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Modelling algal blooms

FINAL REPORT

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EXECUTIVE SUMMARY

This report is the outcome of a two-year project to develop understanding of the dynamics of phytoplankton blooms and an improved ability to model them.

The report refers to the bibliography of submissions already contributed. These describe the important role played by sediments in damping the responses of lakes to external nutrient control. Investigations of the mechanisms involved are presented.

A copy of the model simulating population dynamics, PROTEC 2 version 1-10, is supplied.

A brief guide to its structure, operation and outputs are given.

Strategies for improving the utility of this model, as well as some possibilities for its extension to other aspects of water quality modelling are suggested.

KEY WORDS Algal blooms; nutrients; sediments; models; water-quality management.

1. INTRODUCTION

This is the final report on the research project to develop predictive models to quantify algal blooms in relation to environmental variables.

The project's objectives were:-

- (i) To develop models simulating the impact of vertical structure and mass transfer upon the dynamics of planktonic algae, including cyanobacteria, in lakes and reservoirs.
- (ii) To assess the potential of sedimentary phosphorus to sustain algal growth following reduction in external loading.
- (iii) To expand and enhance formulations to predict behaviour of blue-green algal populations and to incorporate these into a model software package.
- (iv) To recommend a strategy for the production of user-friendly packaging for the software adaptable to particular sites.

2. FORMAT OF THE REPORT

The project, which represented a very considerable departure from orthodox approaches to algal modelling and, thus, something of a speculative venture, has been successful in assembling a working, interactive software to describe changes in algal populations in real water bodies. The progress has been catalogued in previous interim reports, while two further review reports have been presented to NRA under the same contract. These are listed below.

We do not seek to repeat this information at any great length. We present, instead, a copy of the software which we have evolved, together with a guide to its use. We fully acknowledge that the software is not in an off-the-shelf, user-orientated package, although its production was not the object of this part of the contract.

3. BIBLIOGRAPHY

Modelling algal blooms : Interim Report	C.S. Reynolds, A.E. Irish	Dec 1991
Modelling algal blooms : Second Interim Report	C.S. Reynolds, A.E. Irish	Jun 1992
Sediments and the recycling of phosphorus and nitrogen in lakes and reservoirs	C.S. Reynolds, P.S. Davies	Jul 1992
Recycle pathways for phosphorus in lakes: evidence from large limnetic enclosures (Lund Tubes)	C.S. Reynolds	Dec 1992
Modelling algal blooms : Third Interim Report	C.S. Reynolds, A.E. Irish	Dec 1992
In addition, one other piece of work has been completed for NRA		
Biomanipulation. How do we make sure that it is appropriate?	C.S. Reynolds	Feb 1993

4. GUIDE TO USING PROTEC-2 v.1.10

4.1 INTRODUCTION

PROTEC-2 is written in Microsoft® Fortran V5.1 which conforms to the American National Standard Programming Language FORTRAN 77, as described in the American National Standards Institute (ANSI) X3.9-1978 standard. Microsoft® FORTRAN contains many extensions to the full ANSI standard language. In PROTEC-2 the use of these extensions has been kept to the minimum.

PROTEC-2 has been compiled for use on microcomputers under Microsoft® DOS v5.1 or v6.0 with Intel® 80286 & 80287 processors. For speed of operation the model is best run on a microcomputer with at least 33 MHz Intel® 80386 and 80387 processors or better. The model requires at least 490 KB of RAM.

To ease the use of the PROTEC-2 model the data input files must be placed in a specific directory and have specific file names. The data generated from use of the model is similarly written into files, with pre-defined names, in a specifically named directory. The amount of disc space required for running the model depends on the amount of information input into the model. As a ball park figure allow about 25 MB for the output of files from a 600 - day model run with data for a water body of depth 13.9m having three inflows.

4.2 INSTALLATION

The PROTEC-2 model and sample data are provided on a 3½" 1.44 MB floppy disc. The model and sample data requires about 730 KB of disc space for installation.

The floppy disc contains an installation programme INSTALL.BAT which assumes that the floppy disc is mounted in DRIVE A:. Should your 3½" 1.44 MB floppy drive be DRIVE B: then use a suitable editor to change the occurrence of A: to B: in INSTALL.BAT.

To install the model, sample data and set-up the required directories insert the floppy disc in the floppy drive and type **A:INSTALL** or **B:INSTALL** (whichever is relevant). The executable file PROTEC2, **PROTEC2.EXE** is installed on DRIVE C: with the directory path - **c:\packages\protec2\v11**. The sample input data files are installed in the directory: - **c:\datafile\protec2**. The directory **c:\output\protec2** is created for receiving the files produced from running the model. A batch file **PROTEC2.BAT** is copied to the root directory of DRIVE C:. Should you have a batch file directory, and this is included in your PATH statement, then you can move the **PROTEC2.BAT** file to it.

