Exploratory Sensitivity Analysis of a Stream Ecosystem Model

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EXPLORATORY SENSITIVITY ANALYSIS OF A STREAM ECOSYSTEM MODEL

by

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A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Range Ecology

Approved:

UTAH STATE UNIVERSITY
Logan, Utah

1975

ACKNOWLEDGMENTS

The work embodied in this thesis is but a small fraction of the labors undertaken to construct a predictive model of an aquatic ecosystem. As such, I have found the writing of this thesis to be rather difficult, mainly because of my inability to separate the meager contribution that I have made from the wealth of knowledge supplied by others. To all of you I give thanks.

I have had the great pleasure of interacting with a working graduate committee, consisting of David Goodall, Roland Jeppson, Wayne Minshall and Clair Stalnaker. To you I am grateful.

A special thank you must go to Charles Fowler, with whom I have been in almost constant contact during much of the work, whose help and guidance have been incalculable.

Financial support of this work was provided by the National Science Foundation through the International Biological Program Desert Biome and by the Bureau of Reclamation through the Central Utah Project, Grant No. YNE-074-0.

Joseph H. Wlosinski

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ABSTRACT

Exploratory Sensitivity Analysis of a

Stream Ecosystem Model

by

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Utah State University, 1975

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The framework of a stream ecosystem simulation model is described. Using this framework and data from two different geographical areas, a cold desert stream and a generalized mountain stream, exploratory sensitivity analysis was performed on the model. This was accomplished by qualitatively comparing outputs of a series of simulations in which a different level of a driving variable was used in each simulation. Based on these results, recommendations are made for improving the structure of the model.

(227 pages)

INTRODUCTION

One of the objectives of the International Biological Program and of the Analysis of Ecosystems program as listed in the Desert Biome research design of July 1970 is "To synthesize the results of this and previous studies into predictive models of temporal and spatial variation . . .". The studies referred to included the structure and function of desert aquatic ecosystems. To accomplish this end a goal was set out and elucidated at an aquatic specialists meeting in 1970. It stated "Very simply, we have set out to construct a predictive model of a series of rather common desert aquatic ecosystems."

Although much of the field work and validation studies were started much earlier, (Minshall et al., 1971, 1972) work on constructing the model did not begin until the spring of 1972. At that time the objective was to create a general model to cover permanent springs and streams, and temporary waters represented by a playa and intermittent streams (Aquatic Specialists Meeting, 1970. Desert Biome US/IBP). Work proceeded until January of 1973 when the model was very nearly of the form described in the Desert Biome Research Memorandum RM 73-57. Up until that time this author had made no contribution to this work. In July of 1973 a cooperative use and development of the model was undertaken between the Desert Biome personnel and those of the

Cooperative Fisheries Unit of Utah State University who were interested in predicting effects of reduced water flows on stream ecosystems. It was felt at that time that the model could be developed to be general enough to cover streams located in different biomes and modeling efforts were to be centered on moving water. The modeling work has moved in this direction to the present, quite often in a manner that was aptly stated by K. E. Boulding (1964)

> "The general systems man, therefore, is constantly taking leaps in the dark, constantly jumping to conclusions on insufficient evidence, constantly, in fact, making a fool of himself. Indeed, the willingness to make a fool of oneself should be a requirement for admission to the Society of General System Research, for this willingness is almost a prerequisite to rapid learning."

The model at its present level of development is described in Appendix D.[1/] A comparison between it and the Desert Biome Research Memorandum RM 73-57 shows the changes involved in the past year, but comparison can only be qualitative, for the model has not, then or now, been validated.

Clymer (1972) in a paper titled "Next Generation Models in Ecology" states, "Now, studies ranging over several years are beginning to emerge, involving both modeling and measurement and other progressive reconcillation." The aquatic project is of this type, with this thesis being part of the progressive reconciliation mentioned above.

Recommended changes for the model are based on findings in the literature, in field studies, and on an exploratory sensitivity analysis of the present model. According to Noy-Meir and Goodall (1973)

1/ Appendix D is stored in the University Archives of Merrill Library, Utah State University.

> "The purpose (of exploratory sensitivity analysis) is to test the response of a model over a wide range of conditions, in order to get some feeling for its general behavior and to see whether this behavior is at least qualitative over this range . . . Even if the parameter values used are not accurate values for any particular species or site, the trends in the model responses should indicate at least any pecularities in the behavior of the model, which might lead to revision of its structure."

This type of analysis was accomplished by qualitatively comparing outputs of a series of simulations in which a different level of a driving variable was used in each simulation. Two data sets of different Biome types were employed in the analysis, one being a desert stream, the other a mountain stream. Recommendations for model changes are based on these analyses combined with previous knowledge and previously reported studies.

LITERATURE REVIEW

According to W. J. Hudetz (1973) in an article titled "Ecosystem models and simulation" ecosystem modeling is still in its infancy. This seems to be an accepted view at present, especially when compared to other scientific endeavors, but it is a science which is receiving much attention. This can easily be seen by reviewing the bibliographies on ecological models by O'Neill, Hett and Sollin (1970) and Kadlec (1971), the latter having over 600 references. In a survey of aquatic ecosystem models compiled by Parker (1974), 162 models were listed, although the meaning of the term ecosystem may be questioned in many of the models. According to Odum (1971) it is the living organisms and their abiotic environment in a given area with the exchange of materials between these two parts that make up the ecosystem. In the survey by Parker describing such models, nine biological components were listed with respondents checking those components included in a particular model. These biological components were: bacteria, fungi, algae, aquatic macrophytes, zooplankton, bottom fauna, other invertebrates, fish, and other vertebrates. Goodall (1973) mentions that the tendency in ecosystem modeling has been to combine large numbers of biological elements, and he gives reasons for these tendencies as well as the shortcomings of such work. I am not arguing that models should not be called ecosystem models unless they are an isomorphism of the real world, but of the

162 "ecosystem" models listed by Parker, over 75 percent have three or less of the biological components listed, with approximately 40 models having no organisms! Some of the models listing no biological components are directed toward assessing or analyzing pollution and thermal effluents, a formidable task when not considering the organisms of the ecosystem.

Another major point brought out by the survey is the lack of models that have reached the literature. Less than half had any type of published report, with most of the reports being to granting agencies. Only 12 of the 162 models have been described in periodicals.

No other model was found to have the same characteristics as the one embodied in this thesis, that being a general stream, dynamic ecosystem simulation model.

Although at the present time another model with the same purpose is not known, the literature virtually abounds with stream studies needed for model formulation. H. B. N. Hynes (1970) cites over 1200 references used in his book, The Ecology of Running Waters. Although many of these have been used in the formulation of the model, it is not the purpose of this thesis to describe model formulation. An overview of ecosystem modeling also will not be covered for it has been reviewed by Clymer (1972) and Paulik (1972). Clymer lists tables for ecosystems and phenomena modeled as well as the types of mathematics employed. Paulik covers ecosystem modeling in relation to other modeling areas.

In stream systems much of the modeling work has been aimed at predicting water quality (Texas Water Development Board, 1970a, 1970b, 1971; Sharp, 1971; Cleary, 1971; Phillips, 1973; Faulkner, 1972; Greenber, 1973). More ecosystem oriented stream models have been presented by McIntire (1973), Fisher and Likens (1973), Wiegert (1973) and Boling et al. (in press). McIntire presented a model on periphyton dynamics using four level variables and 12 rate variables. Fisher and Likens provided an integrative approach to stream ecosystem metabolism, presenting a static model of the annual flux of energy in a stream ecosystem. Wiegert presented a general ecological model, and discussed the conditions which the mathematical model must satisfy. He then applied this model in a simulation of algal-fly energetics in a thermal spring community. The modeling work of Boling et al. concentrates on the microbial and abiotic decomposition of detritus in a temperate zone woodland stream.

Although exploratory sensitivity analysis (term due to Noy-Meir and Goodall, 1973) has not been found in the literature as such, a few works have been found where driving variables have been changed and their effect on the state variables noted. Much of this work has been done on terrestrial models in connection with the International Biological Program-Tundra Biome (Miller and Tieszen, 1972; Miller, Collier and Bunnell, 1973; Miller, 1974). Although the purpose may not have been to look for peculiarities in the model, Miller (1974) mentions that several changes had been made to the model after the sensitivity analysis.

Brylinsky (1972) studied model sensitivity to photosynthesis, which was a forcing function in his model. Rykiel and Kuenzel (1972) perturbed forcings to measure steady state in their model of the values of Isle Royale.

Terrestrial models from five different biomes (International Biological Program) were tested with parameterized climatic changes by Cooper (1974). Unlike this thesis Cooper used "models [that] have been extensively validated" and drew several major conclusions from the study. Fowler (1973) studied the effect of altered streamflow, and suggested that the "determination of the effect of different climatological conditions on the overall behavior of the system" be studied. This type of approach has been used for this thesis.

OVERVIEW OF THE GENERAL STREAM MODEL

The General Stream model is an abstract, dynamic, nonlinear, stream ecosystem simulation model, in which the ecosystem is envisaged as a horizontally homogeneous stretch of water. It is not general in the sense of the term as used by Levins (1966) who proposed sacrificing realism or precision as a strategy to gain generality.

The General Stream model is general in the sense that specific components of the ecosystem modeled are not specified by the model, but are left to be specified by the user at execution time, along with a series of switches and parameters that control those components. With this control it becomes unnecessary to describe separately the process in which each state variable is involved. Instead, switches and parameters are set in a manner that allows only processes relevant to a particular state variable to occur.

At the present time the main state variables modeled are the quantities of the different organic constituents which make up the plants, animals, heterotrophic microorganisms, detritus and the dissolved component of water, the inorganic constituents, either dissolved or in a particulate state, and certain physical characteristics, such as depth and velocity. Exogenous variables include the materials entering the ecosystem from upstream drift, tributaries, overland flow and from the atmosphere. Materials may exit from the system through downstream flow, by way of withdrawals for irrigation, or in the case of water, by evaporation. Those variables that represent materials which leave the system as downstream flow may be saved and used as input in the case where more than one stretch of stream is to be simulated.

The processes modeled which may affect the plants are photosynthesis, plant respiration, consumption by animals, mortality, leakage, scouring and colonization. The animals may be affected by injestion, respiration, assimilation, egestion, predation, transfer from one size class to another (including reproduction), non-predatory mortality, scouring, colonization and behavioral drift. Decomposition, respiration, lysing, assimilation, consumption by animals, scouring and deposition affect the heterotrophic microorganisms. Organic detritus may be consumed, and along with inorganic detritus may be scoured or deposited.

The computer representation of the model is written in FORTRAN IV, using difference equations over a time step of one day. If the approximation by difference equations over this time step leads to negative values of an essentially non-negative variable, the program reduces the time unit as required. Output can be in graphical or tabular form. Tabulated reports on any day specified may include the weights of any or all components of the system, all allochthonous materials entering the system as well as components leaving by way of the downstream vector, and productivity of the components of the system. Certain physical characteristics may also be included as output. Most of these same variables may be graphed against time through the course of simulation. Output units may be in grams per square meter, grams per cubic meter, or grams per ecosystem where ecosystem is a variable, being defined as the volumn of water contained in the stretch of stream being modeled.

A much more detailed explanation of the model is given in Appendix D.

DATA DESCRIPTION

Exploratory sensitivity analysis on the General Stream model employed two different data sets. One data set was collected on Deep Creek, a cold desert stream, and the other simulated a generalized mountain stram. The latter data set was furnished by C. W. Fowler of the Cooperative Fisheries Unit of Utah State University as part of a grant to study the effects of reducing flow volume in a stream.

Although both studies were conducted at the ecosystem level, many of the components of the ecosystems were purposely deleted from the data sets. In the case of the Deep Creek study more data was available than was actually used in the simulations, with the limitations being set by core storage in the computer. The mountain stream data was limited for the users wished to study the interactions built into the model, so the number of components were kept at a minimum and the parameters used were for generalized groups rather than for specific species. All simulations spanned a period of one year.

Most of the Deep Creek data used for simulation were based on actual field measurements as collected by Desert Biome personnel (aquatic section) as part of the International Biological Program. A detailed description of Deep Creek is given in Desert Biome Research Memorandum Rm 73-48, titled Validation Studies at Deep Creek, Curlew Valley coordinated by G. W. Minshall (1973).

According to Minshall (1973), Deep Creek drains a substantial portion of Curlew Valley, which lies at the Utah-Idaho border north of the Great Salt Lake. The climate of the area is semi-arid, with total annual precipitation from 15 cm at the southern end of the valley to 41 cm at the northern end. There are four sampling stations on Deep Creek, with station 2 being the collection point for most of the data used in simulations for sensitivity analysis. Discharge at station 2 is regulated by Holbrook Springs, which provides a constant discharge of 17°C water at the rate of .46 cubic meters per second. The flow of the spring is supplemented and the temperature significantly reduced during periods of heavy snow melt runoff. During the summer the volume of flow is reduced in areas where water is diverted for irrigation.

For the drift or materials entering the system through upstream flow, four sets of data were used, being collected in January, June, and August of 1971 and April of 1972. Interpolation was used for all periods between collection times. Appendix D contains a complete listing of all input used for simulations for Deep Creek. The values for initial state variables were supplied by G. Wayne Minshall, Idaho State University, who coordinated the aquatic studies project.

There are five species or groups of plants, eight animal species, (of which seven are invertebrates and one a fish), two groups of heterotrophic microorganisms and two size classes of organic detritus. In addition, the eight animal groups are broken down into three to eight size classes for each group.

Initial values for state variables used are listed in Appendix D. Values for the main driving variables were graphed as output for the exploratory sensitivity analysis. Figure 1 indicates values used for daily photoperiod, Figure 2 for radiation, Figure 3 for discharge and Figure 4 for temperature.

The mountain stream simulated had as the main state variables three species or groups of plants, six species or groups of animals, one heterotrophic microorganism and one detrital category. According to Fowler (personal communication) this is obviously a gross simplification but represents what are viewed to be representative of the major groups or 'para-species' within the system. The animals play the roles of detritivores, carnivores and herbivores, and they can be looked at as representatives of larger taxonomic groups. The six animal groups are two species of fish and four species of invertebrates. As in the Deep Creek data deck, each species is further broken down into size categories.

Information concerning constituents from upstream were contained in monthly data sets, with interpolation used between each data set. Appendix C contains listing for the data deck of the mountain stream. Appendix A contains initial state variables for the mountain stream. As was the case for Deep Creek, the driving variables used for the mountain stream were graphed. Figure 5 indicates values used for daily photoperiod, Figure 6 for radiation, Figure 7 for discharge and Figure 8 for temperature.

The parameters used in the simulations were set in several ways. Some of the parameter values were taken directly from the literature,

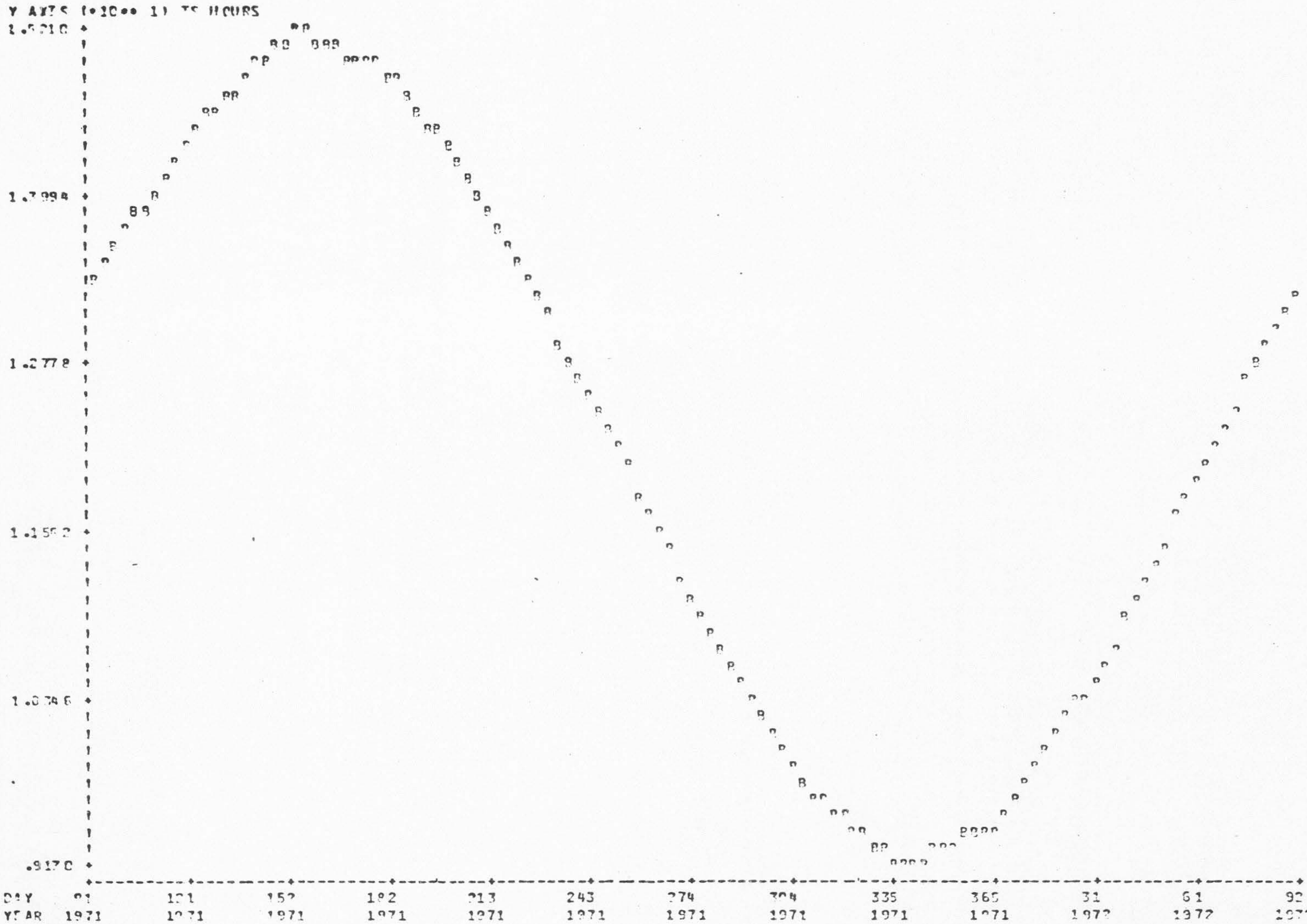

Figure 1. Daily photoperiod used for the Deep Creek simulation.

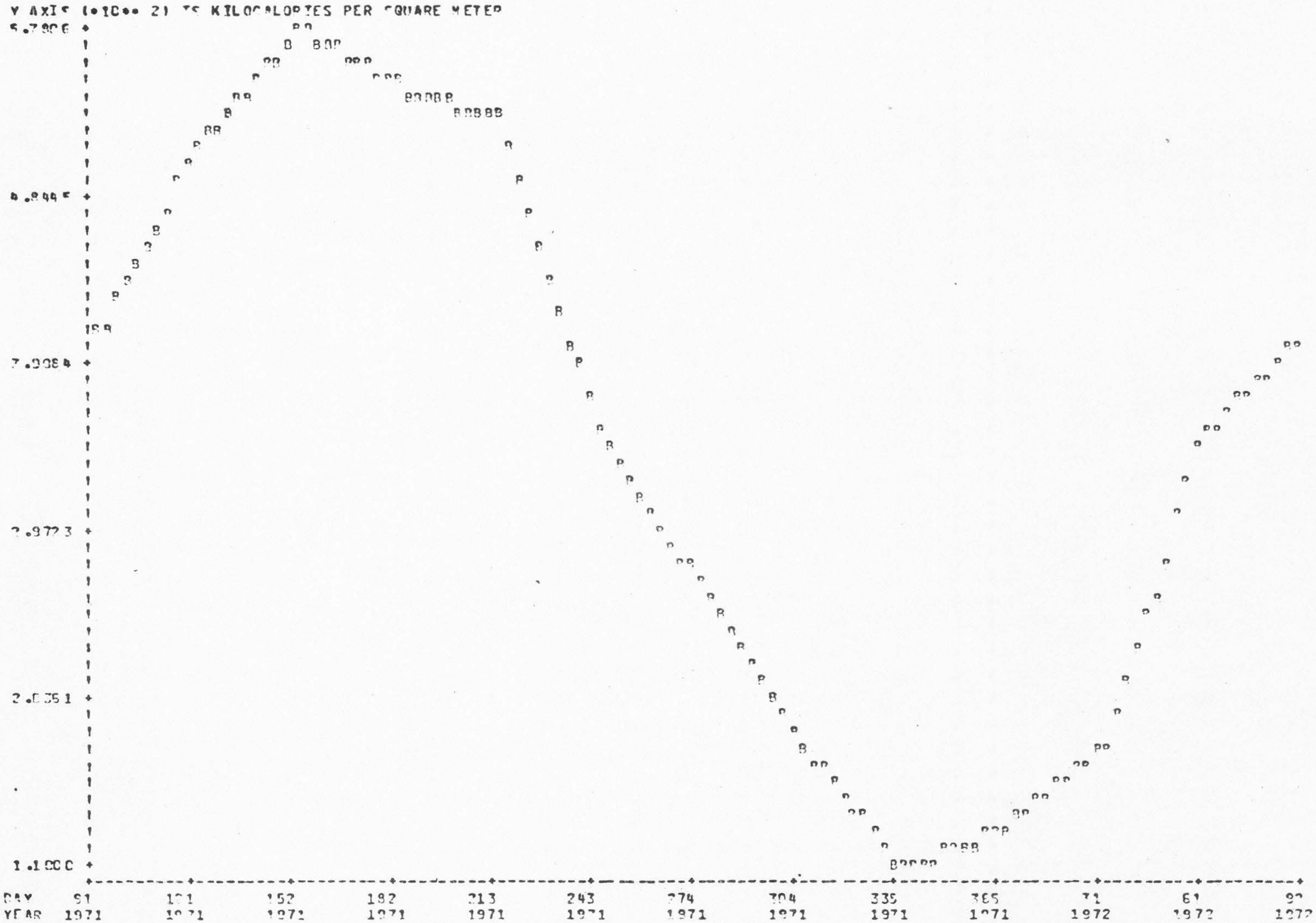

Figure 2. Incoming radiation used for the Deep Creek simulation.

