" economic submodels only 30% of all economic submodels. This implies that these observations can hardly be taken as a basis for the state-of-the-art.

Table 14. Fields of Application of Economic-Ecological Models

# of Models	Submodels Economic Ecological	Agriculture	Forestry	Fisheries	Land Use	Outdoor Recreation	Energy	N.Ren.Res.	Nature Cons.	Diseases	Pests	Water	Soil	Air	Other
1	S → S											1			
2	S ⇄ S			1		1									1
2	S ← S						1							1	
	Simple Models			1		1	1					1		1	1
2	S → C			1	1	1			1			2			
3	S ⇄ C	2	1	1	2				1		1	2	1		
7	S ← C	6							1	2	2	4	3		
	Sim.Econ./Com.Ecol.	8	1	2	3	1			3	2	3	8	4		
2	C → S				1		2	1						2	1
0	C ⇄ S														
3	C ← S				1		1	1							1
	Com.Econ./Sim.Ecol.				2		3	2						2	2
5	C → C	4			2		1	1				5	2	1	
47	C ⇄ C	25	7	14	27	12	15	12	17	1	6	26	12	10	11
8	C ← C	6		2	3	1		1	4	1	1	3	2		
	Complex Models	35	7	16	32	13	16	14	21	2	7	34	16	11	11
	Total	43	8	19	38	15	20	16	24	4	10	43	20	14	14

Given that the complex economic-ecological models with two-way connections form 58% of the sample, a closer look at these models reveals that they are used relatively more often in all applications except diseases (only 25%). As to agriculture, 58% of the applications are complex two-way economic-ecological models, in other fields more than 71% (up to 87.5% in forestry).

Again, the sample is such that no far reaching conclusions can be drawn from this analysis. It is yet remarkable that the most complex type of model distinguished in the survey is applied to such a great extent in most traditional fields of application.

4. POLICY ISSUES AND ECONOMIC-ECOLOGICAL MODELS

4.1. Introduction

In general, models are either built for academic or for policy purposes. According to Websters Dictionary a policy is defined as: (1) a definite course of or method of action, selected from among alternatives and in light of given conditions to guide and determine present and future decisions; (2) a high-level overall plan, embracing the general goals and acceptable procedures.

Policy making is then considered to be the process of shaping policy (i.e., planning), plus the actual choice between alternative (i.e., decision making) and the implementation of the selected alternatives (i.e., management). Both planning and management involve the prediction of impacts and developments in the system as the basis for evaluation and choice.

In environmental policy making three main types of *policy objectives* can be distinguished:

1. Nature conservation objectives (summarized e.g., as minimum exploitation and damage of ecological systems);
2. Economic objectives (expressed, for example, as maximum production of goods and services from ecological systems at the minimum cost);
3. Mixed objectives (for example, maximum sustainable use of resources, i.e., material, energy and information resources, and space and environmental services, at minimum ecological damage and minimum cost).

Policy making involves either a single objective or various objectives. *Integrated* policy making at the interface of economic and ecological systems is multiobjective by definition. *Policy issues* are the policy or managerial questions or problems that are addressed with one of these three types of objectives in mind.

For the evaluation of effectiveness of the different types of economic-ecological models in assorted policy applications, a classification of policy issues is required. We therefore introduce a *classification of policy issues*. It is based on a conceptual separation of the economic system from the ecological system. These subsystems are considered to be connected by flows of matter, energy and information (see Figure 1).

The classification developed from this simple concept of two subsystems and their connecting flows, consists of three classes, each containing three subclasses. The three classes follow the division of policy objectives mentioned above. The three subclasses are based on a distinction between input, output and throughput flows, and combinations of these.

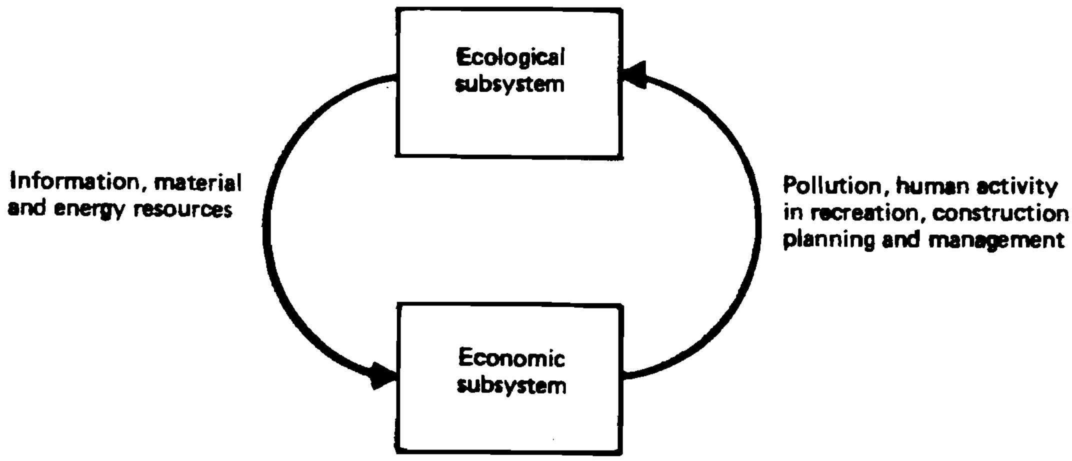


Figure 1. Relationships Between Ecological and Economic Subsystems

The following classes of policy issues have thus been identified:

(a) Ecological Policy Issues (see Figure 2)

Class 1: Ecological impacts of resource use
The concern here is as to what the ecological effects are of the extraction of resources from ecosystems (natural and managed) and which policies might lead to minimization of the impacts.

Class 3: Ecological impacts of pollution and disturbance
The issues are the effects of various types of pollutants and of physical damage due to human activity (such as in recreation and construction). The policies focus on control measures at the receiving end.

Class 5: Ecosystem planning and management
This class contains issues dealing with total ecosystems throughput. Management and, more abstractly, the planning of whole ecosystems, manipulate both inputs and outputs as well as internal structure.

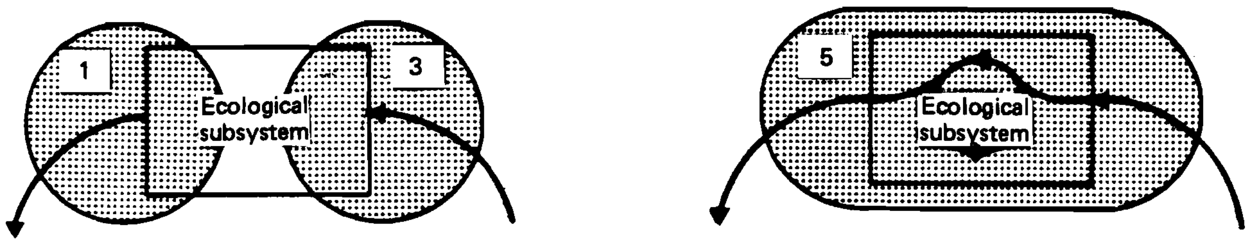


Figure 2. Ecological Policy Issues

(b) Economic Policy Issues (see Figure 3)

Class 2: **Economic impacts of resource development and exploitation**
The issues focus on the economic aspects of resource development: both cost impacts and management of development activity.

Class 4: **Economic impacts of pollution**
Economic aspects (e.g. cost and allocation) of output control, e.g., water pollution control cost, including planning and management aspects.

Class 6: **Economic system planning and management**
In this class the issues of optimal allocation of resource input to the economy and cost-effective material balances are expected.

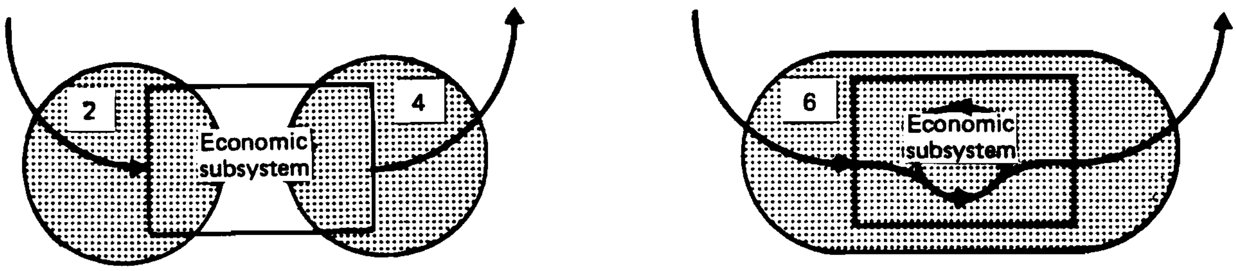


Figure 3. Economic Policy Issues

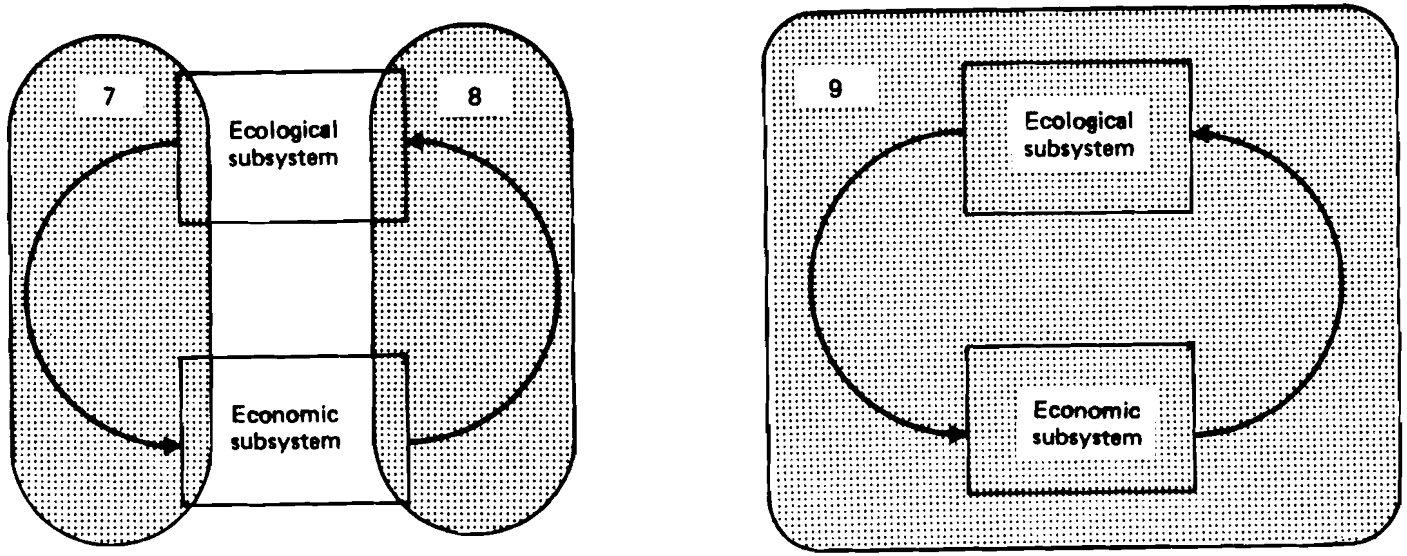
(c) Economic-Ecological Policy Issues (see Figure 4)

Class 7: Sustainable use of resources
The concern is, evidently, how to plan and manage resource use activity (including development) in such a way that a long-term use is guaranteed, considering, e.g., cost aspects and changing demand.

Class 8: Sustainable use of environmental services
The objective here may be phrased as optimal use of the ecological carrying and assimilative capacity in an attempt to plan and manage for minimal negative impact of maximal use of the structure and space offered by the ecological systems.

Class 9: Total system planning and management
The issues in this class involve complete cycles of input-throughput-output. The geographical scale (e.g., local and global) may differ as may the elements that cycle in (or flow through) the system (energy, carbon, phosphates, biomass, pollutants).

Figure 4. Economic-Ecological Policy Issues



4.2. Policy Issues and Model Characteristics

The theoretical classification, presented in the previous section has been used to classify the questions and problems for which the survey models were designed. The questionnaire did not contain a question pertaining to the policy issue at which the model was addressed, since this aspect of the survey was introduced later in the project. We have therefore attempted to identify the policy issues for each of the survey models through the documentation about the model and the project or, in some cases, the model name. In Table 15 the distribution of policy issues of the survey models over the 9 classes is given. As is obvious from the total, 15 studies could not be classified due to lack of reliable information.

Table 15. Distribution of Respondents Over Policy Issue Classes

Class #	Name	# of respondents
1	Ecological impacts of resource use	5
2	Economic impacts of resource development and use	19
3	Ecological impacts of pollution and disturbance	7
4	Economic impacts of pollution	12
5	Ecosysytem planning and management	2
6	Economic system planning and management	7
7	Sustainable use of resources	16
8	Sustainable use of environmental services	3
9	Total system planning and management	14
Total of cases where policy issues could be assessed		85

The great variety of policy issues, or research problems, which were found in the survey can be found in Appendix I, the catalogue of model summaries. This catalogue lists the model descriptions by policy issue class. At first glance, the models which are lumped together from a policy issue point of view look very different. In order to find out to what extent similarities existed within and differences between the models of the 9 policy issue classes, we have examined the properties, characteristics, model structure and fields of application of these groups of models.

For this analysis we have chosen to employ an identical format as in Table 13 where the characteristics of model types, classified by structural properties are listed. In Table 16, the first column shows the 9 policy issue classes in 3 groups, ecological, economic and economic-ecological policy issue classes.

Table 16. Policy Issues and Model Characteristics

policy issue classes	model characteristics																			
	Applied?		Tested?		Dynamics				Purpose			Size				Geogr. Scale				
	Y	N	Y	N	ST	CS	DY	MI	OP	SI	MI	SM	ME	LA	MI	LO	RE	NA	GL	MI
1. Ecological impacts of resource use	4	-	3	2	2	-	2	1	1	4	-	1	2	-	1	-	2	1	-	1
3. Ecological impacts of pollution and disturbance	5	2	5	2	-	-	2	3	-	2	1	2	-	-	3	-	2	1	-	1
5. Ecosystem planning and management	2	-	-	2	2	-	-	-	1	-	-	-	-	-	1	-	1	-	-	1
Totals for Ecological Policy Issues	11	2	8	6	4	-	4	4	2	6	1	3	2	-	4	3	4	1	-	3
2. Economic impacts of resource developments	14	2	13	2	1	2	12	3	5	3	8	10	4	1	2	3	8	2	1	2
4. Economic impacts of of pollution	7	5	6	6	2	1	5	3	7	2	2	6	1	-	5	4	2	1	1	2
6. Economic system planning and management	6	1	4	2	1	-	5	-	3	2	1	1	1	-	4	-	2	-	2	2
Totals for Economic Policy Issues	27	8	23	10	4	3	22	6	15	7	11	17	6	1	11	7	12	3	4	6
7. Sustainable resource use	7	5	6	8	1	-	9	2	4	1	4	4	2	1	6	5	3	2	-	3
8. Sustainable use of environmental services	3	-	2	1	-	-	1	1	-	1	2	-	2	-	-	-	1	-	-	2
9. Total systems planning and management	10	4	8	6	-	2	5	7	-	7	7	5	5	1	3	2	4	2	-	6
Totals for Economic-Ecological Policy Issues	20	9	16	15	1	2	15	10	4	9	13	9	9	2	9	7	8	4	-	11
Sum totals	58	19	47	31	9	5	41	20	21	22	25	29	17	3	25	17	24	8	4	20

Y = yes ST = static OP = optimization ME = medium RE = regional
N = no CS = comparative static SI = simulation LA = large NA = national
MI = mixed DY = dynamic SM = small LO = local GL = global

Since the set of models which is distributed over these classes is the same as in Table 13, it is not surprising to find great similarities in the total frequencies in the columns 'APPLIED?' and 'TESTED?'. Of interest here, of course is the relative frequency of applied and tested models in the various policy issue classes. It is easy to see that the majority of the models in all classes is applied. More models are tested than not, but the difference is slight both in the first group and in the last. Notably in classes 5 and 7 more models are untested than tested. The distribution could suggest that models for issues in which ecological problems are featured are harder to test. We should, however, continuously be aware of the small number of models in these classes.

As to dynamics, a *clear majority of economic and economic-ecological policy models is dynamic*, with "mixed" being second most frequent in both groups and actually most frequent in the total system policies class. There seems to be no preferred model type for ecological policy issues. A closer look at these issues and the respective models shows that the number of purely descriptive, static models included in the survey, is relatively large in these issue classes.

The purpose of building the models (its intended use), is obviously different for each of the three groups of classes. For *ecological policy issues* simulation modeling, most often with *predictive purposes*, occurs most frequently. For *economic issues*, however, *optimization techniques*, or in other words prescriptive models are mostly used. Combinations of purposes are found most often in the group of mixed policy issues.

Small and medium models (most mixed models here mix small and medium) dominate the field in all classes. This, of course, was to be expected given the small number of large models in the survey. Local and regional scale and combinations of these two are the most frequently occurring model aggregation levels.

Summarizing, models for ecological policy issues are generally simulation models of small to medium size for local and regional scales. They are very often applied but not as often tested. Models for economic policy issues are also very much applied and relatively more often tested. Size and scale are similar to the first group, the purpose however differs. Optimization is the preferred technique. The models for economic-ecological *policy* are generally of the same geographical scale as the other two groups. The *combination of simulation and optimization techniques is characteristic*.

4.3. Policy Issues and Fields of Application

In Table 17 the distribution of model application fields, as indicated for each of the survey models in the questionnaire, over the policy issue classes is shown. In Section 2.3 we have illustrated and discussed the point that most survey models are claimed to be applied or applicable to several of the fields which were listed in the questionnaire. This feature is also present in Table 17. Again the totals for each column are generally similar to those of Table 14.

