MODELLING OF ALGAL BLOOMS

Third Interim Report - Project 327
January 1993

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1. INTRODUCTION

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

The project's objectives are:-

(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.

These aspects will proceed simultaneously to some extent. Progress is best reviewed, however, under appropriate sub heads:

Verticality and structure

Fluxes

Nutrient cycling

Software development

2. VERTICAL STRUCTURE, FLUX COMPONENTS AND ALGAL DYNAMICS

Since the second report (1), considerable progress has been made in assembling subroutines into reasonable, plausible simulation models. The appended figures will demonstrate that, beginning with the dimensions of the basin, the rate of hydraulic exchange and the concentrations of nutrients introduced therewith, it is possible to generate the dynamics of algal species and to determine a standing population of each. The crucial further driving variables are the change in day length through the year, determined by latitude, the historic cloud cover (which interferes with the heat flux to the water) and the historic wind-speed (which is the major influence upon how the heat influx is distributed). The model calculates the depth of stratification and its wind resistance (through straightforward Monin-Obukhov and Wedderburn formulations) and, in spite of some rather arbitrary assumptions to simplify the daily heat budgets, it is able to deliver authentic simulations of the temperature and density stratification of actual data (see Second Report, (1), and also Fig. 1).

The further progress which has been made is in being able to update information about the growth conditions in each of n 10-cm horizontal slices, where $n/10$ is the depth of the basin in m, and to increment (or decrease) the standing populations of each of eight algal species accordingly, to calculate the exchange of nutrients, then to allow algae to move up or down according to their own specific motility characteristics and performances and, finally, to integrate the crops and solutes through those slices representing the current mixed-layer depth.

This is actually a phenomenally complex operation which is possible to execute only with modern 386 or 486 processors. The subroutines have been carefully checked, step by step, and, certainly, the outcomes are plausible and, where available, are well-supported by observations. A sample of what is possible is illustrated in this report.

It is perhaps helpful to summarise the sequence of subroutines and then to describe the model run illustrated.

The key subroutines are as follows:

BASIN	-	Assembles from depth data, the number of layers (from bottom to surface), their individual areas and volumes.
COUNTER	-	Calculates day- and week-number base.
FLUSH	-	Logs hydraulic exchanges and calculates water level.
ADDNUT	-	Works out P, N, Si added by the inflows.
HEATER	-	For the day of the year, the given cloud cover and given windspeed, determines the mixed layer depth. This can be greater than the depth of basin (fully mixed) or, if less, can be either less than on the previous day (stratification intensifies), or greater than on the previous day. In

the latter case, Wedderburn-based rules determine the increased depth of mixing.

LITREG - Calculation of daily integral average insolation based on solar day length and radiation intensity and the coefficient of vertical light extinction.

MIXER - An integration of factors, solutes, and suspensoids within the mixed layer,weighted according to diminishing volume vs depth.

ALGAE DES - is an accessible file of relevant details on each species. The model involves eight of these, which are selected at the head of the programme. So far we have constructed file details for about 15 species including motile and non-motile nanoplankters, diatoms, colonial green algae, Oscillatoria and, of course, bloom-forming Microcystis and N_2-fixing Anabaena and Aphanizomenon.

G COEFF - assesses the temperature, light and daylength factors for the day and depth concerned and calculates the coefficient of daily growth for each of the eight selected species.

ALGROW - determines whether the increment due to G COEFF is sustainable and checks that nutrients are available to support the growth of each species. The selective importance of silicon for diatoms and nitrogen depletion for N_2-fixers is accommodated. The subroutine allows increase to the point of the first limitation and recalculates the amounts of each nutrient left in solution.

GRAZER - allows edible algae to be removed as if by filter-feeding zooplankton, itself responding to an algorithm based on temperature-determined biomass increase and the availability of resources.

MOVEIT - allows the algal population to sink or float or swim from one layer to another according to species-specific instructions.

The model executes this loop each day, recalculating as it does, the quantities of each component at each depth, after integrative mixing as appropriate.

The currency of the algal populations is chlorophyll; the nutrient consumption is based on chl : nutrient ratios which are responsive to nutrient availability (i.e. poor chl yield per unit of 'luxury' nutrient; efficient chl yield at limitation). Zooplankton populations are expressed in daily proportional filtration capacity; e.g. "0.5" means 500 ml of every litre is swept clear of edible algae per model day. Note also that the model 'regenerates' to solution the nutrients consumed as food and that the coefficient of light penetration is made sensitive to changes in the chlorophyll standing crop.

The Model Run

Figs 1-15 refer to a set of model executions and are intended to illustrate the capabilities of the simulation programme. The output does conform recognizably with the data available (actually the inputs are well-documented but the outputs are known only rather generally). The Test Reservoir is actually a large (3.5 km^2), exposed pumped-storage reservoir, fed from enriched riverine sources (10 mg l^{-1} silica; 0.85 mg l^{-1} sr phosphorus; 3.8 mg l^{-1} nitrogen), having a filled volume of $27x10^6$ m^3 and a maximum depth of 15.5 m. It occasionally produced problem blooms of Microcystis in recent years, most notably during 1989. The reservoir is said to be only weakly and briefly stratified. Data obtained in 1991 showed only short phases of temperature stratification but a more sustained structure was observed in July, 1902. The reservoir generally supports an untroublesome biomass of diatoms, Rhodomonas, Oocystis and Aphanizomenon.

Our illustrative run is set up for the period January 1991 to August 1992 with the eight algae whose depth-time distributions are illustrated in Figs 4 through to Fig 11 : besides the three genera deliberately simulated, we included Microcystis, Anabaena and three species of diatom (two of Stephanodiscus and Asterionella). Their combined mass (as chlorophyll) is represented in Fig 2 and the depth distribution of which is seen to be normally homogeneous through the (fully) mixed depth but is nevertheless responsive to the predicted changes in stability, well-represented in Fig. 1. The plot representing the depth distribution of light takes account both of the extent of mixing and of the chlorophyll content of the water through each 10 cm slice.

The anticipated modest spring 'bloom' of diatoms (Figs 4-6) is simulated about one month too late in each year and it has to be stated that the spring, 1992 was dominated by Stephanodiscus asterea rather than by Asterionella, although both were certainly present in the reservoir. Attention is also drawn to the sedimentation of parts of the post-maximal crops. Rhodomonas (Fig. 7) was very prominent in both springs, though the model is thought to have exaggerated the scale of the 1991 maximum. The 'spikiness' in 1992 is more authentic and attributable to the more effective simulation of grazing during the second spring (Fig. 12).

The timing and scale of the Oocystis crop in 1992 was successfully predicted by the model. The production of Anabaena in 1992 but not in 1991 (Fig. 9) was also approximately correct whereas the relative differences in abundance of Aphanizomenon (Fig. 11) simulated for the two years reflects reported observations, although we suspect the scale of the 1992 Aphanizomenon crops is likely to be exaggerated. Small numbers of Microcystis were present in both years but in neither case were they as troublesome as in 1989. The model shows for both Aphanizomenon and Microcystis the importance of thermal stability in improving growth opportunities and in concentrating the crops in the near-surface layers - i.e. constituting an elevated risk of blooming.

So far as the nutrients are concerned, the impact of algal growth upon the in-lake concentrations of nitrogen (Fig. 14) and silica (Fig. 15) is approximately predicted, as is that of phosphorus, apart from the scale of decline in July, 1992 (Fig. 13). Future versions of the model will need to further address the efficiency of phosphorus recycling and re-use.