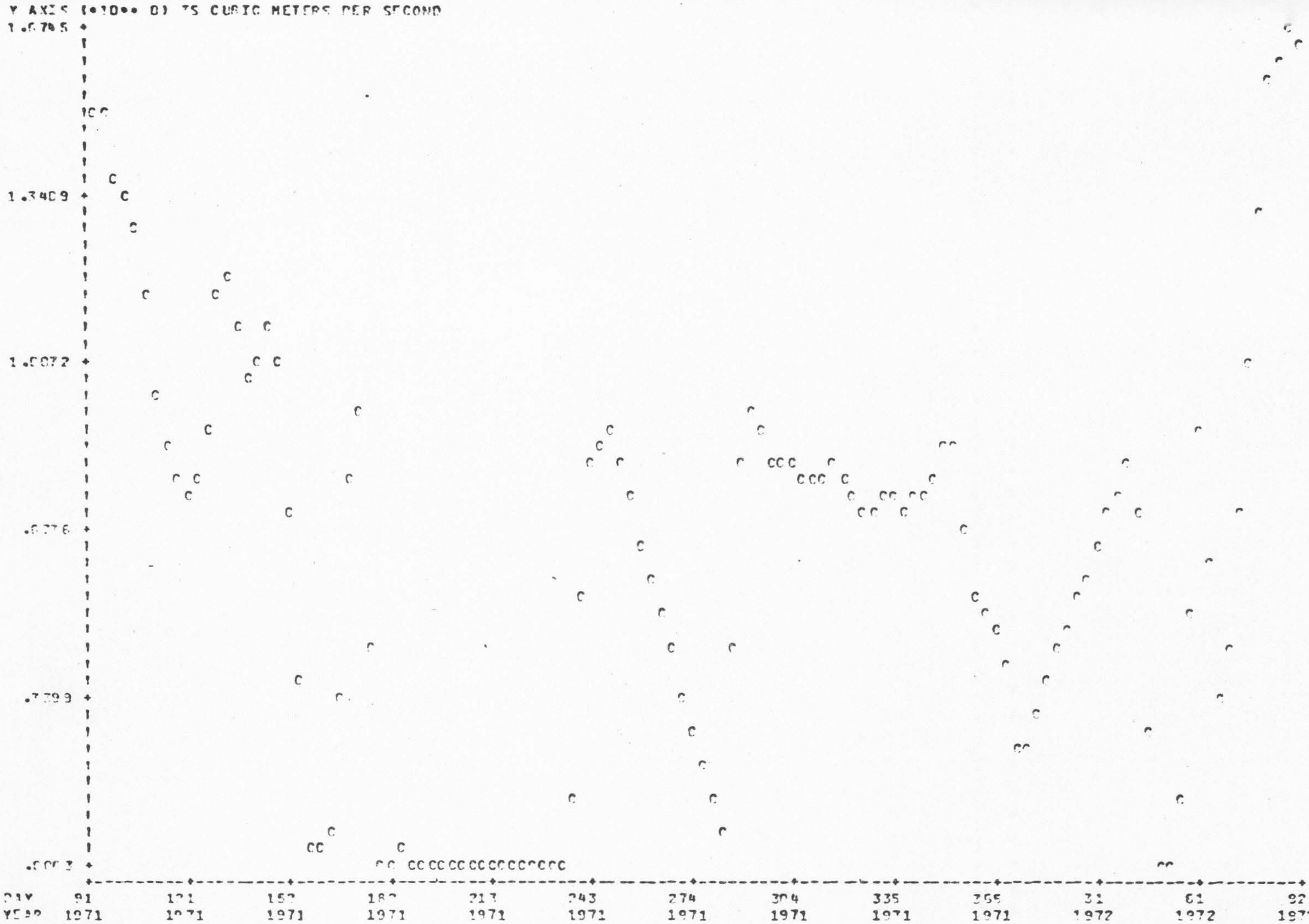

Figure 3. Discharge used for the Deep Creek simulation.

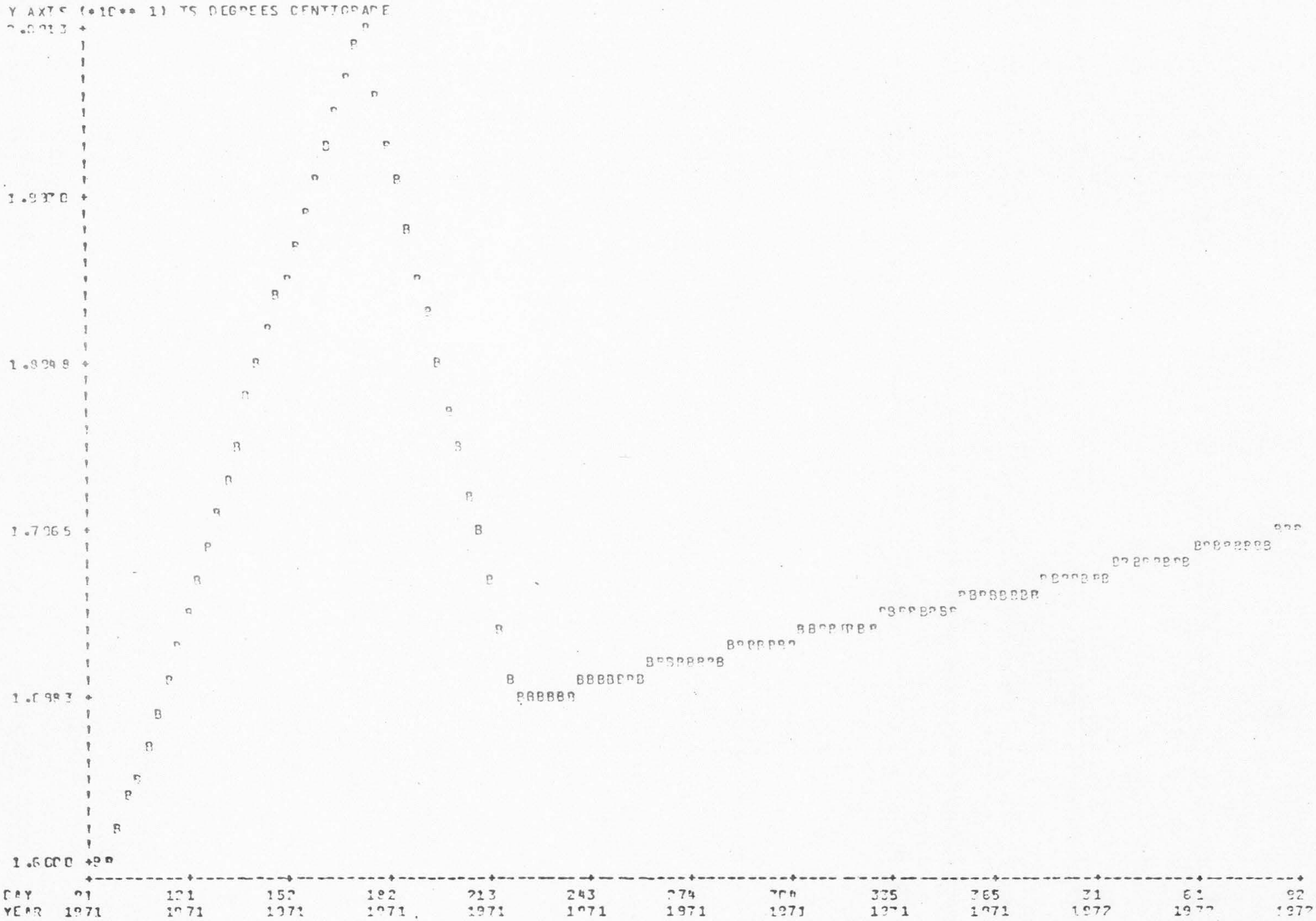

Figure 4. Temperature used for the Deep Creek simulation.

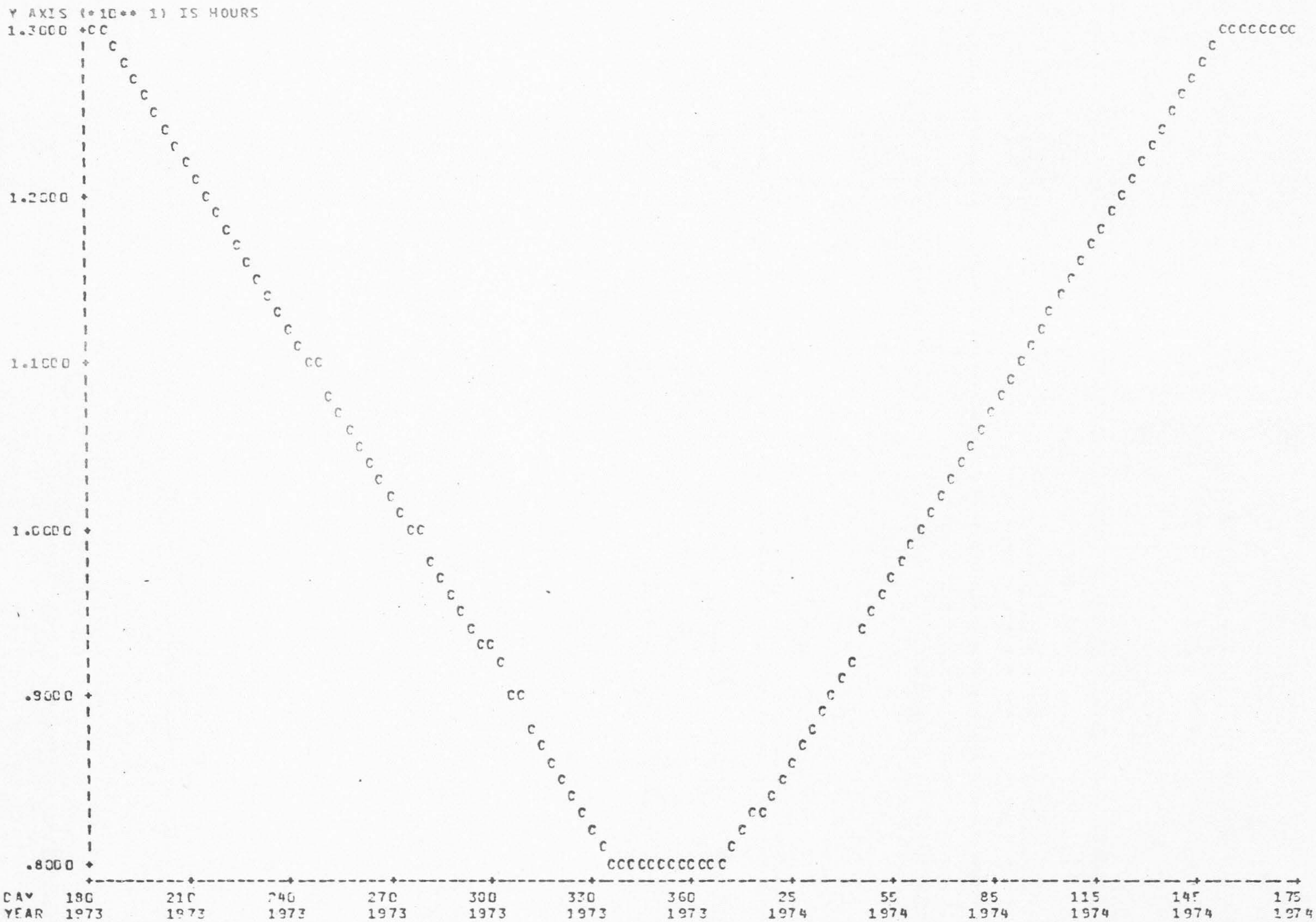

Figure 5. Daily photoperiod used for the mountain stream simulation.

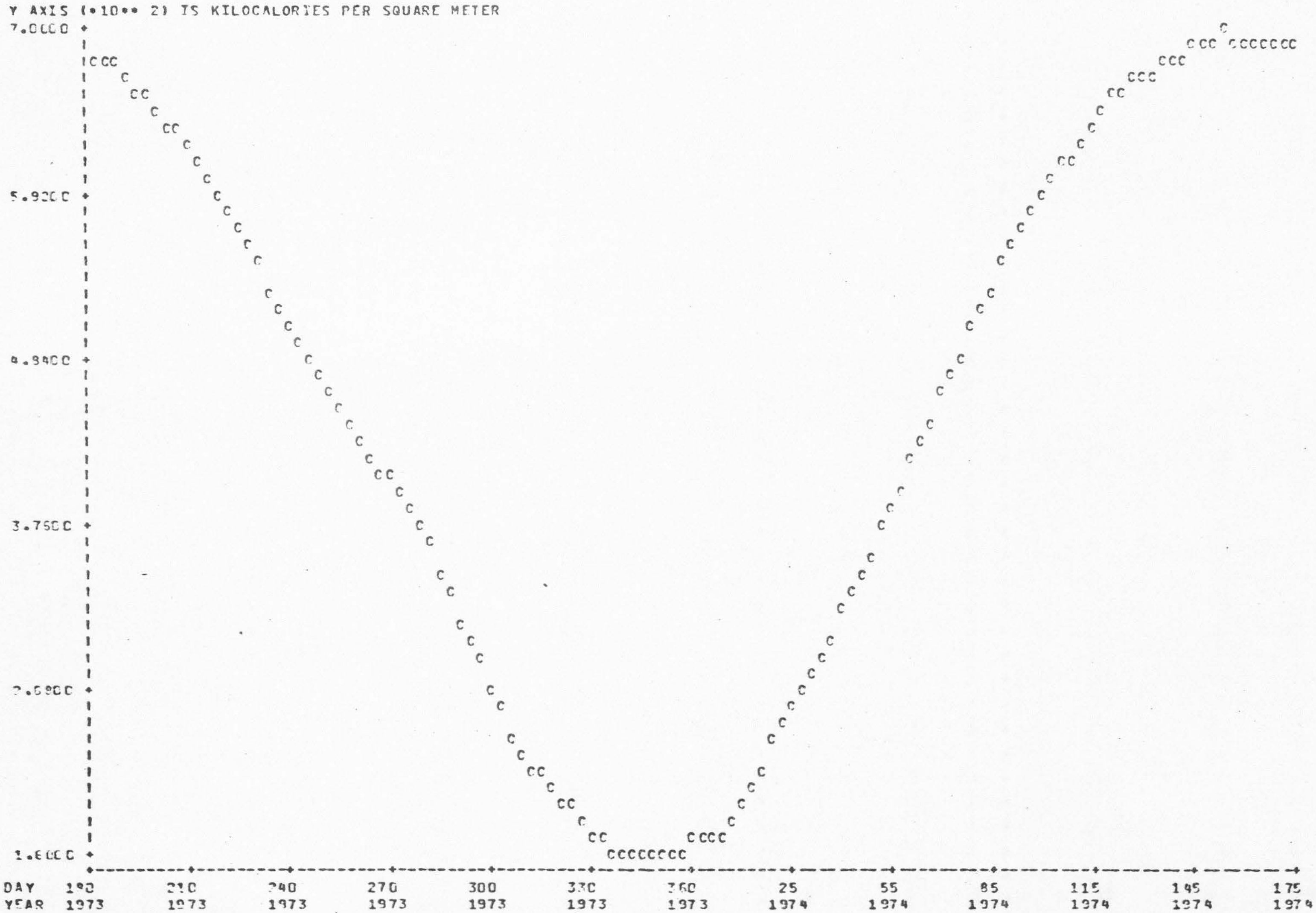

Figure 6. Incoming radiation used for the mountain stream simulation.

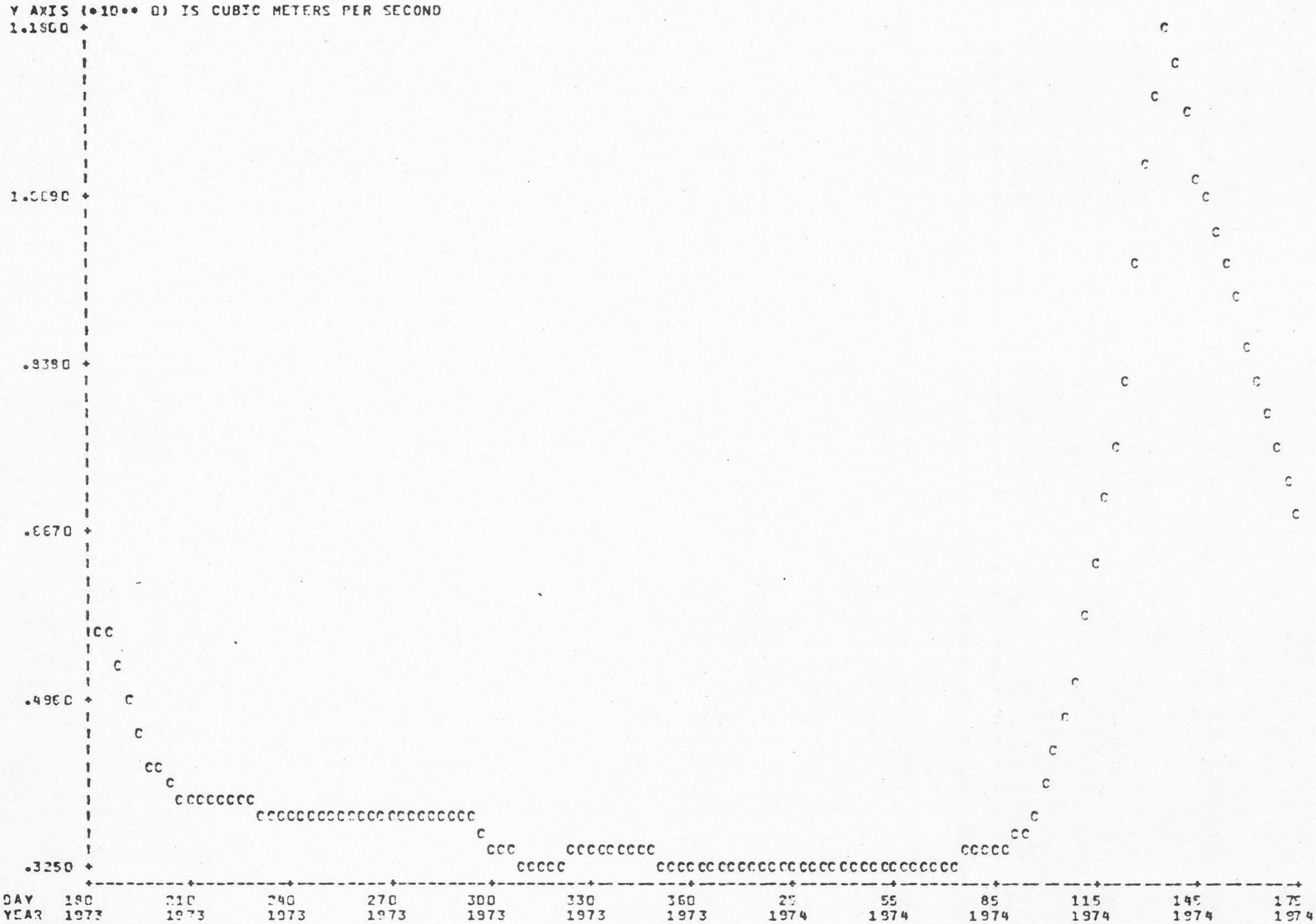

Figure 7. Discharge used for the mountain stream simulation.

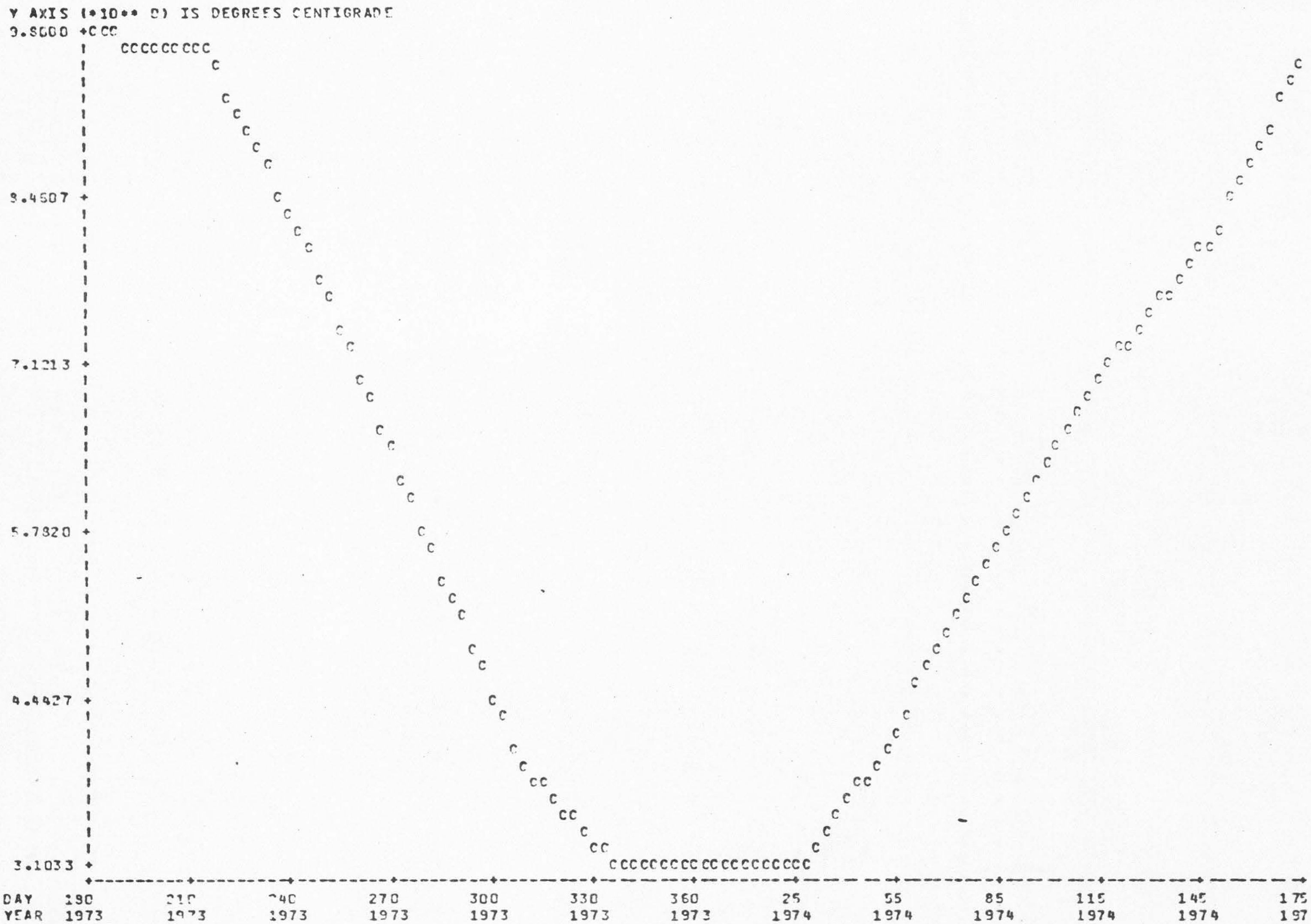

Figure 8. Temperature used for the mountain stream simulation.

as listed in Minshall et al., (1974), with others being set by solving equations in the model to produce solutions to correspond with values found in previously published work or actual field or laboratory study. Most of the parameters, though, were unknown, and had been set either as a "best guess", or by trial and error fitting.

The parameters used for the Deep Creek simulation are listed in Appendix D, and for the mountain stream simulation in Appendix C. It is my opinion that the parameter sets used do not in all cases reflect the best information available at the present time.

EXPLORATORY SENSITIVITY ANALYSIS

The Sperry Rand Univac 1108 computer was used for all exploratory sensitivity analysis. All work involved FORTRAN IV as the programming language.

A simulation would be run during which time values representing state or other variables of interest were collected and stored on an external data file. This step would be repeated once or twice, with different levels of a driving variable or exogenous input being used for each simulation. The model used was as described in Appendix D, except for a slight revision of the main program which allowed for the collection and storage on an external file of state variable values. After a set of runs were made with different levels for a particular exogenous variable, another program would bring together the set of external data files, and simultaneously graphed the variables of interest.

The sets of driving variables changed are listed in Table 1, while Table 2 lists the variables graphed. The main program for bringing together the data files is listed in Appendix B, while the graphing routine was modified from that listed in Appendix D. To make sure the proper external data files were used in the graphing routine all control cards used were printed at the start of each graphing series.

Table 1. The levels of exogenous variables used for exploratory analysis of the general stream model. The standard data for Deep Creek is listed in Appendix D, and for the mountain stream in Appendix C.

Variable(s) changed	Deep Creek	Mountain Stream
Discharge - multiplied by	.5	.5, .25
Temperature - multiplied by		1.1, .9
Temperature - plus and minus	5°	
Solar Radiation - multiplied by	.75, 1.25	.75, 1.25
Inflowing dissolved inorganic constituents - multiplied by	.5, 2.	.5, 2.
Inflowing detritus - multiplied by	.5, 2.	.5, 2.
{ Discharge - multiplied by*	.5	
{ All inflowing constituents - multiplied by	2.	

*Both variables in brackets were changed and simulated as a single perturbation.

Table 2. Variables graphed for exploratory sensitivity analysis of the general stream model.

1. Biomass for each species or group of plants.
2. Total net productivity from the beginning of the simulation for each species or group of plants.
3. Daily net productivity for each species or group of plants.
4. Biomass for each species or group of animals.
5. Total growth (listed as productivity) from the beginning of the simulation for each species or group of animals.
6. Daily growth for each species or group of animals.
7. Biomass for each group of heterotrophic microorganisms.
8. Total growth from the beginning of the simulation for each group of heterotrophic microorganisms.
9. Daily growth for each group of heterotrophic microorganisms.
10. Total biomass for all plants.
11. Total net productivity from the beginning of the simulation for all plants.
12. Daily total net productivity for all plants.
13. Total biomass for all animals.
14. Total growth from the beginning of the simulation for all animals.
15. Daily total growth for all animals.
16. Total biomass for all heterotrophic microorganisms.
17. Total growth from the beginning of the simulation of all heterotrophic microorganisms.
18. Daily total growth for all heterotrophic microorganisms.
19. Mass for each size class of organic detritus.
20. Total mass for all organic detritus.
21. Net gain or loss of organic carbon to the ecosystem.
22. Photoperiod.
23. Radiation.
24. Discharge.
25. Temperature.
26. Depth of water.
27. Amount of water in the ecosystem.
28. Water velocity.