Should your hard disc be partitioned into more than one drive and you want the sample/data files and output files to be written to a drive other than DRIVE C: then the authors will supply a modified version of PROTEC2.

4.3 RUNNING THE MODEL

If the PATH statement contains the path of the batch file PROTEC2.BAT then the model can be run by typing **PROTEC2** at the DOS prompt. If the directory containing the PROTEC2 batch file is not in the path then change to the directory containing the batch file and then enter **PROTEC2** at the DOS prompt. The model automatically finds the input data files and writes the output to files in the directory created during installation.

4.4 THE MODEL

PROTEC2 is supplied with a sample data set so that you can get the *feel* of the model. You can alter the sample data files in the directory - c:\datafiles\protec2 or create your own data files but the data must be in the same format as those in the samples. Before altering the data files or creating your own make a copy of those that already exist in the directory. The structure of the data files is discussed below.

The model works for a cocktail of algae: *Oöcystis*, *Stephanodiscus hantzschii*, *Stephanodiscus astraea*, *Anabaena*, *Rhodomonas*, *Asterionella*, *Microcystis* and *Aphanizomenon*. Information on these algae are embedded within the programme - in a future release of the PROTEC2 model it should be possible to add your own algal types.

4.5 INPUT DATA FILES

The number of input files have been kept to the minimum. Only six input data files are required to run PROTEC2.

INPUT FILES	DESCRIPTION
SITE.DES	Main control data set for the programme. Allows for different scenarios with the mode.
PNLOADS.DAT	Chemical, water temperature and inflow volume for each of up to 10 inflows for each day.
OUTFLOW.DAT	Outflow volume of water.
CLOUD.DAT	Cloud cover data for each day.
WIND.DAT	Wind speed data for each day.
DEPTHS.DAT	Bathymetric data for water body.

4.5.1 SITE.DES

This file is the main control data set for the programme, which permits the model to be run by changing certain of the control variables.

NB: Before making any changes to this file make a copy of the file so that it can be used in the future for reference.

Line No.	Contents of a sample SITE.DES file
1	Small Lake - Somewhere
2	13.9 : starting depth
3	6940.0 : Maximum length of water body
4	3 : number of river inflows, number of outlet
5	WhiteRi YellowR GreenRi :names of inflows (max. 7 characters each)
6	0 610 : iSkip (no. of days skipped), maxD (no. of days run)
7	1.250E-01 1.250E-01 1.250E-01 1.250E-01 1.250E-01 1.250E-01 1.250E-01 1.250E-01
8	0.300E+00 : epso (baseline epsilon)
9	1.150E+00 : resp (rate adjustment for respiration - 15% of temp growth rate)
10	rpflag=1 rmlflag=1 rsflag=1 gflag=1 fflag=1
11	39.1 6.1 3200.0 3000. 4000.0 :No. elements in starting profile: Temp N P Si
12	44.0 6.2 3200.0 3000. 4000.0 :depth, temp, P, N, Si
13	48.5 6.3 3200.0 3000. 4000.0
14	50.0 6.2 3200.0 3000. 4000.0
15	53.0 6.2 3200.0 3000. 4000.0

In the above anything following a colon is a comment.

On line one is a title or description for the water body under study, this name can be up to 70 characters long.

On line two, 13.9 represents the maximum depth in metres of the water column from the profile shown on lines 11 and 15, (53.0 - 39.1 = 13.9). If the depth range alters in the starting profile then the change in value must be shown on line two. The value must have a decimal point.

On line three, the 6940.0 is the maximum surface length in metres of the water body. The value must have a decimal point.

On line four, the 3 represents the number of inflowing streams or rivers into the water body. The maximum number of inflows in the model is set to ten. The figure must be present as an integer and not have a decimal point.

Line five contains the names of the inflowing streams, the names must be seven characters long with each name separated by a blank space character. The model will accept up to ten names.

On line six, the zero value is the number of records to skip so that the starting date is the 1st January. The data must always start on the 1st January. The other value, here 610, is the number of days for the model to run for from the 1st January: providing there is sufficient data in the other input files.

NB: There is no maximum number of days for a model run - the limitation is your data set and the amount of free disc space available.

Line seven, is the proportion of the different algae used in the *cocktail*. The proportion should always sum to one. The values on this line correspond in order to the following algae: *Oöcystis*, *Stephanodiscus hantzschii*, *Stephanodiscus astraea*, *Anabaena*, *Rhodomonas*, *Asterionella*, *Microcystis* & *Aphanizomenon*.

Line eight is the background light extinction value.

Line nine is the rate adjustment for respiration.