Among the fields listed, agriculture, soil, land use, and water are of great concern with both nature conservation, economic, and mixed policy objectives in mind. Nature conservation, as could be expected, occurs most frequently in ecological and economic-ecological policy issue classes. Energy modeling, and related to that, air (quality) modeling is obviously something for economic policy. The same, to a lesser degree, seems to be the case with non-renewable resources. Here sustainability aspects are of some importance, judging by the relative frequency.

Table 17. Policy Issues and Fields of Application

Policy Issue Classes	Fields of application													
	Agriculture	Forestry	Fisheries	Land Use	Outdoor Recreation	Energy	N.Ren.Res.	Nature Cons.	Diseases	Pests	Water	Soil	Air	Other
1. Ecological impacts of resource use	5	1	-	3	-	-	-	3	1	2	3	3	-	-
3. Ecological impacts of pollution and disturbance	5	-	3	4	3	-	-	3	-	2	7	3	1	-
5. Ecosystem planning and management	-	1	1	-	1	1	-	1	-	-	1	-	-	1
Totals for Ecological Policy Issues	10	2	4	7	4	1	-	7	1	4	11	6	1	1
2. Economic impacts of resource developments	10	3	7	11	1	6	6	3	-	1	5	4	3	1
4. Economic impacts of of pollution	3	-	-	2	1	4	2	3	-	-	7	1	4	1
6. Economic system planning and management	2	-	1	3	2	5	2	1	1	-	1	2	1	2
Totals for Economic Policy Issues	15	3	8	16	4	15	10	7	1	1	13	7	8	4
7. Sustainable resource use	10	3	5	3	2	1	3	5	1	4	6	4	-	1
8. Sustainable use of environmental services	1	-	-	2	2	-	-	1	-	-	3	-	2	-
9. Total systems planning and management	7	3	3	13	5	5	4	5	-	1	10	4	1	7
Totals for Economic-Ecological Policy Issues	18	6	8	18	9	6	7	11	1	5	19	8	3	8
Sum totals	43	11	20	41	17	22	17	25	3	10	43	21	12	13

Once again, we stress the problem assessing the meaning of the scores on the question of 'field of application'. In that light it seems not appropriate to formulate any definite conclusion about the relationships between the conceptual policy issue classes and the fields of application distinguished in the questionnaire.

5. POLICY ISSUES AND MODEL STRUCTURE

5.1. Introduction

After having examined the various model characteristics and the model application fields, we now look at the technical structure of the models from the policy issues point of view. The question is whether there are particular model structures used for particular kinds of policy issues. Again we have employed the policy issue classes defined in Section 4.1. In Table 18, three of the four model structure classes (see Section 3) are put on the horizontal axis. The class of "Simple" models, containing only 4 models, is excluded. The survey models are distributed in the resulting matrix according to their technical structure (i.e., the internal complexity of the submodels and the kind of relationship between them) and the policy issue they were developed for.

Table 18 shows the relative frequency of model structure types for particular policy issues. It is of course not surprising, knowing the relative abundance of complex economic-ecological models (type 4c) in the survey, that the center column contains most of the models. It implies, however, that complex, integrated economic-ecological models are also used for policy issues where the concern is much more limited, i.e., ecological or economic policy issues. A more careful survey of the history of each model may reveal some reasons for this.

5.2. A Framework for Selection of Models

The results from Table 18 call, in our opinion, for a critical evaluation of the question whether the choice of complex two-way economic-ecological models is appropriate in each class of policy issues. For the selection of the most adequate models for a particular policy issue, it is necessary to keep the following considerations in mind.

If one submodel is shown to "drive" another submodel, this implies that the driving submodel is considered independent, unless feedbacks are indicated as they are by two-way arrows. In cases where the policy objective includes "sustainability" apparently a mutual dependency between the natural system and society is assumed, implying that models with one-way relationship are not considered adequate. We distinguish ***impact models*** and ***impact indicators*** in Table 19, both with and without feedbacks to a driving model. The indicators are represented by simple submodels, the models involve complex submodels.

In Table 19 we have also indicated for each class of policy issues the model types which are considered adequate and inadequate. Furthermore, we have qualified the various types of adequate models as indicators and integrated models. For example, issues referring to ecological impacts of resource use can, in light of the definitions given above, not be modeled adequately by models in which the ecological submodels are independent, driving submodels. The straightforward choice would be a model consisting of complex ecological and relatively simple economic, driving submodels. If feedbacks are relevant because one suspects that the impacts have an influence on the causing factor, then the two-way type in model class 2 is an adequate choice. If a simple indicator of ecological impacts is preferred

Table 18. Policy Issues and Model Structure

Policy issue class	model structure classes								
	3			4			2		
	Comp.En./Simp.El.			Comp.En./Comp.El.			Simp.En./Comp.El.		
	a.	c.	b.	a.	c.	b.	a.	c.	b.
	En+El	En‡El	En+El	En+El	En‡El	En+El	En+El	En‡El	En+El
1. Ecological impacts of resource use	0	0	0	1	0	2	0	1	0
3. Ecological impacts of pollution and disturbance	0	0	0	1	2	0	2	0	1
5. Ecosystem planning and management	0	0	0	0	1	0	0	0	0
Totals for Ecological Policy Issues	0	0	0	2	3	2	2	1	1
2. Economic impacts of resource use	0	0	1	0	10	2	0	0	0
4. Economic impacts of of pollution	1	0	2	1	5	1	0	0	0
6. Economic system planning and management	1	0	0	0	5	0	0	0	0
Totals for Economic Policy Issues	2	0	3	1	20	3	0	0	0
7. Sustainable resource use	0	0	0	0	8	0	0	0	4
8. Sustainable use of environmental services	0	0	0	0	2	0	0	0	0
9. Total systems planning and management	0	0	0	2	10	0	0	1	0
Totals for Economic-Ecological Policy Issues	0	0	0	2	20	0	0	1	4
Sum totals	2	0	3	5	43	5	2	2	5

Table 19. Selection of Adequate Economic-Ecological Models

Policy issue class	model structure classes								
	3			4			2		
	Comp.En./Simp.El.			Comp.En./Comp.El.			Simp.En./Comp.El.		
	a.	c.	b.	a.	c.	b.	a.	c.	b.
	En→El	En⇄El	En←El	En→El	En⇄El	En←El	En→El	En⇄El	En←El
1. Ecological impacts of resource use	AI	AI,F		AC	AC,F		A	A,F	
3. Ecological impacts of pollution and disturbance	AI	AI,F		AC	AC,F		A	A,F	
5. Ecosystem planning and management	AI	AI,F		AC	AC,F		A	A,F	
2. Economic impacts of resource use		B,F	B		BC,F	BC		BI,F	BI
4. Economic impacts of of pollution		B,F	B		BC,F	BC		BI,F	BI
6. Economic system planning and management		B,F	B		BC,F	BC		BI,F	BI
7. Sustainable Resource use		B-AI,F			AC-BC F			A-BI,F	
8. Sustainable use of Environmental Services		B-AI,F			AC-BC F			A-BI,F	
9. Total systems planning and management		B-AI,F			AC-BC F			A-BI,F	

F Introducing feedbacks between submodels
A Ecological impact model
AI Ecological impact indicator model
AC Complex ecological impact model
B Economic impact model
BI Economic impact indicator model
BC Complex economic indicator model
A-BI Integrated economic (indicator)-ecological model
B-AI Integrated economic-ecological (indicator) model
AC-BC Complex integrated economic-ecological model

because the concern is more on the causal side, i.e., the economic subsystem, or if a simple ecological indicator is the only possibility datawise, class 3 models are appropriate structures. Finally, in case both the impacted system and the causing system are of interest, complex economic-ecological models, with or without feedbacks are the logical choice.

In this way, Table 19 provides an overview of all the types of model structures which are considered "adequate" and "inadequate" for specific policy issues. All the empty cells in Table 19 represent model structures which are not the most appropriate ones for the policy issues in hand.

In using this theoretical framework to check the results from the survey as presented in Table 18, it becomes clear that 12 models have a model structure one would not directly have expected, viz. the models in the cells defined by policy issue class 1 and model structure class 4b, by 6 and 3a, 7 and 2b and 9 and 4a. This together with the fact that almost 75% of the models from the survey claim to work with complex economic and ecological submodels with a two-way relationship leads us to the conclusion that much more attention should be paid to the *selection* of a model structure, adequate for the policy issue at hand. After all, the survey analysis shows that in some cases it could have been possible to keep the model simpler and still adequate.

6. PROBLEMS AND PERSPECTIVES IN ECONOMIC-ECOLOGICAL MODELING

6.1. Introduction

One question in the survey pertained to strong and weak points of the models. Another one asked for general recommendations for further analysis in the field of economic-ecological modeling. The so-derived information forms the main input for this section on problems and perspectives in economic-ecological modeling.

Of course, modeling problems exist in all phases of model development, application and utilization. In this section, however, only those issues are addressed which are directly related to the process of integrated economic-ecological modeling and policy-making.

Three main types of problems can be distinguished in this respect:

- *analytical* problems, i.e., developing economic-ecological models (see 6.2);
- *empirical* problems, i.e., empirically based application of economic-ecological models (see 6.3);
- *policy* problems, i.e., the actual use of results of economic-ecological model studies (see 6.4).

Perspectives of economic-ecological modeling will be dealt with in Section 6.5.

6.2. Analytical Problems

Analytical problems include:

- requirements from monodisciplinary theories for multidisciplinary models. For example, how adequate are monodisciplinary theories for this purpose?

- what is the relevance of general systems theory for integrating economic and ecological models?
- simple versus complex models (also relevant as empirical and policy problem);
- holistic interdisciplinary models or compartmental multidisciplinary ones (with separate economic and ecological options);
- the choice of indicators versus fully descriptive models;
- how to cope with difference–spatial and temporal scales in both economic and ecological systems; different levels of complexity, uncertainty, aggregation, different shapes of specifications, etc.?
- how to select an optimal (appropriate) model for a given purpose;
- the derivation of general economic-ecological methodologies, theories and models from application field oriented approaches.

6.3. Empirical Problems

Problems of empirically based application of economic-ecological models are mostly *data* problems. For instance, difficulties in the acquisition of linked economic-ecological data due to difficulties in measuring ecological impacts of economic causes, or in measuring joint (synergetic) products. These difficulties are often caused by different spatial or temporal levels of measurement, possibly combined with different levels of cardinality and/or ordinality of the data.

A related problem is the evaluation of extra inputs (costs, longer research time, etc.) to acquire missing economic-ecological data necessary for a relatively more complex model, versus the extra results to be expected over a more simple model. Of course, this evaluation problem is more general, but it is of specific relevance in a multidisciplinary context.

6.4. Policy Problems

Problems related to the actual use of economic-ecological models refer mainly to: how to make policy-makers believe in the models and how to stimulate their willingness to use them. They, or their advisors, need a basic understanding of how the models work. Still the translation of models and model output to policy-makers is rather poor. At the same time, the incorporation of the research needs as perceived by policy-makers into the model is regularly inadequate. Interactions between scientists and policy-makers are not very common.

It is our view that the solution of at least part of the policy problems may be stimulated by active cooperation between scientists and senior policy-advisors using user-friendly modeling approaches and modern research techniques as, for instance, multicriteria models defined specifically for interdisciplinary decision processes. This is in line with the conclusions of the 1983 IvM-IIASA workshop on economic-ecological modeling. It is considered more useful to address (senior) policy-advisors than the policy-makers themselves. The latter would never have enough time for (nor interest in) a close cooperation. Their interest is primarily with the results. It is the policy-advisors task to make these clear.

6.5. Perspectives of Economic-Ecological Modeling

A study should be made of the adequacy of common technical methods to analyze interrelations between economics and ecology. The purpose of such a study would be to provide future modelers with a selection scheme (or frame of reference) which may help them to choose appropriate ways to connect economic and ecological models or to apply systems analysis.

Topics for further analysis which were more directly derived from the survey were, next to the question of how to model economic-ecological space-time dynamics, amongst others:

- how to deal with discipline specific constraints in multidisciplinary approaches?
- are many fields of application characterized by severe constraints, which would obstruct the development of a *general* procedure for adequate economic-ecological modeling?
- how to deal with another (third) discipline in economic-ecological modeling?
- how to deal with soft data problems (which seem to be more prominent in multidisciplinary than in monodisciplinary modeling)?

7. CONCLUSIONS

A generally accepted definition and classification of economic-ecological models was not available at the start of the project. The preliminary definition given in the introductory paper of the project was: "a set of mathematical relationships describing any connections between economic and ecological systems". With the results of the survey this definition has been extended. Based on structural differences we now distinguish two major groups of economic-ecological models:

1. "complex, integrated economic-ecological models, consisting of submodels which are accepted as adequately describing the structure and behavior of economic and ecological systems respectively, as well as the structure and functioning of interrelationships between these two systems".
2. "half complex economic-ecological models, consisting of one complex submodel (an internally related set of variables) and one simple submodel (an internally unrelated set of variables), in which the simple submodel is accepted as a clear characterization of key elements of the pertinent scientific discipline".

The survey results are a fair representation of the types of economic-ecologic models in existence. Other structurally different types of economic-ecologic models have not been found in an extensive literature search, although there are variations on the main lines. It is, however, not at all clear whether the number of models per class as found in the survey is representative. In other words, no statistics can be given on the sample.

The majority of the models in the survey is claimed to be complex, integrated economic-ecological. Most of the models have been designed for a specific policy case, and most of them are described as applicable in more than one field. The majority of the models has been applied and tested in some manner. Dynamic models dominate the sample. Systems at the local and regional scale are the ones most often modeled, and when simulated, this is usually done at a one-year time step and with a 20-year horizon. Large models (with hundreds of endogenous variables) are rare. As to the intended use of the models, they are evenly distributed over descriptive/predictive, prescriptive (optimization) and combinations of these two types. In the latter case, the model most often consists of an economic optimization submodel and an ecological simulation model.

Complex, integrated economic-ecological models were found to be applied in all fields of application distinguished. Agriculture, land use and water related problems were the most often mentioned fields. Most of the models were said to be multifunctional.

The majority of the models turned out to have the appropriate model structure for the type of policy issue addressed, at least according to the criteria employed in this study, which regarded the match between the complexity of the relevant submodels and kind of interrelationship between the submodels on the one hand and the character of the systems and interactions involved in the policy problem on the other hand. Only a few models were more complex than necessary in that respect.

Three main types of problems are distinguished in the area of economic-ecological modeling. The analytical problems of this kind of modeling mentioned in the survey are generally related to the lack of integrative theory and methodology. The empirical problems are to a great extent similar to those in other areas of modeling, e.g., data availability but sometimes aggravated due to the different requirements and properties of the two disciplines involved. The policy problems again seem to be an aggravated version of those of monodisciplinary models. It appears to be difficult to establish credibility as a modeler, and more so if one attempts to integrate two, more or less recognized disciplines.

The major analytical future focus is concluded to be the mathematics and multidisciplinary theory of the linkage between recognized economics and equally recognized ecology in models. An important focus in applied modeling will be the development of interactive model building methods, interactive meaning: an intensive cooperation between model user (policy advisors) and model builders.

APPENDIX I: CATALOGUE OF MODEL SUMMARIES

In order to provide an information background for this paper we present here a short description of all the survey models about which we have obtained adequate documentation.

Each summary sheet is coded with the first letter of the modeler's name, or, in the case of more than one modeler, the first listed. The names of the project or model and of the modeler(s) are also given, as well as the country in which the model was developed. Next, the class of policy issues to which the model belongs is indicated and the code for the type of model structure is given. The policy issue is described in key words. After that, a summary of the contents of the modeling project is given. This summary has either been copied or compiled from the model documentation. Each description ends with the references from which we derived the information. It should be mentioned that in some cases it was impossible to define a policy issue because of the absence of background material. Also in other respects this appendix is not always complete, mainly due to missing information in the relevant questionnaires.

The sequence in which the models are described is defined by the 9 classes of policy issues we defined in Section 4.1. In that way one can get an impression of the diversity of policy issues within each class. We start the overview with a review of all the policy issues from which we did not receive any additional documentation. They have among others, been working on the following policy issues:

1. Ecological Impacts of Resource Use

CODE	POLICY ISSUE	MODEL STRUCTURE CLASS
H 03	Resource evaluation for agriculture	4.a
H 06	Computer aided construction of ecological maps for landuse planning	4.b

2. Economic Impacts of Resource Development and Exploitation

CODE	POLICY ISSUE	MODEL STRUCTURE CLASS
P 02	Capacity planning of gas supply systems	4.c.

3. Ecological Impacts of Pollution and Disturbance

CODE	POLICY ISSUE	MODEL STRUCTURE CLASS
M 02	Eutrophication of fresh water areas	4.c.
P 03	Vertical hydrological balance in irrigated soils	2.b.
J 03	Environmental impact analysis of agro-chemicals	4.c.

4. Economic Impacts of Pollution

CODE	POLICY ISSUE	MODEL STRUCTURE CLASS
S 08	Economic control of reservoir eutrophication	4.c.
T 02	Optimal regional effluency fee determination	4.c.

5. Ecosystem Planning and Management

CODE	POLICY ISSUE	MODEL STRUCTURE CLASS
M 03	Environmental quality assessment	1.c.
M 05	Waterflow planning, management and impact analysis	2.b.
P 04	The ecological potential as a limiting factor in regional planning	4.b.

6. Economic System Planning and Management

CODE	POLICY ISSUE	MODEL STRUCTURE CLASS
G 02	Analysis of pastoral industry and social problems in a region	4.c.
W 03	Economic planning	4.c.
C 03	Energy-Economic Analysis of New York State	3.a.

7. Sustainable Use of Resources

CODE	POLICY ISSUE	MODEL STRUCTURE CLASS
B 01	Water requirements and cost analysis in crop production	2.b.
H 04	Production and utilization of bio-resources	4.c.