RESULTS AND DISCUSSION

The exploratory sensitivity analysis conducted resulted in 808 graphs, although only those that resulted in recommendations will be presented. An example of the graphs is presented in Figure 9. Only one variable is graphed per page, with two or three graphs representing the reactions of that variable to a perturbation. If more than one letter is to occupy the same coordinates, only the last letter (alphabetically) is printed.

In ecosystem analysis where a number of state variables are of interest and they are governed by a number of processes, care must be taken in assigning certain outcomes to a particular process. One may see the number of an animal of interest decreasing, (in the real world as well as model output) with the observer concluding that the losses were due to predation. But unless we can look at the dynamics of the system at the time of the loss no valid conclusion can be drawn (in the real world or from the model) regarding any state variable that is associated with more than one rate function. In the case of the model the loss can also be explained by drift out of the system due to a lack of food, or by scouring action during a flood, adults emerging and leaving the system, or by non-predatory mortality. In the case of the General Stream model it would be much too prohibitive to list the change for each time period for each state variable for each process. What was done in the few cases where I could not logically explain the

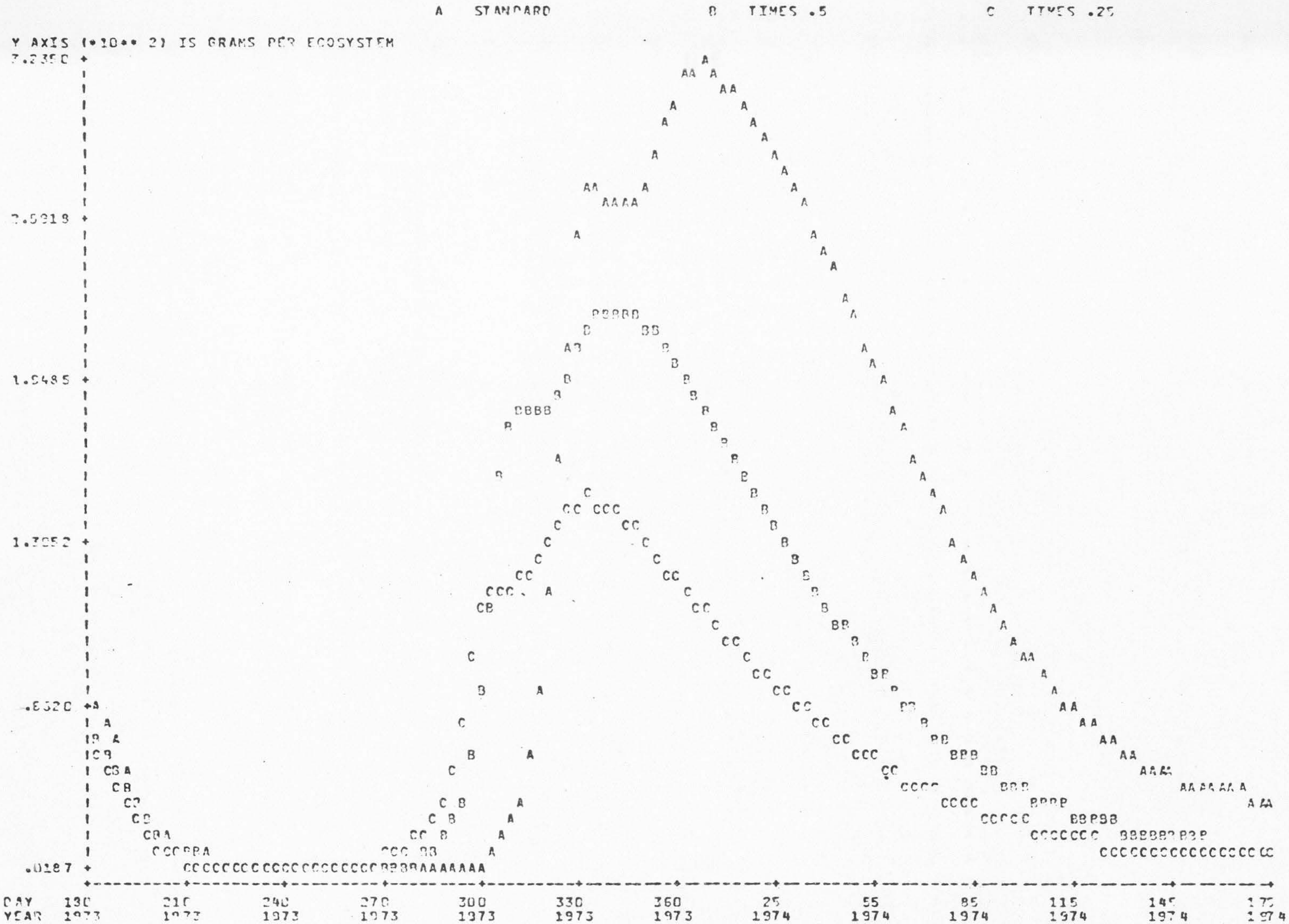

Figure 9. Response of stonefly biomass to changes of flow for the mountain stream simulation.

results, was to rerun the simulation, with extra information being printed about the dynamics of the system at that point during the simulation when the problems arose. The sensitivity analysis should not be construed to be a model validation, for the results were not compared with field measurements.

One of the main variables of interest, especially for the mountain stream, is flow or discharge, because of altered stream flow caused by storage reservoirs. Special care must be taken when viewing the graphs of many state variables due to changes which occur in the flow regime. The dimensions of many of the state variables are grams per ecosystem, but the size of the ecosystem is allowed to change as a function of discharge. These changes occur as changes in width and depth. When output is in square or cubic meter units the value of the state variable is simply divided by the area of the ecosystem or the number of cubic meters of water contained in it. Thus an apparent change in a state variable when viewing output in units per square of cubic meters may be caused by a difference in the size of the ecosystem, whith no other real change occurring. This can be seen graphically in Figures 10, 11, and 12, representing the mountain stream. In Figure 10 the area of the ecosystem is given for three discharge regimes. Line "A" is the standard run, or the area for the ecosystem in all of the subsequent graphs where other variables will be perturbed. Line "B" represents one half standard flow, and line "C" one fourth standard flow. Figure 11 represents total

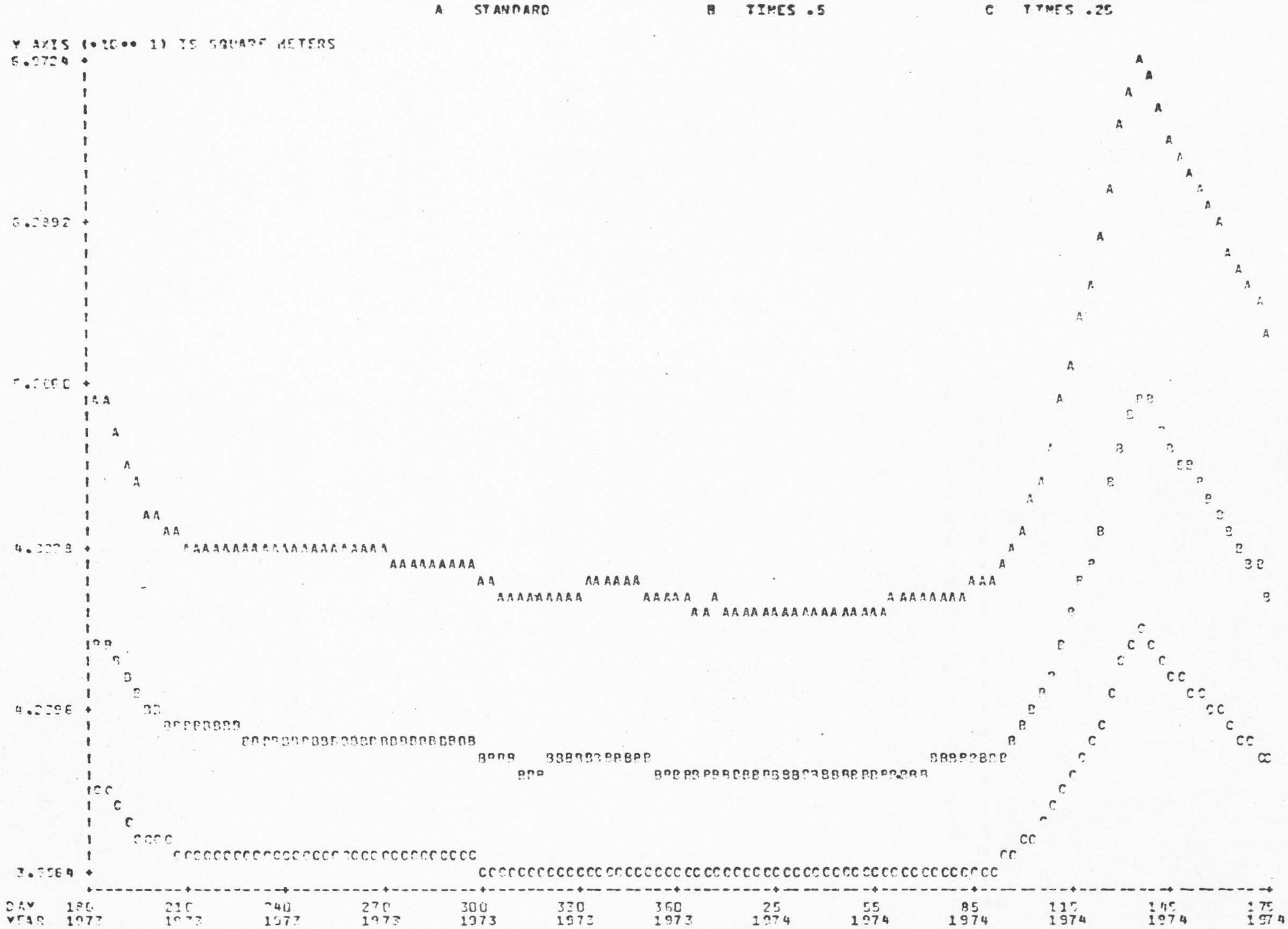

Figure 10. Surface area response to changes of flow for the mountain stream simulation.

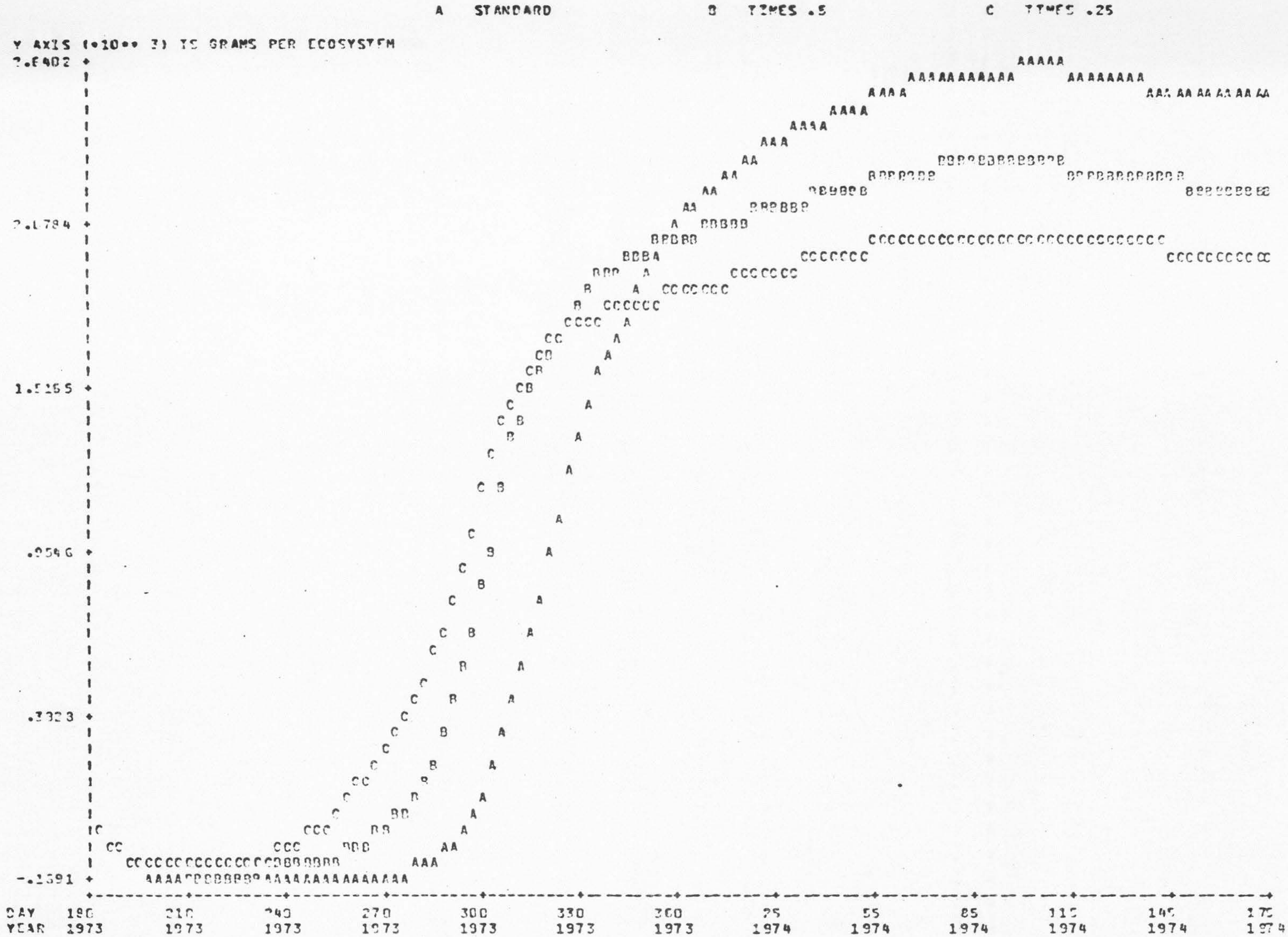

Figure 11. Response of animal productivity to changes of flow for the mountain stream simulation (reported in grams per square meter).

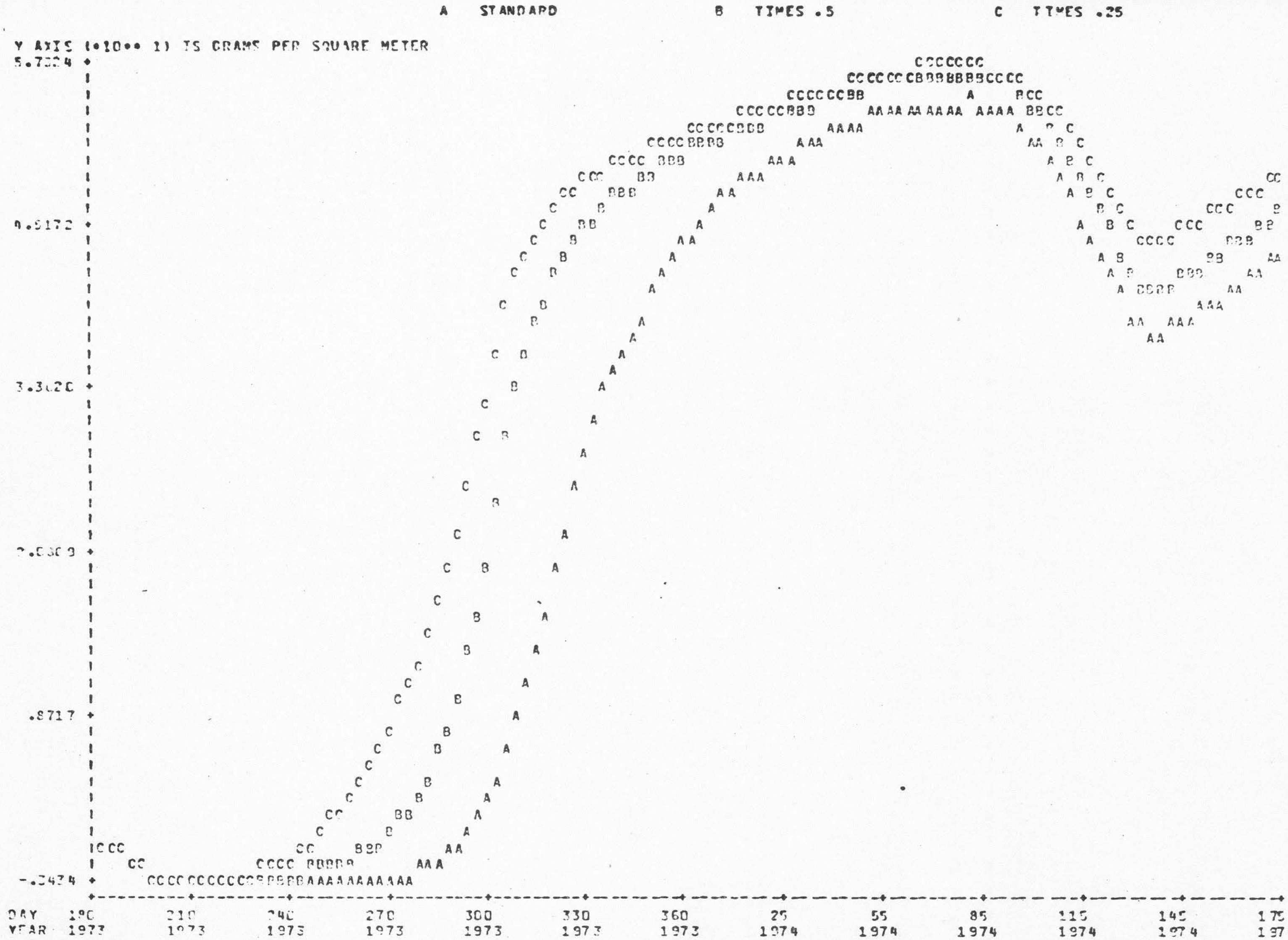

Figure 12. Response of animal productivity to changes of flow for the mountain stream simulation (reported in grams per ecosystem).

animal productivity as reported in grams per square meter. It appears as though total productivity at the end of the simulation for standard flow is lower than for one half and one fourth standard flow, but when we look at the same variable reported in grams per ecosystem (Figure 12) we see that just the opposite is true. The same could hold for reports in grams per cubic meter, for the volume of the ecosystem also changes as a function of discharge. In these cases the state variables are becoming more concentrated as the ecosystem becomes smaller. In the case of fish in the natural system this may be true to a certain extent, but in the case of rooted plants or detritus it is probably wrong, and should be corrected. In the case of motile organisms, even in the real world, it shows the problems and possible mistaken conclusions that can be drawn from values of weight per unit area in a stream ecosystem, especially for streams with a widely fluctuating flow regime.

At the present time in the model, plants and animals are scoured or deposited as a function of velocity, which is itself a function of discharge. Velocity can also affect these organisms in other ways, as pointed out by Hynes (1970). Hynes lists other factors controlling benthic invertebrates, namely temperature, the substratum, and dissolved substances. Although these factors may be interrelated and the mechanisms of their effect on organisms may not be well understood, I believe a "first try" at modeling the habitat should be made.

Earlier it was mentioned that the dynamics of a system are an important aspect of ecosystems analysis. Figures 13 and 14 give an example of how the model can help us identify these dynamics. Both graphs are representations of the mountain stream, Figure 13 showing the plant biomass during the year and Figure 14 the total plant productivity from the beginning of the simulation. We see that throughout most of the year plant biomass during standard flow conditions is lower than when using reduced flows, but that the total productivity is higher for the entire year. Thus, although there was a lower biomass the turnover rate was higher which may be explained by a greater utilization rate by grazers. The same two variables are graphed for Deep Creek (Figures 15 and 16). Here we see that the biomass was higher for most of the year when using standard flow conditions, as was total productivity.

One of the exogenous variables that has very little direct effect on most of the system is the concentration of dissolved inorganic constituents in the water column. In the model it is only directly related to the plants, but even here we see unexpected differences. The total net productivity for all plants for the mountain stream (Figure 17) increases with the increase in concentration of dissolved inorganic constituents, but for the Deep Creek area (Figure 18) we see just the opposite. This was explained by studying the parameter set that was used.

For the mountain stream the plants were limited to a greater extent by the inorganic dissolved constituents, while for Deep

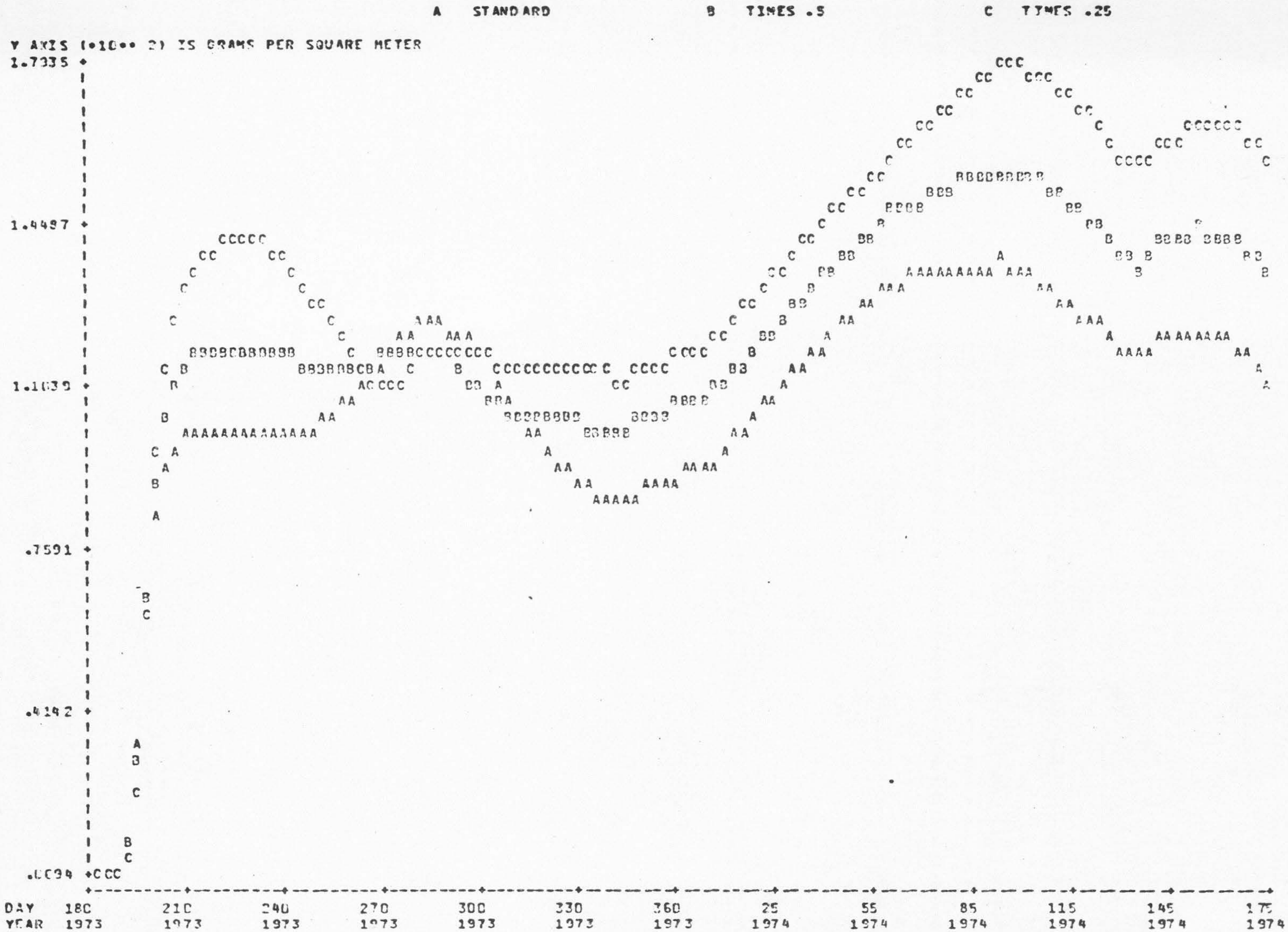

Figure 13. Response of plant biomass to changes of flow for the mountain stream ecosystem.

