APPENDIX 2

Classification of Models, and a Survey of Modelling Experience in Canada

As a preliminary to a survey of environmental modelling in Canada, a system was developed for the classification of models, which may be found useful for other purposes. This system is described in the first section of this Appendix, and a brief report on the survey itself follows.

A2.1 CLASSIFICATION OF ENVIRONMENTAL MODELS

The following constitutes a detailed list of attributes that specify an environmental simulation model in different respects. From these attributes a subset in most cases can be defined that meets the classification needs of a special situation. A coarse classification might, for example, include only A, B and C.

A. Subject, e.g.
- Pollution control
- Environment conservation
- Resource utilization

B. Purpose of Study:
- Decision-making (political, operational)
- Scientific research
- Education and training
- Public information

C. Environmental System being Studied:
- Type (atmosphere, river-stream, lake, groundwater, coastal-estuarine, ocean, land-soil, primary production, agriculture, forest, urban, etc.)
- Size (local, regional, national, global)
- Time horizon (hour, day, week, month, year, decade, century)

D. Size of Modelling Project (small, i.e. <1 man year; medium; big, i.e. >100 man years)

E. System Behaviour or Attributes being Modelled, e.g.
- Environmental breakdown from bearing capacity and/or sensitivity for physical, chemical, thermal, biological, etc. loads

- Environmental transportation, cycling, accumulation, and/or decomposition of nutrients, organic pollutants, inorganic pollutants, heavy metals, water, heat, etc.
- General types of dynamic behaviour (stability, varying diversity, succession, etc.)

F. Model Capabilities:
- Analysis of modes of system behaviour
- Predictions (conditional, unconditional)
- Causal explanations of phenomena of system behaviour
- Development of theory
- Analysis of limiting factors and 'bottlenecks'
- Gaming

G. Model Attributes
- Symbolic form (verbal/graphical/mathematical/algorithmic)
- Basic structure
  a. discrete-event or continuous-time
  b. deterministic or stochastic
  c. ordinary or partial differential equations
- Auxiliary properties
  a. black-box or explicit
  b. noncausal or causal
  c. static or dynamic
  d. open or closed
  e. constant-parameter or variable-parameter
  f. one-level or hierarchical
  g. linear or non-linear
- Order (number of state variables)
- Complexity (low/medium/high interactions among state variables)
- Domain of definition (space, time, subsystem, selected variables)
- Resolution and accuracy
- Variables and relations (input, state variables, outputs, observables, parameters, relation between variables)

H. Model Status
- Under development
- Degree of validation (should be documented)
- Degree of generalization (should be documented)

I. Simulation Characteristics
- Computer language (CSMP 360/DYNAMO/SIMULA 67/ALGOL/FORTRAN V/APL/GPSS/SIMSCRIPT, etc.)
- Computer used (IBM 360/PDP 1145/PACE 680, etc.)
- Conversational capacities (full/some/none)
- Capacities for modular interaction

J. Model Availability
- Availability of documentation (available/in preparation/not available)
- Availability of computer programme (available/in preparation/not available)
- Availability of results (available/in preparation/not available)

A2.2 SURVEY OF ENVIRONMENTAL MANAGEMENT SIMULATIONS IN CANADA (by D. R. Miller)

A2.2.1 Introduction

This report summarizes the results of a questionnaire distributed to simulation modellers in Canada who have been concerned with the design, introduction, and use of simulation models intended for application to environmental management. It is hoped that the results may eventually be correlated with surveys underway or to be undertaken in other countries; for now, we limit ourselves to the results for Canada.

The questionnaires were directed to modellers only. Therefore, there is a clear bias in the answer; all results that follow must be considered to be from the modellers' viewpoint. It is clear that in some cases similar questions directed to real or potential decision-makers would produce somewhat different responses.

Subject to these limitations, the purpose of the survey was threefold. We wished to gather information on

(1) what sorts of systems are being simulated and by whom;

(2) whether correlations exist between 'success' (in the eyes of the modeller) and various other factors, primarily planning and management considerations; and

(3) particular factors limiting progress or further development of models, and whether these are correlated with purposes of the model, the audience to which the model is directed, etc.