8. Sustainable Use of Environmental Services

(only documented models received)

9. Total System Planning and Management

CODE	POLICY ISSUE	MODEL STRUCTURE CLASS
S 11	Cost-benefit analysis of dead-sea project	3.c.
W 01	Total systems analysis	4.c.
A 02	Regional systems analysis for physical planning	3.c.
M 10	Hierarchic sequential decomposition of a regional systems model	4.c.

MODEL SUMMARY SHEET **CODE:** C 01

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Nematodiasis in Sheep[1] Computer Model
MODELER(S): A.P.L. Callinan; F.H. Morley
COUNTRY: Australia

POLICY ISSUE CLASS: 1 **MODEL STRUCTURE CLASS:** 4.b.
POLICY ISSUE: Disease analysis and control program evaluation

---

SUMMARY:

A computer model (NEMAT) of the life cycle of sheep nematodes and of the epidemiology of nematodiasis in sheep was constructed with the purpose of predicting the development of nematodiasis in weaner sheep and to determine optimum nematode control programmes. It has been developed for use in Western Victoria, Australia, but it should also be of use in other localities. NEMAT simulates the growth of perennial rye grass (*Lolium perenne*) and subterranean clover (*Trifloium subterraneum*) pasture and weaner sheep and the development of populations of the sheep nematodes *Ostertagia spp.* and *Trichostrongylus spp.* The development and death rate parameters of the free-living stages of these nematodes were estimated by a direct search optimization procedure specially developed for this study. The death rates of the parasitic stages of *Ostertagia spp.* were determined in a field experiment and expressed as a function of the rate of infection and the time of exposure of the infection. Other probability density functions and deterministic functions needed to complete the quantification of the sheep-nematode system were derived from published reports or personal communications.

NEMAT was validated against data from two independent field experiments. It was then used to evaluate some nematode control programs.

REFERENCES

1 Callinan, A.P.L., F.H.W. Morley, J.H. Arundel and D.H. White (1982) A model of the life cycle of sheep nematodes and the epidemiology of nematodiasis in sheep. *Agricultural Systems*, 9, (1982), pp. 199-225.

MODEL SUMMARY SHEET **CODE:** H 09

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Watershed Ecological Model
MODELER(S): M. Holý; Z. Kos; J. Váska; K. Vrána; J. Mis; Z. Handova
COUNTRY: Czechoslovakia

POLICY ISSUE CLASS: 1 **MODEL STRUCTURE CLASS:** 2.c.
POLICY ISSUE: Erosion impacts in watersheds

SUMMARY:

In the process of verifying and validating the models of agricultural nonpoint source pollution at IIASA, a study was made of the Sedlicky brook (Bohemia, Czechoslovakia) case. The CREAMS model verified at the Sansin research area (Czechoslovakia) has been used as the mathematical instrument.

The validation results of the CREAMS model for the boundary conditions between the field level and the watershed level seem to show that, under certain conditions, it can be applied to small watersheds. For large watersheds, modification of the hydrology submodel is necessary in order to describe the comprehensive hydrologic phenomena, particularly the interflow and some of the subsurface flow.

REFERENCES

Description of the model has not been published yet. Background references:

1 Holý, M. (1980) *Soil Erosion*, Pergamon Press.

2 Holý, M. *et al.*(1981) Erosion and water quality as modeled by CREAMS, IIASA, CP-81-35.

3 Holý, M. *et al.*(1982) Procedures, Numerical Parameters and Coefficients of the CREAMS Model, IIASA, CP-82-23.

4 Holý, M. *et al.*(1982) Modelling of Erosion Processes, CSAV, 6/1982, *Academia* Praha (in Czech).

MODEL SUMMARY SHEET **CODE:** R 03

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: WAFLO
MODELER(S): M.J.S.M. Reijnen; J. Wiertz
COUNTRY: Netherlands

POLICY ISSUE CLASS: 1 **MODEL STRUCTURE CLASS:** 2.c.
POLICY ISSUE: Water resource management

SUMMARY:

This study is concerned with an increasing drinking water demand and the impact on nature conservation of alternative winning plans. The Research Institute for Nature Management started a one year research program. The study area covers about 37,000 ha of mainly rural area with sandy and loamy soils and several brooks. The study concerned groundwater bound spontaneous vegetation only (20,000 ha to be actually studied).

The study covers:

- a vegetation map on scale 1:25,000 with a legend based on ca. 900 vegetation samples.
- a statement of the vulnerability of the spontaneous vegetation for groundwater withdrawal.

Using STIBOKA calculations, water supply to the rooted soil zone was computed for each element of the soilmap, simulating a drawdown of the water table of 0, 10, 25, 50, 75, and 100 cm respectively. Putting in the frequency of vegetation types by supposing the vegetation map (map 2) vulnerability analysis was based on average species composition of the mapped elements using Ellenberg (1979) and Londo (1975) ecological indicatory figures. Seven doses-effect formulas were postulated, moreover, one formula was added for mapped elements rich in easily decomposable organic matter.

REFERENCES

1 Reijnen, M.J.S.M. & J. Wiertz (1981) Spontaneous vegetation and groundwater-withdrawal in a rural area of 370 km^3 in: S.T. Tjallingii & A.A. de Veer (1981) *Proc. Int. Congr. Neth. Soc. Landscape Ecol.*, Veldhoven Pudoc Wageningen, pp. 280-281.

2 Reijnen, M.J.S.M., A. Vreugdenhil, & H.M. Beije (1981) Vegetatie en grondwaterwinning in het gebied ten zuiden van Breda. Rapport RIN, Leersum, pp. 140.

3 Holst, A.F. van & W.J.M. te Riele, (1982) Waterhuishouding westelijk Noord Barbant; bodemkundig agrohydrologisch onderzoek. Concept-rapport Stiboka, Wageningen.

4 IWACO (1982) Rapportage over fase 1 van het onderzoek betreffende het gebied ten zuiden van Breda: eerste berekeningen naar de te verwachten grondwaterstandsdalingen bij verdergaande grondwaterwinning. Rapport 30. 173-2 IWACO/P.W. Noord Brabant, Boxtel, 'S-Hertogenbosch. pp. 29.

MODEL SUMMARY SHEET **CODE:** A 01

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Linear Multiobjective Program for Fuelwood and Charcoal
MODELER(S): J.C. Allen; J.L. Cohon
COUNTRY: U.S.A.

POLICY ISSUE CLASS: 2 **MODEL STRUCTURE CLASS:** 3.c.
POLICY ISSUE: Planning and management of fuelwood plantations

SUMMARY:

A linear program was formulated to schedule planting and harvesting of exotic species and regenerating woodland, to determine how much wood should be burned as fuelwood and how much converted to charcoal, and to choose which towns and villages can collect fuelwood on foot and which should receive truck shipments of charcoal in order to meet fuel demands according to stated objectives over a five year planning period. Two objectives were identified; that of minimizing the tree planting, maintenance, and harvest costs, and that of minimizing the amount of time spent collecting fuelwood and transporting charcoal. The program was solved repeatedly with different weighted combinations of the two objectives, under three sets of assumptions:

(1) a base case with coefficients corresponding to conservative estimates of currently attainable growth rates of natural woodland and exotic species, and current pit kiln charcoal technology,

(2) an efficient kilns scenario which assumes that a doubling of kiln efficiency is attainable, and

(3) a fast growth scenario which assumes that a tripling of the growth rate of the exotic species can be achieved.

REFERENCES

1 Allen, J.C. (1983) Planning Fuelwood Plantations in Dodoma Region. Tanzania: A Linear Programming Approach Center for Energy Policy Research, RFF, Working Paper, January 1983.

MODEL SUMMARY SHEET **CODE:** B 03

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: I.I.E.D. Marine Programme
MODELER(S): J.R. Beddington
COUNTRY: U.K./England

POLICY ISSUE CLASS: 2 **MODEL STRUCTURE CLASS:** 4.b.
POLICY ISSUE: Economic impact of reopening herring fisheries

SUMMARY:

An analysis of the demand for herring in various countries in the Community and in Norway indicates that the volume of landings largely determines the price of imports.

Analysis of the implications of these demand relationships indicates an approximate value of the long-term cost of the by-catch by the sprat fishery of young herring of £2 million per year.

The existence of different demand relationships within the Community affords the possibility for assessing the economic implications of different allocations of the TAC. These possibilities are explored both between the Community and Norway and within the Community.

Approximate calculations on the fleet size and composition needed to take different TAC levels are made. The costs associated with these fleets are investigated and simple calculations of profitability are presented.

Some qualitative assessment of the effect of various TAC levels on secondary industry within the Community is described.

REFERENCES

1 Beddington, J.R., & F.E. McAllister (1981) Economic studies on the implications of the reopening of the North sea herring fishery. Commission of the E.C. Directorate General for Fisheries.

MODEL SUMMARY SHEET **CODE:** B 08

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Decide
MODELER(S): J.W. Bowden; D. Bennett
COUNTRY: Australia

POLICY ISSUE CLASS: 2 **MODEL STRUCTURE CLASS:** 4.b.
POLICY ISSUE: Planning and management of phosphate fertilizers in farming

---

SUMMARY:

The "Decide" method of making phosphate fertilizer recommendations (Bowden and Bennett, 1976) attempts to reconstruct a fertilizer response curve for each farming situation (normally a paddock) by combining the accumulated experience of research workers with the farmer's knowledge of his own farming conditions. "Decide" could be classed as a response curve prediction method of making fertilizer recommendations.

The response curve chosen is the exponential or Mitscherlich curve:

$$Y = A(1 - B \exp(-CX)) \quad (1)$$

Where Y is yield per unit area, A is the maximum yield per unit area, B is the relative response to the applied nutrient. The rate of nutrient applied (X) is standardized to kg P ha^{-1} and the curvature coefficient (C) has reciprocal dimensions to X.

The optimum rate of phosphorus to apply is determined using marginal returns theory including a rate of return (R) and a future value of the fertilizer (V) for the years following the one in which the yield is derived. V has values ranging from 0 to 1. The optimum rate equation is:

$$X_{opt} = ln(ABCPy / Px(1+R-V)) / C \quad (2)$$

where Py is the price of a unit of product, Px is the price of a unit of fertilizer.

Thus we have a seven parameter (A, B, C, Px, Py, R and V) model which must be solved for any given farming situation.

REFERENCES

1 Bennett, D., & J.W. Bowden (1976) "Decide"—An aid to efficient use of phosphorus. Reviews in Rural Science III (Proc.-Symposium "Prospects for improving efficiency of phosphorus utilization", G.J. Blair, ed.).

MODEL SUMMARY SHEET **CODE:** C 02

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Optimal Fisheries Investment
MODELER(S): A. Charles
COUNTRY: Canada

POLICY ISSUE CLASS: 2 **MODEL STRUCTURE CLASS:** 1.c.
POLICY ISSUE: Optimal investment planning in fisheries

SUMMARY:

The problem of determining optimal investment levels and optimal capital stocks is a pervasive one in the economics literature. A major complication in determining such optimal investment strategies is the frequent lack of malleability of capital, a problem which is particularly prevalent in resource industries. Most models of fisheries management problems have concentrated on the dynamics of the resource stock, treating the capital stock as given.

In the model

(i) time is considered to be discrete between fishing seasons although continuous within each season,

(ii) decision variables are end-of-season escapement and yearly investment, and

(iii) delays are allowed between the time at which investment decisions are made and the time at which these investments come on-line.

In addition, a dynamic programming approach is utilized, allowing us to study arbitrary stock-recruitment functions, including the Beverton-Holt and Ricker forms, and to obtain detailed comparative dynamic results. Specifically we describe the effect on optimal investment/escapement policies of the following factors:

(i) discrete-time vs. continuous time analysis,

(ii) investment delays,

(iii) fecundity and carrying capacity of the stock,

(iv) fish price,

(v) capital cost,

(vi) discount rate, and

(vii) depreciation rate.

A stochastic version of the model is used to study the role of uncertainty in fisheries investment problems.

REFERENCES

1 Charles, A. (1982) Optimal fisheries investment: comparative dynamics for a deterministic seasonal fishery. U.B.C., Dept. of Economics, Resources Paper No. 85, Vancouver, Canada.

2 Charles, A. (1982) Optimal fisheries investment under uncertainty. U.B.C., Dept. of Economics, Resources Paper No. 86, Vancouver, Canada.

MODEL SUMMARY SHEET **CODE:** C 04

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: COPLAN
MODELER(S): R.D. Child; G.R. Evans
COUNTRY: U.S.A.

POLICY ISSUE CLASS: 2 **MODEL STRUCTURE CLASS:** 4.c.
POLICY ISSUE: Long range planning and ranch management strategies

SUMMARY:

This handbook has been developed to describe a kind of natural resource decision framework for ranch management called COPLAN. It was developed as an aid to the basic long range planning process. It enables the development of management strategies from a least cost allocation of the available physical resources on the basis of either maximizing economic return from a ranching operation, or achieving a set of goals at a minimum expense.

The information system for developing data for the resource allocation is described with detailed instruction for completing the COPLAN "data forms". An example is developed and the input data and output information are described.

The mathematical basis for each element of the COPLAN matrix is described, as well as flow charts for each subroutine of the computer program.

REFERENCES

1 Child, R. D. & G.R. Evans (1978) COPLAN–Computer Optimization Planning System, Range Science Series No. 19.

MODEL SUMMARY SHEET **CODE:** C 07

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT:	Pelagic Whaling Models
MODELER(S):	C.W. Clark
COUNTRY:	Canada

POLICY ISSUE CLASS: 2 **MODEL STRUCTURE CLASS:** 3.c.
POLICY ISSUE: Pelagic whaling economics

SUMMARY:

In the economic analysis of the pelagic whaling industry we first examine the traditional economic theory of a common-property resource, and enquire to what extent the theory fits the whaling industry, and to what extent the industry departed historically from the theory. We then examine the question of economically 'optimal' exploitation of the whale resource. The first of these analyses pertains to limiting cases of unrestricted competition in the exploitation of whales, and the second to sole jurisdiction over, and private ownership of, whale stocks.

Neither of these paradigms, obviously, is wholly realistic. Pelagic whaling was competitive, but the number of competitors was limited to the whaling firms of a few high-technology nations. Also, the International Whaling Commission provided at least some degree of institutional control of the competitive scramble for whales. Our simplistic models (from the institutional point of view) will nevertheless indicate quite clearly the economic losses resulting from unfettered competition, as well as the scope and incentive for mutual agreement to reduce these losses.

A proper study of these questions demands the use of mathematical models of the considerable degree of technical complexity. We, however, keep these mathematical difficulties to a minimum.

REFERENCES

1 Clark, C.W. & R. Lamberson (1982) *Marine Policy*, April 1982, pp. 103-120.

MODEL SUMMARY SHEET **CODE:** C 08

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Gulf of Carpentaria Prawn Fishery
MODELER(S): C.W. Clark
COUNTRY: Canada

POLICY ISSUE CLASS: 2 **MODEL STRUCTURE CLASS:** 4.c.
POLICY ISSUE: Performance of prawn vessel classes

SUMMARY:

We present a bioeconomic model of an intermediate degree of complexity and realism of the prawn fishery of the Gulf of Carpentaria and adjacent waters in Northern Australia. The model employs 21 parameters to describe the performance of two classes of vessel exploiting several stocks of prawns. The model predicts the number of vessels of each class entering the fishery under free access, and the prediction is compared with available data. The model is also used to obtain estimates for the economically optimal number of vessels of each type.

REFERENCES

1 Clark, C.W., and G.P. Kirkwood, (1979) Bioeconomic model of the Gulf of Carpentaria prawn fishery, *J. Fish. Pres. Board Can.*, 36, pp. 1304-1312.

MODEL SUMMARY SHEET **CODE:** C 12

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT:	The Energy Embodied in the Products of the Biosphere
MODELER(S):	R. Constanza
COUNTRY:	U.S.A.

POLICY ISSUE CLASS: 2 **MODEL STRUCTURE CLASS:** 4.c.

POLICY ISSUE: Embodied energy evaluation of resources

SUMMARY:

Solar energy is the basis for the operation of the biosphere. It is used directly by plants to power the photosynthetic reaction. It is also used indirectly, since the other required inputs to plant production (nutrients, water, etc.) are the products of solar-driven biohydrogeologic processes. Given this we may ask: how much solar energy is required directly and indirectly, to produce or concentrate the "commodities" of the biosphere?

This paper develops an input-output (I-O) model of the biosphere, using recently published data on global water, carbon, nitrogen, phosphorus, biomass, and other material and energy flows. The model is used to estimate the direct and indirect solar energy cost, or embodied solar energy, of these commodities. The embodied solar energy intensities thus derived are analogous to fossil fuel energy intensities which have been calculated for economic systems. Recent studies have indicated that embodied energy and economic value are correlated when the system boundaries are drawn in an all-inclusive way. Thus, embodied solar energy intensities may be useful for valuing (shadow pricing) environmental goods and services and quantifying environmental impacts in units comparable with economic impacts.

REFERENCES

1 Constanza, R. & C. Neill (1981) The energy embodied in the products of the biosphere. Proc. ISEM symposium "Energy and ecological modelling", Louisville, Kentucky.

MODEL SUMMARY SHEET **CODE:** F 01

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Waterlogging and Salinity Control in West Pakistan
MODELER(S): M.B. Fiering; H.A. Thomas, Jr.
COUNTRY: U.S.A.

POLICY ISSUE CLASS: 2 **MODEL STRUCTURE CLASS:** 4.c.
POLICY ISSUE: Waterlogging and salinity control in irrigation

---

SUMMARY:

This paper describes the application of systems analysis and digital computer simulation to the control of waterlogging and salinity in West Pakistan. The details of the project are not nearly so important here as the nature of the systems approach and the demonstration of digital computer applicability to civil engineering problems. The history of waterlogging and salinity of agricultural lands in West Pakistan is the by-product of a truly remarkable system of crop irrigation which has been employed in increasing intensity over a period of some 3,000 years. During the early part of this century British hydraulic engineers initiated the barrage system of irrigation and began to divert large quantities of water from the mighty Indus River and the five great tributaries that drain the Punjab region of the subcontinent. The economic and technological aspects of the remedy, a well field of truly heroic proportions, are discussed: the role of the digital computer is seen to be essential to the concept and thrust of an operations research solution.