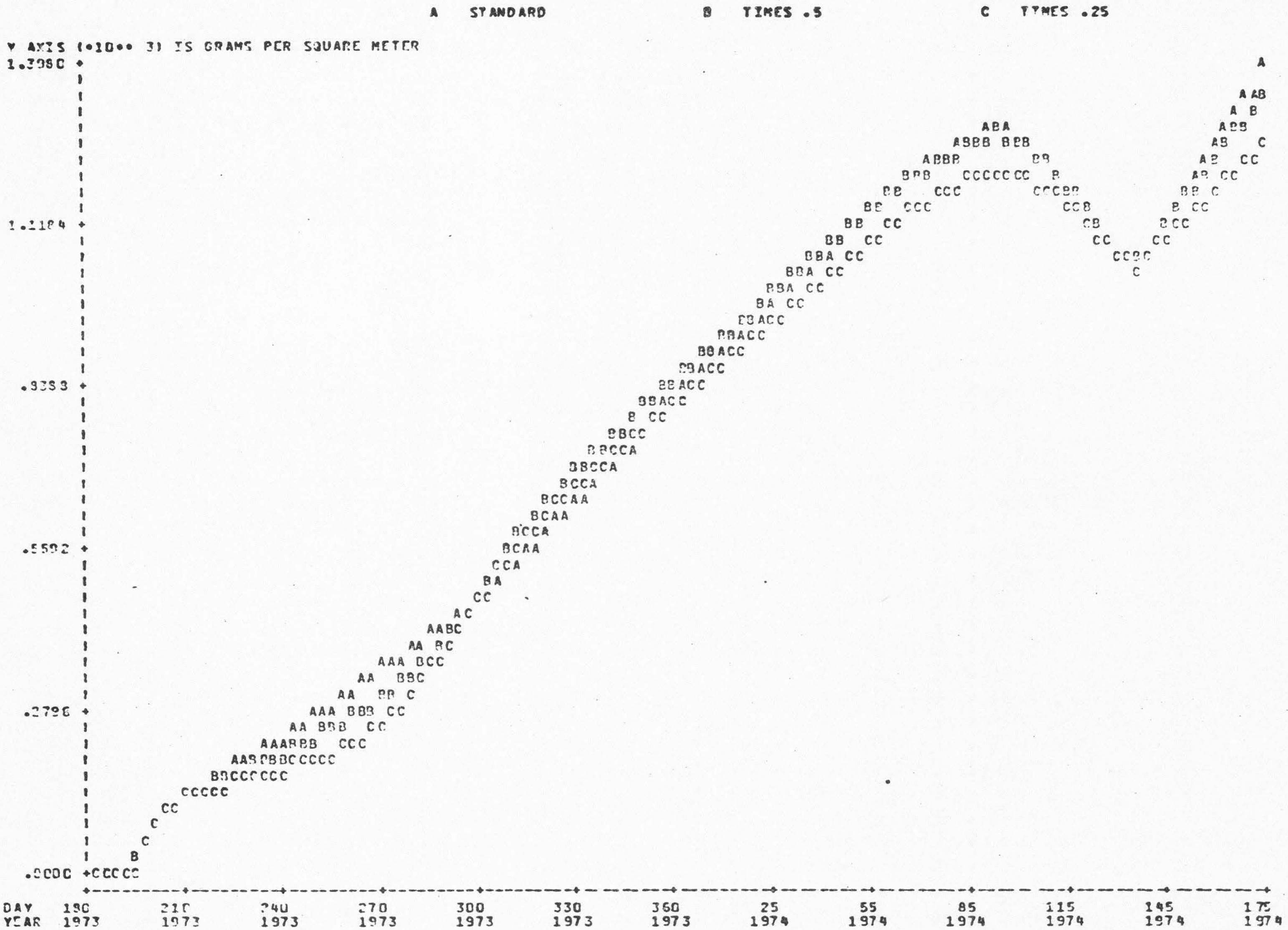

Figure 14. Response of plant productivity to changes of flow for the mountain stream.

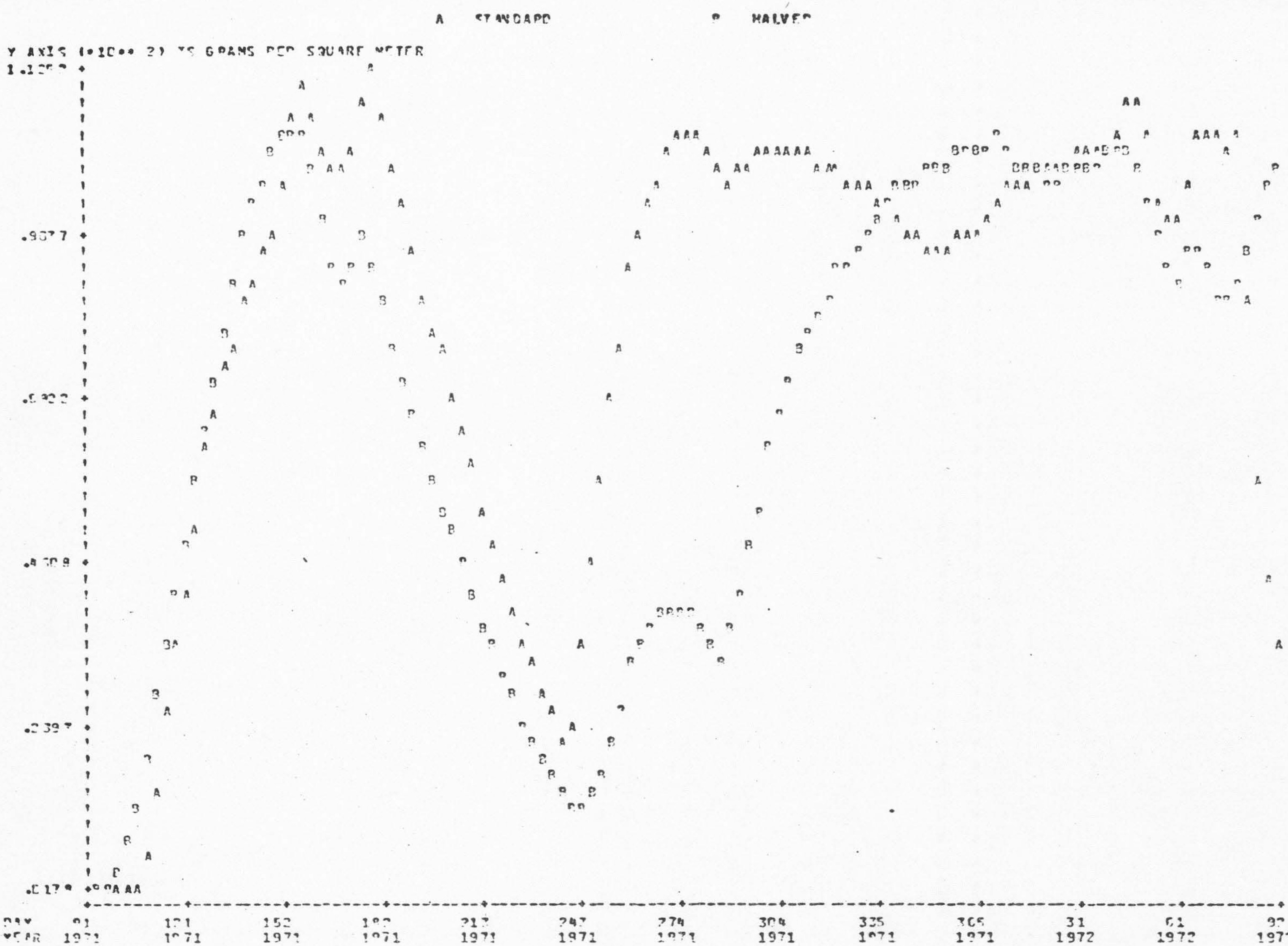

Figure 15. Response of plant biomass to changes of flow for the Deep Creek simulation.

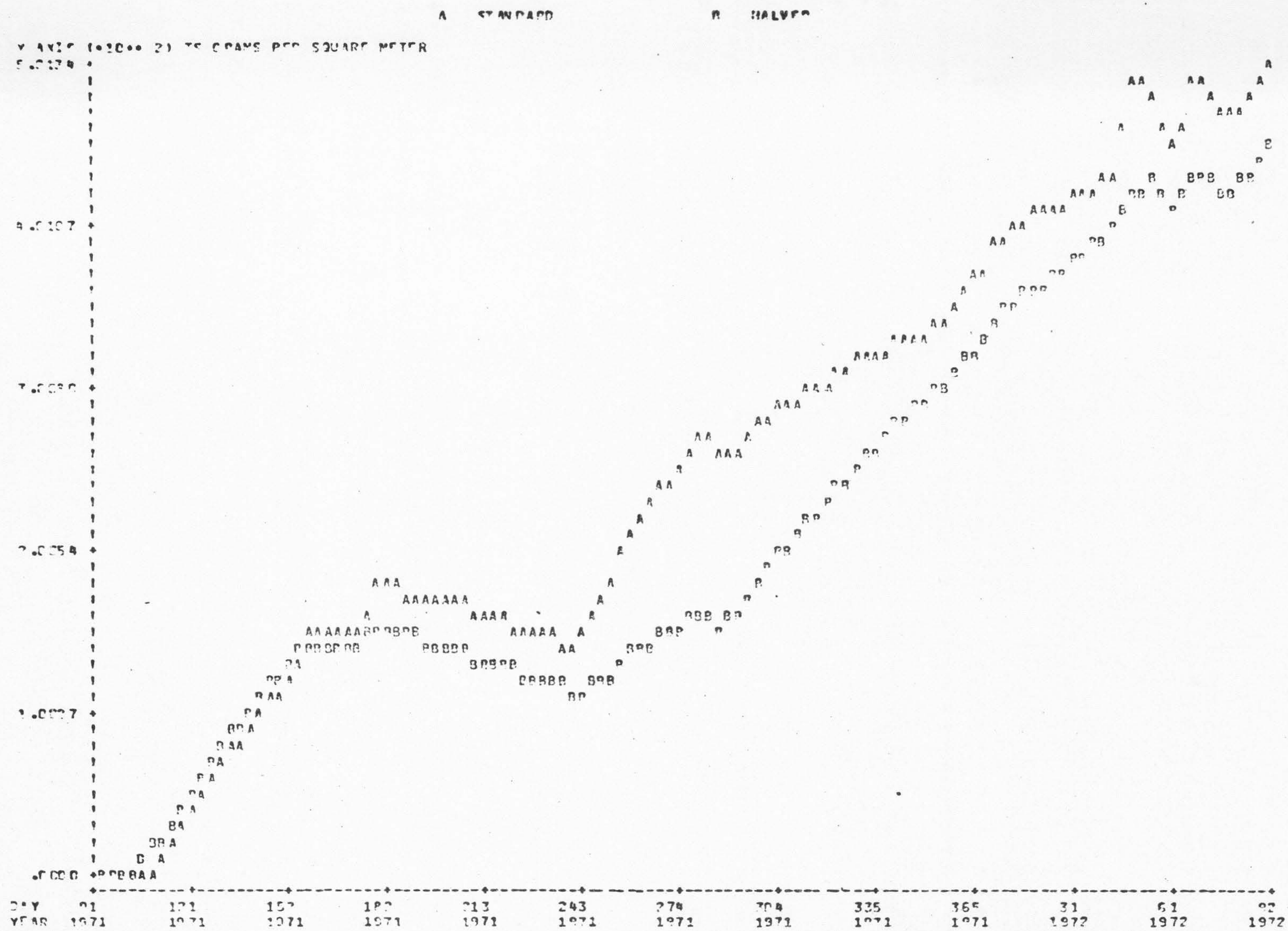

Figure 16. Response of plant productivity to changes of flow for the Deep Creek simulation.

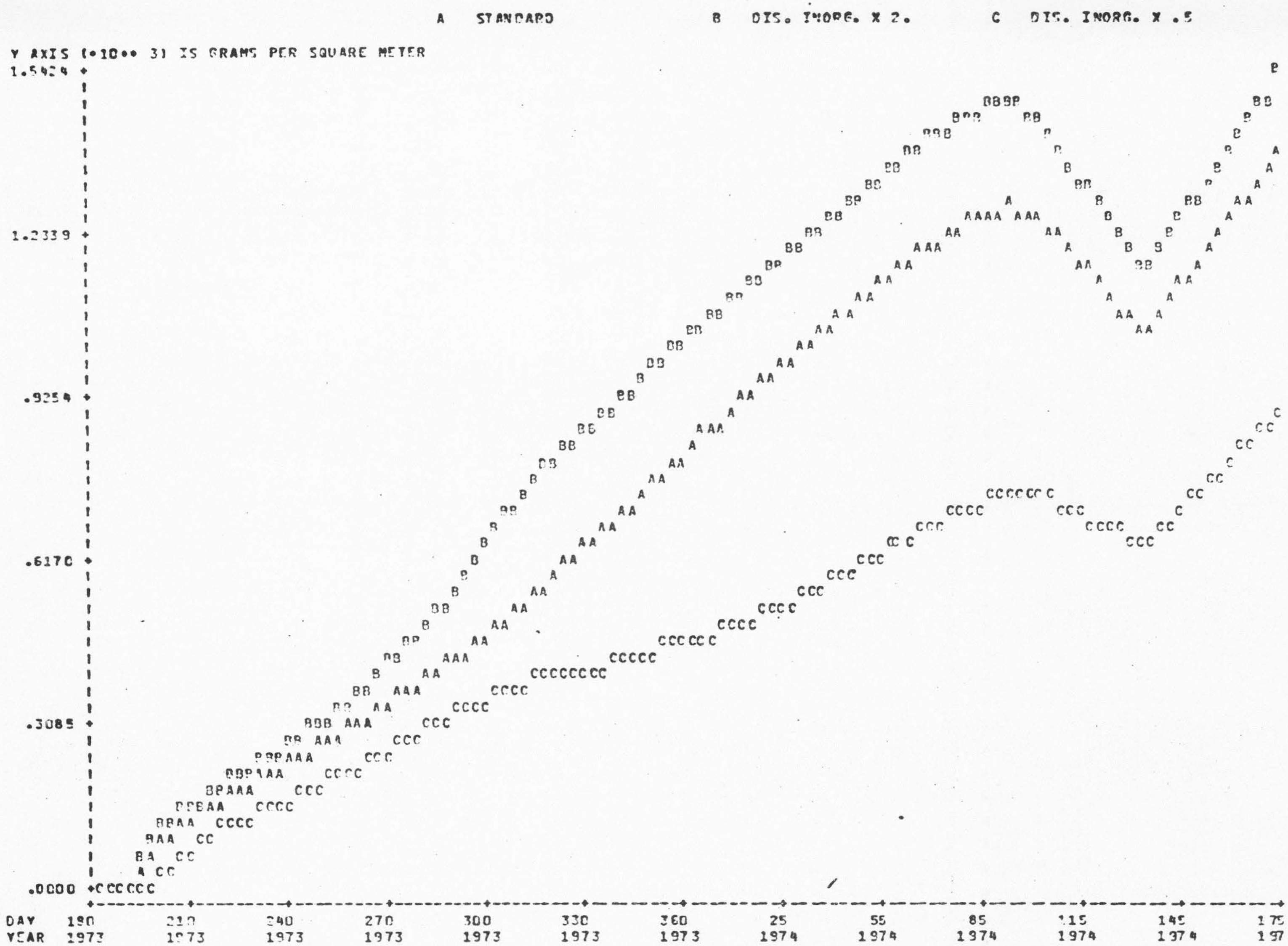

Figure 17. Response of plant productivity to changes of concentrations of dissolved inorganic constituents for the mountain stream simulation.

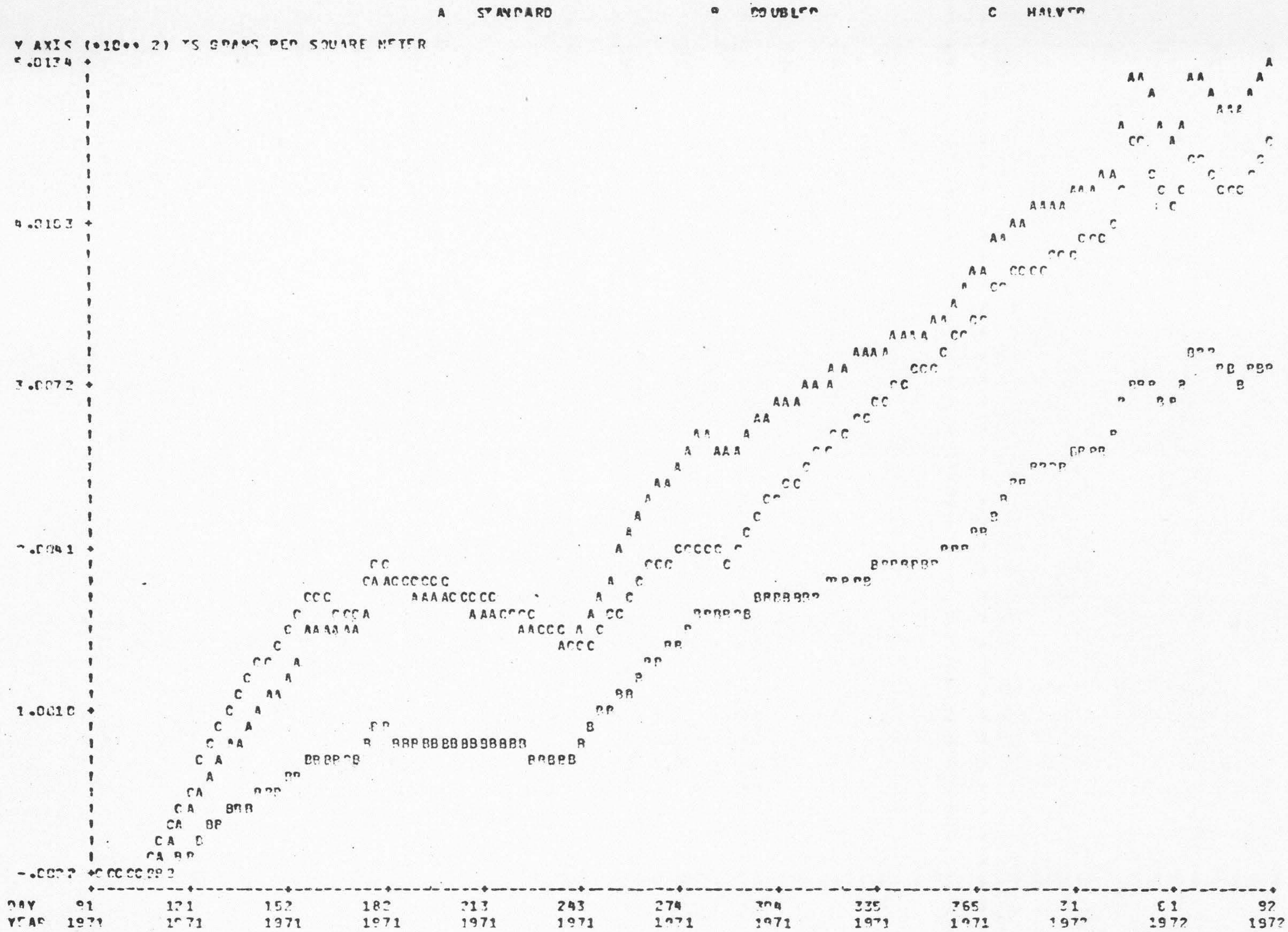

Figure 18. Response of plant productivity to changes of concentrations of dissolved inorganic constituents for the Deep Creek simulation.

Creek light was also a limiting factor. Since suspended inorganic constituents absorb incoming radiation the increased concentration allowed less light to reach the plants which in turn lowered productivity. In the case of Deep Creek, lowering the concentration also leads to lower productivity, thus showing the interrelationships between light, plant growth and nutrient concentration.

This series of graphs (along with the series for radiation differences) is also useful in studying the response of the rest of the ecosystem brought about by a change in the plants, for these two factors directly affect only the primary producers. The parameters for the mountain stream were purposely set so the ecosystem modeled would represent an autotrophic system (Fowler, personal communication) and the response of the system shows the dependence of the rest of the community on the producers (Figures 19, 20, and 21). In contrast the same graphs of the Deep Creek ecosystem (Figures 22, 23, and 24) do not show this dependence to the extent of the mountain stream system. According to the model, unlike the mountain stream, Deep Creek over the year is a heterotrophic system. This was verified because over a one year period gross photosynthesis was greater than community respiration for the mountain stream, while just the opposite was true for Deep Creek.

As was previously mentioned radiation is another factor influencing directly only plants in the model, with all other responses of the system to radiation being indirect and attributable to a change in plants. Figure 25 shows total plant productivity

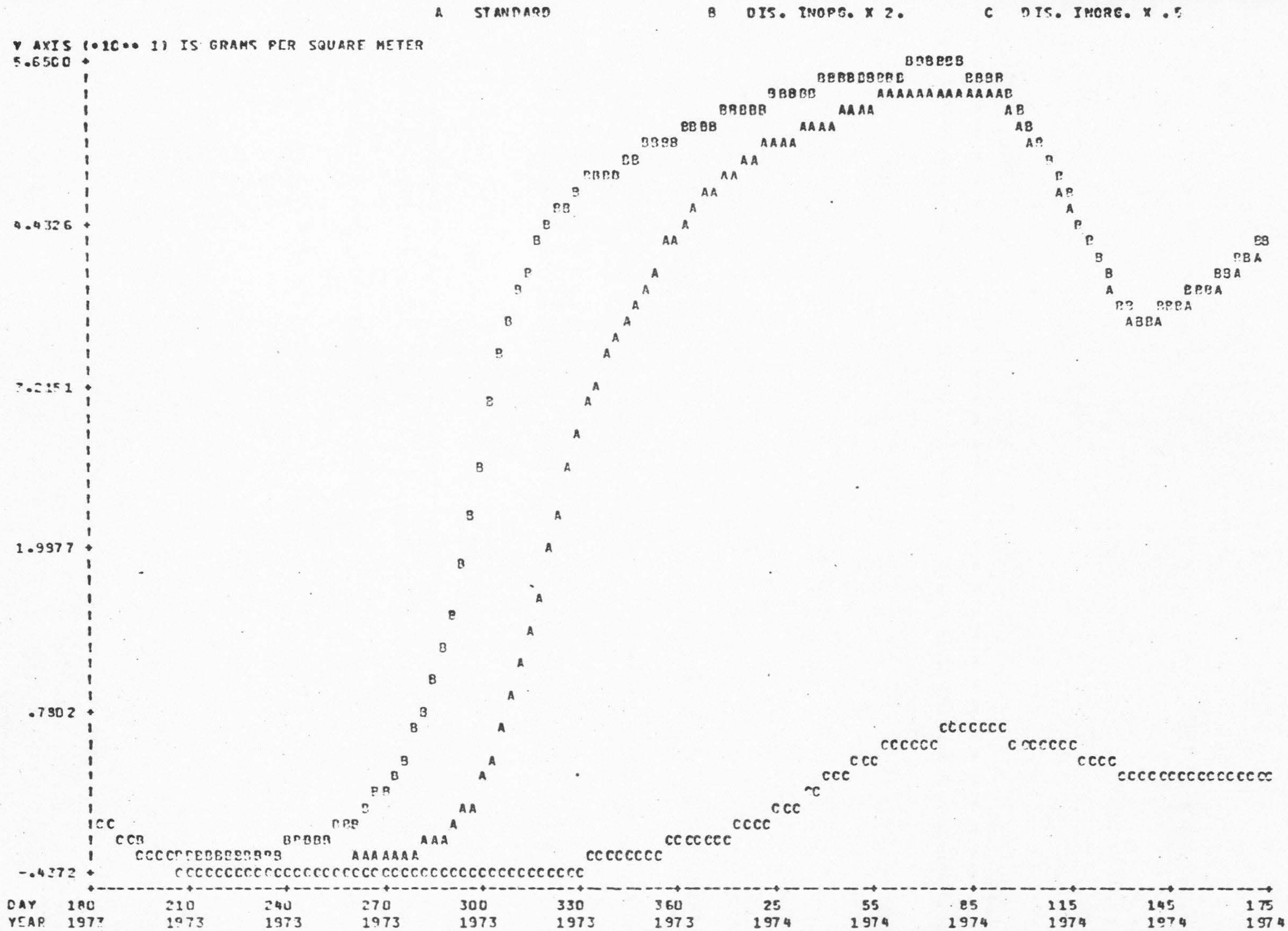

Figure 19. Response of animal productivity to changes of concentrations of dissolved inorganic constituents for the mountain stream simulation.