Fig 1: Test Reservoir

Water Temperature profile

Model using data Test Reservoir 1991 - 1992

21 December 1992

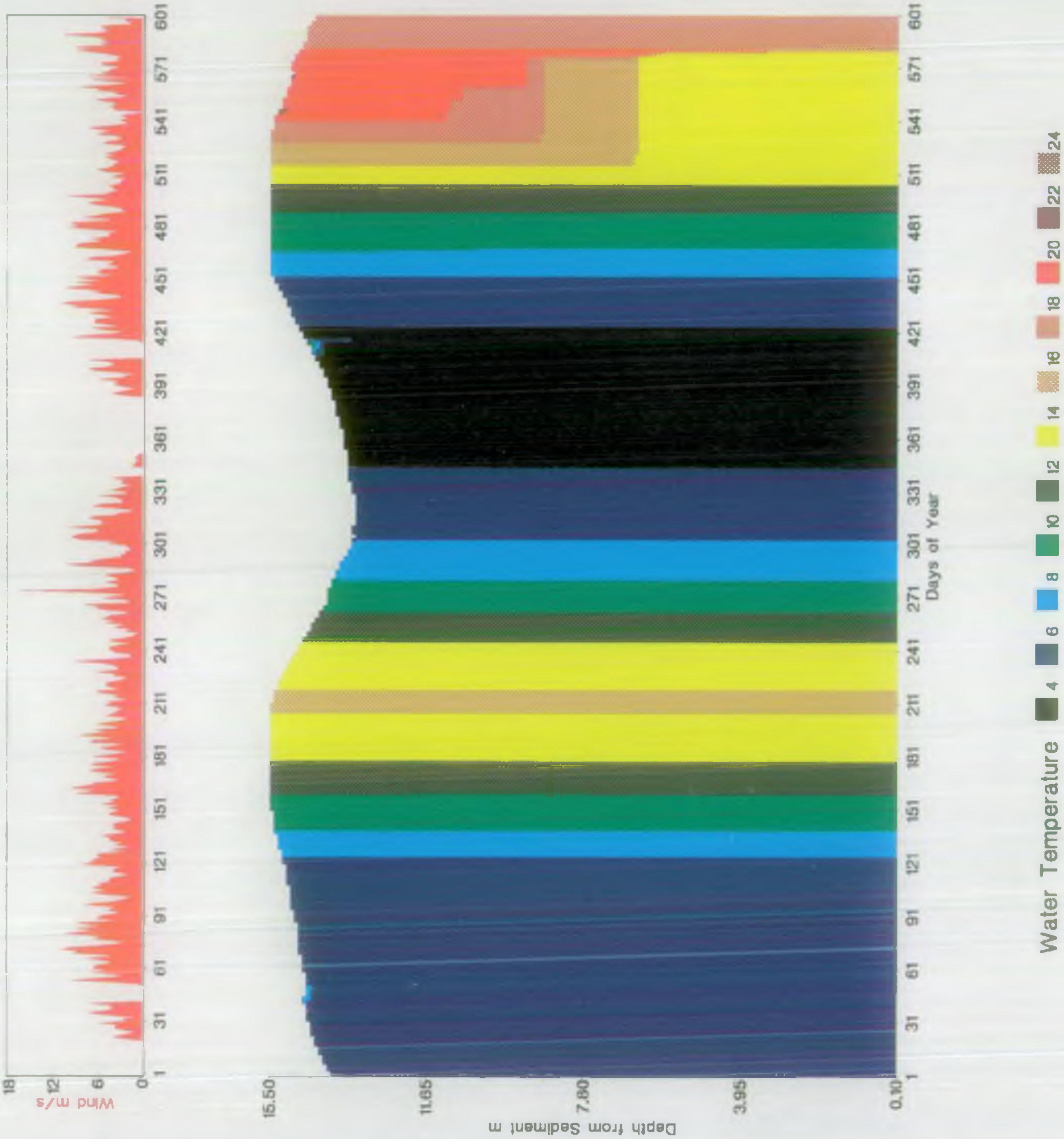


Fig 2: Test Reservoir

Chlorophyll profile with changing inflowing nutrients

Model using data from Test Reservoir 1991 - 1992

22 December 1

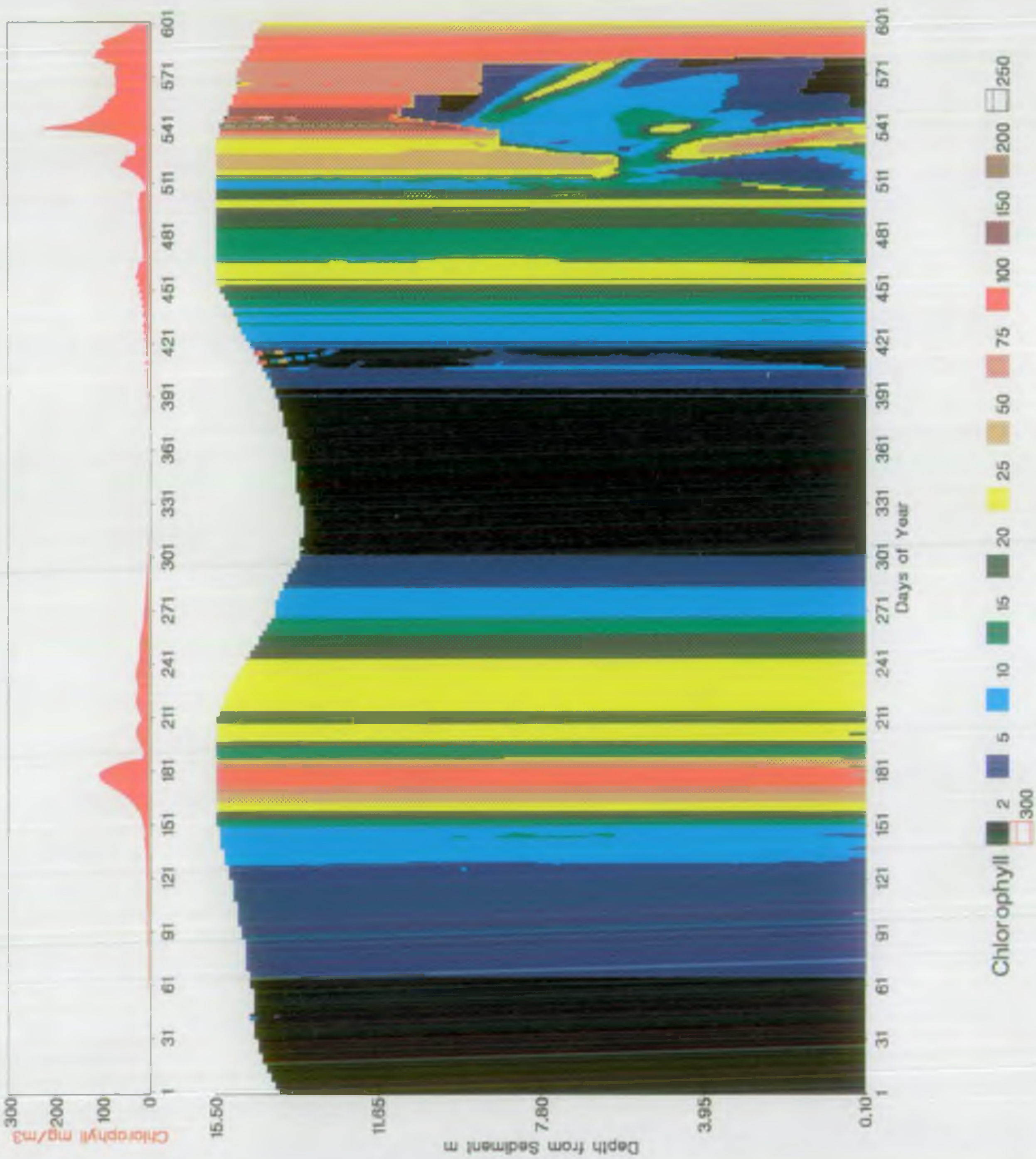


Fig 3: Test Reservoir

Light profile with changing inflowing nutrients
Model using test data Test Reservoir 1991 - 1992