REFERENCES

1 Fiering, M.B. (1965) Revitalizing a Fertile Plain, a Case Study in Simulation and Systems Analysis of Saline and Waterlogged areas. *Water Resources Research*, Vol. 1(1) 41.

MODEL SUMMARY SHEET **CODE:** J 02

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Adaptive Programming Model for Agricultural Production
MODELER(S): V. Johansson
COUNTRY: Sweden

POLICY ISSUE CLASS: 2 **MODEL STRUCTURE CLASS:** 4.c.
POLICY ISSUE: Agricultural production planning and management

---

SUMMARY:

An available interregional programming model on agricultural production in Sweden has been coordinated with a market model. The main purpose has been to include demand functions for agricultural products. Furthermore some components in a price regulation system have been quantified. The new algorithm is based on a decomposed linear programming approach. Depending on dual values from the programming model a revised matrix is generated by the market model. The extended model will mainly be applied in situations with significant changes in the exogenous factors.

REFERENCES

1 An Adaptive Programming Model for Agricultural Production in Sweden. Paper presented at European Symposium on "Decision and Information in Agribusiness", Kiel, 27-29 May 1982.

2 En adaptiv programmeringsmodell för den svenska jordbruksproduktionen (Material to be published).

MODEL SUMMARY SHEET **CODE:** K 01

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Carrying Capacity of the U.S.A.
MODELER(S): R. Kaufmann; C.A.S. Hall
COUNTRY: U.S.A.

POLICY ISSUE CLASS: 2 **MODEL STRUCTURE CLASS:** 3.b.
POLICY ISSUE: Carrying capacity of the U.S.A.

SUMMARY:

The energy return on investment (EROI) for imported petroleum has been assessed by examining how much energy is used domestically to produce the goods exchanged directly or indirectly for foreign oil. The EROI for imported liquid petroleum has varied from 16.5 for 1 in 1963, to a peak of 23.1 for 1 in 1971, to a low of 4.6 for 1. The EROI for imported natural gas had a similar pattern over time. Yet, despite rising dollar and energy costs for imports, most domestic alternative fuels are not substituting for domestic or imported petroleum in large part because their energy return on investment is still less than the calculated values for petroleum.

One measure of the quality of a fuel resource is its energy return on investment (EROI), which is calculated in a similar manner for both domestic and foreign sources: it is the ratio of the energy delivered to society from a particular source divided by the quantity of energy required to make it available for use in the economy. The EROI for a domestic source of fuel is calculated by dividing the quantity of energy delivered to the non-petroleum producing sectors of the economy by the quantity of energy it takes to find, extract, process and deliver that fuel.

REFERENCES

1 Kaufmann, R.K. (1982) Energy consumption and real GNP in the U.S.: 1929-1981. Complex Systems Research Center, U. of New Hampshire, Durham, N.H.

2 Kaufmann, R.K. & C.A.S. Hall (1982) Energy return on investment for imported petroleum: 1963-1981. C.S.R.C., U. of New Hampshire/Cornell University.

MODEL SUMMARY SHEET **CODE:** L 01

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Embodied Energy/Dollar Relationship
MODELER(S): M.J. Lavine; T.J. Butler
COUNTRY: U.S.A.

POLICY ISSUE CLASS: 2 **MODEL STRUCTURE CLASS:** 4.c.
POLICY ISSUE: Environmental resource and impact evaluation by embodied energy

---

SUMMARY:

- This study shows that the use of embodied energy values can provide a consistent means for pricing environmental factors. Such prices may facilitate a more comprehensive consideration of the economic effects of many kinds of environmental policy decisions.
- Air, land, water, minerals, biota, and other natural resources are used by the U.S. economy. In this project we evaluated those resources in embodied energy terms, which express the amount of energy used directly and indirectly in the ecosystem's production and use of those resources. The embodied energy values estimate the amount of work that can be achieved with the use of those resources. Using both time-series (for years 1929-1976) and cross-sectional (87 sector economy) data for the U.S. economy, we regressed the constant dollar value of the economy's output on the embodied energy value of the corresponding input. We found that economic value appears to be achieved where and when work is achieved in the economy, and in constant ratio with the embodied energy value of the inputs to the economic process.

REFERENCES

1 Lavine, M.J. and T.J. Butler, (1982) Use of Embodied Energy Values to Price Environmental Factors: Examining the Embodied Energy/Dollar Relationship. Final report The National Science Foundation on grant PRA-8003845. Center of Environ. Research, Cornell University, Ithaca, N.Y.

MODEL SUMMARY SHEET **CODE:** M 04

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Structure and Evaluation of a Multispecies Fishery
MODELER(S): R. McKelvey
COUNTRY: U.S.A.

POLICY ISSUE CLASS: 2 **MODEL STRUCTURE CLASS:** 3.b.
POLICY ISSUE: Common property resource exploitation

SUMMARY:

A simple analytical model has been constructed to incorporate the main features of a multispecies fishery. A fleet of specialized boats ("shrimpers") is supplemented by a back-up fleet of flexible general-purpose vessels ("mid-water trawlers"). The trawlers, which may ordinarily harvest ground-fish and rock-fish, will be attracted into the shrimp fishery only in a good year.

One must model both short-term ("in-season") fishing patterns and long-term evolution of the shrimper fleet.

The dominant stochastic elements of the shrimp fishery are taken to be the variation of annual recruitment and of seasonal market price. Once these are set (at the beginning of the season), the within-season operation of the fishery proceeds (in the model) in a wholly deterministic fashion.

REFERENCES

1 McKelvey, R. (1982) Economic Regulation of Targeting Behavior in a Geographically Extensive Multispecies Fishery. Interdisciplinary Report 19A (May 1982), Department of Mathematical Sciences, University of Montana.

2 McKelvey, R. (1982) The Fishery in a Fluctuating Environment: Coexistence of Specialist and Generalist Fishing Vessels in a Multipurpose Fleet. Interdisciplinary Report 20 (August 1982), Department of Mathematical Sciences, University of Montana.

MODEL SUMMARY SHEET | **CODE:** M 06

ECONOMIC-ECOLOGICAL MODELING PROJECT | **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: BALBEI
MODELER(S): F.H.W. Morley
COUNTRY: Australia

POLICY ISSUE CLASS: 2 **MODEL STRUCTURE CLASS:** 4.b.
POLICY ISSUE: Economic effects of pasture fertilization

SUMMARY:

The effects of fertilizer on pasture production may be estimated without great difficulty, but the value of the application depends on its effect on animal production, the measurement of which presents formidable problems. The estimation by simultion models of responses by animal production may therefore be a valuable aid to decision-making.

This paper estimates the effect on animal production of an increase of 20 percent in pasture growth rate. Twenty percent was chosen because a difference in yields of adjacent plots of 100 kg/ha can be detected by eye. This would be approximately 20 percent of the amount of pasture present a few weeks after grazing ceases on heavily grazed plots in the late autumn when test strips or plots are used to detect responses.

Models have been constructed of systems of production of young sheep for meat and wool or flock replacements, and of young beef cattle grown for meat or herd replacements. In the sheep models pasture growth was generated by functions simulating a Mediterranean pattern of growth. In the cattle systems the actual rainfall at Balcarce, Argentina was used to generate pasture growth. The models are similar in many respects to those published by Vickery and Hedges and McKinney. The objective functions are expressed as gross margins in $A/ha, using Australian costs and prices that seem likely to apply in the next few years. All systems are assumed to be based on ***long-established improved pastures*** to which maintenance levels of superphosphate have been consistently applied.

REFERENCES

1 Evaluation by animal production of increases in pasture growth using computer simulation Proc. 12th Int. Grassland Cong., Moscow (1971), 3, pp. 320-5.

MODEL SUMMARY SHEET **CODE:** M 07

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: DROUGHT
MODELER(S): I.H.W. Morley
COUNTRY: Australia

POLICY ISSUE CLASS: 2 **MODEL STRUCTURE CLASS:** 4.c.
POLICY ISSUE: Agricultural management

SUMMARY:

In this study, inventory analyses of inputs and outputs generated by various policies have been made over a range of drought frequencies and durations. A farmer can attempt to meet all (or some) of his anticipated needs by making hay. Alternatively he may prefer not to conserve fodder but to purchase wheat (or other feed) when he needs it. Of course, there are many possible strategies, but this study is limited to an analysis of these two techniques of providing fodder, although neither of these may be the best available strategy.

The existence of many inaccurately known variables in the system makes necessary the examination of the whole production system by a model that takes account of variation. This can be done by simulation with a model in which changes in the values of components of the model can be studied in relation to other components and the whole system of production.

This model should be applicable to much of the wheat–sheep and high-rainfall zones of Eastern Australia.

The criteria chosen for comparison of strategies were:

(i) affluence

(ii) variability of bank-balance

(iii) the amount of wheat used in the century

(iv) the amount of hay made, and the fixed and variable costs involved.

REFERENCES

1 Horley, E.R.W. & G.Y. Graham, *Fodder Conservation for Drought in Systems Analysis in Agricultural Management*, (ed. G.B. Dent and J.R. Anderson) Wiley, Sydney, NSW, pp. 212-236.

MODEL SUMMARY SHEET **CODE:** 0 01

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Urbanization and Environmental Conservation
MODELER(S): I. Orishimo
COUNTRY: Japan

POLICY ISSUE CLASS: 2 **MODEL STRUCTURE CLASS:** 3.c.
POLICY ISSUE: Effects of environmental change on urbanization

---

SUMMARY:

Although some attributes of the environmental quality of a location are reflected in the land or property rent and others are reflected in the local tax level through the public expenditures for environmental quality control in a location, these embodiments are not necessarily complete. Accordingly, we look at aspects of environmental quality that are not embodied in the rent or in the tax level of the location. In this case, therefore, we consider that all such environmental qualities of a location should be reflected in a different type of utility function for the location.

Therefore, we consider one-parameter families of utility functions generated by a parameter, which expresses the location, or the set of environmental qualities. Our model is a pure exchange economy with commodities and consumers. The following assumptions are basic for the economy:

(1) free location option: each consumer can move and live where he likes;

(2) free consumption option: each consumer can consume any commodity wherever he lives.

By assumption

(1) each consumer's location choice does not depend on the choices of others, and by assumption

(2) his location choice does depend on his holding (e.g., his commodity bundle may constrain location choice).

In this paper, under some specific conditions, we derive a location equilibrium for households, given an initial resource endowment.

REFERENCES

1 Orishimo, I. (1982) *Urbanization and Environmental Quality*, Kluwer-Nijhoff Publishing Co., Boston.

MODEL SUMMARY SHEET **CODE:** P 06

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Optimal Operations of a Single Purpose Reservoir
MODELER(S): E. Plate; B. Treiber; O. Schmidt
COUNTRY: F.R.G.

POLICY ISSUE CLASS: 2 **MODEL STRUCTURE CLASS:** 4.c.
POLICY ISSUE: Management of irrigation reservoirs

SUMMARY:

Irrigation studies are considered to be a very important contribution to the solution of world food problems. A dynamic programming approach has been used to analyze the optimal use of reservoir systems for controlled irrigation. Dependent on the function of the cultivated land, the optimal water utilization is calculated.

REFERENCES

1 Schmidt, O. (1981) Die Optimierung des Speiekerbetriebes für die Bewässerung mittels Simulation. Mitt. Inst. Wasserbau III, Heft 18.

MODEL SUMMARY SHEET **CODE:** S 06

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Potential for Industrial Expansion
MODELER(S): M. Slesser
COUNTRY: Scotland

POLICY ISSUE CLASS: 2 **MODEL STRUCTURE CLASS:** 4.c.
POLICY ISSUE: Energy resource evaluation for industrial expansion

---

SUMMARY:

While energy is accepted as essential to economic activity, in development planning it tends to be treated as something always available at a money cost. Since energy is the driving force of the economy, this approach can result in unrealistic economic projections. A better feel for the potential for world economic expansion may be gained by examining how fast the world's supply of useful delivered energy can expand. This may be done using a simple energy for energy feed-back model (PIE-em) which indicates that expansion is indeed constrained.

REFERENCES

1 Slesser, M. (1982) A Thermodynamic Constraint on the Rate of Global Development. Presented at: Energy, Money, Materials and Thermodynamics. Inst. Chemical Engineers, London.

MODEL SUMMARY SHEET **CODE:** B 04

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: SALMO (Simulation with an Analytical Lake Model)
MODELER(S): J. Benndorf; F. Recknagel
COUNTRY: D.D.R.

POLICY ISSUE CLASS: 3 **MODEL STRUCTURE CLASS:** 2.a.
POLICY ISSUE: Eutrophication of lakes

SUMMARY:

A short description of a dynamic ecological model of the pelagic zone of reservoirs and lakes is given. SALMO involves only three state variables (two groups of phytoplankton, zooplankton, orthophosphate), but nevertheless a great number of internal control mechanisms is considered. The applicability of this model to quite different water bodies is checked by comparing simulation results with observations. Four water bodies are used for these comparisons: Lake Stechlin (deep, oligotrophic), Saidenbach reservoir (deep, mesotrophic), Bautzen reservoir (shallow, hypereuthrophic) and Bleiloch reservoir (deep, hypereutrophic, high light extinction). In spite of numerous deviations between simulations and observations, the general result of this validation justifies the use of SALMO in water quality management. The relative comparison of simulated scenarios is regarded to be the most adequate method of such an application because it minimizes the influence of the inaccuracies of the model. An example of a scenario analysis for decision making in the management of a multi-purpose reservoir is given in detail.

REFERENCES

1 Benndorf, J. & F. Recknagel (1982) Problems of application of the ecological model SALMO to lakes and reservoirs of different trophic state. *Ecological Modeling*.

MODEL SUMMARY SHEET **CODE:** J 03

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Agrochemical Effects on the Environment
MODELER(S): R. Johnson; G. Auble
COUNTRY: U.S.A.

POLICY ISSUE CLASS: 3 **MODEL STRUCTURE CLASS:** not known
POLICY ISSUE: Environmental impact analysis of agrochemicals

SUMMARY:

The model simulates the effect of corn agroecosystem decisions on crop production, economic returns, and environmental indicators. The model is composed of five interacting submodels:

(1) a Production Strategies submodel which is used for decisions concerning tillage, planting, fertilizer and pesticide applications, and harvest;

(2) a Hydrology/Chemical Transport submodel which represents soil hydrology, erosion, and concentrations of fertilizers and pesticides in the soil, runoff, surface waters, and percolation;

(3) A Vegetation submodel which simulates growth of agricultural crops (corn and soybeans) and weeds;

(4) a Pests submodel which calculates pest population levels and resulting crop damage; and

(5) an Environmental Effects submodel which calculates indicators of potential fish kills, human health effects, and wildlife habitat.

The most persistent data gaps encountered in quantifying the model were coefficients to relate environmental consequences to alternative pest management strategies.

While the model developed in the project is not yet accurate enough to be used for real-world decisions about the use of pesticides on corn, it does contain the basic structure upon which such a model could be built.

The model was used for the simulation of policy scenarios, and examination of techniques to address institutional conflicts.

The model is a fairly simple model simulation developed in a "workshop" style. It was agreed to be useful in training students, extension specialists, farmers, researchers, and chemical producers in collaborative problem solving methods.

MODEL SUMMARY SHEET **CODE:** L 02

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Phosphorus Transformation Model
MODELER(S): A. Leonov
COUNTRY: U.S.S.R.

POLICY ISSUE CLASS: 3 **MODEL STRUCTURE CLASS:** 4.a
POLICY ISSUE: Phosphorus eutrophication in a lake

SUMMARY:

Transformation of the phosphorous compound in Lake Balaton was described in the mathematical model BALSECT (Balaton Sector Model). This model, which deals with five types of phosphorous compounds, reflects the basic interactions between these compounds in accordance with the consecutive conversion of phosphorous compounds in the water environment. The rates of change in the phosphorous transformation processes are modeled to be dependent on and regulated by environmental factors, such as temperature, radiation, water balance, and nutrient watershed load. The model also takes into account the wind action on the horizontal interbasin transport of phosphorous as well as phosphorous exchange between sediment and water. The improved version of the possible watershed nutrient loading was used in this study. On the basis of the analysis of the turnover time values, the details of the cycling of the individual phosphorous compounds and the total P are presented in this report. The explanation of the trends in the phosphorous cycling in terms of turnover time is considered useful and important for understanding the regime of the phosphorous transformation within the Lake Balaton Ecosystem for the different environmental conditions and changeable nutrient loading. Thus, the simulation results and calculated values of turnover time may be used for the formulation of suggestions concerning the water quality management of this lake.

REFERENCES

1 Leonov, A.V. (1982) Transformations and turnover of phosphorous compounds in the Lake Balaton Ecosystem, 1976-1978. IIASA, Working Paper WP-82-27.

MODEL SUMMARY SHEET **CODE:** T 03

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Nitrification in Water Ecosystems with Agrochemicals
MODELER(S): D. Toth; V. Svetlosanov; A. Leonov; T. Kmet
COUNTRY: Czechoslovakia; U.S.S.R.

POLICY ISSUE CLASS: 3 **MODEL STRUCTURE CLASS:** 2.b.
POLICY ISSUE: Impact analysis of agrochemicals in fresh water

SUMMARY:

Of the transformation processes in the water environment, nitrogen transformation is perhaps the most interesting because nitrogen and its compounds (both organic and mineral), affect the development of practically all aquatic microorganisms and therefore determine the trophic state and the quality of a water environment. Nitrogen compounds are present in sewage and other waste water discharged into water bodies.