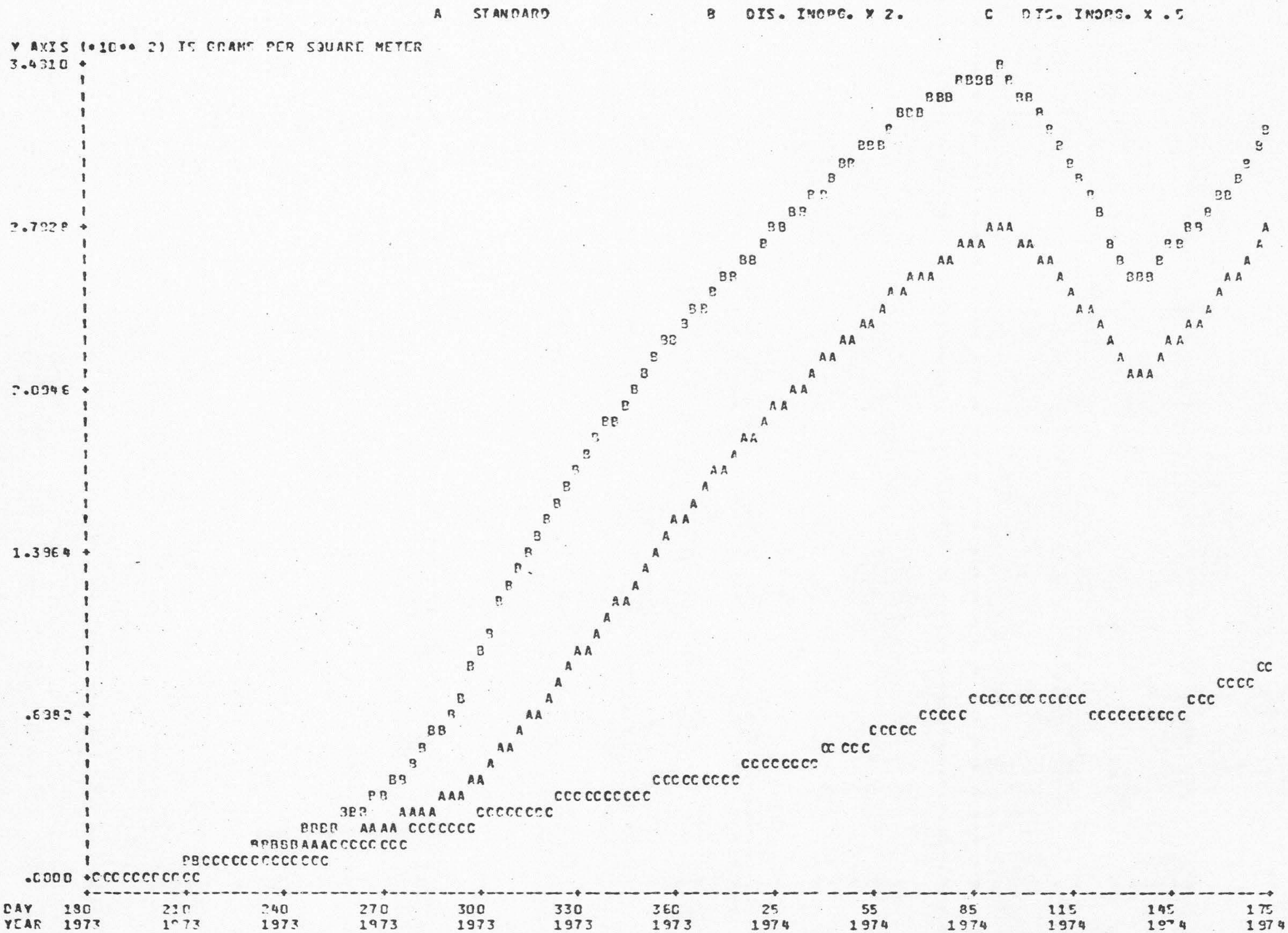

Figure 20. Response of microbial productivity to changes of concentrations of dissolved inorganic constituents for the mountain stream simulation.

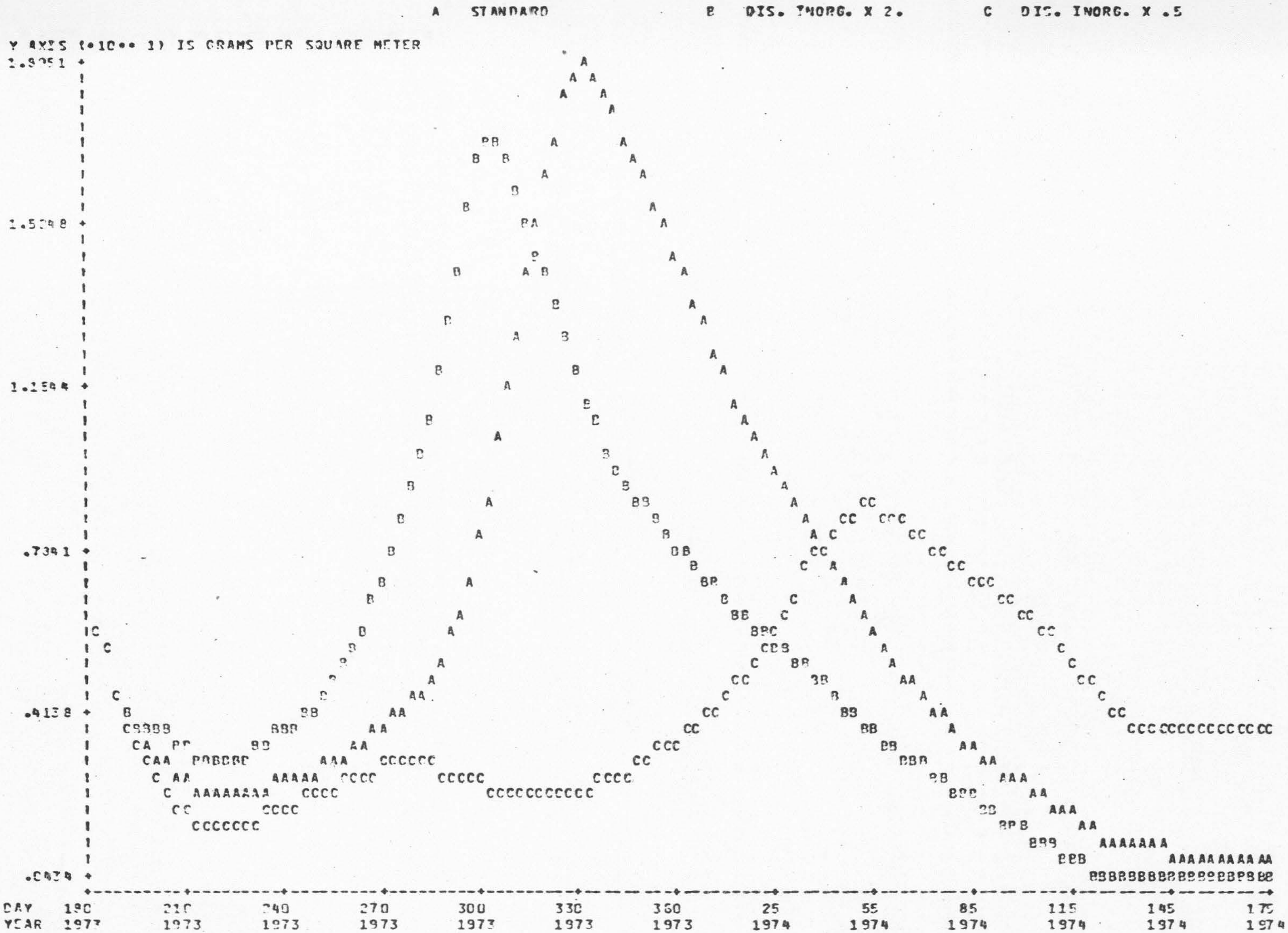

Figure 21. Response of the mass of organic detritus to changes of concentrations of dissolved inorganic constituents for the mountain stream simulation.

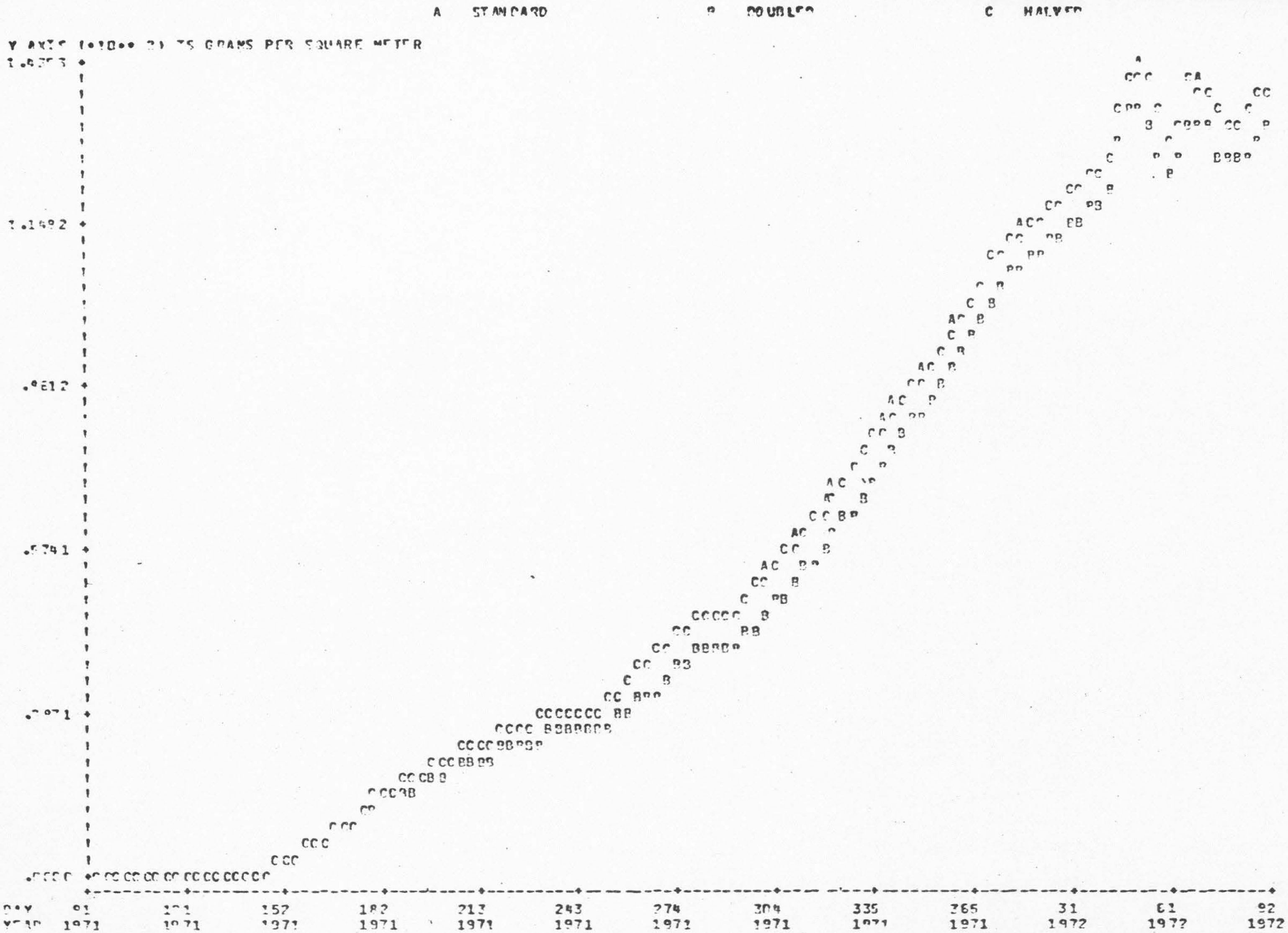

Figure 22. Response of animal productivity to changes of concentrations of dissolved inorganic constituents for the Deep Creek simulation.

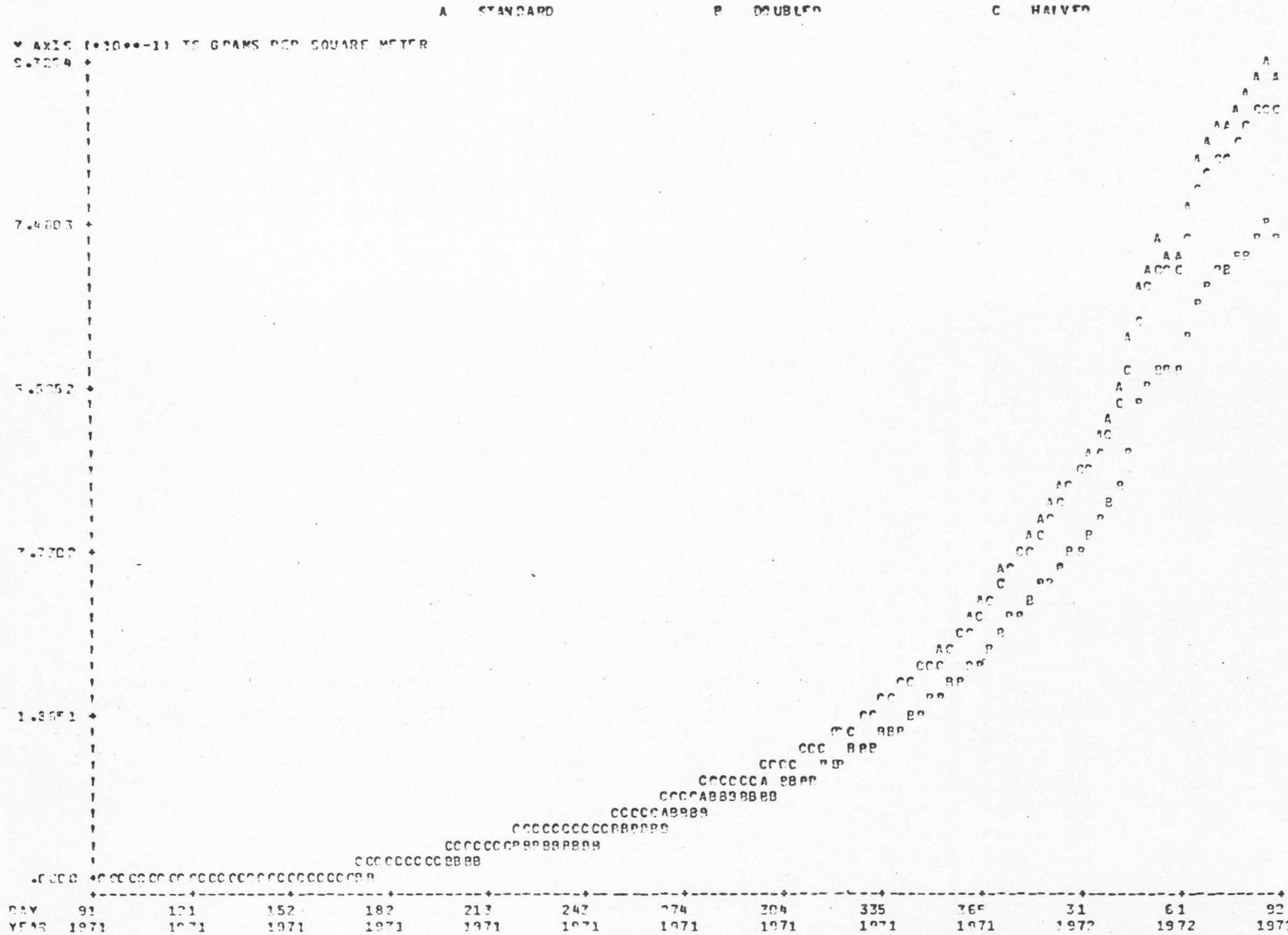

Figure 23. Response of microbial productivity to changes of concentrations of dissolved inorganic constituents for the Deep Creek simulation.

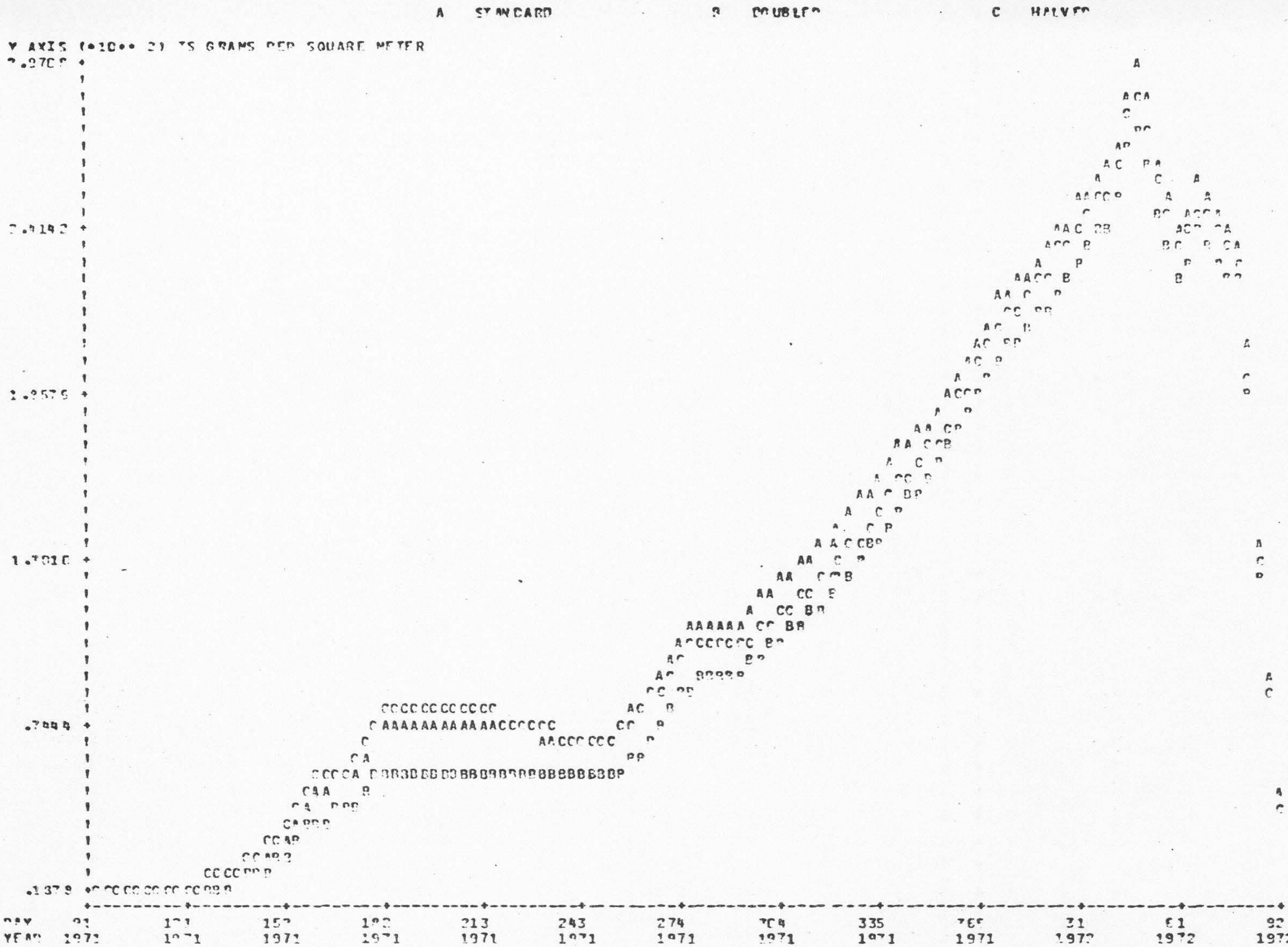

Figure 24. Response of the mass of organic detritus to changes of concentrations of dissolved inorganic constituents for the Deep Creek simulation.

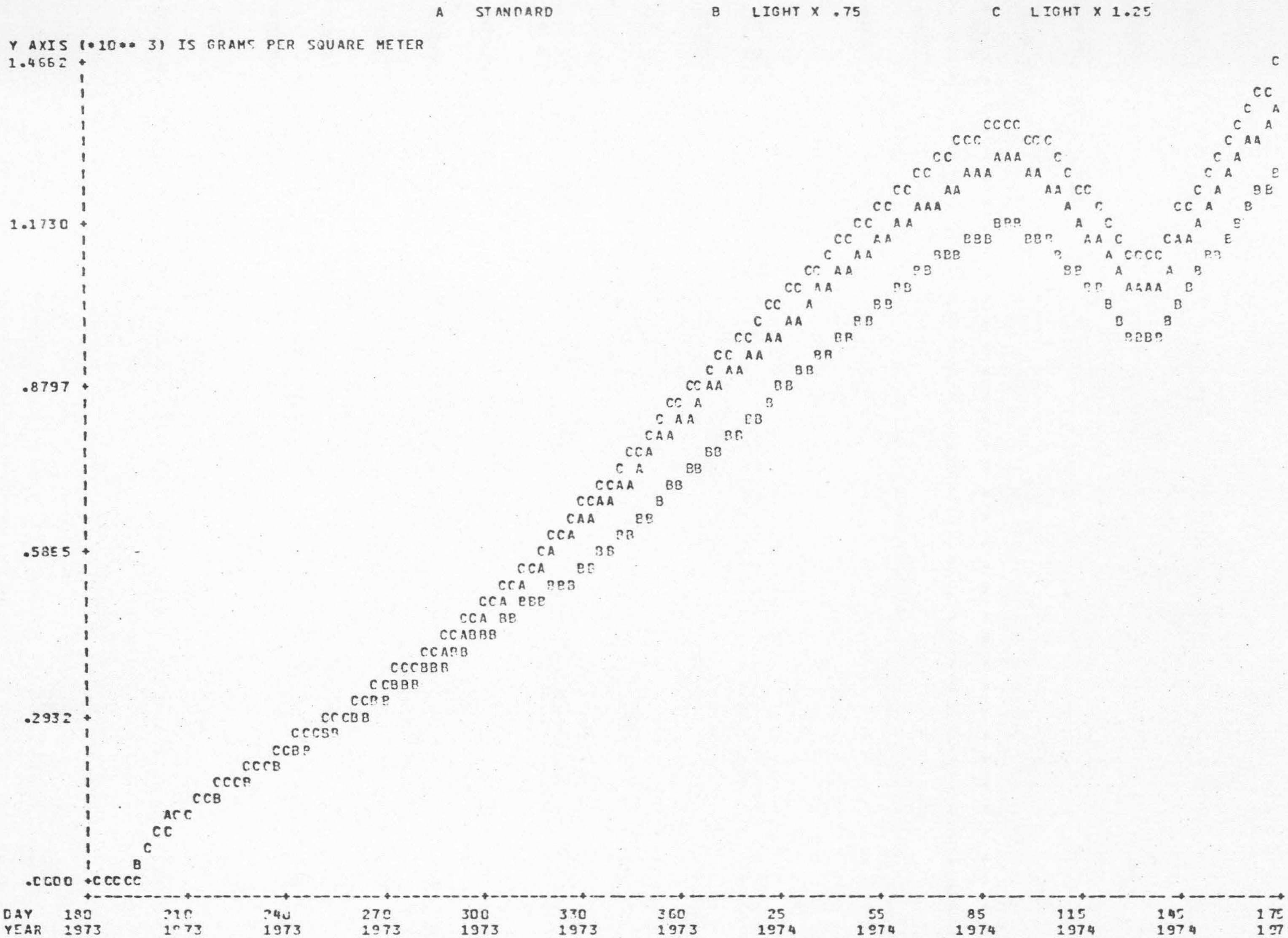

Figure 25. Response of plant productivity to changes of radiation for the mountain stream simulation.

for the mountain stream not to be greatly affected by different radiation intensities, but by looking at individual plants we see major differences which have been "averaged out" for total plant net productivity. Figure 26 shows that lower radiation conditions were more favorable for blue green algae total productivity, while just the reverse was true for green algae as shown in Figure 27. The response of total animal productivity (growth) is also not very great (Figure 28) but as for the plants a portion of the differences of particular animal species or cohorts are averaged and not seen.