22 December 1992

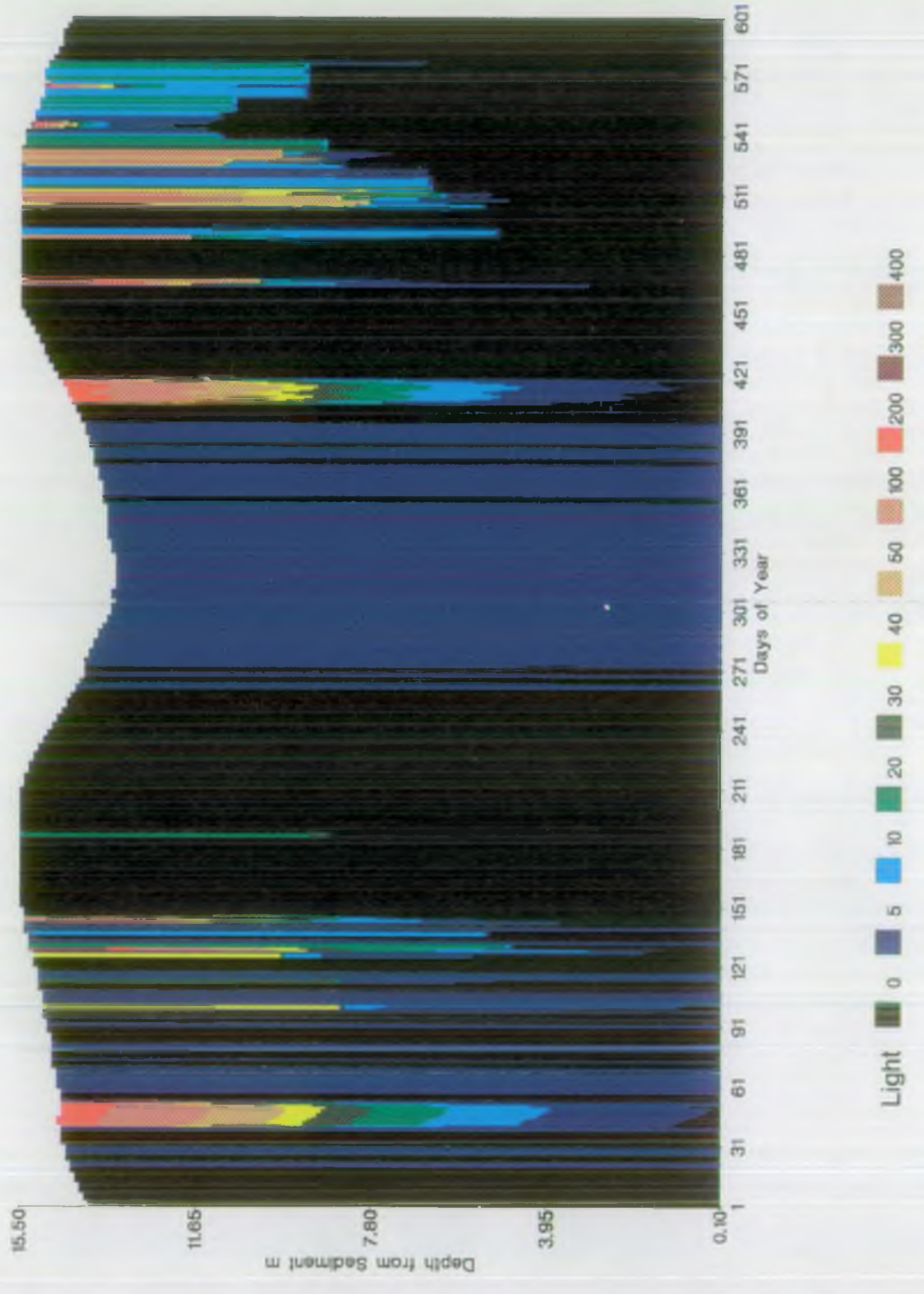


Fig 4: Test Reservoir

Stephanodiscus hantschzii profile with changing inflowing nutrients
Model using test data Test Reservoir 1991-92

22 December 1992

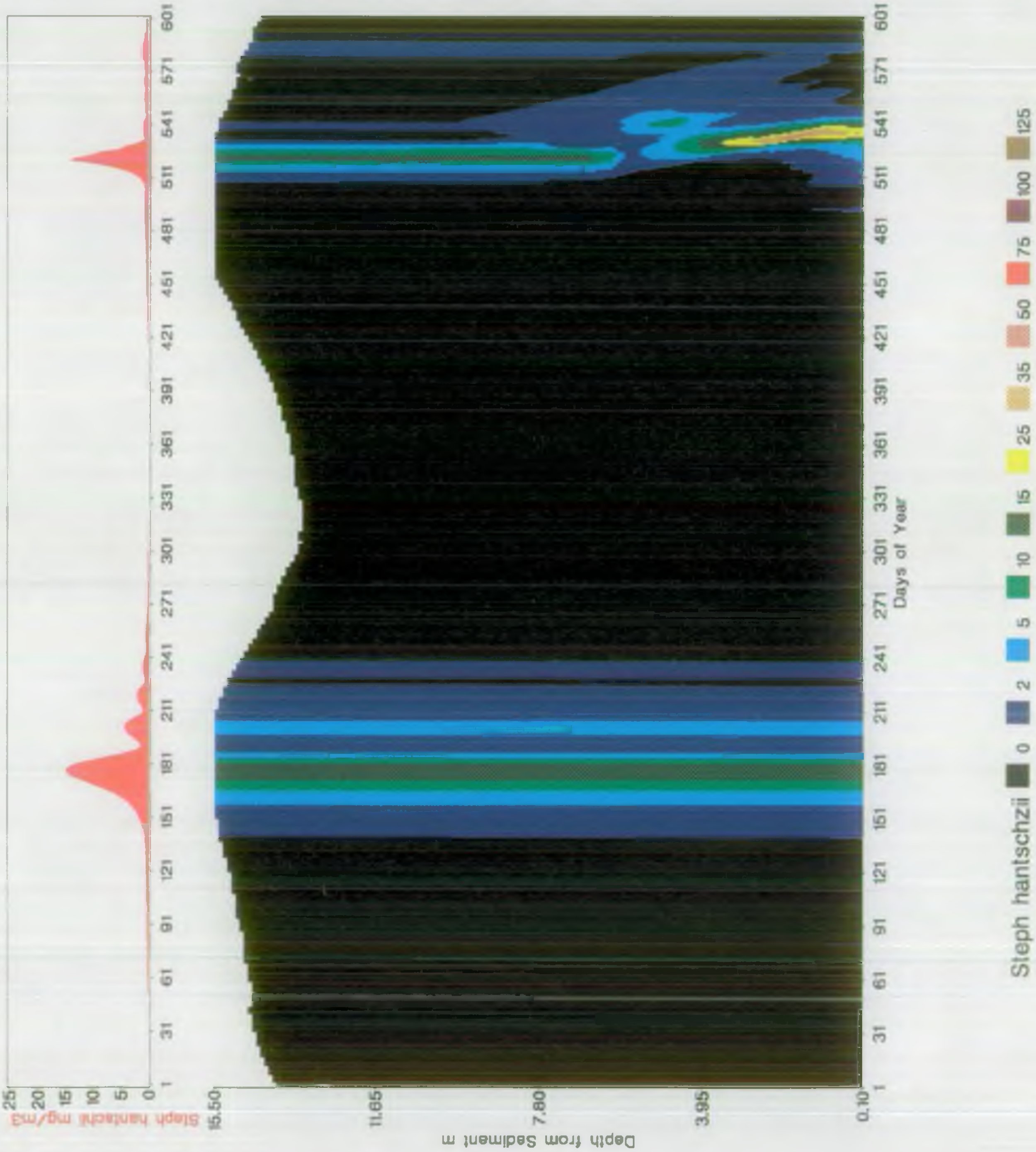
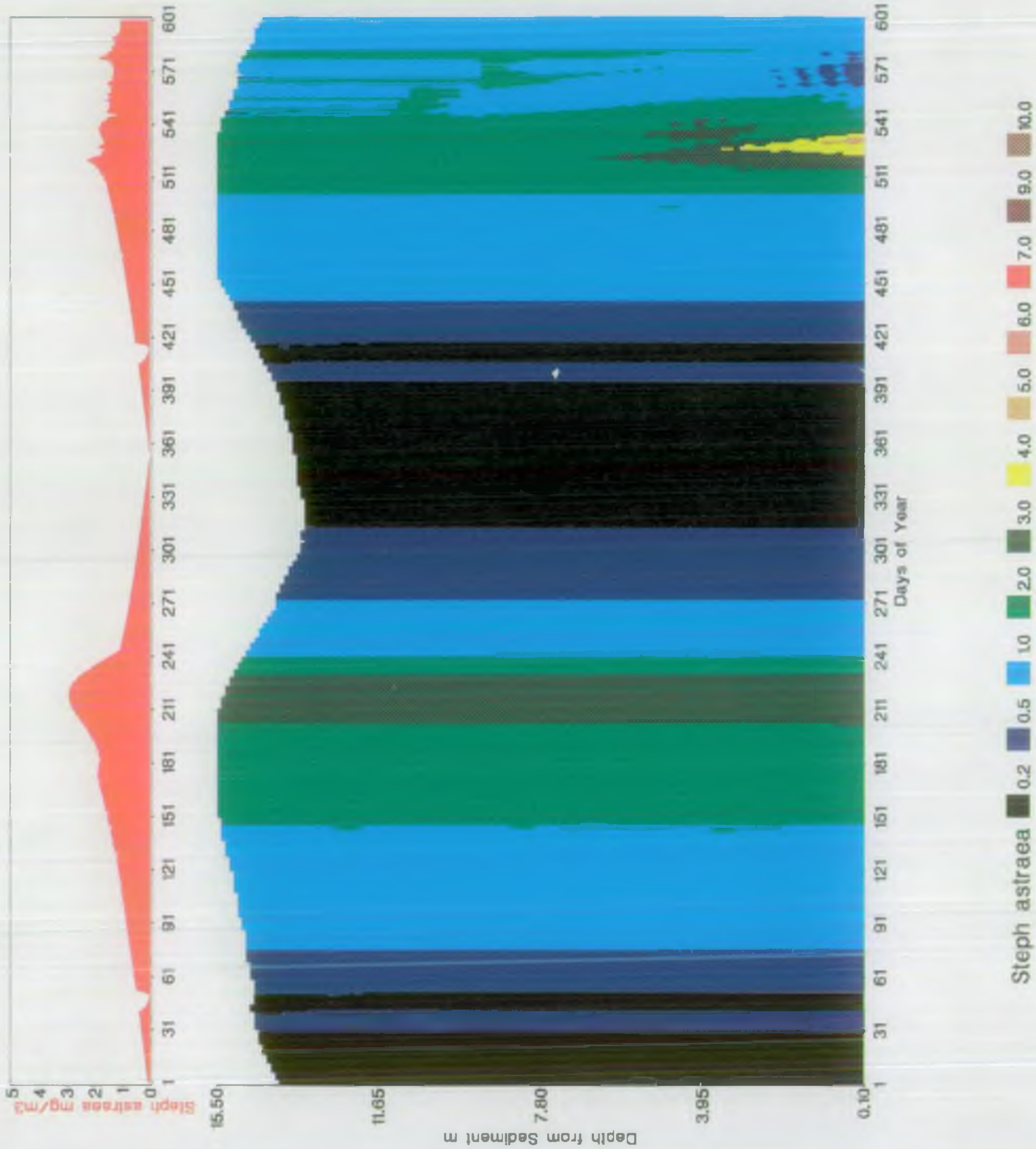