Therefore, it is quite understandable why during the last few years nitrogen transformation has been the subject of study at descriptive and experimental levels, as well as by mathematical modeling techniques.

Experimental data were analyzed with the help of the mathematical model developed at IIASA and intended for understanding processes of nitrogen transformation in water environments. The results of model description of nitrogen compound dynamics are evaluated by statistics to find a quantitative criteria in model assessment. In the discussion of simulation results, attention was focused on the analysis of bacterial activities in the conversion of organic as well as mineral nitrogen forms. The results reported here are considered to be the basis for the simulation of nitrogen dynamics in water bodies and for studying various aspects of ecology and aquatic ecosystem behavior.

REFERENCES

1 Toth, D., & V. Svetlosanov (1982) Some Effects of Pesticides on Water Ecosystem Stability (Influence of Agricultured Area on Water Reservoir Stability). IIASA, Collaborative Paper.

2 Leonov, A., & D. Toth (1981) The Study of Nitrogen Transformation in Fresh Water: Experiments and Mathematical Modeling. IIASA, Collaborative Paper CP-81-24.

MODEL SUMMARY SHEET **CODE:** V 03

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: VENLA
MODELER(S): M. Virtanen; E. Rautalahti-Miettinen; J. Sarkkula
COUNTRY: Finland

POLICY ISSUE CLASS: 3 **MODEL STRUCTURE CLASS:** 2.a.
POLICY ISSUE: Effects of a pulp mill on an ice-covered lake

SUMMARY:

A two-dimensional BOD-DO model, including a two-dimensional hydrodynamic submodel for calculating the water flow, has been applied to a recipient of a pulp and paper mill. The concentration of DO is considered to be dependent on BOD loading, reaeration and benthic oxygen demand. The agreement between calculated and observed values is good. The alternative loadings have been calculated for low, mean and high flows. On the basis of the results it is possible to find an appropriate solution to improve the state of the recipient.

REFERENCES

1 Rautalahti-Miettinen, E., J. Sarkkula & M. Virtanen (1981) The Effects of a Pulp Mill on an Ice-Covered Lake System. *Aqua Fennica*, 11, pp. 36-42.

MODEL SUMMARY SHEET **CODE:** B 06

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Multicriterion Control of Nutrient Loading
MODELER(S): I. Bogardi; L. David; L. Duckstein
COUNTRY: Hungary; U.S.A.

POLICY ISSUE CLASS: 4 **MODEL STRUCTURE CLASS:** 4.c.
POLICY ISSUE: Control of nutrient loading to a lake

SUMMARY:

The control of nutrient loading into a water body is approached from a multiobjective viewpoint. The example of phosphorous (P) loading into Lake Balaton, Hungary, is used as a case study. The element P is chosen because it appears to be the limiting factor of eutrophication in the lake considered, as in many other lakes. About one-half of P loading originates from nonpoint sources; furthermore, the mechanism is poorly known and only few observation data are available. The objective of eutrophication control is to minimize P loading and maximize agricultural revenue. These two objectives often appear to be in conflict. A discrete set of alternative control methods is defined, consisting of controlling a mix of the following elements: point sources, runoff, fertilizer type and application, cropping management, erosion, and sedimentation. The system dynamics is provided by a previously developed stochastic model, whose output is an empirical probability density function (pfd) of P-loading reflecting the control policy. A compromise solution of "satisfactum" can then be chosen as a mix of the best ranked policies.

REFERENCES

1 Duckstein, L., I. Bogardi & L. David (1982) Dual objective control of nutrient loading into a lake. *Water Resources Bulletin* Vol. 18 (1) pp. 21-26.

MODEL SUMMARY SHEET **CODE:** F 02

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Real-Time Control of Ostiglia Power Plant
MODELER(S): G. Fronza; P. Bolzern; P. Bacci
COUNTRY: Italy

POLICY ISSUE CLASS: 4 **MODEL STRUCTURE CLASS:** 1.b.
POLICY ISSUE: Cost-effectiveness evaluation of emission control

---

SUMMARY:

Real-time control of air quality implies the intermittent reduction of pollutant emissions to avoid an impending violation of standards. A policy of real-time control for sulfur dioxide release from a power plant is described in the paper. By this policy, future emissions are reduced when forecast maximum concentrations in a defined area exceed prescribed reference values. The reduction is proportional to the expected magnitude of the violation of the standard. In terms of power plant operation, control is implemented by mixing a cleaner fuel with standard fuel, while maintaining the power production scheduled for the plant. The policy is tested by computer simulation of an actual case. The results are illustrated by cost-effectiveness curves, and by evaluating defined cost and effectiveness measures for different values of the control variables.

REFERENCES

1 Bolzern, P. & G. Fronza (1982) Cost-Effectiveness Analysis on Real-Time Control of SO_2 Emission from a Power Plant. *J. Environ. Manag.*, V. 14, pp. 253-263.

MODEL SUMMARY SHEET **CODE:** H 01

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Triple Layer Model
MODELER(S): W. Hafkamp
COUNTRY: Netherlands

POLICY ISSUE CLASS: 4 **MODEL STRUCTURE CLASS:** 4.a.
POLICY ISSUE: Multiple objective decision making

SUMMARY:

This study aims at showing the potential of multiple objective analysis for analyzing conflicts in a spatial-economic-environmental system. After a brief introduction to interactive approaches to multiple objective decision models, a conceptual framework for an interregional system will be designed, while next an operational application will be given. Various empirical results of an interregional model for the Netherlands will be presented.

REFERENCES

1 Hafkamp, W. & P. Nijkamp (1982) Conflict analysis and compromise strategies in integrated spatial systems. Research Memorandum 8225, Department of Economics, University of Amsterdam.

MODEL SUMMARY SHEET **CODE:** H 08

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Energy Industry and Environmental Damage Cost
MODELER(S): N.H. Highton
COUNTRY: U.K./England

POLICY ISSUE CLASS: 4 **MODEL STRUCTURE CLASS:** 3.a.
POLICY ISSUE: Environmental damage cost in energy production

SUMMARY:

The purpose of this paper is to estimate optimal allocations or "policies" and to test the sensitivity of these to marginal damage cost (or taxes) for aggregate SO_2 emissions.

Given that fossil fuels exist in finite quantities the problem is to choose feasible consumption paths for coal, oil and natural gas which maximize the net present value of consumer surplus less the cost of extraction and distribution (or conversion) and the cost arising from sulfur dioxide emission and abatement. The model is therefore an application of conventional resource depletion theory.

Abatement techniques and marginal abatement costs are studied and the impact of environmental damage costs on energy prices is estimated, with the implications for optimal energy consumption over time, as well as SO_2 emission.

REFERENCES

1 Highton, N.H. & M.G. Webb (1981) Pollution abatement costs in the electricity supply industry in England and Wales. *J. of Industrial Economics*, Vol. XXX, No. 1, pp. 49-65.

2 Highton, N.H. & M.G. Webb (1982) Electricity supply and pollution control. *Resources and Energy*, 4, pp. 265-280.

3 Webb, M.G. & N.H. Highton (1982) The internationalisation of environmental costs in a long run model of the U.K. energy sector. Institute of Social and Economic Research, University of York, England.

MODEL SUMMARY SHEET **CODE:** H 10

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Economic Consequences of Intended Pollution Control
MODELER(S): A. Houweling
COUNTRY: Netherlands

POLICY ISSUE CLASS: 4 **MODEL STRUCTURE CLASS:** 3.b.
POLICY ISSUE: Economic impact of pollution control

SUMMARY:

A "variation" model has been developed to assess the economic consequences of policy alternatives for environmental pollution and noise abatement. A dynamic approach has been chosen. The abatement sector, measured in terms of production volume, has been divided into private and governmental abatement production.

The economic model describes the Dutch economy both in terms of demand and supply. Technological development is considered to be exogenous.

The yearly costs of "anti-pollution activities" of industries and households are expressed in percentages of production and consumption respectively.

REFERENCES

1 Kosten en macro-economische gevolgen van het voorgenomen milieubeleid. (Tweede Kamer der Staten Generaal, zitting 1980-1982, nrs. 16495).

2 Economische gevolgen van voorgenomen milieubeleid, een tijdpadanalyse. (Centraal Planbureau, Den Haag, 1982, Monografie 23).

MODEL SUMMARY SHEET **CODE:** P 01

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Dynamic Externality and Economic-Ecological Interaction
MODELER(S): D.W. Pearce
COUNTRY: Scotland

POLICY ISSUE CLASS: 4 **MODEL STRUCTURE CLASS:** 4.b.
POLICY ISSUE: Cost-benefit analysis for environmental policy

SUMMARY:

This study sets out to place the subject matter of environmental management in a context wider than that traditionally used by economists. This traditional context is defined by the use of "neoclassical" welfare economics which, in its modern form, has been revived in the form of cost-benefit analysis. The authors establish that this framework neglects the overall functions of the ecosystem as a life-support system and argue that the partial nature of welfare economics assessments of environmental programmes will cause a neglect of the "ecodimension" effects. They propose a model in which ecological impacts are integrated into the standard economic model, securing results which differ considerably from those of the latter approch. In particular, they show that consideration of ecological effects dictates much stricter environmental standards than would otherwise be the case.

REFERENCES

1 Pearce, D. (1976) The Limits of Cost-Benefit Analysis as a Guide to Environmental Policy, *Kyklos*, Vol. 29, pp. 97-112.

2 Torres, S.A. & D.W. Pearce Welfare Economics and Environmental Problems, *Intern. J. Environmental Studies*, (1979) Vol. 13, pp. 191-200.

MODEL SUMMARY SHEET **CODE:** P 08

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT:	Economic-Ecological Model for Nitrogen Emissions Management
MODELER(S):	P. Point
COUNTRY:	France

POLICY ISSUE CLASS: 4 **MODEL STRUCTURE CLASS:** 4.b.

POLICY ISSUE: Nitrogen emissions management

SUMMARY:

The model focuses on the integration of economic and ecological points of view in favor of an optimal policy against nitrogen pollution.

The analysis consists of a linear optimization model in which the cost of pollution (nitrogen) abatement is minimalized subject to constraints regarding variables like maximum concentration, the nitrogen quantity used, the nitrogen effluent quantity, the observed concentration in water and the level of nitrogen emission abatement.

An important parameter, which is estimated by means of the linear regression method, is the "transfer" coefficient which measures the contribution of each nitrogen-source to the observed concentration.

An explorative application of the model, that will be further developed, has been established in the basin of "Haut-Aveyron".

REFERENCES

1 Point, P. (1983) "Eléments pour une gestion des effluents azotés dans les eaux de surface". Laboratoire d'Analyse et de Recherche Economiques. Rapport de Recherche A.S.P. Piren–89p + Annexes Janvier 1983.

MODEL SUMMARY SHEET **CODE:** W 02

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Locational Aspects of Air Quality Policies
MODELER(S): E. Werczberger
COUNTRY: Israel

POLICY ISSUE CLASS: 4 **MODEL STRUCTURE CLASS:** 3.b.
POLICY ISSUE: National energy and land use

SUMMARY:

Integration of air quality considerations into land-use planning requires two kinds of policies:

(1) air-quality management, i.e., control of the location and quantity of pollutant emissions to ensure maintenance of air-quality standards; and

(2) locational policies which prevent pollution-sensitive activites such as housing or hospitals from locating in high-pollution areas.

For an efficient program of action, both types of policies must be considered. Hence land-use planning and air-quality policy cannot be separated. The point of departure is the linear programming formulation of the urban land-use system first proposed by Herbert and Stevens. Air-quality policy is introduced by requiring for each urban activity maintenance of the appropriate air-quality objective at the site at which a unit of the activity is located. The consideration of zoning regulations and of spatially differentiated air-quality objectives results in a mixed-interger programming model.

A further elaboration in this area is an application of goal programming to the planning of industrial location in the context of air-pollution policy. Goal programming is a modification of linear programming that is designed to solve problems characterized by a large number of conflicting objectives. The solution is obtained by expressing all objectives as constraints and minimizing the deviation of the allocation from the respective targets and standards. If lexicographic ordering of objectives prevails, the constraints can be introduced in order of their importance.

REFERENCES

1 Werczberger, E. (1974) A Mixed Integer Programming Model for the Integration of Air Quality Policy into Landuse Planning. Papers of the R.S.A. Vol. 33, pp. 141-154.

2 A Goal Programming Model for Industrial Location involving Environmental Consideration. *Environment and Planning A*, 1976, 8, pp. 173-188.

MODEL SUMMARY SHEET **CODE:** A 04

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Economic Growth and the Environment
MODELER(S): R. d'Arge; K.C. Kogicho
COUNTRY: U.S.A.

POLICY ISSUE CLASS: 6 **MODEL STRUCTURE CLASS:** 4.c.
POLICY ISSUE: Economic growth and effluent charge impact

SUMMARY:

A Harrod type of model is analyzed with regard to the rate of consumption over time where the model includes a simplified depiction of the interaction between the economy and natural environment. Empirical estimates of the impact of effluent charges on the comparative international advantage of selected countries are also presented. The major conclusion is that national and international economic policies and national environmental policies are not separable.[1] An extremely simple model of waste generation is used, based on the conservation of matter-energy principle, and with the consumption behavior of the economy's inhabitants assumed to be predetermined. The model is generalized to an optimal control problem where consumption and waste generation are allowed to be regulated, and an attempt is made to integrate the non-mutually exclusive processes of resources extraction and waste generation. The materials balance view of a closed resource system indicates that tonnages of raw materials extraction utilized by an economy are approximately equal to tonnages of waste products generated by the economy in the long-run.[2]

REFERENCES

1 d'Arge, R.C. (1971) Essay on Economic Growth and the Environment *Swedish Journal of Economics*.

2 d'Arge, R.C. & K.C. Kogicho (1973) Economic Growth and the Environment, *Review of Economic Studies*, Vol. XL (1) pp. 61-77.

MODEL SUMMARY SHEET **CODE:** G 01

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT:	Latin American World Model (Bariloche Model)
MODELER(S):	G.C. Gallopin and A.O. Herrera
COUNTRY:	Argentina

POLICY ISSUE CLASS: 6 **MODEL STRUCTURE CLASS:** 4.c.

POLICY ISSUE: Optimal policy for Latin American development

SUMMARY:

The Bariloche World Model is basically a strategy to fight the misery, hunger, malnutrition and lack of basic human rights of two thirds of the world population. The model is consciously political, one-sided, socialistic and is based on Latin America experience. It does not describe trends but postulates political development objectives.

The limits of confronted misery are indicated in relation to available resources, such as minerals, energy and intellectual human potential.

The model is a decision model, meant to aid in formulating political goals.

REFERENCES

1 Herrera, A.O. (ed.) (1977) *Un Monde pour Tous*, Presses Universitaires de France.

2 Herrera, A.O. *et al.* (1976) Catastrophe or New Society? IDRC-064e, International Development Research Center, Ottawa.

3 Handbook of the Latin American World Model. UNESCO 55.77/WS/11 (1977).

MODEL SUMMARY SHEET **CODE:** H 02

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Personal Transportation Model
MODELER(S): M.E. Hanson
COUNTRY: U.S.A.

POLICY ISSUE CLASS: 6 **MODEL STRUCTURE CLASS:** 3.a.
POLICY ISSUE: Impacts of transportation energy policy

SUMMARY:

The Personal Transportation Model is a relatively simple, disaggregate, and flexible model developed at the University of Wisconsin-Madison as a planning tool for considering mid- to long-term transportation and urbanization options. The model has been applied in both industrialized and developing countries to demonstrate the consequences of alternatives in urbanization patterns, energy pricing, technology, and air pollution controls. Consequences are expressed in terms of energy use by fuel, emissions, and population distributions. Analysis suggests some major transportation options; for example: high population density development in large cities, combined with electric-based mass transit, non-motorized vehicles, and auto-free zones. Development status, economic base, institutions, domestic energy, resources, cultural values, and national goals affect both the desirability and the feasibility of options.

Quantitative results are expressed in a matrix that includes, for each hypothetical policy action, a measure of energy use impact on one scale and political acceptability on the other. Political acceptability is initially measured in terms of the positions of actors in a bureaucratic politics paradigm.

REFERENCES

1 Hanson, M. & W. Foell (1981) Transportation systems planning and energy management: an international perspective. Presented at 3rd International Conference Energy-Use Management (ICEUM-III). Berlin, F.R.G. (October 1981).

2 Hanson, M. (1980) Personal transportation energy options. ERC-Report 80-113/IES-Report 112. University of Wisconsin, Madison, Wisc.

MODEL SUMMARY SHEET **CODE:** K 02

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: SPAMO
MODELER(S): L.H. Klaassen
COUNTRY: Netherlands

POLICY ISSUE CLASS: 6 **MODEL STRUCTURE CLASS:** 4.c.
POLICY ISSUE: Spatial problems in recreation, energy and land use

---

SUMMARY:

The objective is to indicate and suggest new lines of research in order to get closer to integral or comprehensive planning. A scheme is designed, called SPAMO (Spatial Model).

The scheme contains, logically, four sub-models. The first sub-model is called SPAMOS (SPAtial MOdel; Social infrastructure and residential model); it refers to residential location and contains the factors that determine the attractiveness of a given region for residential location, and the factors by which they, in turn are influenced.

The second sub-model (SPAMOL) represents the labor market as it functions on its own and as it is influenced by factors in the other sub-models.

The third sub-model is the industrial location model (SPAMOI), the fourth the transportation model (SPAMOT).

We will treat the concepts of distance, potential and accessibility later more extensively. Here it may suffice to state that these concepts form the backbone of spatial economics where 'space' is essentially a multidimensional concept.

The essential function of the potential in models like SPAMO is that it accounts for the relations between regions.