In the Deep Creek graph series even less variability occurred in plant productivity (Figure 29) as a function of the change of light. This seems to be in direct contradiction to the results of the series on changes in dissolved inorganic constituents, which showed radiation as being limiting. This apparent anomaly can be explained by calculating the amount of radiation actually reaching the stream bottom. Radiation passing through water is absorbed by the water itself, by the plants above the plant in question, organic and inorganic detritus as well as the dissolved constituents. By using the parameter set for Deep Creek and the state variables on the last day of simulation, radiation reaching the bottom of the stream for the standard run was 14.5 kilocalories per square meter per hour. The decrease in radiation (25 percent)

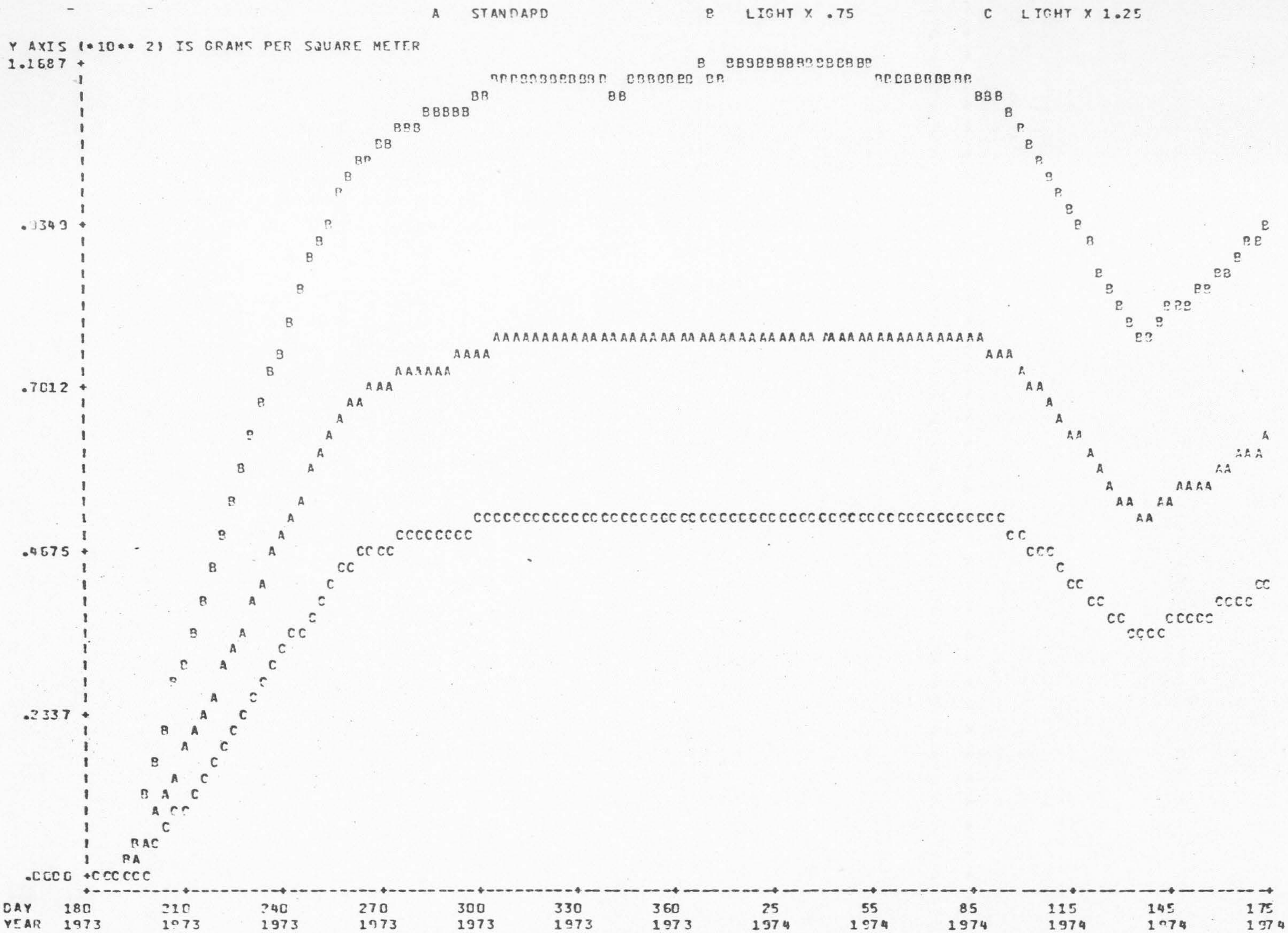

Figure 26. Response of blue-green algae productivity to changes of radiation for the mountain stream simulation.

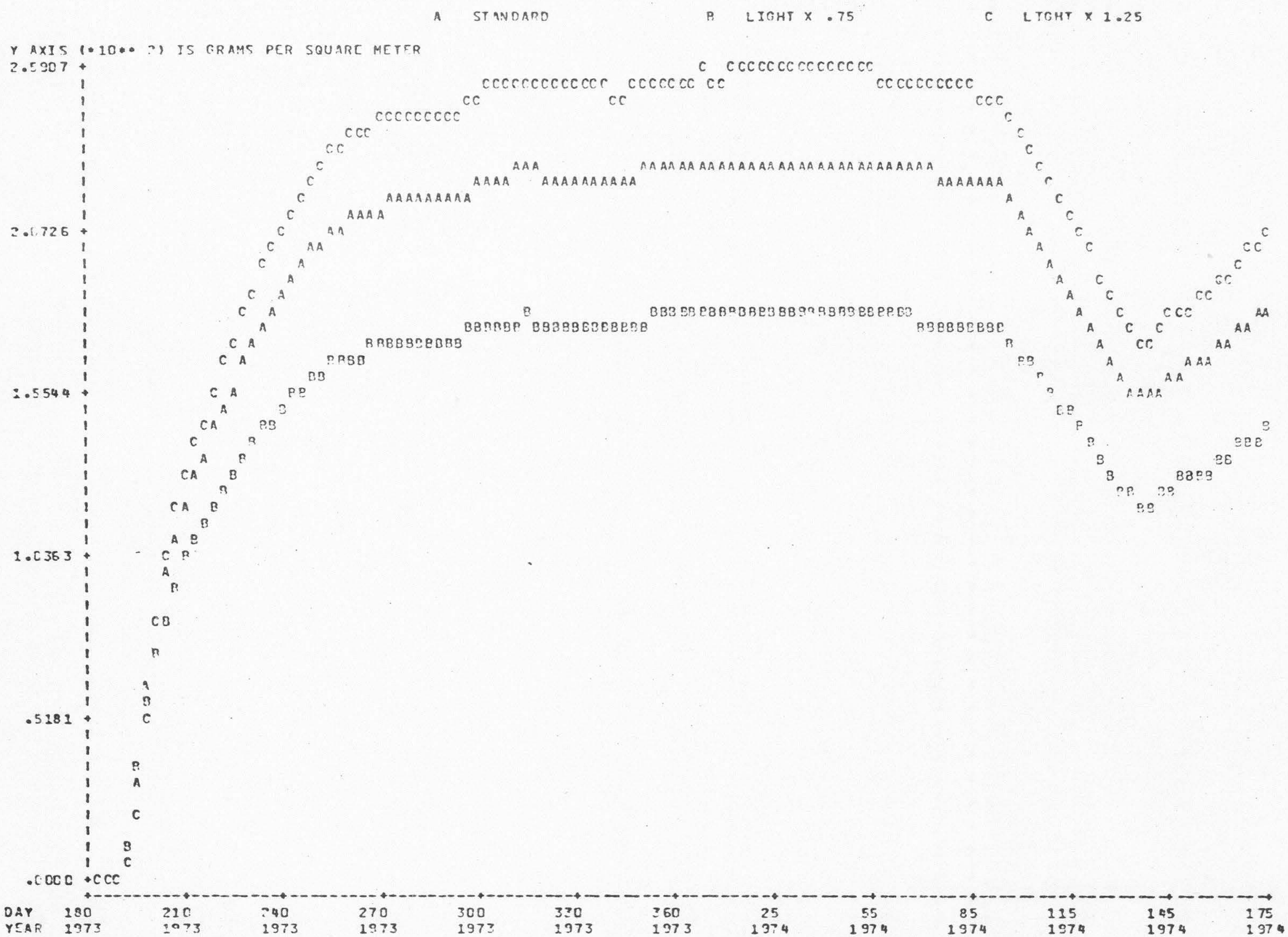

Figure 27. Response of green algae productivity to changes of radiation for the mountain stream simulation.

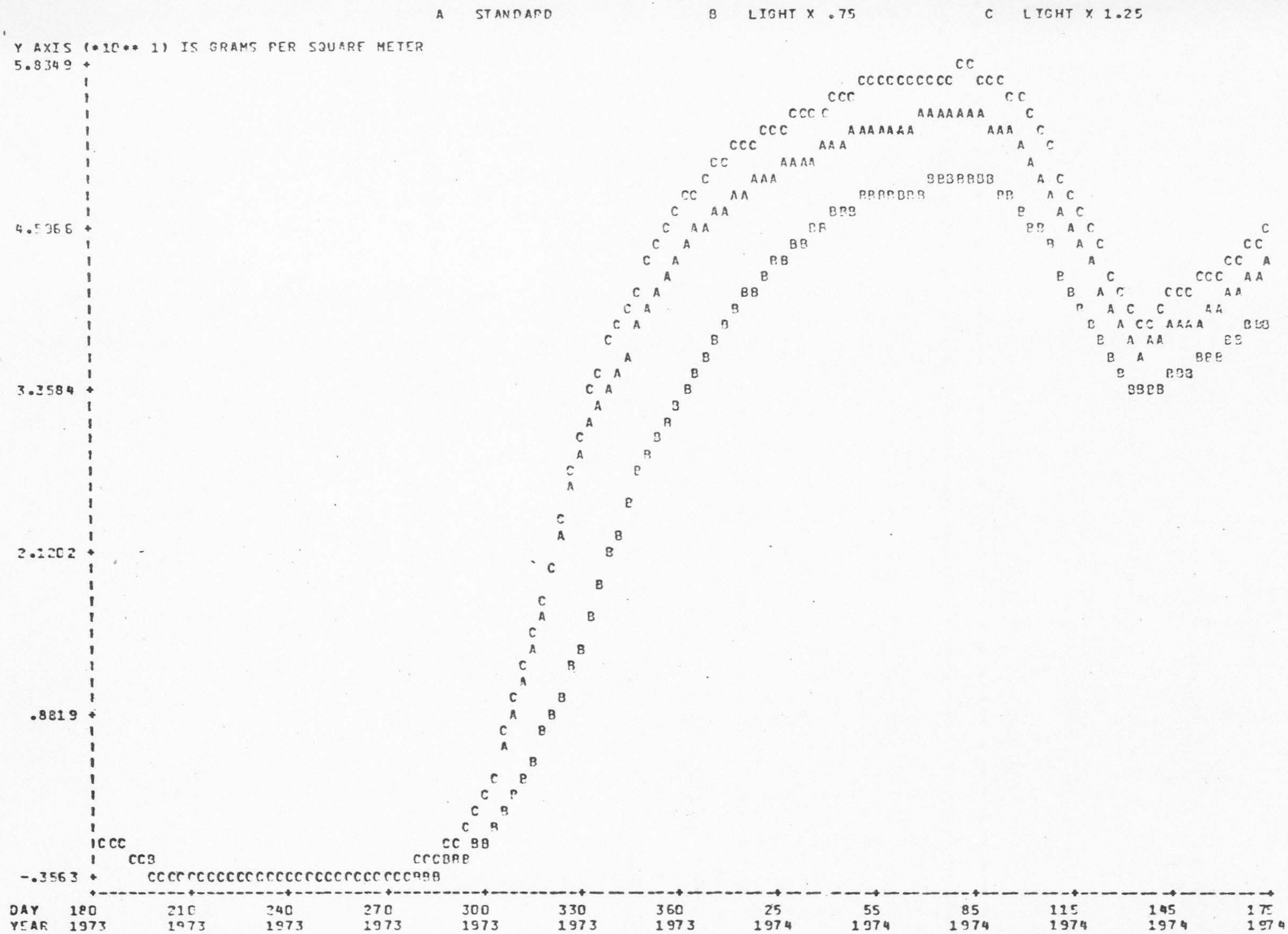

Figure 28. Response of animal productivity to changes of radiation for the mountain stream simulation.

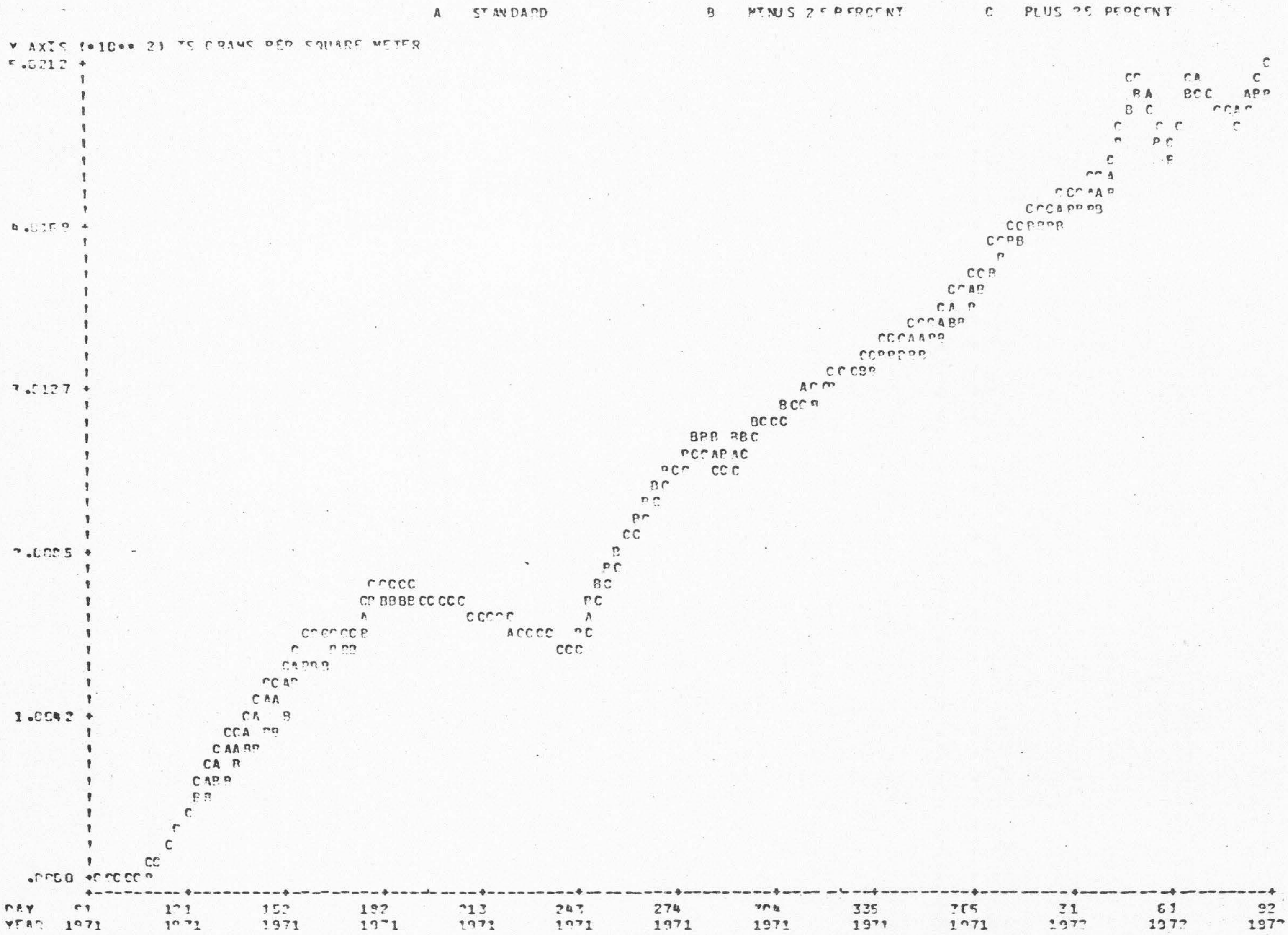

Figure 29. Response of plant productivity to changes of radiation for the Deep Creek simulation.

resulted in 10.9 kilocalories per square meter per hour reaching the bottom, while doubling the concentration of dissolved inorganic constituents allowed only 3.7 kilocalories per square meter per hour to reach the bottom. Although the decrease in radiation reaching the stream bottom is unrealistic (being caused by a faulty parmeter setting), the argument is still valid.

In the case of radiation absorption by plants a problem arises because at present all the plants above the one in question absorb radiation. This occurs because plants are handled as though they grow as a sheet or continuum across the stream, which is usually not the case as pointed out by Hynes (1970).

In the Deep Creek graph sets, the representation for biomass of some invertebrates had an unexplainable drop on day 44 of 1972. This can be seen in Figure 30 for Simulium argus, a black fly. The same was also true for Hydropsyche occidentalis, a caddisfly, and to a lesser extent to Baetis tricaudatus and Hyallela azteca, a mayfly and amphipod, respectively. By rerunning the simulation and studying the dynamics of these animals it was seen that the decline was due mainly to the behavior function (from Appendix D):

$$Z_{53} = \min [1., \{ P_{58_h} P_{59_h}^{(P_{25_h}/Z_{25_h})}] \quad (1)$$

where:

Z_{53} = The fraction of the animal cohort under consideration which leaves the ecosystem as a function of the carrying capacity.

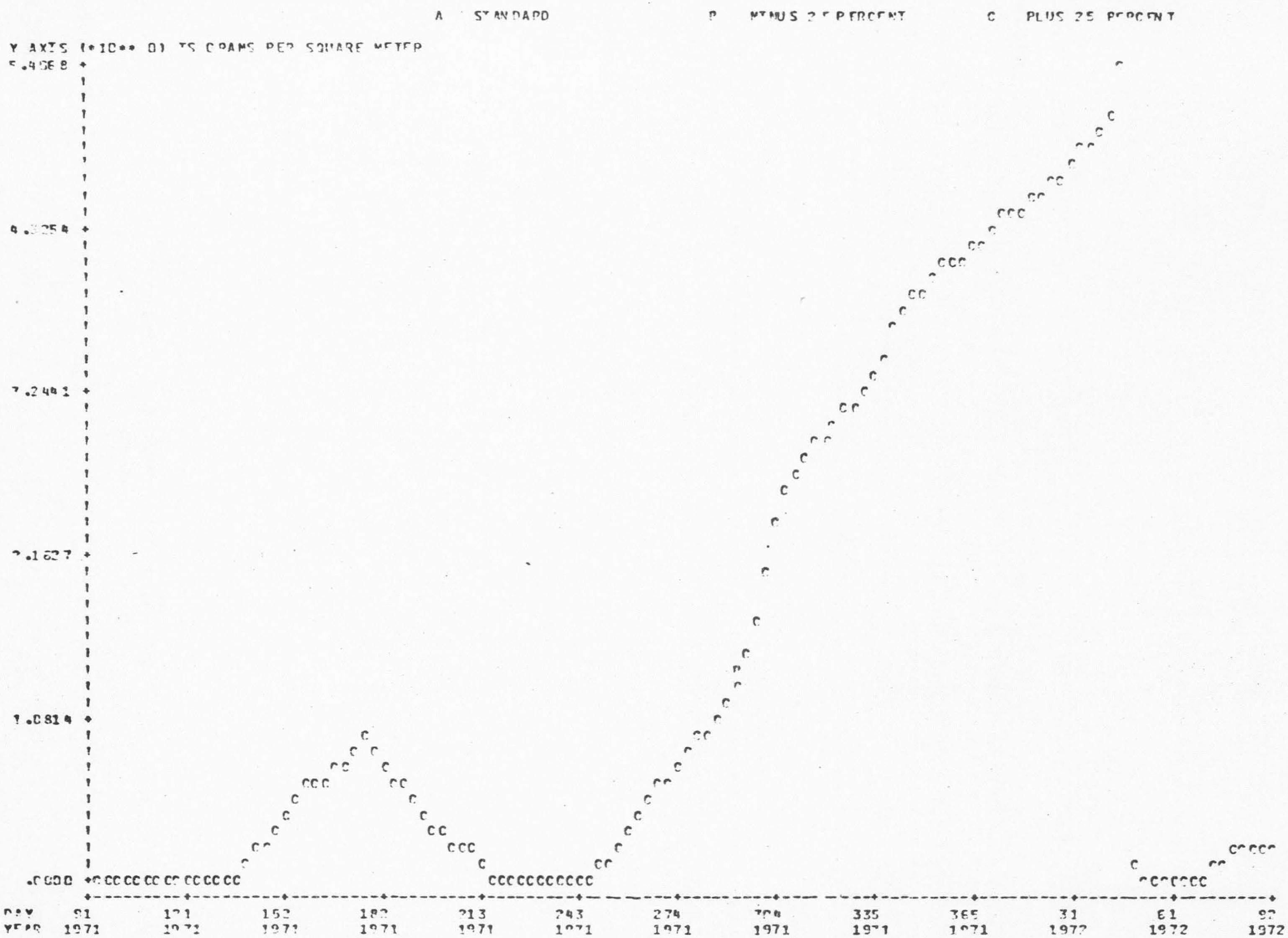

Figure 30. Response of the biomass of Simulium argus to changes of radiation for the Deep Creek simulation.

P_{58_h} and P_{59_h} are constants.

P_{25_h}/Z_{25_h} = the ratio of the maximum amount of food the h'th cohort can injest in a time period to the amount actually injested based on the food supplies available.

The ratio P_{25_h}/Z_{25_h} was much higher than was expected, and since P_{25_h} is a constant, Z_{25_h} now becomes the figure of interest.

$$Z_{25_h} = P_{25_h} \{1. - \exp(-P_{26_h} Z_{8_h})\} \qquad (2)$$

where:

Z_{25_h} = the total possible intake for a unit of biomass for the h'th animal group.

P_{25_h} = the maximum possible intake of the h'th animal cohort in grams per gram.

P_{26_h} = a constant determining curvature in a graph of the equation.

$Z_{8_h} = Z_7/X_{81}$

and

Z_7 = the sum of the weighted foods of the animal group currently under consideration.

X_{81} = the area of the ecosystem

Z_7 is calculated by multiplying a preference-availability factor for a particular food by the amount of that food and then summing over all foods. The problem is associated with this step, for if a food source happens to be entering the system with upstream flow, the total amount entering the system is used in the calculation.

On day 44 in 1972 the flow was drastically reduced which in turn lowered the amount of food for suspended detritus feeders. This lowered Z_7 which lowered Z_{8_h} which in turn lowered Z_{25_h}.

Feeding in the model is based in part on the components of predation as set out by Leopold (1933) and elaborated by Holling (1959), that being prey and predator density. In calculating the amount of food available to a consumer the model does not necessarily take into account the density of the food source. Instead the total amount of the food available in a time period is used in the calculations, a problem that should be resolved, for food carried by moving water plays an important role as a food source (Hynes, 1970).