Fig 5: Test Reservoir

Stephanodiscus astraea profile with changing inflowing nutrients
Model using test data Test Reservoir 1991-92

22 December 1992



22 December 1992

Fig 6: Test Reservoir

Asterionella profile with changing inflowing nutrients
Model using test data Test Reservoir 1991-92

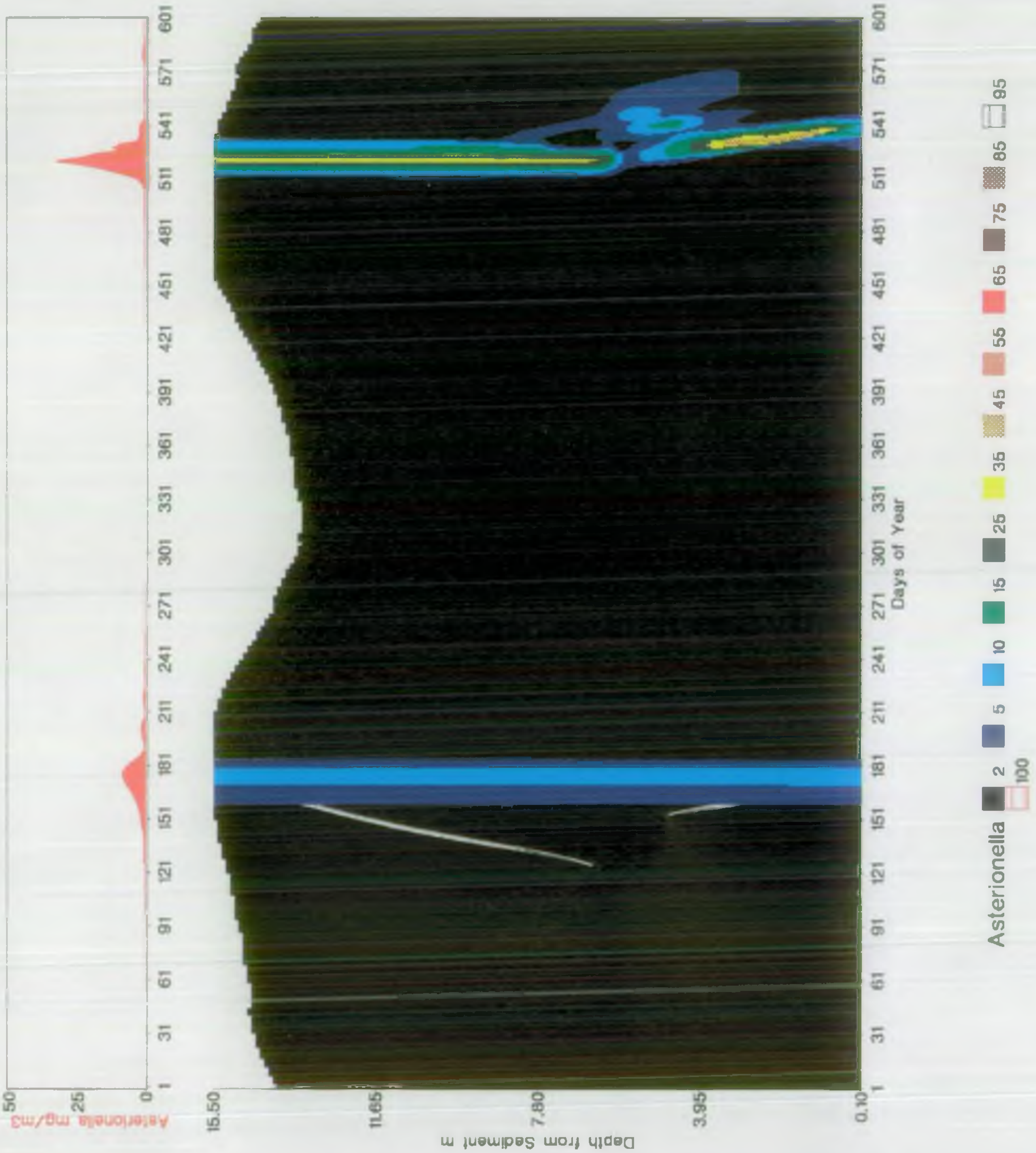


Fig 7: Test Reservoir

Rhodomonas profile with changing inflowing nutrients
Model using test data Test Reservoir 1991-92

22 December 1992

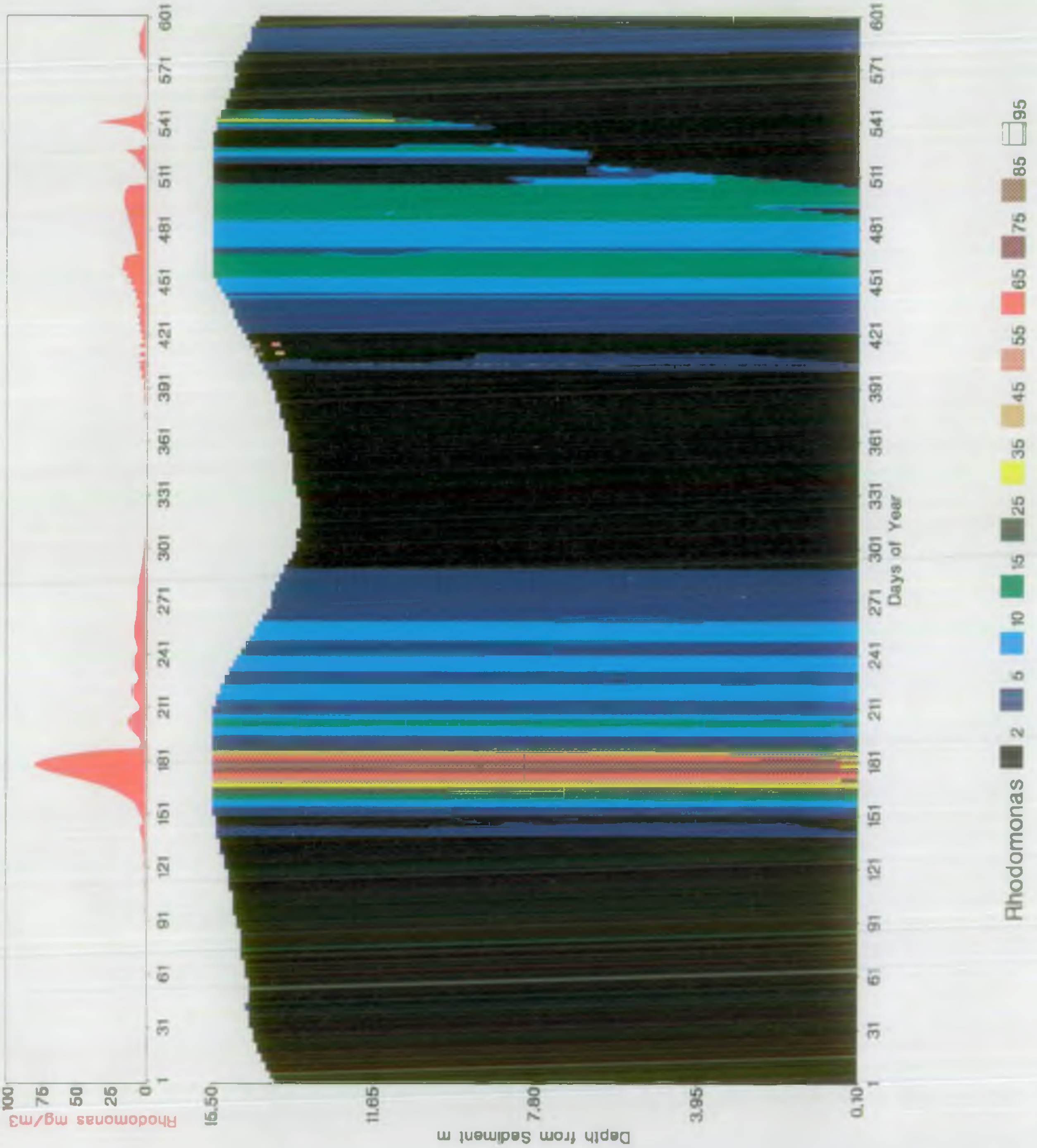


Fig 8: Test Reservoir

Oocystis profile with changing inflowing nutrients
Model using test data Test Reservoir 1991-92