The distance function determining the weight comprises two important elements. First, the generalized transportation costs, and second, the influence of these costs on the propensity to make use of a certain amenity.

Although the model as it is presented in the SPAMO-scheme might suggest a static structure, it can quite easily become a dynamic model. Into each of the relations a time-lag can be built, should the situation require it. This seems particularly interesting as far as the introduction of infrastructural improvements is concerned.

REFERENCES

1 Klaassen, L.H., J.H. Paelinck, & G. Wagenaar, *Spatial Systems*, Gower Publ., Aldershot.

MODEL SUMMARY SHEET **CODE:** B 02

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Multicriterion Dynamic Management of an Aquifer
MODELER(S): A. Bardossy; I. Bogardi, L. Duckstein
COUNTRY: Hungary; U.S.A.

POLICY ISSUE CLASS: 7 **MODEL STRUCTURE CLASS:** 4.c.
POLICY ISSUE: Management of a multipurpose reservoir

SUMMARY:

A methodology is developed for the dynamic multiobjective management of a multipurpose regional aquifer. In a case study of bauxite mining in Western Hungary, it was found that ore deposits are often under the piezometric level of a karstic aquifer, while this same aquifer also provides recharge flows for thermal springs. $N+1$ objectives are to be minimized, the first one being the total discounted cost of control by dewatering or grouting; the other N objectives consist of deviations of recharge flows from ideal values at N control points. However, there is no agreement among experts as to a set of deviation values that would constitute a "sound environment", for this reason, a fuzzy set analysis is used and the N environmental objectives are combined into a single fuzzy membership function. The constraints include ore availability, various capacities, and the state transition function which describes the behavior of both piezometric head and underground flow. The model is linearized and solved as a dual-objective dynamic program by multiobjective compromise proramming. A numerical example with $N=2$ appears to lead to realistic control policies.

REFERENCES

1 Bogardi, I., L. Duckstein & A. Bardossy (1982) Regional Management of an Aquifer for Mining Under Water Hazard: A Dynamic Multiobjective Approach. 25th Annual Meeting of the Western Regional Science Association, Santa Barbara, California, 26 February 1982.

MODEL SUMMARY SHEET **CODE:** B 05

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Murray River Land Use Study (TOPAZ-WA)
MODELER(S): D. Bennett
COUNTRY: Australia

POLICY ISSUE CLASS: 7 **MODEL STRUCTURE CLASS:** 1.c.
POLICY ISSUE: Land use allocation and merit evaluation

SUMMARY:

The model consists of a set of data transformation programs which have been used to determine the merit of different uses and, combined with a linear program, to allocate the land uses within the catchment of a proposed dam. The model has been applied to the catchment of the Western Australian Murray River, where salt pollution as a consequence of land clearing has to be reduced before the river is potable. Rectification of this salinity problem can be achieved either by engineering (building two dams and diverting the saline headwaters) or by vegetational means (reforestation). The model uses pricing procedures for the products of the land use activity, the water and the salt to compare alternative plans.

REFERENCES

1 Bennett, D. & J.F. Thomas (eds.) (1982) *On Rational Grounds–Systems Analysis in Catchment Land Use Planning*, Elsevier, Amsterdam.

2 Bennett, D., P.A. Downes, J.F. Thomas, & R. Sharpe (1977) Linear programming as an aid to catchment land use planning. Proc. of 3rd National Conference, Adelaide, Australia.

MODEL SUMMARY SHEET **CODE:** C 05

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: EIEIO
MODELER(S): K.R. Christian; M. Freer
COUNTRY: Australia

POLICY ISSUE CLASS: 7 **MODEL STRUCTURE CLASS:** 2.b.
POLICY ISSUE: Management of grazing systems

SUMMARY:

The construction of computer simulation models offers one way of integrating experimental information into a comprehensive and quantitative description of the interacting processes involved in grazing systems. Such models may be used to assess the net impact of specific techniques on whole-farm management, and to define priorities for further experimental research.

In practice farm management policies are based on frequent and complex evaluations of current conditions, and not on an arbitrary and inflexible timetable. The central problem in grazing management is the dynamic allocation of resources. Our model provides a general structure which will enable specific strategies to be amalgamated into a whole-farm system. Further applications which suggest themselves and which could be incorporated by direct extensions of the model include worm control programs, pasture nutrient cycling, the use of special purpose pastures, the integration of animal production with crops for grazing and grain production, and combinations of animals of different breeds or species.

The model operates at three levels of organization: the biological system, managemental control of the biological system and optimization of the managerial control. The coordination of these levels necessitates a more systematic approach than has been undertaken hitherto. The most important features of this approach are:

(a) the classification of the various types of animals and feed resources, combined with a systematic coding of the classification structures, and

(b) a scheduling routine that automatically ensures that the various program operations or events are carried out at the correct times.

REFERENCES

1 Christian, K.R. *et al.* (1978) *Simulation of Grazing Systems*, Pudoc Wageningen.

MODEL SUMMARY SHEET **CODE:** C 10

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Schooling Strategy and Purse Seine Tuna Fishery
MODELER(S): C. Clark; M. Mangel
COUNTRY: Canada; U.S.A.

POLICY ISSUE CLASS: 7 **MODEL STRUCTURE CLASS:** 2.b.
POLICY ISSUE: Management of fish stocks

SUMMARY:
This paper describes mathematical models of exploited fish stocks under the assumption that a certain portion of stock becomes available through a dynamic aggregation process. The surface tuna fishery is used throughout as an example. The effects of aggregation on yield-effort relationships, indices of abundance, and fishery dynamics are discussed. The predictions of the theory are notably different from those obtained from general-production fishery models, particularly in cases where the available substock has a finite saturation level. Possible effects include fishery "catastrophes" and lack of significant correlation between catch-per-unit-effort statistics and stock abundance. Various management implications of the models are also discussed.

REFERENCES

1 Clark, C.W. & M. Mangel (1979) Aggregation and Fishery Dynamics: A Theoretical Study of Schooling and the Purse Seine Tuna Fisheries, *Fishery Bulletin*, 77(2), pp. 317-337.

MODEL SUMMARY SHEET **CODE:** C 11

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT:	Optimal Fishery Capacity
MODELER(S):	C.W. Clark; F.H. Clarke; G.R. Munro; J.R. Beddington; A. Charles; M. Mangel
COUNTRY:	Canada; U.K.; U.S.A.

POLICY ISSUE CLASS: 7 **MODEL STRUCTURE CLASS:** 4.c.

POLICY ISSUE: Irreversible investment in resource exploitation

---

SUMMARY:

This paper studies the effects of irreversibility of capital investment upon optimal exploitation policies for renewable resource stocks. It is demonstrated that although the long-term optimal sustained yield is not affected by the assumption of irreversibility (except in extreme cases), the short-term dynamic behavior of an optimal policy may have profound implications for problems of rehabilitation of overexploited fisheries and other renewable stocks.

REFERENCES

1 Clark, C.W., F.H. Clarke & G.R. Munro (1979) The Optimal Exploitation of Renewable Resource Stocks: Problems of Irreversible Investment, *Econometrica*, Vol. 47, No. 1.

MODEL SUMMARY SHEET **CODE:** H 05

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT:	Long Term Consequences of Technological Development
MODELER(S):	Z. Harnos; I. Vályi; C. Csáki
COUNTRY:	Hungary

POLICY ISSUE CLASS: 7 **MODEL STRUCTURE CLASS:** 4.c.

POLICY ISSUE: Impact of technological development on agriculture

SUMMARY:

Task 2 of IIASA's Food and Agriculture Program is concerned with the study of the long range consequences of technological development in agriculture. In order to carry out these investigations a series of case studies incorporating the region-specific nature of resource inputs and the environmental impacts of agricultural production is planned.

In the Hungarian case study producing regions within the country are treated as basic units of investigation. A region is the framework within which the major technical, technological, ecological and physical processes will be studied. However, the whole country will be covered region by region and conclusions will be drawn on the national level as well.

The methodology of the study, the regional-national recursive model-system developed for the investigation is now at the intermediate stage of development, but as yet no actual data have been run.

REFERENCES

1 Csáki, C., Z. Harnos, & I. Vályi (1982) Methodology for the investigation of long-term consequences of technological development in Hungarian agriculture--an IIASA/FAP Task 2 Case Study, IIASA, Working Paper WP-82-62.

MODEL SUMMARY SHEET **CODE:** J 04

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: IRDEC
MODELER(S): J.W. Jones; D.P. Swaney
COUNTRY: U.S.A.

POLICY ISSUE CLASS: 7 **MODEL STRUCTURE CLASS:** 2.b.
POLICY ISSUE: Irrigation management for crop production

SUMMARY:

The complex nature of crop production lends itself to simple production functions only in a general statistical sense. In order to investigate the effects of irrigation decisions at different points within the growing season, a detailed simulation model is useful.

A simulation model which integrates the effects of weather variables and irrigation schedules on the crop on a daily time-step basis is too complicated to be considered a simple production function. Furthermore, for simulation models requiring weather data at a time resolution of one day or less, a stochastic treatment of these inputs is extremely difficult. For instance, in order to generate rainfall probabilities, time series data of 20 years or more are typically used for a particular location. Obviously, historical records of weather data for periods of decades at a resolution of one day are relatively rare.

Finally, if each weather variable needed in the simulation model could be treated as a random variable for each day, the magnitude of the optimization problem in terms of processing time would be enormous.

In order to avoid some of the problems of formal optimization of the irrigation decision, we shall place some reasonable constraints on the irrigation options available to the user, and treat the weather variables not as true random variables, but as variables whose average effect on model results can be estimated from a medium-sized sample (10-20 years) of historical weather data from the same location.

The model has been designed to study irrigation management in two modes. First, specific strategies are input to the model, and, second, the resulting yield, profit and energy relationships are used for comparing different strategies.

REFERENCES

1 Swaney, D.P., J.W. James, W.G. Boggess, G.G. Wilkerson & J.W. Mishoe (1981) A crop simulation method for evaluating within season irrigation decisions. A.S.A.E. Paper no. 81-4015, St. Joseph, Michigan.

MODEL SUMMARY SHEET **CODE:** M 01

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Multiseasonal Agricultural Pest Management
MODELER(S): M. Mangel; R.E. Plant
COUNTRY: U.S.A.

POLICY ISSUE CLASS: 7 **MODEL STRUCTURE CLASS:** 4.c.
POLICY ISSUE: Pest management

SUMMARY:
A framework is presented for analyzing the trade-off between economic yield from a crop and buildup of resistance to pesticide caused by repeated applications of pesticide. We begin with the case of age independent pest dynamics, in which pests infest a field by arriving from an external pool. We initially assume that the pest genetics of interest are single locus, two allele with resistance to pesticide dominant and susceptible pests more fit in the absence of spraying. The pesticide is applied only once during the season, with timing and intensity of the application as control variables. Interseasonal pest and crop dynamics are studied by solving appropriate ordinary differential equations. Intraseasonal pest dynamics are assumed to follow the Hardy-Weinberg formula. We show that the three class diploid model can be replaced by a two class haploid model with essentially no change in the results. We develop a model, based on partial differential equations, for the case in which pest dynamics depend upon age and show that the partial differential equation model can be replaced by a pair of coupled ordinary differential equations. The main operational conclusion in this paper is that the timing of the application of pesticide can be used to control buildup of resistance and that the intensity of the application can be used to control the crop yield.

REFERENCES

1 Mangel, M. & R.E. Plant (1982) Multiseasonal Management of an Agricultural Pest, I: Development of the Theory, II: The Economic Optimization Problem. Dept. of Math., U. of California, Davis.

MODEL SUMMARY SHEET **CODE:** N 01

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Water-Related Conflict Resolution
MODELER(S): H.P. Nachtnebel; L. Duckstein; I. Bogardi; A. Bardossy
COUNTRY: Austria; U.S.A.; Hungary

POLICY ISSUE CLASS: 7 **MODEL STRUCTURE CLASS:** 4.c.
POLICY ISSUE: Water resources development

SUMMARY:

The purpose of this study is to demonstrate the evaluation and ranking of long range water resource development plans for an Austrian subregion. After a regional survey the objectives that the systems are intended to fulfill are defined. Alternative plans are analyzed and compared within a preliminary screening using a comprehensive cost-effectiveness approach. Ranking of candidate systems is performed by multiobjective programming techniques to select a preferred set of alternatives and their corresponding actions. In a subsequent approach the framework for a dynamic systems model is developed to determine the sequence and combination of actions. An extension of compromise programming is adapted to evaluate conflicting objectives throughout the planning horizon.

REFERENCES

1 Nachtnebel, H.P., L. Duckstein & I. Bogardi (1982) Evaluation of conflicting regional water requirements: an Austrian case study. Optimal allocation of water resources, (Proc. of Exeter Symposium, July 1982). IAHS Publ. No. 135.

2 Nachtnebel, H.P., I. Bogardi, & L. Duckstein (1982) Multicriterion analysis for regional water resource development. Part I: Cost-effectiveness approach. *Env. Systems Analysis and Management*, (S. Rinaldi, ed.) North Holland, Amsterdam.

MODEL SUMMARY SHEET **CODE:** R 01

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Forest Rotation with Fire-Risk
MODELER(S): W. Reed
COUNTRY: Canada

POLICY ISSUE CLASS: 7 **MODEL STRUCTURE CLASS:** 1.c.
POLICY ISSUE: Risk-cost assessment in forestry

SUMMARY:

The effects of the risk of fire or other unpredictable catastrophe on the optimal rotation period of a forest stand are investigated. It is demonstrated that when fires occur in a time-independent Poisson process, and cause total destruction, the policy effect of the fire risk is equivalent to adding a premium to the discount rate that would be operative in a risk free environment. However when the probability of fire depends on the age of the stand, or when part of the stumpage value can be salvaged after a fire, the effect of fire risk is not so simple. In all cases a modified form of the Faustmann formula is derived and a "marginal" economic interpretation given. When viewed in this light the optimal rotation policies can be seen as infinitesimal look-ahead stopping rules.

REFERENCES

1 Reed, W.J. (1983) The effects of the risk of fire on the optimal rotation of a forest. *J. of Environm. Econ. & Management.*

MODEL SUMMARY SHEET **CODE:** R 02

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Effects of Environmental Variability in Management
MODELER(S): W. Reed
COUNTRY: Canada

POLICY ISSUE CLASS: 7 **MODEL STRUCTURE CLASS:** 1.b.
POLICY ISSUE: Planning of fisheries exploitation

SUMMARY:

A stochastic harvesting model based on a discrete-time Markov population model is discussed. The population model generalizes the well-known deterministic stock-recruitment model, and can describe the dynamics of a population living in a fluctuating environment. Indeed, its form is the one often tacitly adopted by fisheries scientists in the estimation of stock-recruitment curves. The steady state of the model is discussed both in the case when it is unexploited and in the case when it is subject to a regular exploitation.

A constant-escapement feedback policy is shown to be optimal in maximizing expected discounted net revenue from an animal resource whose dynamics are described by a stochastic stock-recruitment model, provided that unit harvesting costs satisfy certain conditions. The optimal escapement in this model is compared with that in the corresponding deterministic model and it is shown how the way in which unit harvesting costs vary with population abundance can be important in determining the relative sizes of the optimal escapements. Usually, the optimal stochastic escapement is no less than the optimal deterministic escapement.

Much of the theory on which fisheries management is based assumes that the dynamics of the exploited population are deterministic. It is the purpose of this paper to investigate some of the consequences relevant to management of including a stochastic component, representing a small degree of environmental fluctuation in the basic dynamic model. Much of the discussion will be centered around the (deterministic) concept of maximum sustainable yield (MSY).

The sensitivity to harvesting in a discrete-time, age structured model of an animal population is considered. Density-dependence and stochasticity are confined to the first year of the life-cycle. Sensitivity is characterized by (a) the characteristic return time, and (b) the relative variance (coefficient of variation) of recruitment and yield. Harvesting effects the return time and relative variance through two mechanisms:

(1) a displacement of the equilibrium down the stock-recruitment curve, and

(2) a change in the shape of the "fecundity profile".

REFERENCES

1 Reed, W.J. (1978) The Steady State of a Stochastic Harvesting Model. *Math. Biosciences*, 41, pp. 273-307.

2 Reed, W.J. (1979) Optimal Escapement Levels in Stochastic and Deterministic Harvesting Models. *J. Env. Econ. & Manag.* 6, pp. 350-363.

3 Reed, W.J. (1981) Effects of Environmental Variability as they Relate to Fisheries Management. In: Haley, K.B., *Applied Operations Research in Fishing*, Plenum, New York.

4 Reed, W.J. (1982) Recruitment Variability and Age Structure in Harvested Animal Population, Math. Biosciences.

MODEL SUMMARY SHEET **CODE:** S 03

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Cornell Alfalfa Pest Management
MODELER(S): C.A. Shoemaker; D. Onstad
COUNTRY: U.S.A.

POLICY ISSUE CLASS: 7 **MODEL STRUCTURE CLASS:** 4.c.
POLICY ISSUE: Pest control

SUMMARY:

Pest management is a multistage decision process in a stochastic and observable system. A control model of a pest ecosystem is characterized by discontinuous cost functions and nonlinear, stochastic state equations describing the interaction among a large number of ecosystem components. Dynamic programming has been the optimization technique which has been most widely applied to pest management analysis, but several other optimization methods have also proven useful.

A procedure is presented for calculating the optimal integration and timing of biological, chemical and cultural methods for the control of a univoltine pest population in a random environment. The procedure describes a system of high dimension by two nested models: a stochastic dynamic programming problem with four state variables and a more detailed differential equation model describing the effect of management and weather on population demography and crop yield.