From the standpoint of the present volume, it would appear that the second of these is of greatest concern and it, together with the third, will occupy most of what follows.

A2.2.2 Methodology

Questions were asked in five general areas:

1. Purpose of the model, including the audience to which it was directed;

2. degree of success of the entire exercise including implementation of the model and its use in decision-making (in the opinion of the modeller);

3. problems encountered during model development and implementation;

4. planning and managerial factors that might serve as predictors of success; and

5. technical details of how the simulation was carried out.

Analysis was by a variety of methods, primarily 2 x 2 contingency tables or by a total enumeration of results.

A2.2.3 Results

Some interesting correlations appeared between success, as defined herein, and various possible predictors. Among the latter were whether institutional support was received during the early stages of model development; whether a substantial amount of time was devoted to the pre-proposal stage; whether organized literature searches or surveys were done as part of the planning; whether an attempt was made to involve ultimate users at an early stage, specifically by giving managers of the system itself some voice in management of the simulation study; and the establishment of a quantitative criterion of success for the simulation work.

Of these five possible predictors, the fourth was highly significant. Of the studies reported in which such formal coordination existed, projects had a ten-to-one ratio of success; where such coordination did not exist, the average project was not regarded as successful by the modeller. A relationship also seemed to exist between success and whether or not a literature search or state-of-the-art survey was conducted before the simulation work began. In those cases where it was, there were no reported failures; in cases where such a study did not take place, one in five of the simulation projects was regarded as less than successful. There was no visible relationship between success and advance support received by planners from their own organizations, or with time spent in the pre-proposal stage.

The audience to which a simulation study is directed is important. Cases where model output was to be used by technical staff or research staff had a significantly better ($p < 0.05$)* success level than cases where model results were to be used by policy formulation groups, or middle or high-level management. On the other hand, there does not seem to be any relationship between success and the purpose of the simulation study, i.e., whether it was designed ultimately to produce recommendations or some more technical contribution such as research on the system itself.

There does, however, seem to be a relationship between purpose of the simulation and difficulties encountered in the project. In those studies undertaken for the purpose of research on the system itself, lack of understanding of mechanisms, or of availability of data, were most often cited as impeding further progress. Where policy recommendations were the purpose, lack of user credibility was cited as impeding further progress more often than any other factor.

It is perhaps interesting that documentation was not given as a reason for impeding further progress or as a source of disappointment in any case. Neither was limitation of hardware. Furthermore, refusal of the user to help in model formulation and shortage of interdisciplinary cooperation were only listed in isolated cases. If the purpose of the simulation is ignored, and the total number of cases is

*The figure quoted is the probability that the standard chi-square statistic will equal or exceed the observed value by chance alone; an exact calculation is used for small numbers.

examined where particular factors impeded further development, lack of understanding of mechanisms together with shortage of data account for substantially more than half of all problems reported.

No significant relationship existed between the audience to which the simulation study was directed and the difficulties encountered, although there is a slight indication that studies aimed at the research staff encounter problems of understanding of mechanisms slightly more often.

Other combinations of questions which produced no information were the relationships between problems encountered and institutional support, time in preparation, or advance completion of a literature search.

Concerning the type of system modelled, little information is available, largely because the sample covered was too small to involve more than one or a very small number of studies of systems of any given type. It is perhaps worth observing that one of the main features of the environmental simulation studies reported was their diversity.

Finally, some comments might be made on details of the modelling procedure.

No cases were reported in which such a simulation study had been carried out on an analogue or hybrid computer; the vast majority of studies were carried out on digital computers using FORTRAN, although a number of other standard languages were mentioned. Most models were deterministic, and a wide range of complexity was observed: 20% of those reported had fewer than 10 state variables, while 30% had more than 200. In most cases models were dynamic and proceeded by the solution of differential equations in time; however, some 30% were optimization models using linear programming or some other standard optimization technique. In no case was there what could be called a statistically significant relationship between modelling techniques and success of the undertaking or its absence, or between particular technical approaches and the type of system being modelled.

A2.2.4 Conclusions

Results of this survey do not permit sweeping statements to be made concerning simulation modelling for environmental management in Canada, let alone in other countries, but perhaps certain suggestions do appear.