22 December 1992

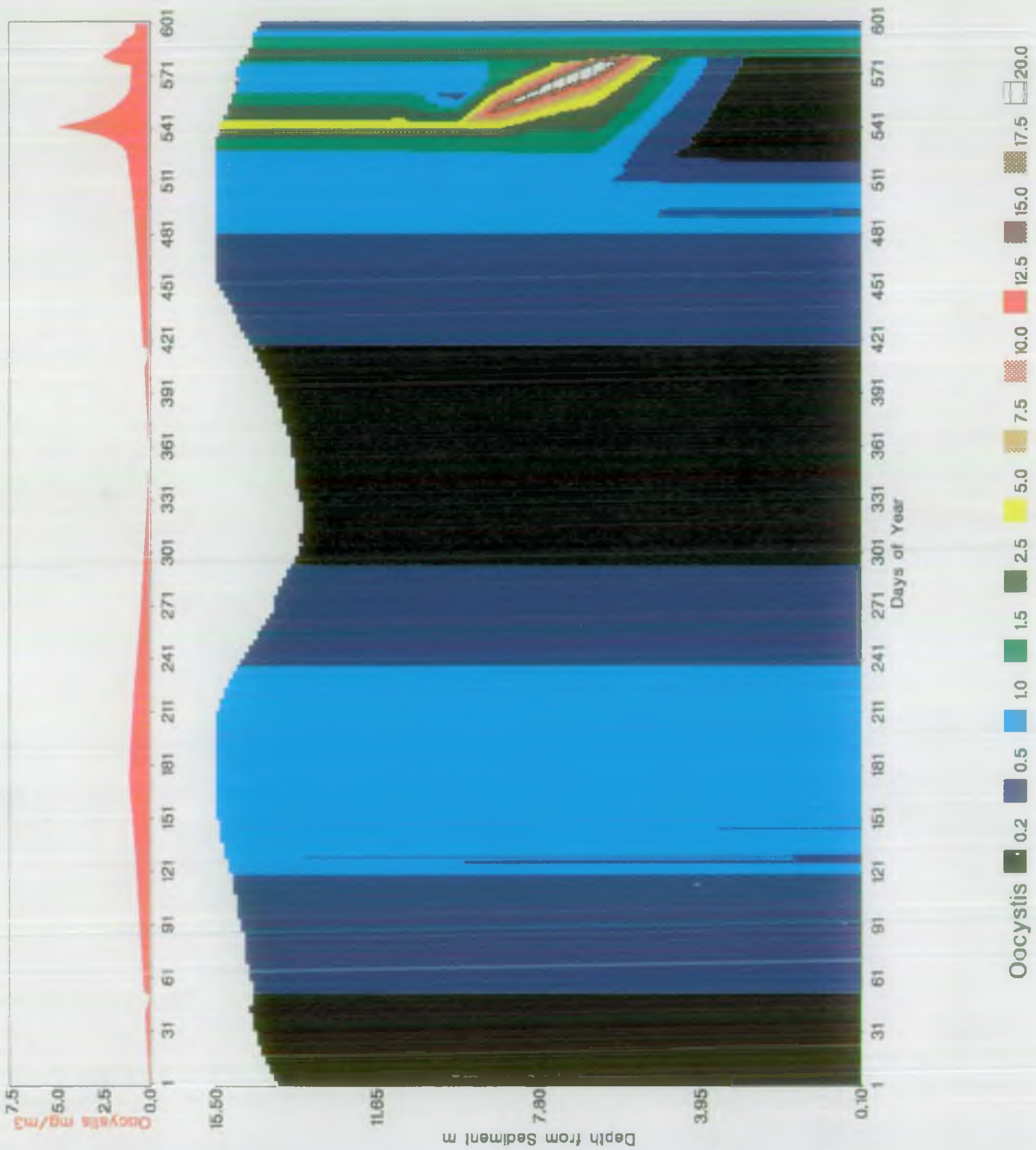


Fig 9: Test Reservoir

Anabaena profile with changing inflowing nutrients
Model using test data Test Reservoir 1991-92

22 December 1992

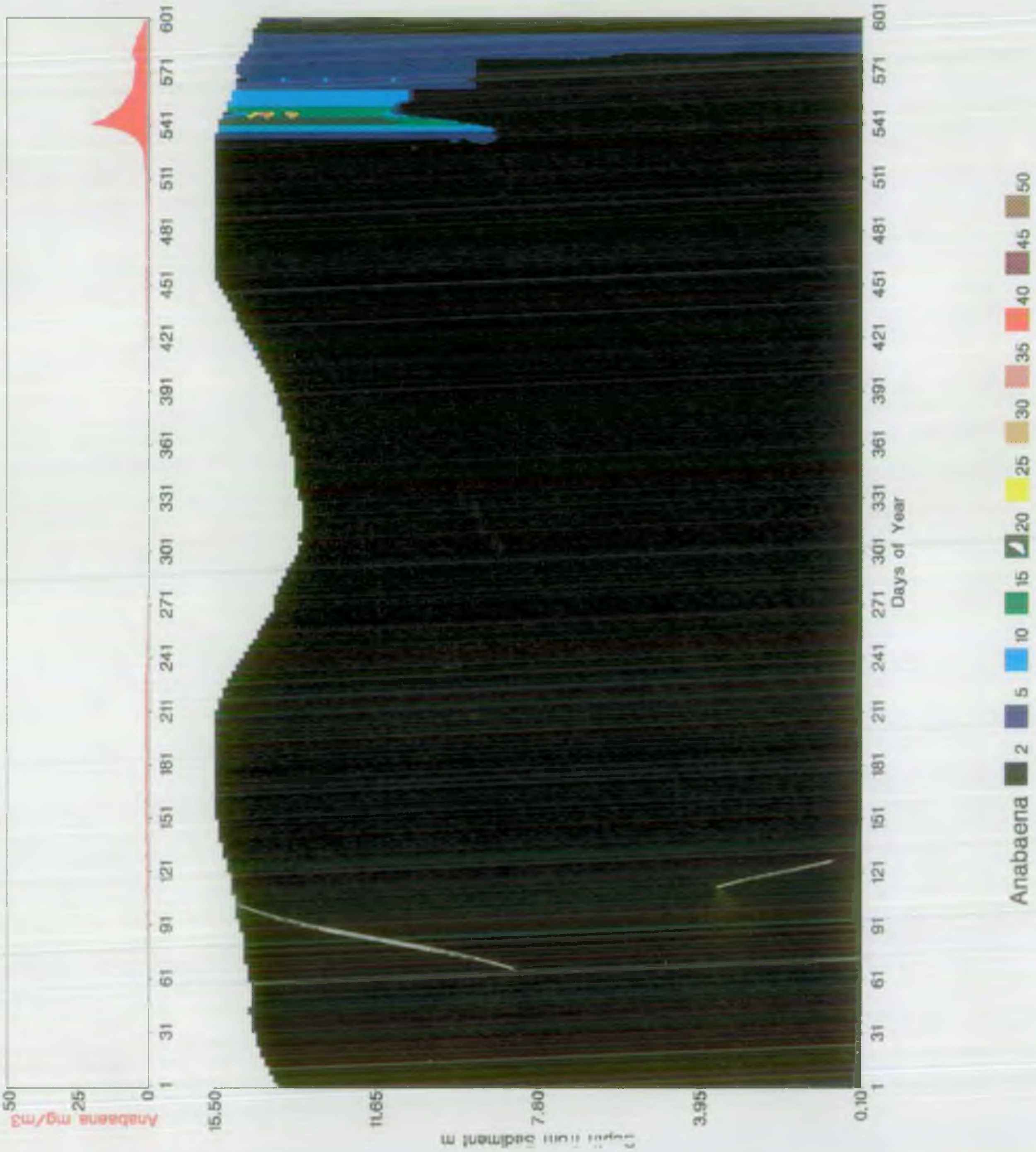


Fig 10: Test Reservoir

Aphanizomenon profile with changing inflowing nutrients
Model using test data Test Reservoir 1991-92