The effect of temperature on state variables also was studied. Although the change for different driving variables was not constant, it appears as though a temperature perturbation affects the system to a greater degree than does a change in other driving variables. This may be explained by the number of processes affected by temperature. For the same reason it becomes extremely difficult to explain changes of state through time.

One variable that showed what was thought to be abnormal behavior was total productivity for Rhinichthys osculus (Western speckled dace) at Deep Creek as shown in Figure 31. The standard run shows abnormally fast growth starting near day 182, 1971 which corresponds to egg deposition, and another burst of growth starting at day 1, 1972. This second burst of growth corresponds to the time when juveniles become mature fish, which

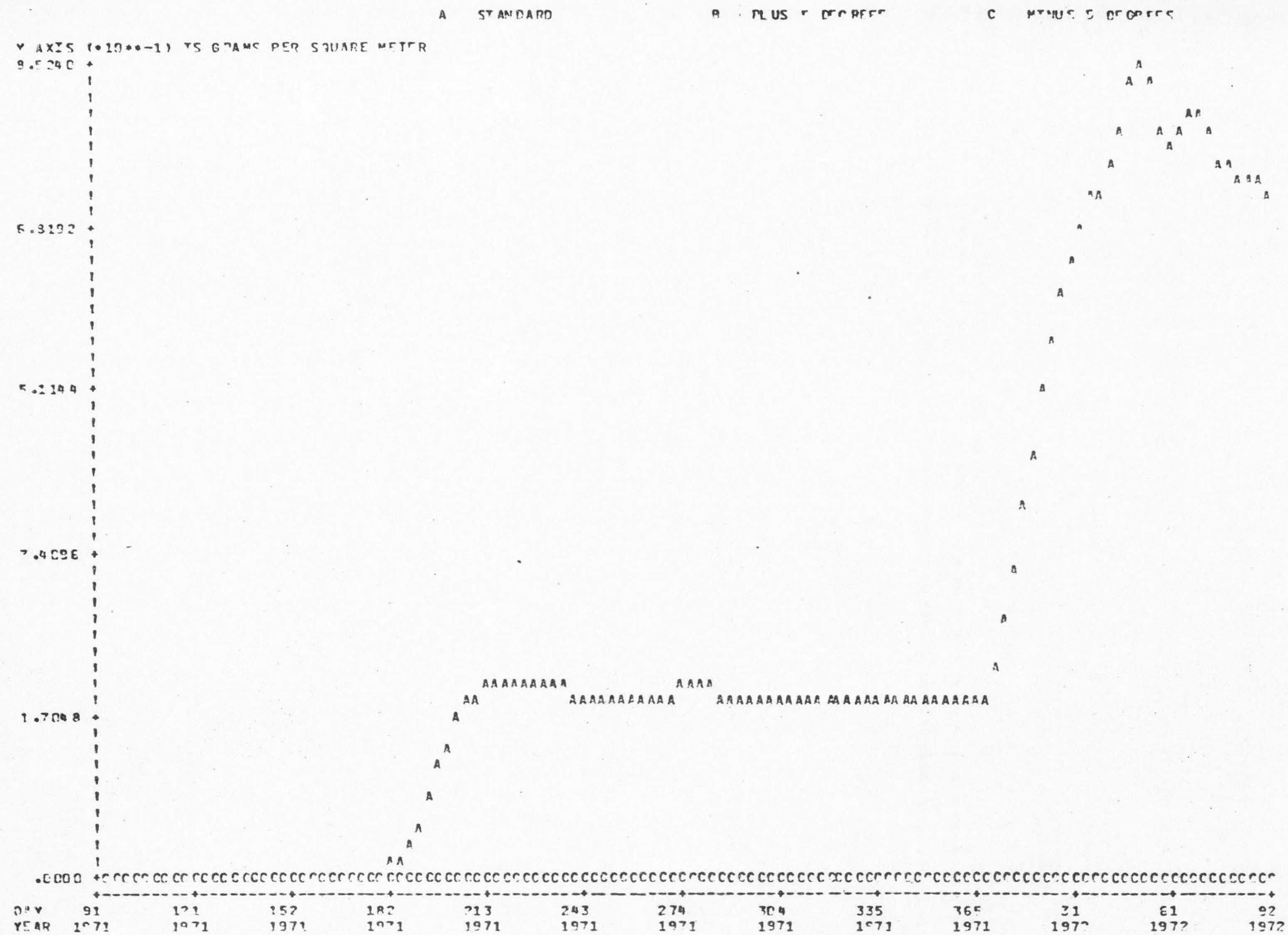

Figure 31. Response of productivity of Rhinichthys osculus to changes of temperature for the Deep Creek simulation.

is arbitrarily set on January 1. In both cases growth occurs until an upper limit set for the species is reached. This growth appears to be much faster than occurs in a natural system. Even more disturbing is the difference in productivity attributable to a temperature change of either plus or minus five degrees. This is due to the function for egg deposition, which has upper and lower threshold limits with the temperature falling outside of these threshold limits. Both of the problems mentioned could be caused by a faulty parameter set, but nevertheless these functions should be studied.

Temperature values are read at the same time as blocks of data representing inflowing materials from upstream, which in the case of Deep Creek was four times per year and for the mountain stream twelve times. Since the ecosystem noticeably responds to a temperature change, temperature should be tracked more accurately in the model. Figures 32, 33, 34, and 35 show the response of the main trophic levels and detritus to a temperature change at Deep Creek. Similarly, graphs 36, 37, 38, and 39 show the response of the mountain stream.

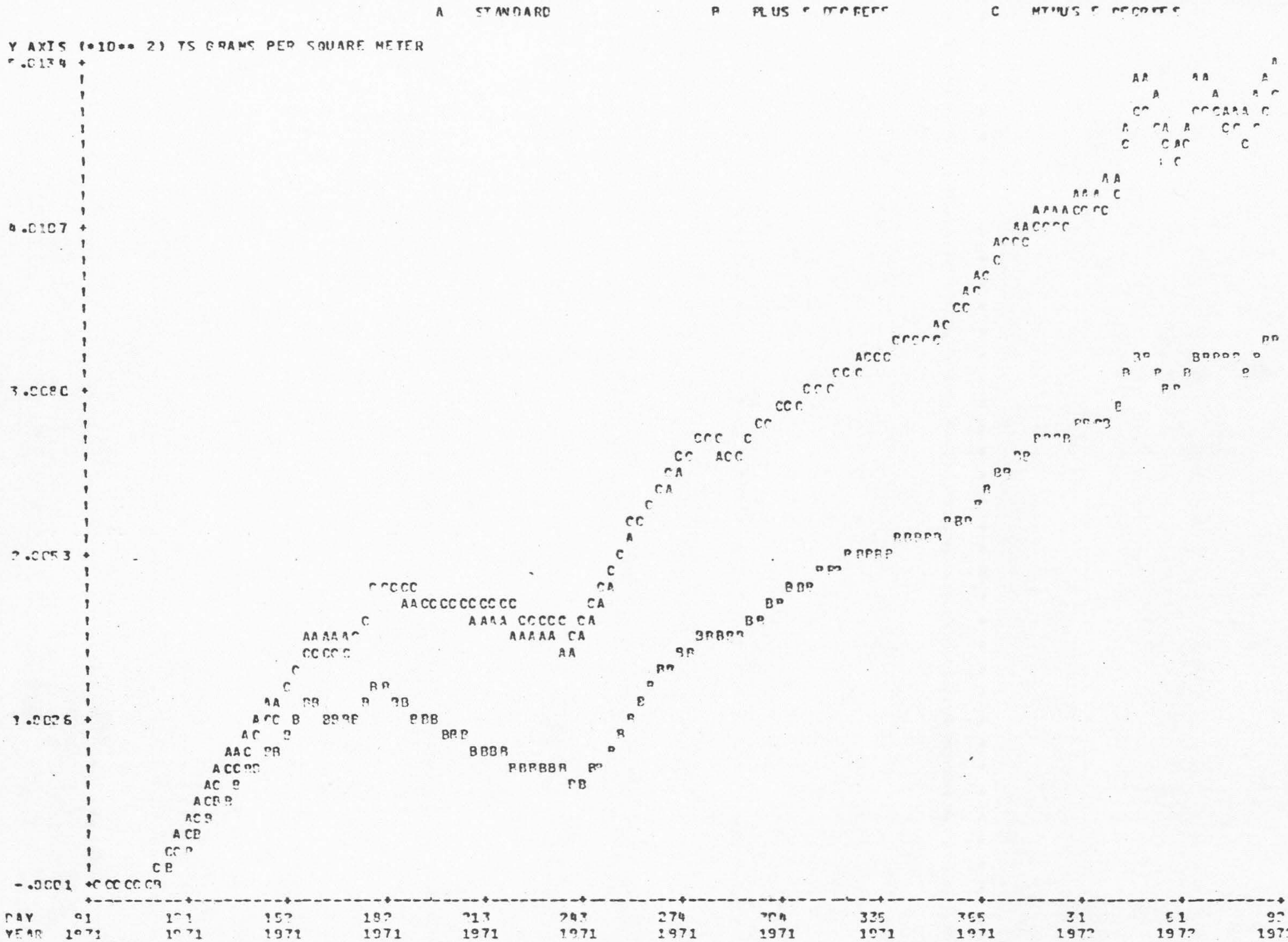

Figure 32. Response of plant productivity to changes of temperature for the Deep Creek simulation.

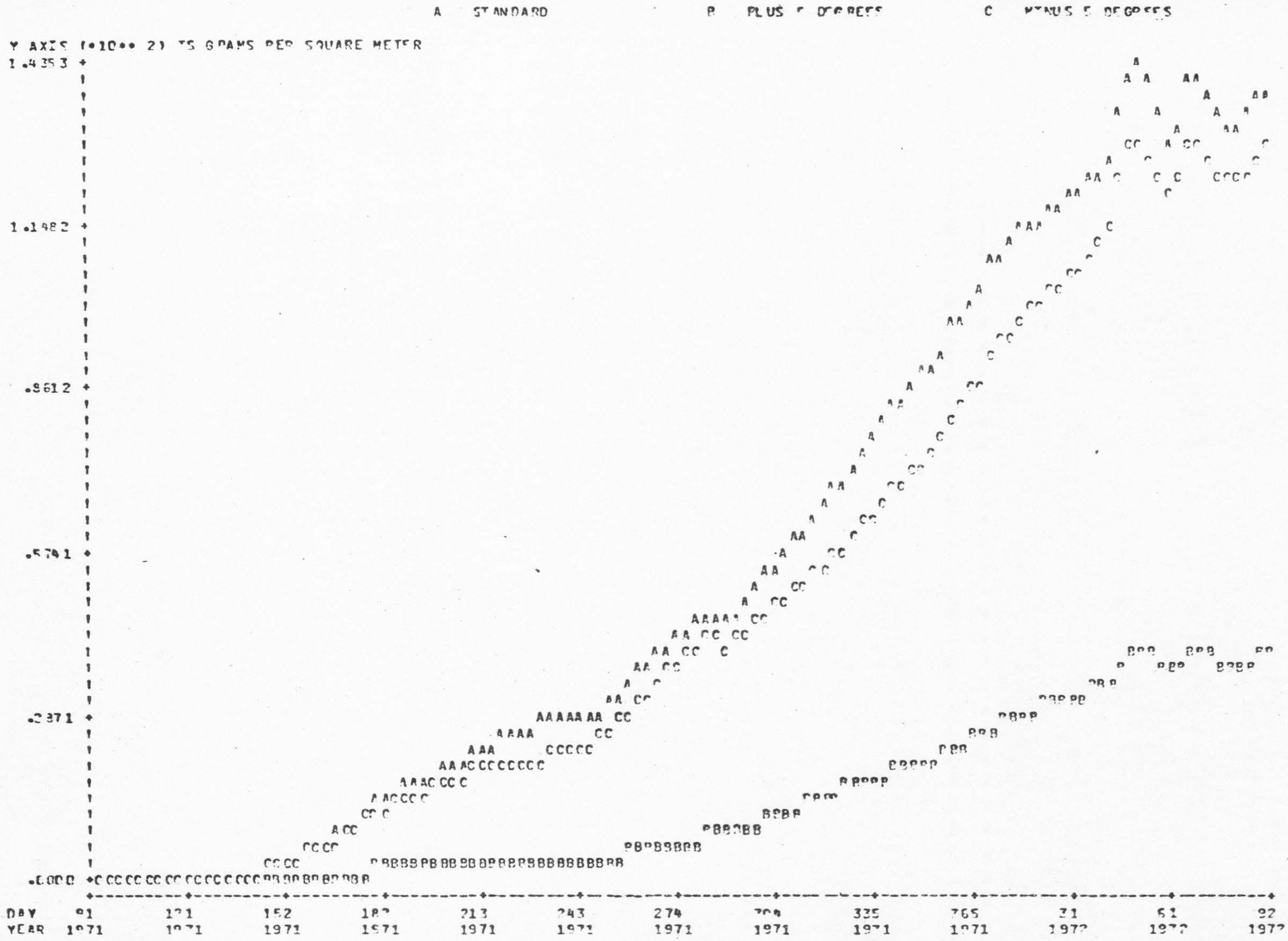

Figure 33. Response of animal productivity to changes of temperature for the Deep Creek simulation.

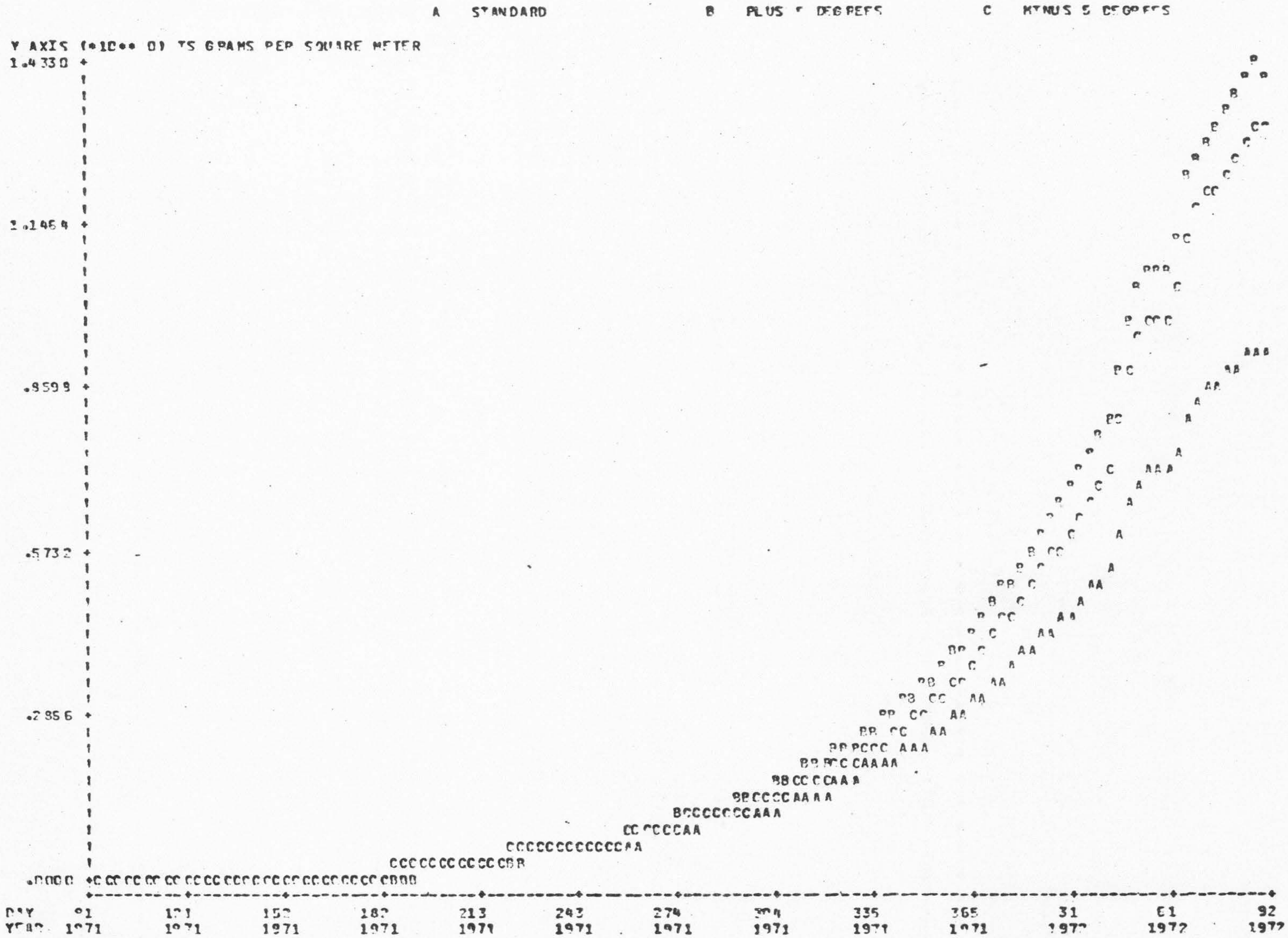

Figure 34. Response of microorganism productivity to changes of temperature for the Deep Creek simulation.

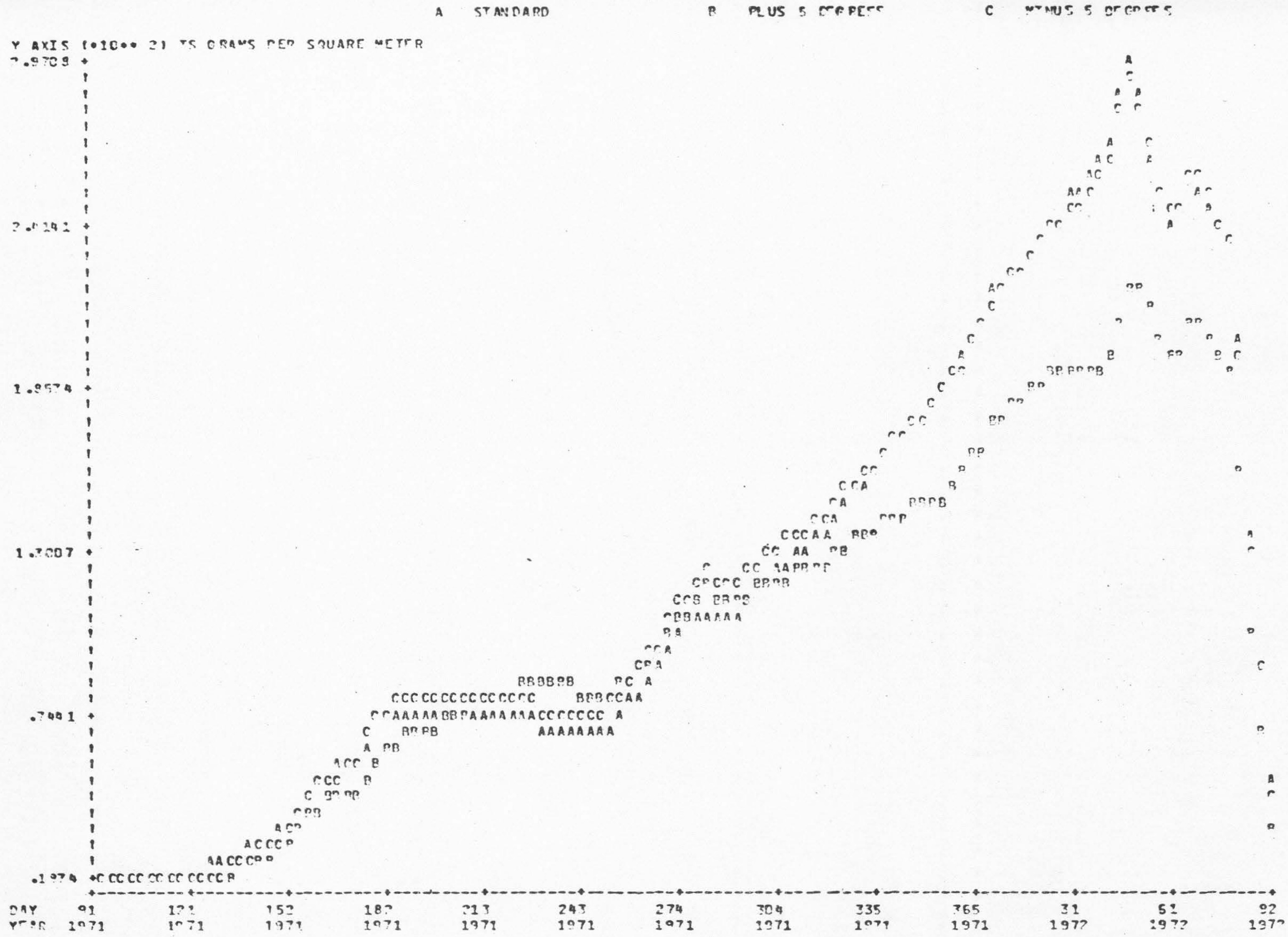

Figure 35. Response of the mass of organic litter to changes of temperature for the Deep Creek simulation.

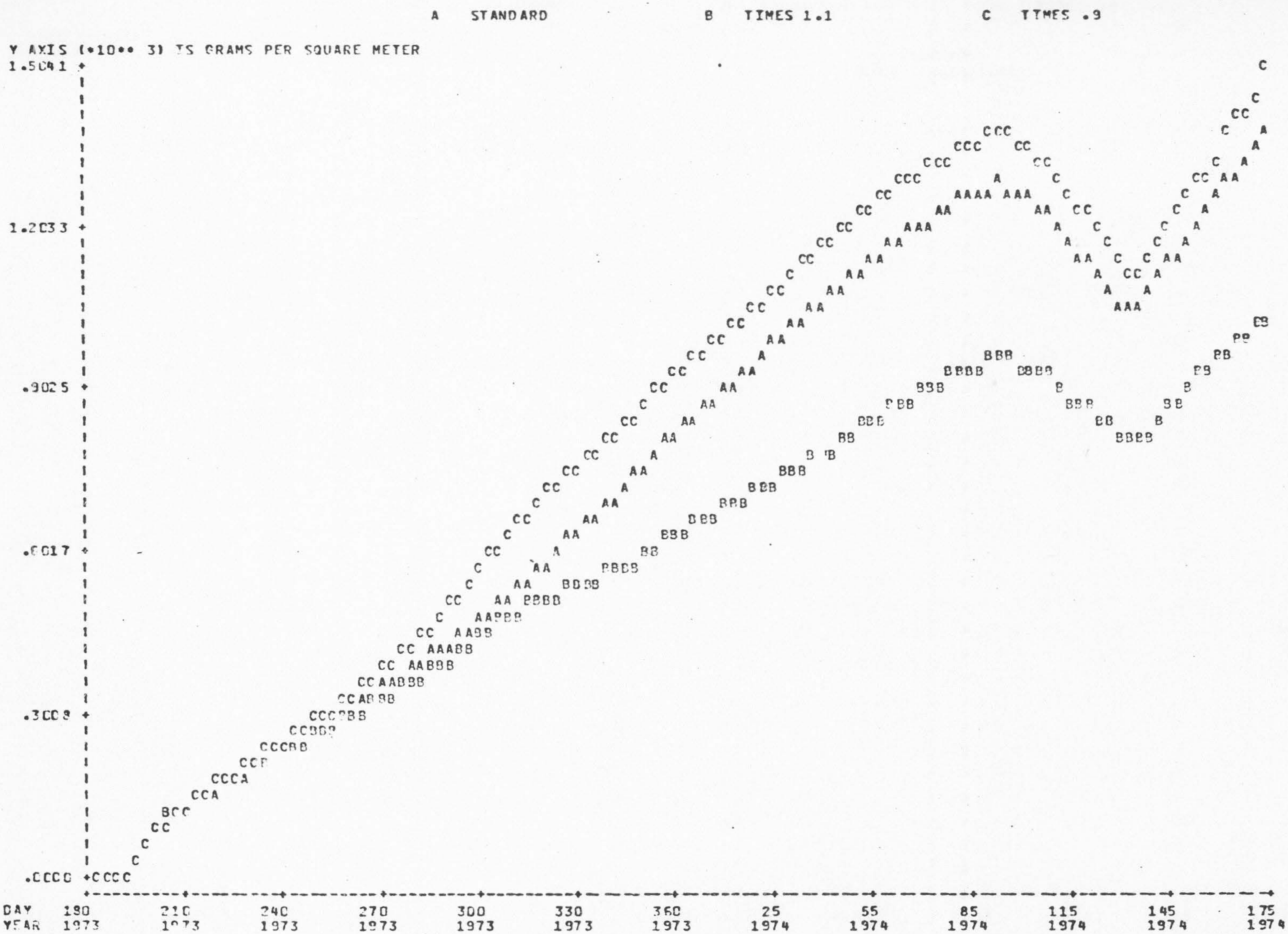

Figure 36. Response of plant productivity to changes of temperature for the mountain stream simulation.