Line ten are the flag values. The positioning of these values in the file is critical. **rpflag** is the phosphorus flag; **rnflag** is the nitrogen flag; **rsflag** is the silica flag; **gflag** is the grazing flag; **fflag** is a flow flag. All these flags can individually or in combination have the values of the flags changed from 1 to 0 - **except fflag. DO NOT change the value of the fflag** as this part of the programme has not been fully written and tested. Any value changed from a 1 to a 0 provides unlimited resources for the item of the flag. **Movement of the 1s from their present column position will result in unpredictable results. To change values overwrite the present 1 values.** Make a copy of the file so that it can be used in the future for reference - in case values are typed in the wrong position.

Lines eleven to fifteen contain information on water temperature, P, N & SiO₂ for the first day of the model run. The values correspond to a given depth covering the whole water column. The first value, as shown on line eleven, is at the bottom of the water body while those values on line fifteen represent the surface values. There are five columns between lines eleven and fifteen. The component order of the columns are as follows: depth in metres; water temperature degrees Celsius; phosphorus mg m⁻³; nitrogen (nitrate + ammonia) mg m⁻³; silica as SiO₂ mg m⁻³. The value 39.1 m was assumed to be the base of the reservoir above sea level.

NB: The difference in depths between the base of the reservoir, line eleven, and the surface, line fifteen, must be shown on line two of this file.

4.5.2 PNLOADS.DAT

This file contains the information on nutrients, water temperature and inflow volume for each of the inflows; in the sample provided - three inflows. It is important that the format shown is used. The data may however be entered in free format for each record.

Day N ^o .	Inflow N ^o .	Inflow volume	Water Temperature	P	N	SiO ₂
1	1	1.534	5.	593.84	8150.0	4235.
1	2	0.435	5.	758.85	10100.0	7200.0
1	3	0.0	5.	101.0	73.0	7235.0
2	1	1.10	5.1	605.9	8200.0	4200.0
2	2	0.400	5.2	740.2	9050.0	6800.0
2	3	0.10	5.1	120.2	85.0	7802.0

0

If there are days without any inflow always make sure that there are records for each of the three inflows for a day. Do not miss out records.

4.5.3 OUTFLOW.DAT

This file contains data on the outflow volume of water in $\text{m}^3 \text{sec}^{-1}$. The file contains two columns, the first is a Day Number from 1st January and the other is the outflow volume in $\text{m}^3 \text{sec}^{-1}$. Data in this file can be in free format, but the data columns must be as specified.

4.5.4 CLOUD.DAT

This file contains just one column - the cloud cover which is measured in parts of eight. The first data value corresponds with the first day of January. There are no day number values in this file at present.

4.5.5 WIND.DAT

This file contains two columns. The first column is the day number starting on the 1st January and the second column is the wind speed in metres sec⁻¹. Data in this file can be in free format.

4.5.6 DEPTHS.DAT

This file contains bathymetric data in three columns for the water body. The data consists of a series of depth values above sea level for the volume of the water beneath that depth, in 10³ m³, and the surface area, in 10³ m², of the water layer at this depth. The first line of the file contains values for the mud surface and the last line values for the maximum depth of the water column. The maximum depth of water in the water column is set to 50 m. i.e. 500 slices of 10 cm. The order of the columns in the file is as shown in the table below.

Depth metres	Area 10 ³ m ²	Volume 10 ³ m ³
39.10	0.00	0.00
46.00	1669.00	3642.00
54.00	3523.33	23855.00
54.60	3530.00	25969.00

4.6 OUTPUT DATA FILES.

The following output data files are produced after running the model.

NB: In the output data files the bottom of the water body or mud surface is zero metres.

OUTPUT FILES	DESCRIPTION
PRED.SE1	Output file of algal & chemical predictions.
RATE.SE1	Output file of algal rate predictions.
INTCOL.OUT	Output file of an integrated 5m column of algal & chemical predictions.
INPUTS.PAR	Output file of information on the parameters used in the model run.
DEPTHS.PAR	Output file of calculated bathymetric data.
BOUNDARY.OUT	Output file of the water surface layer for each day of the model run.
INPT.SE1	

4.6.1 PRED.SE1

This file contains the predictions for algae as Chlorophyll mg m^{-3} , and for chemical nutrients in terms of mg m^{-3} .

PRED.SE1 is usually a very large file! For each day there is a depth record. As the water column was sliced into 10 cm sections this can result in a large number of records for each day. There are sixteen output variables written in columns.

NB: In this file the bottom of the water body or mud surface is zero metres.