22 December 1992

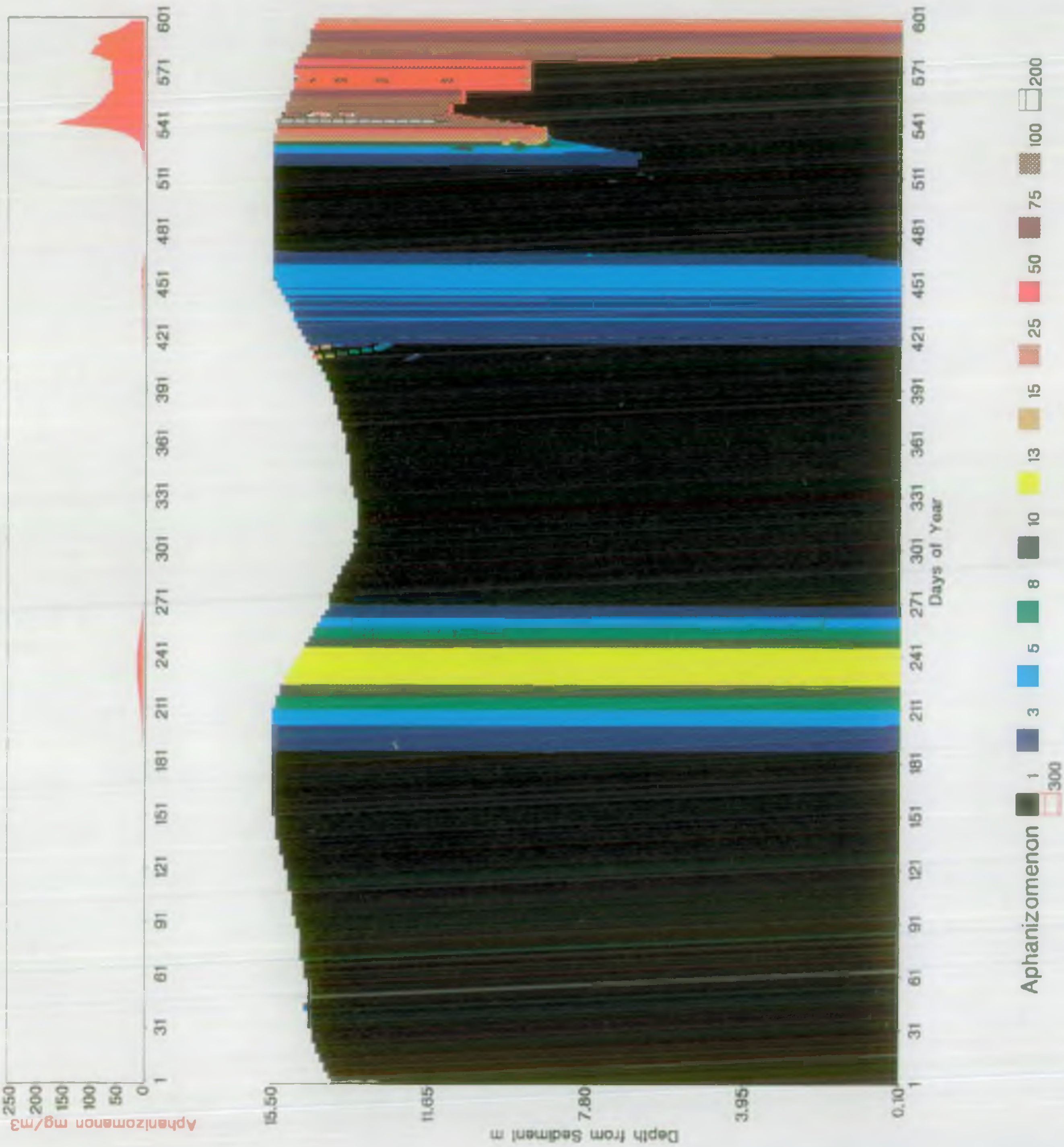


Fig 11: Test Reservoir

Microcystis profile with changing inflowing nutrients

Model using test data Test Reservoir 1991-92

22 December 1992

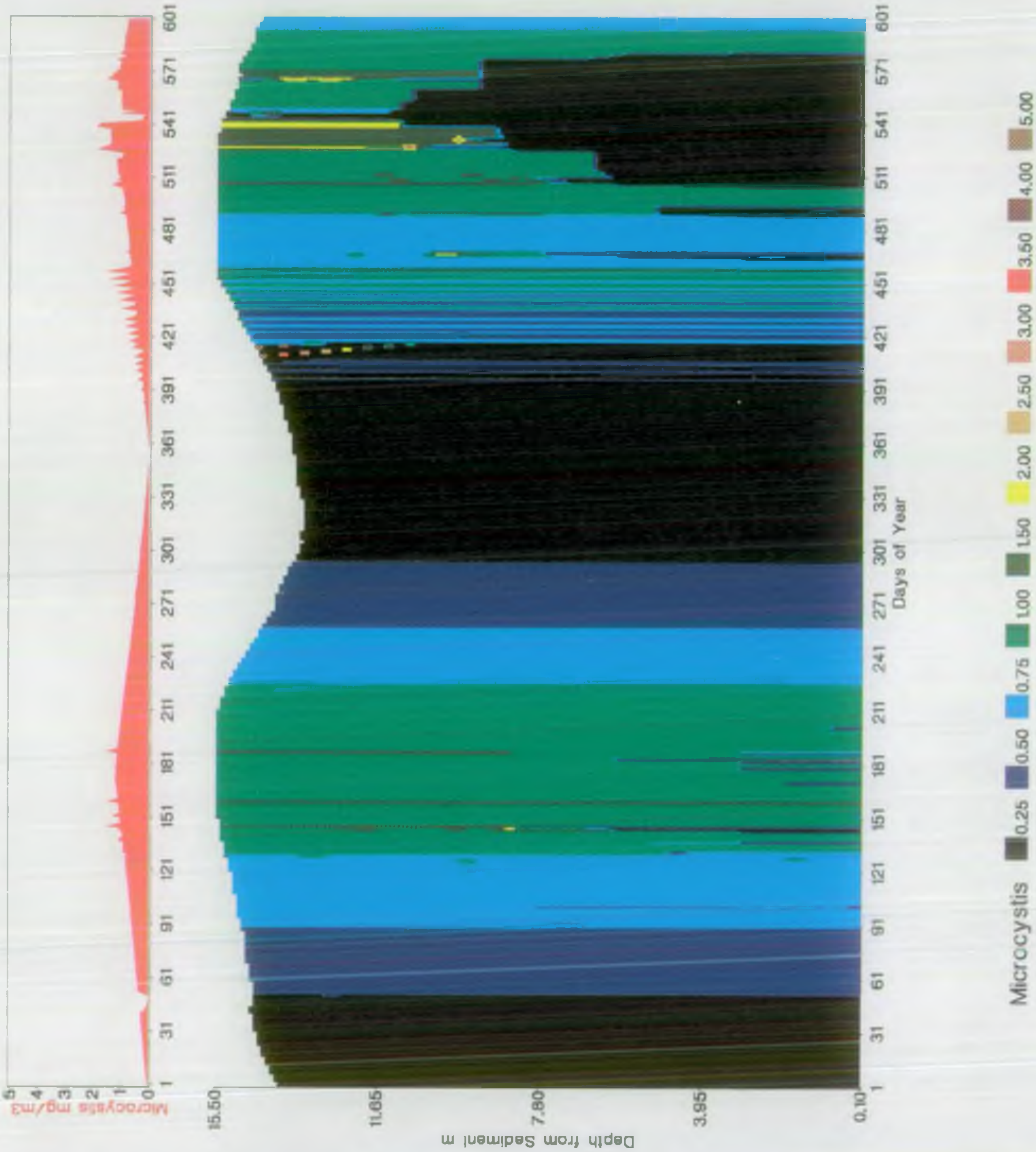


Fig 12: Test Reservoir

Grazing profile with changing inflowing nutrients
Model using test data Test Reservoir 1991-92