A stochastic dynamic model is developed to analyze the integrated control of alfalfa weevil in central New York. The management alternatives considered include biological control by the parasitoid *Bathyplectes cuculionis*, cultural control by early harvesting and chemical control by insecticides. The optimal policies depend upon pest and parasite densities, weather, length of planning horizon, and a number of parameters describing population dynamics. Sensitivity analysis on the parameters indicate that the policies are most sensitive to weather and weevil densities and least sensitive to parasite attack rates. The model results indicate that early harvesting is usually the most effective control procedure for alfalfa weevil management in central New York.

Two simulation models and one optimization model were used to obtain management policies for maximizing nutrient yield and minimizing the damage from the alfalfa weevil, *Hypera postica*. The policies included harvesting schedule, harvesting method and possible insecticide treatment. The benefits of a biological control agent (a parasitoid) were also studied.

REFERENCES

1 Shoemaker, C.A. (1981) Applications of Dynamic Programming and other Optimization Methods in Pest Management. In: *IEEE Transactions on Automatic Control*, Vol. AC-26, 1981.

2 Shoemaker, C.A. (1981) Optimal Integrated Control of Univoltine Pest Population with Age Structure. *Operations Research* Vol. 30, No. 1, pp. 40-61.

3 Shoemaker, C.A. & D.W. Onstad (1982) Optimization Analysis of the Integration of Biological, Cultural and Chemical Control of Alfalfa Weevil. (*Environmental Entomology*).

4 Onstad, D.W. & C.A. Shoemaker (1983) Management of Alfalfa and the Alfalfa Weevil. Dept. of Env. Eng., Cornell Univ., Ithaca, New York.

MODEL SUMMARY SHEET **CODE:** S 05

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Bioeconomic Models of Fisheries
MODELER(S): W. Silvert
COUNTRY: Canada

POLICY ISSUE CLASS: 7 **MODEL STRUCTURE CLASS:** 4.c.
POLICY ISSUE: Optimal utilization of resources

SUMMARY:

The research has focused on various aspects of resource utilization in fisheries.

1. The problem of determining the optimal economic strategy for exploitation of a fish population when the stock has been driven to a low level and is threatened with extinction if overexploitation continues. Two very simple models are investigated in detail and only very simple optimization techniques are used.
2. A simple model (to show how) the research component of fisheries management can be measured and used to plan an optimal strategy. The management objectives are taken to include avoidance of risk and maximization of yield.
3. The methodology of top-down modeling, which is the process of describing a set of models which generate output consistent with the experimental data and then analyzing the structure of these models to arrive at a smaller set of acceptable models.
4. A strategy for coupling biological and economic models is presented and illustrates how these questions can be quantified and integrated to arrive at a bioeconomically optimal management strategy.
5 A theoretical basis for the optimization of sampling design is presented and illustrates the methodology by calculations based on the cod fishery in the northern Gulf of St. Lawrence.

REFERENCES

1 Silvert, W. (1977) The Economics of Over-Fishing. *Trans. Am. Fish. Soc.*, Vol. 106, No. 2, pp. 121-130.

2 Silvert, W. (1978) The Price of Knowledge: Fisheries Management as a Research Tool. *J. Fish. Res. Board Can.*, Vol. 35, pp. 208-212.

3 Silvert, W. (1981) Topdown Modelling in Marine Ecology. In: Dubois, D.H., *Progress in Ecol. Engin. and Management by Marine Ecology*. ISEM.

4 Silvert, W. (1982) Optimal Utilization of a Variable Fish Supply. *Can J. Fish. Aquat. Sci.* 39, pp. 462-468.

5 Silvert, W. & L.M. Dichic (1982) Multiple Interactions between Fish and Fisherman. In: Mercer, M.C. (ed.), *Can. Spec. Publ. Fish. Acquat. Sci.*, pp. 163-169.

6 Silvert, W. (1982) Topdown Modelling of Multispecies Fisheries. In: Mercer, M.C. (ed.) *Can. Spec. Publ. Fish. Acquat. Sci.*, pp. 163-169.

7 Silvert, W. & H. Powles (1982) Applications of Operations Research to the Design of Field Sampling Programs. *Can. Spec. Publ. Fish.*

MODEL SUMMARY SHEET **CODE:** S 10

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Cattle Tick Control
MODELER(S): R.W. Sutherst; G.A. Norton; N.D. Barlow, G.R. Conway; M. Birley; H.N. Comins
COUNTRY: Australia; U.K./England

POLICY ISSUE CLASS: 7 **MODEL STRUCTURE CLASS:** 2.b.
POLICY ISSUE: Cattle disease control

SUMMARY:

The performances of three control methods for cattle tick in Australia—acaricides, pasture spelling and tick resistant cattle—are assessed separately and in combination, using a population model and data obtained in the South-East Queensland region. In each case, the optimal strategy is first determined by computer search and is then assessed on the basis of its performance against low and high tick populations, its robustness, its long-term effects, its impact on the development of acaricide resistance, and its additional costs of fencing, feeding and handling.

REFERENCES

1 Sutherst, R.W., G.A. Norton, N.D. Barlow, G.R. Conway, M. Birley & H.N. Comins (1979) An Analysis of Management Strategies for Cattle Tick (*Boophilus Microplus*) Control in Australia. *J. of Applied Ecology* 1b, pp. 359-382.

MODEL SUMMARY SHEET **CODE:** W 05

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: SICM (Soybean Integrated Crop Management)
MODELER(S): G.G. Wilkerson; J.W. Jones; D.P. Swaney
COUNTRY: U.S.A.

POLICY ISSUE CLASS: 7 **MODEL STRUCTURE CLASS:** 2.b.
POLICY ISSUE: Crop management

SUMMARY:

The soybean crop growth model was developed as part of a project to develop models to aid in the farm management decision-making process. In order to adequately fulfill this objective, the model had to meet several criteria. First, it had to be as simple as possible, to keep computer memory requirements and run time to a minimum, so that it could be used interactively. To make decisions on either a preseasonal or intraseasonal basis, multiple simulations are required in order to determine the outcome of each of the alternative choices under a variety of possible weather regimes.

A further requirement was that the model responds to variations in weather inputs, such as temperature, rainfall, and radiation. Even if all the necessary water is supplied through irrigation, and other stresses, such as defoliation by insects, are prevented, yields vary between localities and between years at the same locality due to variations in weather.

It was also essential that the model respond accurately to the stresses of concern to us; primarily, water, insects, and diseases.

Finally, we incorporated differences in the phenological development of the crop depending upon variety, planting date, location, and daily temperature. The usefulness of the crop growth model would be greatly extended if it could accurately predict the development of the crop with the incorporation of a subroutine to predict the passage of the crop from one growth stage to the next.

REFERENCES

1 Wilkerson, G.G., J.W. Jones, K.J. Boote, K.I. Ingram & J.W. Mishoe (1981) Modeling Soybean Growth for Crop Management. Presented at American Soc. of Agr. Engineers Summer Meeting, Orlando, Florida, 1981.

MODEL SUMMARY SHEET **CODE:** A 05

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Integrated Environmental Model (IEM)
MODELER(S): J.W. Arntzen; L.C. Braat; F. Brouwer, J.P. Hettelingh
COUNTRY: Netherlands

POLICY ISSUE CLASS: 8 **MODEL STRUCTURE CLASS:** 4.c.
POLICY ISSUE: Regional environmental impacts of urban development

---

SUMMARY:

An integrated environmental model has been developed as an instrument for spatial planning on a regional level for the medium-long term. It is a result of a methodological study in which economic, geographical and spatial elements are analyzed in relation to natural environment. A case-study with this type of modeling has been carried out in the Dutch region West-Brabant. At this moment the IEM consists of five modules: a demograhic, economic, ecological, facilities and intermediate module, their effects being integrated in a spatial framework.

Institution and activities, that can be considered "causes" of environmental impacts are described in either the ***economic*** or the ***facilities submodel*** of the IEM. Economic production and related variables are separated from the activities and structure related to households. As these variables are largely dependent on size and composition of the human population, both submodels are connected with a ***demographic submodel,*** which generates these data via a cohort-survival model and migration and commuter analysis. In the ***ecological submodel*** both "structure" and "process"-themes have been included. These themes can be divided into biotic and abiotic themes. The theme "ecosystem structure" refers to the layers, zones and surface area of the systems involved. The ***intermediate submodel*** deals with spatial aspects such as surface area, location, dispersion and distance. With this submodel spatial dimensions are introduced into the interactions between variables of other submodels.

The model has been applied to an urban development plan, indicating direct and indirect environmental impacts in relation to socio-economic effects of the plan.

REFERENCES

1 Arntzen, J.W., L.C. Braat, F. Brouwer, & J.P. Hettelingh (1981) Geintegreerd Milieumodel. IVM-publicaties 81/7.

2 Brouwer, F., J.P. Hettelingh, & L. Hordijk (1982) An Integrated Regional Model for Economic-Ecological-Demographic-Facility Interactions. In: Papers for the Regional Science Association, Vol. 52.

3 Ploeg, S.W.F. van der, & L.C. Braat (1982) Integrated Environmental Models and the Landscape. Proc. of VIth International Symp. on Problems of Landscape Ecol. Research, Piestany, Czechoslovakia.

MODEL SUMMARY SHEET **CODE:** L 04

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Water Quality-Cost Optimization Models
MODELER(S): D.P. Loucks
COUNTRY: U.S.A.

POLICY ISSUE CLASS: 8 **MODEL STRUCTURE CLASS:** 4.a./b.
POLICY ISSUE: Water quality management

SUMMARY:

The achievement of regional water quality goals, especially in the more developed areas of the world, often involves substantial capital investments and changes in public attitudes concerning resource management. The economic impacts may include not only the cost of facilities designed to reduce the discharge of contaminants into natural waters or to improve the quality of waste-receiving waters, but also any limitations on continued unrestricted economic development in a particular region or river basin. Those responsible for the formulation and approval of water quality plans or management policies must have a means of estimating and evaluating the temporal and spatial economic and environmental or ecological impacts of these plans and policies. This need has stimulated the development and application of a wide range of mathematical modeling techniques for predicting various physical and economic impacts of alternative pollution control plans and policies.

REFERENCES

1 Biswas, A.K. (ed.) (1981) *Models for Water Quality Management*, Ch. 1, McGraw Hill, N.Y.

MODEL SUMMARY SHEET **CODE:** S 07

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Lower Delaware Valley Model
MODELER(S): W.O. Spofford Jr.; C.S. Russell; R.A. Kelly
COUNTRY: U.S.A.

POLICY ISSUE CLASS: 8 **MODEL STRUCTURE CLASS:** 4.c.
POLICY ISSUE: Regional environmental quality assessment

SUMMARY:

The regional residuals management model consists of the following components:

1. Residuals generation and discharge models: describe the factors influencing the generation, modification (e.g., treatment), and final discharge to the environment of residuals – gaseous, liquid and solid – from individual production and consumption activities, including relevant costs.
2. Environmental modification models: describe the options available for improving the assimilative capacity of the environment, including their costs.
3. Environmental quality models: translate the time and spatial patterns of residuals discharges into time and spatial patterns of the resulting states of the natural environment (described by ambient residuals concentrations and population sizes of biological species of interest).
4. Damage functions: relate time and spatial patterns of ambient residuals concentrations to the resulting impacts on receptors – man, animals, plants, and structures – in physical, biological, and economic terms.
5. Management strategies: consist of alternative sets of measures that effect one or more points in the management system, together with the cost and benefits associated with each strategy.

REFERENCES

1 Spofford, W.O., Jr., C.S. Russell, & R.A. Kelly (1976) Environmental Quality Management: An Application to the Lower Delaware Valley. Washington, D.C., Resources for the Future.

2 Spofford, W.O., Jr. (1973) Total Environmental Quality Management Models. In: R.A. Deininger, (ed.) *Models for Environmental Pollution Control*, Ann Arbor, Mich., Ann Arbor Science Publishers, Inc. (Resources for the Future Reprint No. 130, 1976).

3 Kelly, R.A. & W.O. Spofford, Jr. (1977) Application of an Ecosystem Model to Water Quality Management: The Delaware Estuary. In: C.A.S. Hall & J.W. Day, Jr., (eds.) *Ecosystem Modeling in Theory and Practice: An Introduction with Case Histories*, John Wiley and Sons, New York.

4 Russell, C.S. & W.O. Spofford, Jr. (1977) A Regional Environmental Quality Management Model: An Assessment. In: *J. of Environmental Economics and Management*, Vol. 4, No. 2, June, pp. 89-110 (Resources for the Future Reprint No. 147, 1977).

MODEL SUMMARY SHEET **CODE:** A 03

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Regional Systems Model of Gotland
MODELER(S): I.M. Andréassen; H. Ahlblom; A.M. Jansson; K. Limburg; T. Nilsson; J. Zucchetto
COUNTRY: Sweden; U.S.A.

POLICY ISSUE CLASS: 9 **MODEL STRUCTURE CLASS:** 4.c.
POLICY ISSUE: Regional resource planning and total impacts

SUMMARY:
This report presents a methodology for tying together a regional complex of systems of man and nature in a coherent, systematic, and quantitative fashion. As part of this methodology the island of Gotland (Sweden) was modeled as a number of subsectors which contain storages of matter, energy and money, exchanging these quantitites with one another and the outside world. In particular, the present study focuses on the flows of energy in the region as one measure common to both systems. Also presented are detailed analyses of energy and economic flows for many activities, and, in some instances, an analysis of the historical use of energy. Simulation techniques for trying to predict future impacts on the system are illustrated in terms of a water-nitrogen model.

REFERENCES

1 Jansson, A.M. & J. Zucchetto (1978) Energy, Economic and Ecological Relationships for Gotland, Sweden. A Regional Systems study. Ecological Bulletins 28, Stockholm, Sweden.

2 Limburg, K. (1982) A simulation model for two competing fisheries. Univ. of Florida, Center for Wetlands, Gainesville, Florida.

3 Spiller, G., A.M. Jansson & J. Zucchetto (1981) Modelling the effects of regional energy development on groundwater nitrate pollution on Gotland, Sweden, Proc. ISEM Conference 1981, Louisville, Kentucky.

4 Zucchetto, J. (1981) Energy diversity of regional economies. Proc. ISEM Conference, 1981, Louisville, Kentucky.

5 Zucchetto, J. & A.M. Jansson (1979) Total energy analysis of Gotland's agriculture. *Agro-Ecosystems*, 5, pp. 329-344.

6 Zucchetto, J. & A.M. Jansson (1981) Systems analysis of the present and future energy/economic developments on the island of Gotland, Sweden. Proc. ISEM Conference, 1981, Louisville, Kentucky.

7 Zucchetto, J., A.M. Jansson & K. Furgane (1980) Optimization of economic and ecological resources for regional design. *Resource Management and Optimization*, Vol. 1 (2), pp. 111-143.

MODEL SUMMARY SHEET **CODE:** B 07

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: SPIRE-POTAME
MODELER(S): J.P. Bordet; R. Barre; P. Mirenowicz
COUNTRY: France

POLICY ISSUE CLASS: 9 **MODEL STRUCTURE CLASS:** 4.a.
POLICY ISSUE: Management of water supply and water quality

SUMMARY:

The project involves a methodological study to design a comprehensive model of water policy, considering air, water and soil pollutants.

The objective was to work out and utilize a prospective water resources management device to govern the choice of investments, taking into account population distribution, economic factors, environment and their interlinking with natural resources. Also brought to light were the implications of the choice of strategies for resource development as well as for flood prevention guarantees, water supply security, water resources, draw off, conveyance and distribution of water, production, refuses of pollution, sewage plant, and the design and implementation of reservoir-dams and water-treatment stations.

REFERENCES

1 Biswas, A.K. (ed.) (1981) *Models for Water Quality Management*, McGraw Hill, N.Y.

2 Rapport final pour Ministère de l'Environnement (SPIRE).

3 Rapport final pour Agence Seine-Normandie (POTAME).

MODEL SUMMARY SHEET **CODE:** B 09

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Franklin County/Apalachicola Bay Model
MODELER(S): W.R. Boynton
COUNTRY: U.S.A.

POLICY ISSUE CLASS: 9 **MODEL STRUCTURE CLASS:** 4.c.
POLICY ISSUE: Regional land use planning and oyster fisheries management

---

SUMMARY:

This project aimed at determining the best mix of developed areas and self-renewing fisheries for a coastal county in Florida. The work to date has focused on evaluating the sensitivity of the local oyster fishery to additional developments of the tourist, retirement, shipping, and cattle industries.

It represents corollaries of Lotka's principle in models by showing all energy sources available to an area, especially those that are dominant and/or expected to change. Interaction processes that degrade part of the inflowing energy to build higher quality flows and structures are also shown. The diagrams emphasize pathways that recycle materials suspected of limiting major processes. Both energy and economic models have been developed from these diagrams.

The economic model presented here is aimed at evaluating the effects of changing levels of natural inputs and urban development on the oyster-based economy of Franklin County. To be sure that all important interactions and storages were included within the model, system boundaries were defined one level larger than the fishery, namely the county level.

The modeling combines all component processes in the system of interest. The final diagram is both an easily understood synthesis of processes in the study area and a visual picture of a system of nonlinear differential equations describing the behavior of each state variable.

In this model, evaluated equations were simulated on an Applied Dynamics AD-80 analog computer. Data needed to evaluate flow rates, initial conditions, transfer coefficients, and some validation graphs were obtained from ongoing studies, literature sources, and personal interviews.

The model was tested against field observations to determine if the factors chosen for inclusion in the model were the important ones and whether the coefficients were approximately correct.

REFERENCES

1 Boynton, W.R., D.E. Hawkins & C. Gray (1977) A modeling 'approach' to Regional planning in Franklin County and Apalachicola Bay, Florida. In: C.A.S. Hall & J.W. Day, Jr. (1977) *Ecosystem Modeling in Theory Practice*, J. Wiley and Sons, N.Y.