The clearest would seem to be that simulation studies suffer from lack of involvement and meaningful contribution by the decision-makers themselves early in the stage of model development. Lack of user credibility was never reported in cases where the user had been involved in management of the simulation project itself. Furthermore, user credibility was cited as a problem far more often than willingness of the user to help, perhaps indicating that it is not the decision-maker who refuses to consider the advantage of model development, but rather the modeller who neglects to involve him.

It is also to be observed that differences in specialized training between the modeller and the user has a perceptible effect; people who are closest to technical operations, i.e., technical or research staff, find it much easier to accept recommendations based on simulation studies.

A2.2.5 Questionnaire Distributed to Simulation Modellers in Canada

General Information

By 'Environmental Management Simulations' we mean computer simulation studies undertaken with the hope of providing information which could be used in formulating management policies. The subject is not restricted to any particular ecosystem, time or distance scale, etc.

The purpose of the study is twofold. One is to survey the state of the environmental simulations to find out what kinds of systems are being modelled and by whom, and what sorts of simulation techniques are most prevalent. The other is to test certain hypotheses about implementation and effect on decision makers.

Concerning decision-makers: Bearing in mind that management policies are rarely based on one consideration alone, we regard the results of simulation studies as being 'implemented' if they have been of significant importance in policy decisions, although not a single dominant factor.

The unit of study is the project. If an individual or institution has been involved with several such simulation projects, a form should be sent in for each one. On the other hand, if a number of models has been used within a single project and for largely the same purpose, we would like you to answer with one questionnaire referring to the entire collection.

This questionnaire may be reproduced or copied without restriction. Replies will be confidential and no individual, project or institution will be mentioned by name.

Please print this identification information:

Name of Project (if any) ______________________________
Date of Initiation ______________ Date of Termination ______________
Principal Project Staff: Director(s): ______________________________
Other Principals: ______________________________
Institution: ______________ Address: ______________________________
Supporting Agency (if funded) ______________________ Amount $________

Note: Check marks (√) may be used for most questions.

I. Purpose of Simulation Study

A. What was the *main* purpose of the simulation effort?

_____ policy decision, government agency
_____ policy decision, private sector
_____ policy recommendation
_____ help in short-term management
_____ educational or training device
_____ research on system
_____ research in simulation
_____ other (specify) ______________________________

B. To what extent has the purpose of the study been achieved or model results implemented?

______ fully operational
______ not yet, but on schedule
______ delayed, but implementation likely
______ original purpose re-defined
______ disappointed in results or implementation so far

Comments:

II. Use in Decision-Making

A. If decisions are made on the basis of model performance, what was the highest level at which model output was used?

______ technical staff
______ research staff
______ policy formulation groups
______ middle management
______ high-level policy makers
______ other (specify) ______________________

B. If the model's utility as a policy-making device was disappointing, can you identify why?

______ lack of time
______ lack of funds
______ insufficient user credibility
______ lack of facilities (hardware)
______ insufficient documentation
______ failure to identify users
______ other (specify) ______________________

III. Distance Scale (for model)

local ______________________
regional ______________________
national ______________________
global ______________________

IV. Time Scale (for model)

day-to-day operations ______________________
short-term (1 year or less) ______________________
few years ______________________
long-term ______________________
steady-state only ______________________

V. Classification of System Modelled

Please make the *one* choice in *each* category which you feel most nearly describes the system (not the model). Place further explanation under 'Additional Comments'.

A. Type of System
_____ man made
_____ natural
_____ man's impact on environment
_____ impact of environment on man
_____ other (specify) ______________________________

B. Major System Components
_____ atmosphere
_____ rivers, streams, lakes
_____ groundwater
_____ coastal/estuarine
_____ oceans
_____ land/soils
_____ primary production
_____ ecosystem (list compartments) ________________________
____
_____ economic sector
_____ human sector
_____ technological sector
_____ other (specify) ______________________________

C. Major Issue of Concern (check major category and proper component)

1. _____ Resource Management

nonrenewable	_____	(specify) ________________
agricultural crop	_____	(specify) ________________
forest	_____	
fishery	_____	
wildlife	_____	(specify) ________________
other	_____	(specify) ________________