22 December 1992

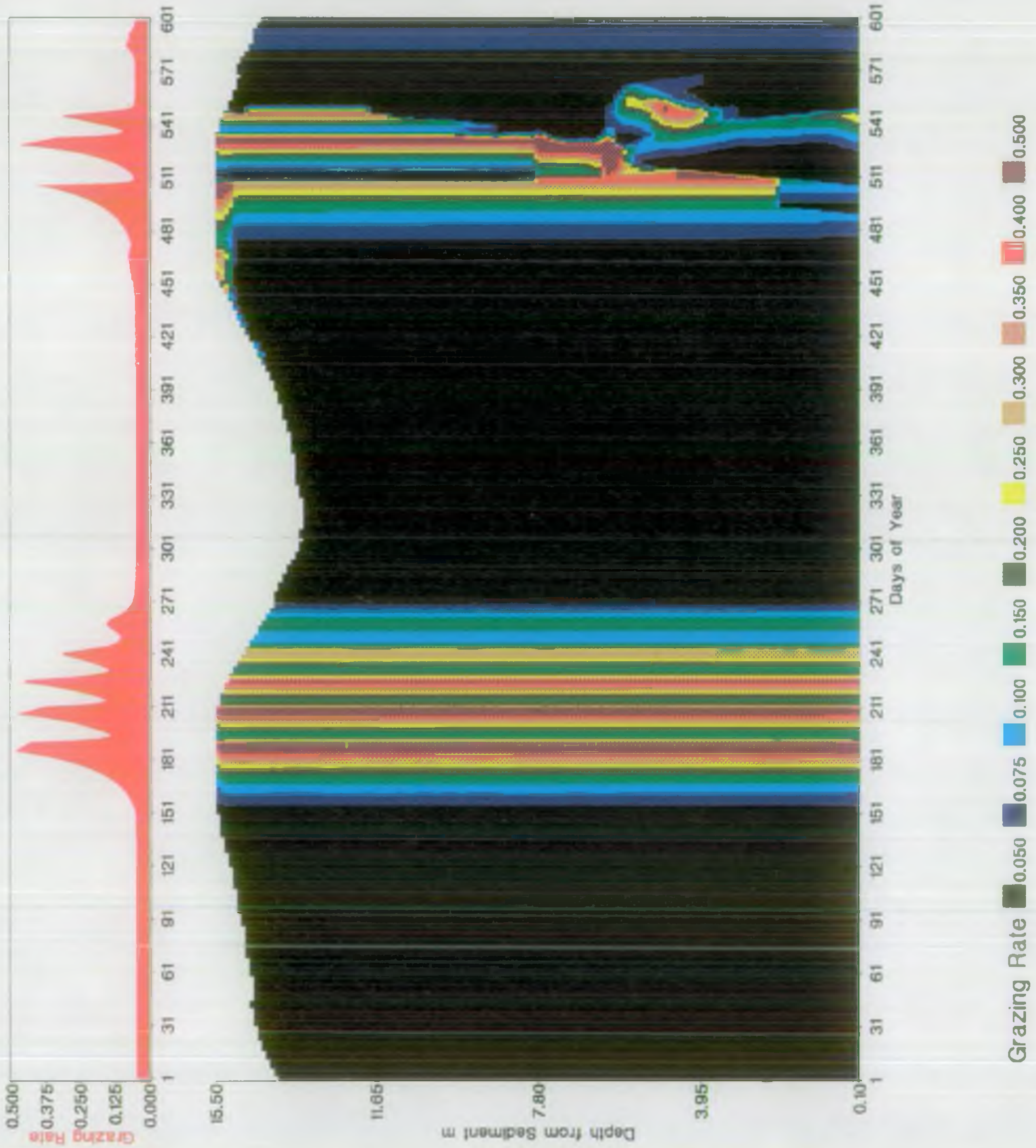
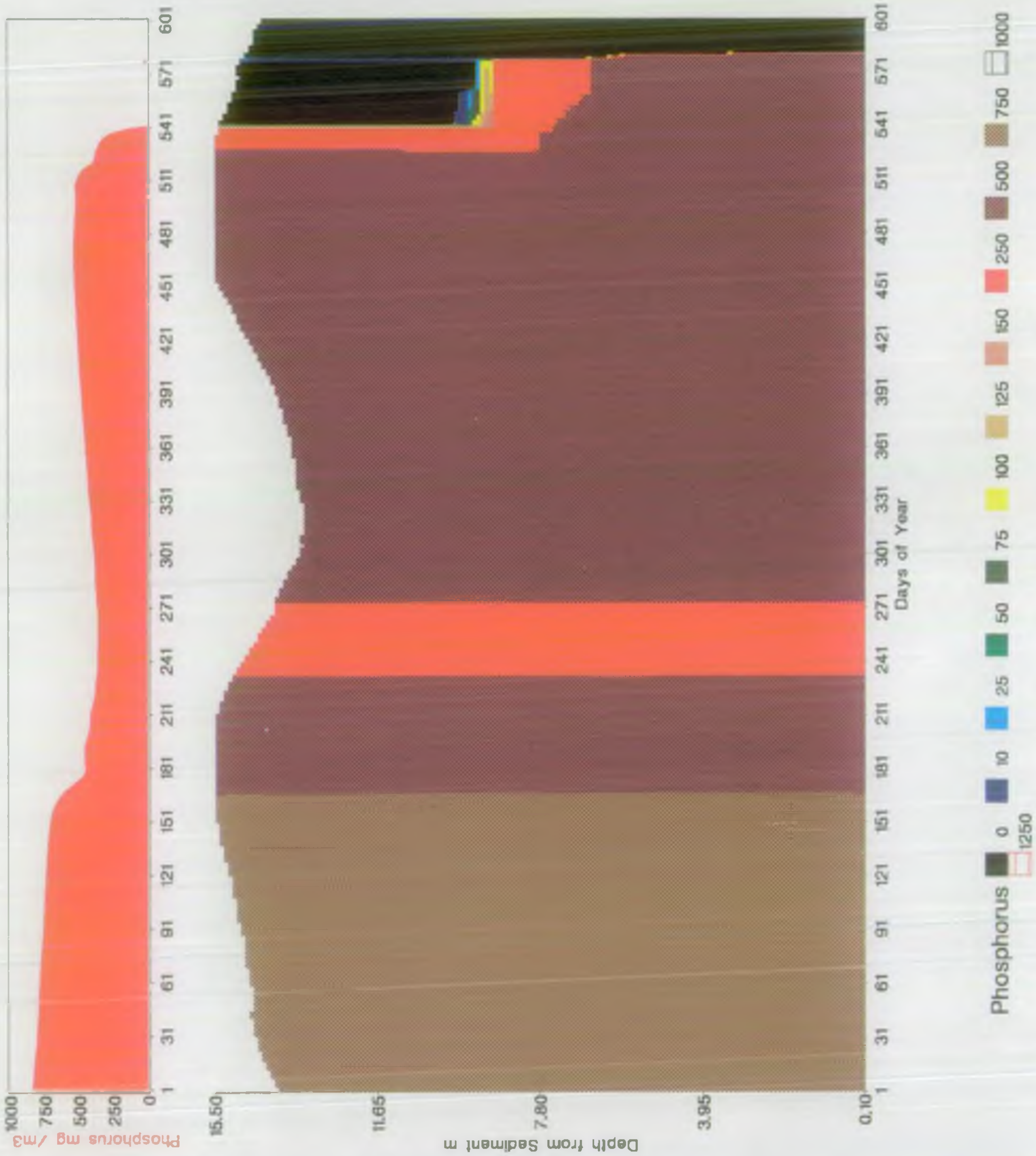


Fig 13: Test Reservoir

Phosphorus profile with changing inflowing nutrients
Model using test data Test Reservoir 1991 - 1992