Column	Variable
1	Day number.
2	Depth in metres - 10 cm slice
3	<i>Oöcystis</i>
4	<i>Stephanodiscus hantzschii</i>
5	<i>Stephanodiscus astraea</i>
6	<i>Anabaena</i>
7	<i>Rhodomonas</i>
8	<i>Asterionella</i>
9	<i>Microcystis</i>
10	<i>Aphanizomenon</i>
11	Total Chlorophyll
12	Light
13	Water temperature
14	Phosphorus
15	Nitrogen
16	Silica

4.6.2 RATE.SE1

This file contains growth rate information, and like the PRED.SE1 file this file can be very large as it includes depth records for each 10 cm slice of the whole water column for each day. RATE.SE1 contains 11 output variables written in columns.

NB: In this file the bottom of the water body or mud surface is zero metres.

Column	Variable - Growth Rate
1	Day number
2	Depth in metres - 10 cm slice
3	<i>Oöcystis</i>
4	<i>Stephanodiscus hantzschii</i>
5	<i>Stephanodiscus astraea</i>
6	<i>Anabaena</i>
7	<i>Rhodomonas</i>
8	<i>Asterionella</i>
9	<i>Microcystis</i>
10	<i>Aphanizomenon</i>
11	Grazing rate

4.6.3 INTCOL.OUT

This output file contains the predictions as an integration of the top 5 metres of the water column. This is a much smaller output data file than either PRED.SE1 or RATE.SE1 as there is only one record for each day. The output is written in 18 columns.

Column	Integrated variable 5-m column
1	Day Number
2	<i>Oöcystis</i>
3	<i>Stephanodiscus hantzschii</i>
4	<i>Stephanodiscus astraea</i>
5	<i>Anabaena</i>
6	<i>Rhodomonas</i>
7	<i>Asterionella</i>
8	<i>Microcystis</i>
9	<i>Aphanizomenon</i>
10	Total Chlorophyll
11	Water temperature
12	P
13	N
14	SiO ₂
15	Grazing
16	Inflow m ³ sec ⁻¹
17	Cloud
18	Wind

4.6.4 BOUNDARY.DAT

This is an output file of the daily depth above the mud surface of the water surface layer. The first column is the day number, the second column is the depth of the water in metres.

NB: In this file the bottom of the water body or mud surface is zero metres.

4.6.5 INPUTS.PAR

This file has information on the parameters used in the model run - useful print out.

4.6.6 DEPTHS.PAR

Calculated bathymetric data for the water body used in the model.

4.6.7 INPT.SE1

This file contains the algal seed from the inflows, incident light and day length. There are 11 columns containing output.

Column	Variables
1	Day number
2	<i>Oöcystis</i>
3	<i>Stephanodiscus hantzschii</i>
4	<i>Stephanodiscus astraea</i>
5	<i>Anabaena</i>
6	<i>Rhodomonas</i>
7	<i>Asterionella</i>
8	<i>Microcystis</i>
9	<i>Aphanizomenon</i>
10	Incident light
11	Day length

5. FORMATION OF OUTPUTS

The outputs from the programme as supplied are in tabular format. The graphical representation of data, shown in the second and third interim reports, for example, require the output of data to the files of a suitable and appropriately licensed graphics package. We have used Harvard Graphics®, SAS Graphics® and looked at extensions to Windows®. For the present, the FBA is able to advise NRA on appropriate methodologies, although we recommend the development of an integrated graphical output into the fully-fronted, user friendly, interactive programme, envisaged as an objective of a third, optional year of contract.

6. CONCLUSIONS

The completion of Protec 2 v 1.10, together with the attendant review reports, fully meets the objectives of the R&D Project; particular acknowledgement should be made of NRA's willingness to support the modelling aspect of this work which, by common consent, was speculative and by no means guaranteed to succeed.

The most difficult step to overcome was the simulation of water column responses to fluxes of heat and momentum. The transport of solutes and particles across the surfaces of differentiation - the boundaries intermediate between waters of different density or between those dissipating mechanical energy or not - proved relatively straightforward. Given that we can now calculate the flux rates of particles across those boundaries and that we can extrapolate these to fluxes of oxidisable carbon, the possibility exists to derive a BOD-flux and, not so remotely, a deep-water O_2 concentration and a redox potential. The latter then opens the further possibility of predicting resolution and reprecipitation of iron and manganese and, hopefully, that of any associated phosphate. These developments perhaps represent a further extension of the two-year R&D project which might be considered by the National Rivers Authority.

7. ACKNOWLEDGEMENTS

We have been grateful to our colleagues, Simon Courteney and Denise Wright, for repeated advice and suggestions during the past two years, and to Dr John Hilton and Eric Rigg who have modified certain parts of PROTEC 1 which we have subsequently added to PROTEC 2. We also express our appreciation to Kirsty Ross for her capable assistance in the final stages of the production of this report.