MODEL SUMMARY SHEET **CODE:** B 10

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: IODZH (Integraal Drinkwater Onderzoek Zuid Holland)
MODELER(S): A.H.M. Bresser; P.K. Koster; B.H. Tangena; W.K. Pluym; P.J. de Bruijn
COUNTRY: Netherlands

POLICY ISSUE CLASS: 9 **MODEL STRUCTURE CLASS:** 4.c.
POLICY ISSUE: Water resource management

SUMMARY:

The system study is the center around which all the other substitutes have been built. It consists of two interrelated mathematical models, describing the development of the water supply system as a function of time under changing circumstances and policies. The most detailed model is a simulation model (in FORTRAN) that calculates production allocation and capacity expansion and the time dependent effects on a number of objectives related to the water supply system, such as water quality, reliability, costs, energy consumption, production of waste materials and also some institutional aspects.

The simulation process generates numerous alternative solutions, one better than the other (considering the effects). To direct the search for 'good' solutions an optimization model has been constructed (single time step) multiple objective: APEX is used. This model gives the best solution for each of the objective functions.

Interactive use of both models leads to a detailed description of good solutions and an ordering of inferior alternatives.

REFERENCES

1 Interimrapport IODZH, The Hague, August 1981 (Interim report).

2 Eindrapport IODZH (in print), The Hague, May 1983 (Final report).

3 Quarterly report NIWS, Nr. 25, June 1981.

MODEL SUMMARY SHEET **CODE:** B 11

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Effects of Herbicides in South Vietnam
MODELER(S): M.T. Brown
COUNTRY: U.S.A.

POLICY ISSUE CLASS: 9 **MODEL STRUCTURE CLASS:** 4.c.
POLICY ISSUE: Impacts of war on ecosystems and cities

SUMMARY:

This chapter investigates with the aid of an analog computer the country of South Vietnam, during the period 1960 through 1970, from the point of view of the ordering energies of biotic and industrial processes and the disordering energies of war. It includes calculations of the disordering effects of the extensive U.S. bombing, herbicide spraying, and Rome plowing on ecosystems and cities. Quantitative calculations are made on the changes in land quality following these disruptions and the ways in which these changes effect the economy and population distribution patterns of the people of South Vietnam. Finally, we investigate what some of the ramifications of different levels of U.S. foreign aid, and hence new ordering energies, might mean to the reconstruction of Vietnam.

REFERENCES

1 Brown, M.T. (1977) War, Peace and the Computer: Simulation of Disordering and Ordering Energies in South Vietnam. In: C.A.S. Hall & J.W. Day, Jr. (1977) *Ecosystem Modeling in Theory and Practice*, Wiley, New York.

MODEL SUMMARY SHEET **CODE:** C 06

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Linear Multiobjective Program for Fuelwood and Charcoal
MODELER(S): R. Christianson; M.T. Brown; L.C. Braat
COUNTRY: U.S.A.

POLICY ISSUE CLASS: 9 **MODEL STRUCTURE CLASS:** 4.c.
POLICY ISSUE: Regional development and balance of payments

SUMMARY:

The subject of this modeling exercise is Lee County, Florida. Primary emphasis is on understanding the nature of dominant flows (with assumed equational structure via H.T. Odum energy modeling) in a relatively simple aggregated three compartment model. Also important is the exchange function between the system modeled and the next larger system in the hierarchical scheme of local/county/state/nation. A linear combination of embodied energy out for embodied energy in is used. Of interest was the time history behavior of the system using the exchange function as opposed to simple monetary exchange, a presumably less complete gauge of relative value from an energetic standpoint.

REFERENCES

1 Christianson, R.A. (1982) A simulation model of Lee County. University of Florida, Dept. of Env. Engin. Sciences., Gainesville, Florida.

MODEL SUMMARY SHEET **CODE:** I 01

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Ecologic-Economic Model for Integrated Development
MODELER(S): S. Ikeda; H. Hakanashi
COUNTRY: Japan

POLICY ISSUE CLASS: 9 **MODEL STRUCTURE CLASS:** 4.c.
POLICY ISSUE: Integrated development planning of a land-marine system

---

SUMMARY:

This paper is concerned with developing an ecologic-economic model which analyzes interactions between land-development and marine-use plans so as to make both plans integrated and consistent with each other. The area of concern is divided into coastal and inland-sea zones. Each zone includes economic activities such as land cultivation, light and heavy (secondary) industries, fishery and marine culture, transportation, recreation (swimming, sports, fishing, ...), as well as ecologic behaviors of chemical materials, planktons, fish and so on. As an important application, the east part of the Seto Inland-Sea Area which is surrounded by the second largest industrial base in Japan, comprising Osaka and Hyogo, is studied.

REFERENCES

1 An Ecologic-Economic Model for Supporting Land-Marine IRD. Proc. of IFAC Symp. Water, Land Resources Systems, 1980.

MODEL SUMMARY SHEET **CODE:** L 03

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Simulation/Optimization Model to Resolve Economic/Ecological Conflicts

MODELER(S): S.C. Lonergan

COUNTRY: Canada

POLICY ISSUE CLASS: 9 **MODEL STRUCTURE CLASS:** 2.c.

POLICY ISSUE: Implications of management on land and water use

---

SUMMARY:

The present work represents an attempt at linking economic/ecological systems from a more eclectic perspective and concentrates on the implications of using different value metrics to evaluate the economic/ecological interface. Application of the model includes the Choptank River watershed in Maryland (discussed subsequently) and Lake Ontario and reflects an interest not in our decisions as to where to look, but in our conclusions as to what we have seen.

The proposed method of analysis involves linking an ecosystem simulation model with an economic optimization model to facilitate regional land-use planning.

The management problem is not strictly bounded by standards, but when certain standards are violated, a high monetary penalty results to the objective function. Elements of both these approaches, contribution to the constraint function(s) and the utilization of steady-state equations which interact via a penalty function, are included in the model.

REFERENCES

1 Lonergan, S.C. (1982) A methodological framework for resolving ecological/economic problems. 27th North American R.S.A. Meeting, pp. 117-133.

MODEL SUMMARY SHEET **CODE:** M 09

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: MAB 7

MODELER(S): N. Müller; H. Lieth; T. Witte; K.F. Schreiber; K. Neumann

COUNTRY: F.R.G.

POLICY ISSUE CLASS: 9 **MODEL STRUCTURE CLASS:** 4.c.

POLICY ISSUE: Regional system interactions

SUMMARY:

The project proposes a multidisciplinary case study to investigate the ecology, the economy, and the social structure and processes in the intensive agrarian region of South Oldenburg. The aim of the study is the elaboration of a method, by which models of ecological, economical and social systems can be connected with each other into an interactive model package. In this manner we hope to create a tool for the objective investigation and possible prediction of reactions by single persons or the society to ecologically dangerous situations.

REFERENCES

1 German MAB National Committee (ed.), MAB Contribution 7: Interactions between ecological, economical and social systems in regions of intensive agriculture, 2nd edition, Bonn 1982.

2 Witte, T. (1982) Einzel- und gesamtwirtschaftliche Teilsysteme agrarischer Intensivgebiete, Osnabrück.

MODEL SUMMARY SHEET **CODE:** N 02

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: ARIES
MODELER(S): R.V. O'Neill; J.B. Mankin; J.R. Krummel
COUNTRY: U.S.A.

POLICY ISSUE CLASS: 9 **MODEL STRUCTURE CLASS:** 4.c.
POLICY ISSUE: Regional environmental problems

SUMMARY:

The adaptability of a general framework for regional environmental analysis must depend on the ability to filter through a myriad of factors that operate within a region. The approach presented here accomplishes this by proposing three categories of state variables. This approach implies the hypothesis that these categories will include all the information needed to characterize the state of the system. In addition, dynamic descriptions of the interactions among these state variables should be sufficient to address broad classes of regional problems.

The three categories of the state variables are:

(1) assets of a region

(2) human culture, and

(3) environmental pattern.

Generally, the assets of a region consist of those economically demanded resources that originate from within the defined region. These could include energy resources, agricultural output, or power-generating stations. The parameters associated with human culture can include population growth, value systems, economic demands, energy requirements, or government policy decisions. Environmental aspects become most apparent in the pattern category, which largely reflects alterations of spatial pattern. Within pattern we can describe forest islands, crop monocultures, rangeland degradation, road building, or wilderness areas. In addition, we must include a fourth category, externalities, defined as influences or forcing functions that affect the regional system regardless of the internal state of the system, e.g., precipitation input to a range ecosystem or economic pressure to extract fossil fuels.

REFERENCES

1 Mankin, J.B., J.M. Klopatek, R.N. O'Neill & J.R. Krummel (1981) A regional modelling approach to an energy-environment conflict. Proc. ISEM, Louisville, Kentucky.

2 Krummel, J.R., J.M. Klopatek, J.B. Mankin & R.V. O'Neill (1980) A simulation approach to a regional resource environment conflict. Proc. Summer Computer Simulation Conference, La Jolla, Cal.

MODEL SUMMARY SHEET **CODE:** R 04

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Urbanization and Environmental Planning and Design
MODELER(S): P. Rogers; C. Steinitz
COUNTRY: U.S.A.

POLICY ISSUE CLASS: 9 **MODEL STRUCTURE CLASS:** 4.c.
POLICY ISSUE: Environmental planning

SUMMARY:

This research has produced a complex yet easily used system for analyzing the effectiveness and consequences of planning strategies. The research provides a set of tools for proposing alternative strategies and for determining their outcomes.

To provide the information needed to make planning choices, it was first necessary to understand the physical, environmental, economic and demographic systems that cause and react to the suburban growth process. Research team members developed 28 computer models to describe collectively the pressures and consequences of suburban growth.

This methodology is extremely flexible to insure the applicability of the research to the greatest number of purposes and users. The individual models may be operated separately to address specific tasks, or linked in a variety of ways to respond to more complex questions beyond the scope of any single model. When linked together the models exchange information through a shared computer programming system and a common data base.

In standard operation, the models describe projected conditions in the study area that are likely to exist at various times in the future. By imposing constraints, users of the system can test the consequences of alternative strategies specified as plans, programs, policies, purchases, new capital facilities, new legislation, changes in basic assumptions and priorities or any combination of these. The efficiency and cost-effectiveness of the analysis system allow the models to cycle quickly through alternative strategies and to produce detailed sets of evaluations for purposes of comparison. The analysis can be performed at various levels of spatial aggregation, i.e., the region, a town, a watershed and other functional zones as determined by users' needs.

REFERENCES

1 Steinitz, C., H.J. Brown & P. Goodale (1976) Managing Suburban Growth: a Modeling Approach. Landscape Architecture Research Office, Grad. School of Design, Harvard Univ., Cambridge, Mass.

MODEL SUMMARY SHEET **CODE:** S 01

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: KESS (Kompact Emission Simulation System)
MODELER(S): R. Schieter; H. Bossel; E. Schosse
COUNTRY: F.R.G.

POLICY ISSUE CLASS: 9 **MODEL STRUCTURE CLASS:** 4.c.
POLICY ISSUE: Total environmental impact assessment of spaceheating systems policies

---

SUMMARY:

Energy supply systems have impacts on the environment: resources are used in construction and operation, pollutants are emitted, costs are made and additional risks are created.

The objective of the project was to develop a predictive basis for estimates of the environmental impacts of energy laws and standards.

The instrument developed consists of:

1. *Process data bank:* a documentation of technical, economic and ecological data of 42 energy processes.
2. *Standards documentation:* a collection of existing standards for each of the processes.
3. *Calculation program:* a program to calculate the total of quantifiable effects.
4. *Reference scenario:* a scenario for the future without change in policy.

REFERENCES

1 Bossel, H. (1981) Abschätzung der Umwelteinwirkungen energierelevanter Rechtsnormen und Gesetzesvorhaben im Bereich der Raumwärme: Aufgabenstellung, Instrument, Anwendung. ISP-Hannover/Oeko-Freiburg/Infras-Zürich.

MODEL SUMMARY SHEET **CODE:** T 01

ECONOMIC-ECOLOGICAL MODELING PROJECT **IIASA/IVM-AMSTERDAM**

MODEL/PROJECT: Flood plain management models
MODELER(S): K.C. Tai
COUNTRY: U.S.A.

POLICY ISSUE CLASS: 9 **MODEL STRUCTURE CLASS:** 4.a.
POLICY ISSUE: Impact analysis in flood plain management

SUMMARY:

Flood plain management models include the evaluation of the impact of project alternatives on the economy, the environment and the ecology. They help to assess the quality of the planning action besides rationalizing the solution of the planning process.

The water management models using regional input-output modeling, trace the hydrologic-economic linkages as well as the environmental-ecological linkages based on assumptions of general and pseudo-general equilibrium.

REFERENCES

1 Flood Plain Management Models for Economic, Environmental & Ecological Impact Analysis. In: Jørgensen, S.E. (ed.) *State-of-the-Art in Ecological Modelling*, Proc. Conf. on Ecological Modelling, Copenhagen, 28 Aug.–2 Sept., 1978, pp. 405-415.

APPENDIX II: QUESTIONNAIRE

QUESTIONNAIRE FOR AN INTERNATIONAL SURVEY AND COMPARISON OF MODELS DEALING WITH RELATIONSHIPS BETWEEN ECONOMIC AND ECOLOGICAL SYSTEMS

INSTITUTE FOR ENVIRONMENTAL STUDIES
Free University, Amsterdam, The Netherlands

and

INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
Laxenburg, Austria

NAME: ------------------------------

ADDRESS: ---------------------------

Q U E S T I O N N A I R E

1. GENERAL INFORMATION

1.1 Name of the model or project:

1.2 Name(s) and address(es) of responsible organizations:

1.3 Name(s) of modeller(s):

Address and telephone number for further information (if not the same as in 1.2):

1.4 Which are the one or two most representative publications about the model or project? Please give full references if you cannot send copies to us:

(We would greatly prefer to receive these publications from you.)

2. PURPOSE OF THE MODEL

Which of the following alternatives do you consider to be the main purpose of the model?

- Application to a general policy issue ○
- Application to a specific (policy) case ○
- Analytical interest (only potential relevance for policy) ○

3. FIELDS AND EXTENT OF APPLICATIONS

3.1 We have listed a number of possible fields of application. All fields may involve planning, management, control, evaluation, etc. Please tick the fields (more than one is possible) you deal with in the model:

- Agriculture ○
- Forestry ○
- Fisheries ○
- Land use ○
- Outdoor recreation ○
- Energy ○
- Non-renewable resources ○
- Nature conservation ○
- Diseases ○
- Pests ○
- Water ○
- Soil ○
- Air ○

Otherwise please define:

- ○
- ○

3.2 To what extent has the model been applied?

- Applied in an actual policy context ○
- Applied in a research context ○
- Not yet applied but operational ○

4. MODEL TESTING

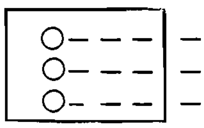
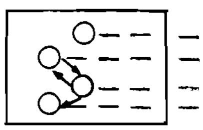
We would like to know if and how the model has been tested:

- ▶ Tested by comparison of performance with other models in relation to the same set of historical data ○
- ▶ Tested against data, other than used for calibration of the model ○
- ▶ Tested by repeated success in prediction ○
- ▶ Not yet tested ○

5. TYPES OF ECONOMIC-ECOLOGICAL MODELS

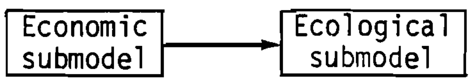
The two questions below are meant to get some general idea about the structure of your model. Explanation of these questions can be found in the background paper.

5.1 What is the *internal structure* of the model?

		Economic submodel	Ecological submodel
▶ The submodel consists of separate variables. There are no internal interdependencies.		○	○
▶ The submodel consists of a set of variables which are (partially) interrelated.		○	○

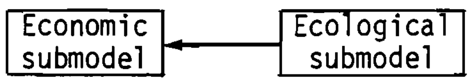
5.2 What *relationships between* the Economic and the Ecological submodel exist in your model? If the model contains sets of submodels, please indicate all relationship types present.

▶ One-way relation, economics drives ecology



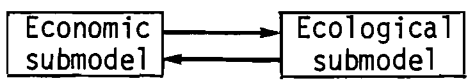
○

▶ One-way relation, ecology drives economics



○

▶ Two-way relation, interdependent submodels



○

6. BASIC MODEL CHARACTERISTICS

	Economic submodel	Ecological submodel
6.1 Please indicate your submodels in the following categories:		
▸ Static	○	○
▸ Comparative static	○	○
▸ Dynamic	○	○
6.2 What is the geographical scale of the system(s) modelled?		
▸ Local	○	○
▸ Regional	○	○
▸ National	○	○
▸ Global	○	○
6.3 As regards the time scale,		
▸ what time period is covered in the anlaysis?	....	....
▸ what time intervals are used?	....	....
▸ what is the time horizon of prediction	....	....
6.4 Please indicate the category your submodels belong to		
▸ optimization	○	○
▸ simulation	○	○
▸ otherwise	○	○

6.5 Please indicate roughly how many *endogenous* variables are incorporated in the model:

	1 - 10	10 - 100	more than 100
Socio-economic variables	○	○	○
Ecological variables	○	○	○

6.6 We would be interested in any more specific information regarding your model, e.g., particularly strong points or possible weak points. Please use space below:

7. SOME REQUESTS FOR ADDITIONAL INFORMATION

7.1 Which topics do you think should deserve special interest and attention in our comparative study?

7.2 Which models in the field of application of your own model (see question 3.1) do you consider most representative of the best in the field?

Model Name *Model Builder*
(name and address, if available)

A --

B --

C --

D --

E --

7.3 Could you please indicate for each of the models you mentioned above (7.2) which features you consider particularly useful.

A --

B --

C --

D --

E --

7.4 Our mailing list is attached to this questionnaire. If you know of model builders who you feel should join the network but are not included, please mention their names and addresses below:

WE THANK YOU FOR YOU COOPERATION!