22 December 1992



22 December 1992

Fig 14: Test Reservoir

Model using test data Test Reservoir

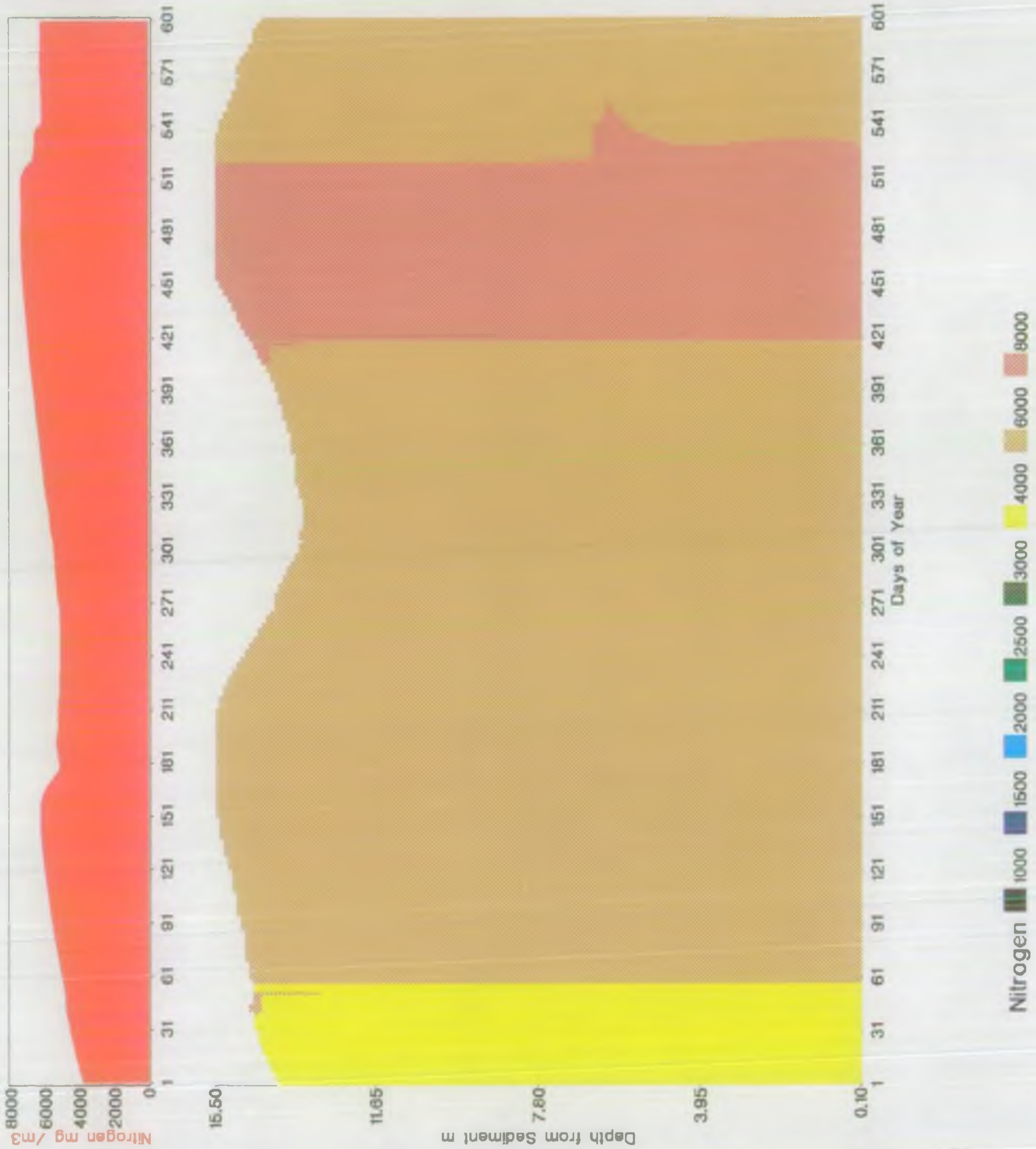
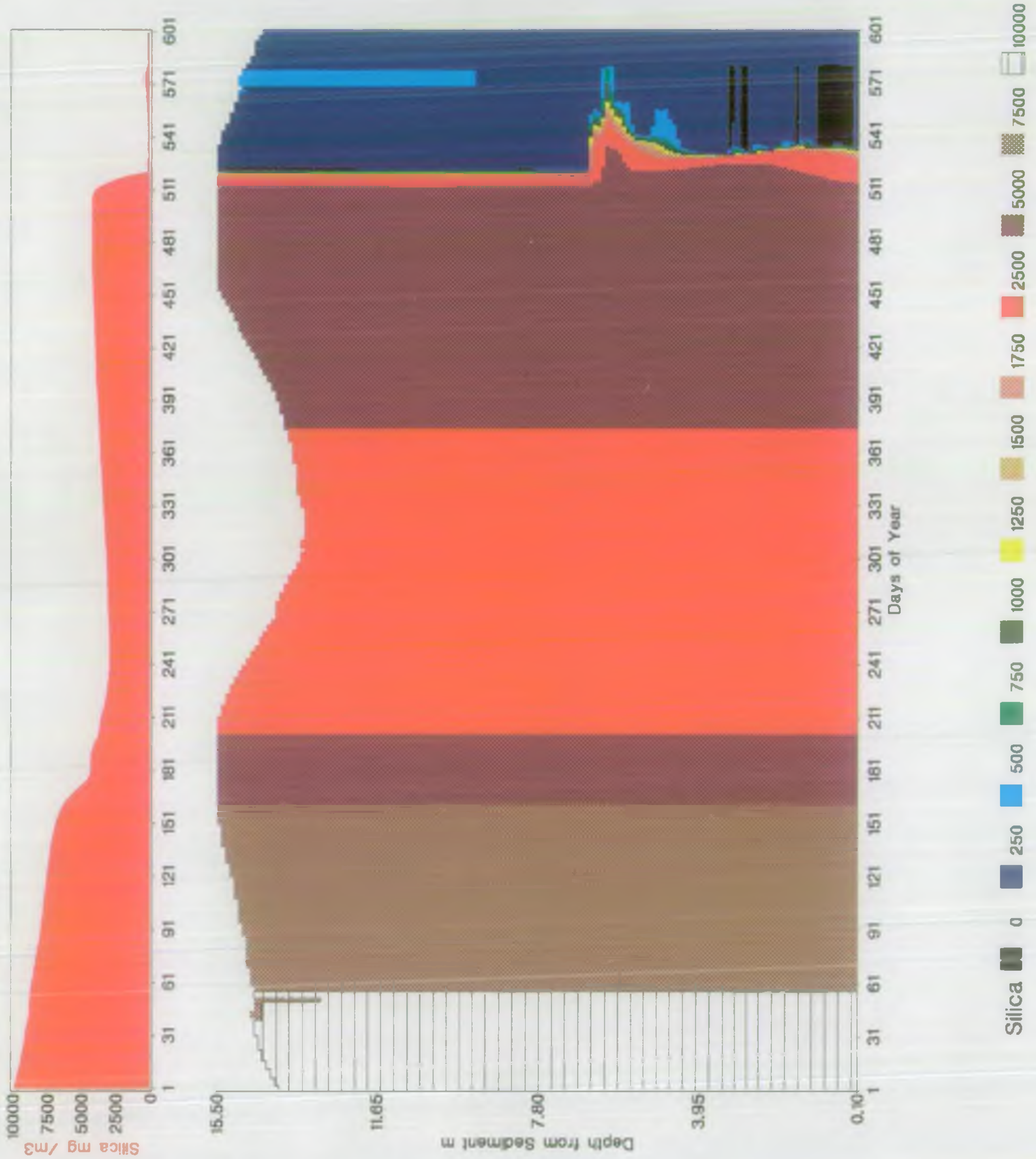


Fig 15: Test Reservoir

Silica profile with changing inflowing nutrients
Model using test data test Reservoir 1991-92

22 December 1992



3. NUTRIENT CYCLING

In several of the runs conducted during the model development, we have used data sets from smaller local lakes. In many instances we have had to augment the inputs of phosphorus in order to simulate the biomass more authentically and to reflect the in-lake concentrations of nutrients through the entire year. It is clear that systems are not exclusively maintained by the nutrient loads but that they rely to variable extent on the internal fluxes. It was this realisation, indeed, which prompted us to investigate the matter more fully and which, in part, has been enabled through NRA support.

During the year we have completed a deep review of the literature, not necessarily on recycling itself, but to help us to construct budget principles in respect of lakes, depending upon their morphometry, catchment and hydraulics, basin eutrophication and sediment behaviour. A valid picture has emerged (2) which is prompting us to explore the possibility of using experimental and assaying techniques as an aid to better prediction of post-restoration recovery rates following the implementation of schemes to reverse eutrophication and its consequences. The NRA is advised of this development, especially, since its technology is likely to be in considerable demand in the decade or so.

In addition, the re-analysis of the data assembled during the Blelham Enclosure experiments with particular reference to phosphorus cycling has also been completed and submitted (3). This has shown, quite remarkably, the assumed pathways in large or deep lakes (i.e. where shallow water is proportionately small) are correctly judged to recycle nutrients rather poorly but that when the shallow margins are large in relation to the whole, nutrient re-use is prolific. Moreover, the role of the shallow sediments in releasing nutrients is shown to be mechanically-, rather than redox-driven. By extension, very shallow lakes will recycle nutrients most efficiently : it is little wonder that these have proved to be the most difficult to restore and whose recovery has taken much longer than loading models would predict (4). We consider these observations to be novel and important to the philosophies of lake function and management. This is why we have sought NRA sanction to publish these data at the earliest opportunity.

4. SOFTWARE PRODUCTION

No formal attempt has been made to improve the packaging and user-friendliness of the model. Now we have incorporated the full range of components intended, a full run of the model requires the processing of 8-9 Mb of information with increments for longer periods (the run illustrated used slightly over 13 Mb but the period is longer than one year; "writing to file", in order to prepare graphical outputs, is particularly consumptive of disc-space.

5. ASSESSMENT

The modelling has proceeded at least as well as desired and within the envisaged time-frame. The additional work on phosphorus and nitrogen recycling has been completed and reported. The final six months of the contract will be directed towards refinement of the model.

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(1) Reynolds C.S. & Irish, A.E. (1992). Modelling algal blooms. Second interim report. Freshwater Biological Association, Ambleside.

(2) Reynolds, C.S. & Davies, P.S. (1992). Sediments and the recycling of phosphorus and nitrogen in lakes and reservoirs. Freshwater Biological Association, Ambleside.

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