2. _____ Environmental transport (including cycling and bioaccumulation) of various agents

nutrients	_____	(specify) ________________
organic pollutants	_____	(specify) ________________
inorganic pollutants	_____	(specify) ________________
heavy metals	_____	(specify) ________________
heat	_____	(specify) ________________
other	_____	(specify) ________________

3. _____ Environmental Impact (of what? specify) ________________

physical	_____
chemical	_____
biological	_____
ecosystem	_____
economic	_____
social	_____
public health	_____

4. _____ Other (specify) ______________________________

Additional comments:

VI. Development

A. While the proposal/initial plans for this project were being prepared, did the planners receive support from their own organization?

- ______ no
- ______ some (release time, for example)
- ______ substantial (travel, student or other assistance)
- ______ not applicable (part of their regular duties)
- ______ not applicable (other reason) ______________________

B. Approximately how long was spent in the pre-proposal or pre-initiation stage?

- ______ less than 1 month
- ______ 1 to 3 months
- ______ 4 to 11 months
- ______ 12 months or more

C. Was an organized literature search or state-of-the-art survey done as part of the planning?

- ______ yes
- ______ no
- ______ not necessary
- ______ not applicable

D. Which *one* or *two* factors do you presently see most important in *impeding* further development or successful application of this modelling project?

- ______ lack of interdisciplinary coordination
- ______ inadequate understanding of mechanisms
- ______ mathematical techniques inadequate
- ______ cost of programming/computing too great
- ______ cost of data gathering too great
- ______ insufficient data available (regardless of cost)
- ______ validation problems were encountered
- ______ user not willing to help
- ______ user does not accept conclusions
- ______ documentation inadequate
- ______ time (man-months of effort)
- ______ other (specify) ______________________
- ______ no problems

Comments on limiting factors

VII. Documentation

- ______ fully prepared and available
- ______ prepared and public, but not yet published
- ______ public but not complete
- ______ complete but proprietary
- ______ in preparation – will be public
- ______ in preparation – will not be public
- ______ not available

VIII. Is there any common membership or formal coordination between the groups managing the model and managing the system itself?

_______ yes   _______ no   _______ not applicable

IX. Has there been an attempt to provide a *quantitative* criterion of 'success' of the entire modelling project?

_______ yes
_______ discussion, but not yet implemented
_______ general belief that this cannot be done in this case

X. *Details of Modelling Procedure*

Please make the one choice in each category you feel most nearly describes the model(s). Further explanation may be included under 'Additional Comments'.

Equipment used

_____ digital computer (what kind? brand _____ model _____)
_____ analogue/hybrid (how large? e.g. how many amplifiers?
____
_____ no large computer involved

Computer Language (if digital computer used)

_____ not applicable
_____ one of APL, PL/1, ALGOL, BASIC (circle which one)
_____ other high-level general purpose language (specify) ______________
_____ standard simulation language (specify) ____________________
_____ machine-level language (specify) ________________________
_____ new language developed for this project

Model Character

_____ descriptive (based on empirical description)
_____ analytic (based on assumed system responses)
_____ normative (based on desired standards)

Probabilistic Structure of Model

_____ deterministic
_____ stochastic
_____ features of both

Complexity: Number of State (describing) Variables is

_____ less than 10
_____ 10 to 40
_____ 40 to 200
_____ 200+

Treatment of Time

_____ static (steady-state)
_____ dynamic (historical)
_____ other (features of both)

Mathematical Foundation (where applicable)

_____ solution of linear equations
_____ solution of nonlinear equations (standard methods)
_____ new equation-solving technique developed in this project
_____ linear programming
_____ other standard optimization technique (specify) ____________
_____ new optimization technique developed in this project
_____ other operations research technique (inventory, queueing theory, etc.) (specify) ____________
_____ game theory
_____ differential or difference equations in time
_____ differential or difference equations – other
_____ partial differential or difference equations
_____ stability analysis
_____ other (specify) ____________

Stability of Model Structure

_____ model developing continuously
_____ changes can be included easily
_____ model development completed; no further changes planned

Interaction

_____ fully interactive with user
_____ interactive through trained personnel
_____ some interactive features
_____ non-interactive

Additional Comments Concerning Modelling Details