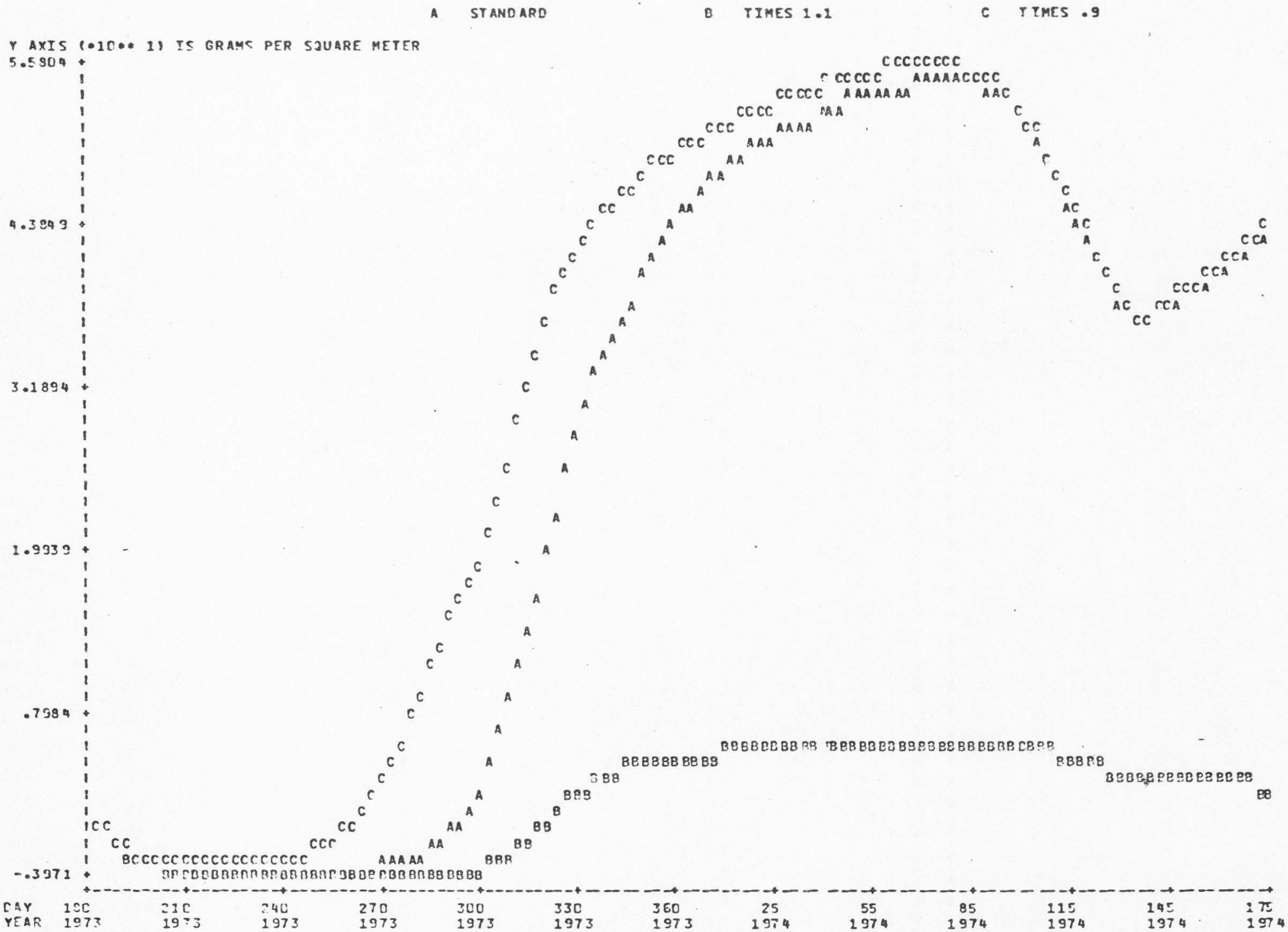

Figure 37. Response of animal productivity to changes of temperature for the mountain stream simulation.

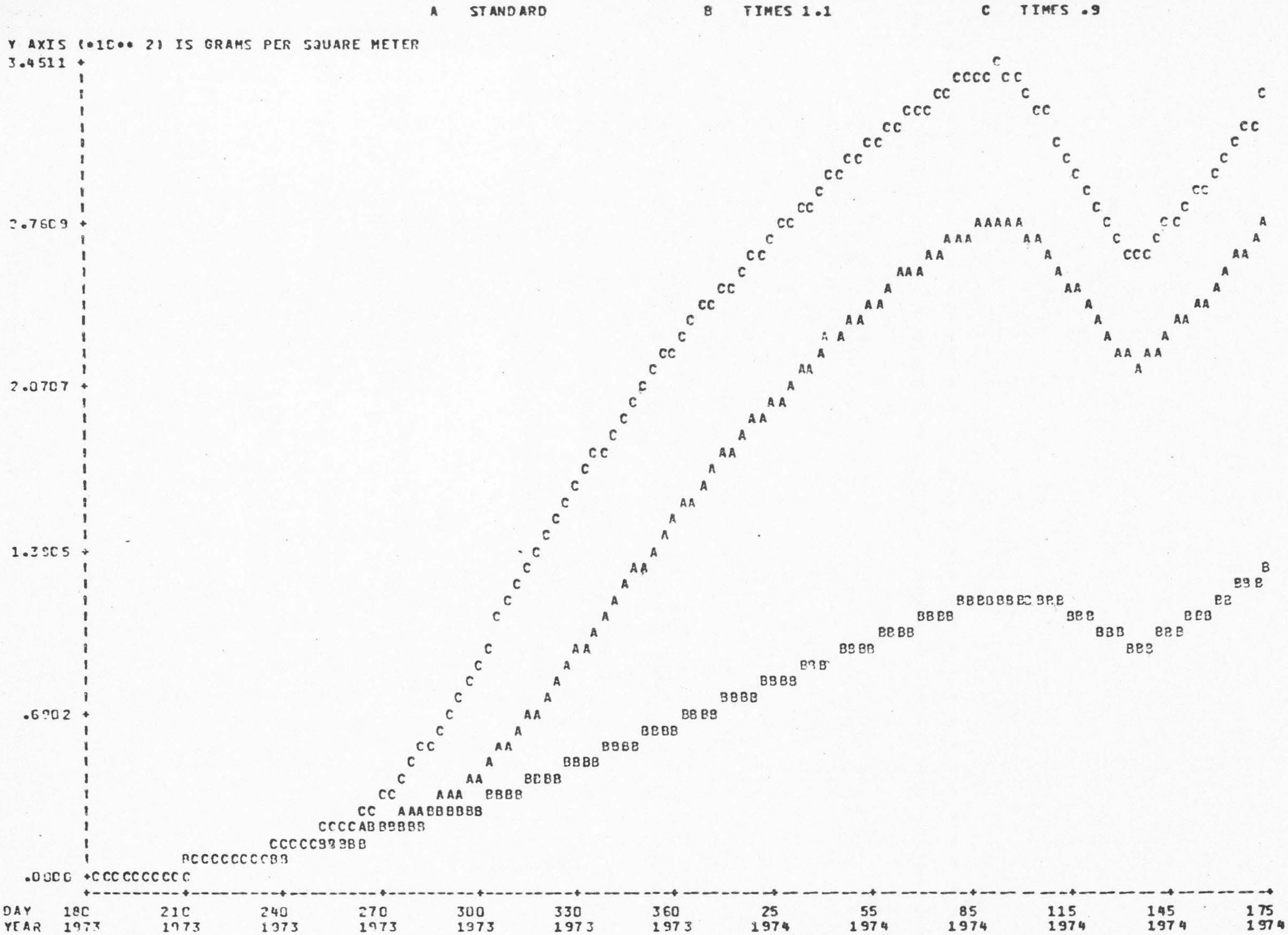

Figure 38. Response of microorganism productivity to changes of temperature for the mountain stream simulation.

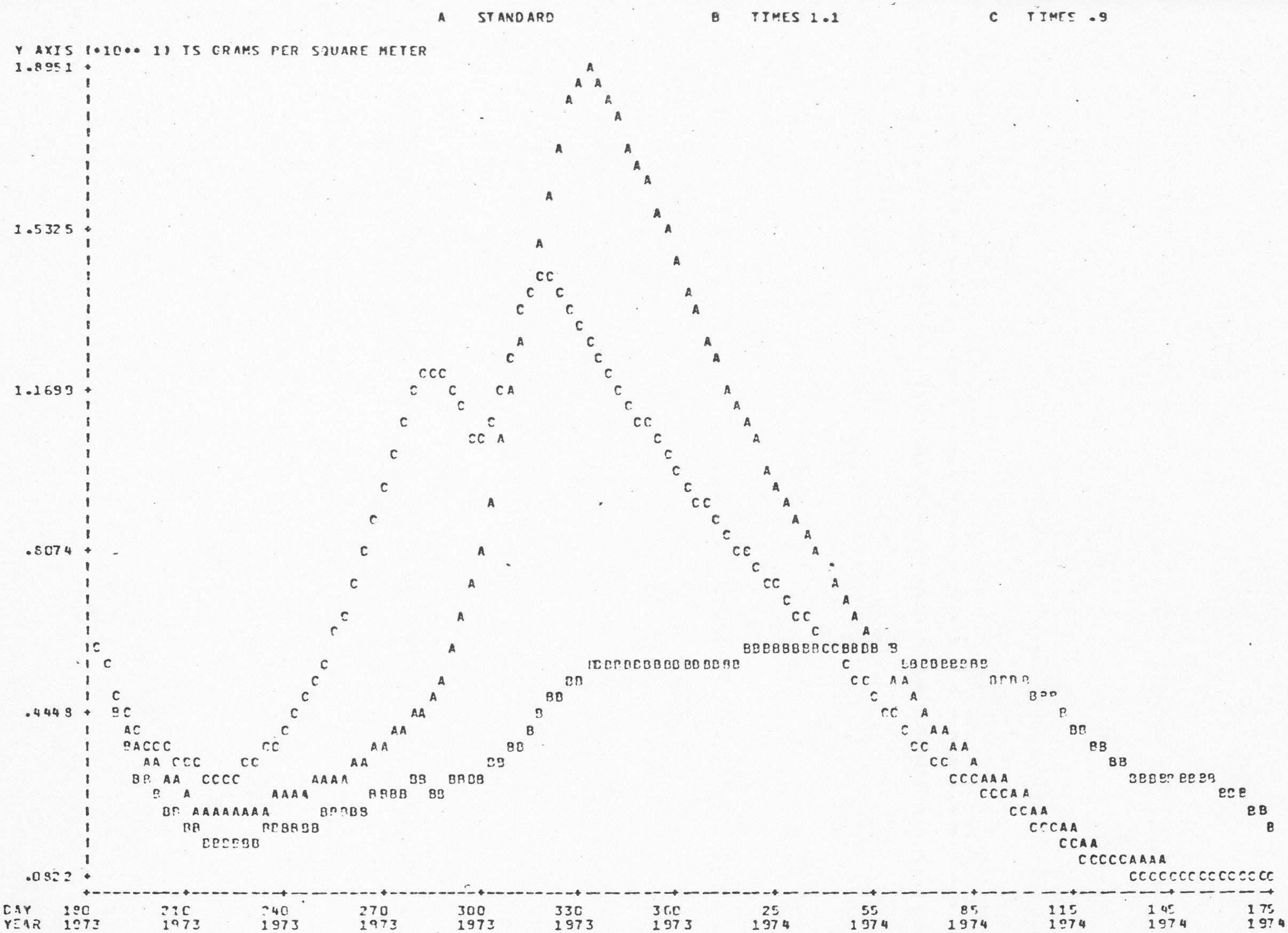

Figure 39. Response of the mass of organic litter to changes of temperature for the mountain stream simulation.

CONCLUSIONS AND RECOMMENDATIONS

1. The model as presented has the potential of being a theoretical as well as a managerial tool. Its theoretical value is its use in studying the dynamics of the total ecosystem through time. This is possible because the model tracks through time all exchanges of constituents between the ecosystem and the surrounding biosphere, the mass of all components of the system, and the productivity of trophic levels, either in daily increments or total productivity for the entire simulation period. In addition all the fluxes for particular levels may be followed through time. As a managerial tool it could be used as presented in the thesis, that being to study the change of the ecosystem given certain perturbations.

2. Exploratory sensitivity analysis is a valid means of examining the response of the model over a range of driving variables. The graphs presented show how the model has been analyzed in this manner with the results aiding in suggesting revisions for parts of the structure of the model. In addition, exploratory sensitivity analysis has helped in showing faulty parameters used for the simulations.

3. A better means of modeling changes that occur as the discharge changes should be sought. An increased discharge causes the size of the ecosystem to change, covering greater areas of the stream bottom. The opposite occurs as the discharge decreases.

When the size of the ecosystem increases or decreases state variables (e.g., plants and detritus) may be covered or uncovered by water, a process which is not now modeled. Since the area of a stream which may be wetted or dried is in itself a very complex ecosystem and its modeling not within present objectives, I recommend simply adding or subtracting a value equal to the average value for non-motile constituents occurring in the ecosystem as depth increases or decreases.

4. Work should be undertaken to model the heterogeneity found in a stream ecosystem. In the model a plant is handled as a solid sheet across the stream, absorbing radiation and thus shading all plants beneath it. In many instances in a stream system this is not the case, as pointed out by Hynes (1972). In the model problems then arise, because plants occurring below other plants may be shaded to a much greater extent than is found in the stream being modeled.

5. It has been pointed out in many studies and reviewed by Hynes (1972) that the velocity of water and the type of substratum are important factors regulating the occurrence and distribution of much of the biota in streams. At present these are not handled in the model, and steps should be undertaken to model these phenomena.

6. A better means of providing more continuous temperature input should be incorporated into the model. It has been pointed out that the ecosystem is affected more by a change in temperature than by other driving variable changes, and that at present, only a few measured temperature values are read as data. By tracking

temperature more closely the model should have more predictive value. I recommend reading daily value for temperature.

7. Any animal in the system may ingest any food within or passing through the ecosystem. Foods may be any animal, plant, decomposer or detritus category, with ingestion being controlled by a preference-availability factor and the amount of the foods available. I believe the total amount of food passing through the ecosystem should not regulate the amount of food ingested by a consumer. Given otherwise identical streams a consumer (in the model) in a larger stream would be allowed to ingest more than a similar consumer in a smaller stream. Although food passing in the immediate vicinity of an invertebrate may affect the amount ingested, I do not believe food meters away from an invertebrate affects its ingestion, a problem that should be corrected. By dividing the foods entering the ecosystem by the cross sectional area of the stream, this problem should be alleviated.

8. The processes modeled involving animal growth should be examined for their realism. Although the problem may be attributable to a faulty parameter set, it was pointed out that growth of the western speckled dace (Figure 31) was thoughtto be abnormally fast, a problem also occurring with other animal representatives of both Deep Creek and the mountain stream.

9. Discontinuous functions should be examined for their realism. As was seen in Figure 31 a temperature change caused egg deposition to be completely halted. This occurred because of the discontinuous nature of the function, a possible problem that should be further studied.

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APPENDIXES

Appendix A

Initial Values for State Variables Used for the Mountain Stream Simulation

TEMPLE FORK (LOGAN RIVER), LEVEL II STREAM SYSTEM

INITIAL REPORT ON JUNE 29 1973

MEAN DEPTH	MEAN FLOW	MEAN WIDTH	MEAN VELOCITY	TOTAL VOLUME	AREA
.44 METERS	.575 CUM/S	2.77 METERS	.692 MPS	16.64CU.M	55.34 SQ. M.

THE FOLLOWING CONSTITUENTS ARE ORGANIC AND ARE PRINTED IN GRAMS (OR KCAL.) PER SQ. METER, AVERAGED OVER 20.0 METERS OF STREAM.

CONSTITUENTS OF PRIMARY PRODUCERS

	CARBON	ENERGY	NITROGEN	PHOSPHORUS
GREEN ALGAE	2.00000	20.00000	.32000	.02000
BLUE GREEN ALGAE	2.00000	20.00000	.32000	.02000
DIATOMS	3.00000	30.00000	.48000	.03000
ALL SPECIES				
TOTAL	7.00000	70.00000	1.12000	.07000

CONSTITUENTS OF ANIMAL BIOMASS

	CARBON	ENERGY	NITROGEN	PHOSPHORUS
STONEFLIES				
EGG	.000000	.000000	.000000	.000000
NYMPH I	.800000	8.000000	.013300	.004440
NYMPH II	.400000	4.000000	.006700	.000220
TOTAL	1.200000	12.000000	.020000	.004660
MAYFLIES				
EGG	.000000	.000000	.000000	.000000
NYMPH I	.210000	2.100000	.003500	.001169
NYMPH II	.750000	7.500000	.012500	.004100
TOTAL	.960000	9.600000	.016000	.005269
CADDISFLIES				
EGG	.000000	.000000	.000000	.000000
LARVAE	2.000000	20.000000	.033300	.011100
PUPAE	1.000000	10.000000	.016700	.005500
TOTAL	3.000000	30.000000	.050000	.016600
DIPTERANS				
EGG	.000000	.000000	.000000	.000000
LARVAE	.075000	.750000	.001250	.000420
PUPAE	.037500	.375000	.000630	.000208
TOTAL	.112500	1.125000	.001880	.000628
BROWN TROUT				
EGG	.000000	.000000	.000000	.000000
LARVAE	.012500	.125000	.002100	.000690
JUVINILE	.050000	.500000	.083300	.002780
ADULT I	.125000	1.250000	.021000	.006900
ADULT II	.312500	3.125000	.052080	.017360
TOTAL	.500000	5.000000	.158480	.027730
CUTTHROAT TROUT				
EGG	.000000	.000000	.000000	.000000
LARVAE	.012500	.125000	.002100	.000690
JUVINILE	.050000	.500000	.083300	.002780
ADULT I	.125000	1.250000	.021000	.006900
ADULT II	.312500	3.125000	.052080	.017360

TOTAL	.500000	5.000000	.158430	.027730
TOTAL, ALL SPECIES	6.272500	62.724997	.404340	.082617

POPULATIONS ARE PRINTED IN NUMBERS PER SQ. METER, AVERAGED OVER 20.0 METERS OF STREAM.
AVERAGE WEIGHTS ARE EXPRESSED AS GRAMS OF CARBON (DRY WT.).

	POPULATIONS	WT. OF AVE. IND.
STONEFLIES		
EGG	.0000	.000000
NYMPH I	800.0000	.100000-02
NYMPH II	200.0000	.200000-02
TOTAL	1000.0000	
MAYFLIES		
EGG	.0000	.000000
NYMPH I	1000.0000	.210000-03
NYMPH II	250.0000	.300000-02
TOTAL	1250.0000	
CADDISFLIES		
EGG	.0000	.000000
LARVAE	7999.9999	.250000-03
PUPAE	1000.0000	.100000-02
TOTAL	8999.9999	
DIPTERANS		
EGG	.0000	.000000
LARVAE	100.0000	.750000-03
PUPAE	50.0000	.750000-03
TOTAL	150.0000	
BROWN TROUT		
EGG	.0000	.000000
LARVAE	6.0000	.208333-02
JUVINILE	.0500	.100000+01
ADULT I	.0250	.500000+01
ADULT II	.0200	.156250+02
TOTAL	6.0950	
CUTTHROAT TROUT		
EGG	.0000	.000000
LARVAE	6.0000	.208333-02
JUVINILE	.0500	.100000+01
ADULT I	.0250	.500000+01
ADULT II	.0200	.156250+02
TOTAL	6.0950	

CONSTITUENTS OF HETEROTROPHIC MICROORGANISMS

MICROBIAL TYPE	CARBON	ENERGY	NITROGEN	PHOSPHORUS
DECOMPOSERS	6.000000	60.000000	1.000000	.060000
TOTAL	6.000000	60.000000	1.000000	.060000

SUSPENDED DETRITUS CONSTITUENTS

DETRITUS TYPE	CARBON	ENERGY	NITROGEN	PHOSPHORUS
DETRITUS	.000000	.000000	.000000	.000000

	CARBON	ENERGY	NITROGEN	PHOSPHORUS
TOTAL	.000000	.000000	.000000	.000000

BIOLOGICALLY ACTIVE SEDIMENTS

DETRITUS TYPE	CARBON	ENERGY	NITROGEN	PHOSPHORUS
DETRITUS	6.000000	60.000000	1.700000	3.333000
TOTAL	6.000000	60.000000	1.700000	3.333000
TOTAL DETRITUS	6.000000	60.000000	1.700000	3.333000

DISSOLVED CONSTITUENTS	CARBON	ENERGY	NITROGEN	PHOSPHORUS
IN WATER	.00000	.00000	.00000	.00000
IN BENTHOS	.00000	.00000	.00000	.00000
TOTAL	.00000	.00000	.00000	.00000

AVERAGE IN ECOSYSTEM	CARBON	ENERGY	NITROGEN	PHOSPHORUS
	25.27250	252.72499	4.22484	3.54562

THE FOLLOWING CONSTITUENTS ARE INORGANIC AND ARE PRINTED IN GRAMS PER SQ. METER AVERAGED OVER 20.0 METERS OF STREAM.

SUSPENDED PARTICULATE MATTER(INORGANIC)

SIZE	SEDIMENT
SILT	10.00000
TOTAL	10.00000

BENTHIC PARTICULATE MATTER(INORGANIC)

SIZE	SEDIMENT
SILT	10.00000
TOTAL	10.00000

ALL P.M. 20.00000

DISSOLVED INORGANIC CONSTITUENTS

	CARBON	NITROGEN	PHOSPHORUS
IN WATER	5.23000	.87000	.29000
IN BENTHOS	18.00000	3.00000	1.00000
TOTAL	23.23000	3.87000	1.29000

PH IN WATER COLUMN 8.00 PH IN BENTHOS 8.00 WATER COLUMN TEMP. 8.50 BENTHOS TEMP. .00 DEGREES CENTIGRADE

Appendix B

Main Program for Graphing Results of Exploratory Sensitivity Analysis

```
C     AQUATIC     MAIN    FOR GRAPHING EXPLORATORY SENSITIVITY
      DIMENSION TITLES(70,10),YAXISS(70,10) ,ORIGIN(70)
      DIMENSION AMAXI(70),AMINI(70),ALGRAF(5,70,120),STATE(20)
      COMMON/DIAG2/FIG(5,120),EXPLAN(5,5),TITLE(10),YTITLE(10),
     1 XDOT(71), XMAX, XMIN, YMAX, YMIN, NOSYM, INITYR,IGPP,TITLE2(10)
      DATA BLANK/'  '/,HIGH/1.E20/
      WRITE(6,3)
    3 FORMAT(1H1)
    5 READ(5,10)(STATE(I),I=1,20)
      WRITE(6,20)(STATE(I),I=1,20)
      DO 30 I=1,20
   30 IF (STATE(I).NE.BLANK) GO TO 5
   10 FORMAT(20A4)
   20 FORMAT(1X,20A4)
      READ(5,21)JDAY,IYR,NDAY,NXPLOR,IGPP
   21 FORMAT(16I5)
      INITYR=IYR
      READ(5,10)(TITLE2(I),I=1,10)
      DO 50 I=1,NXPLOR
      READ(5,10)(TITLES(I,J),J=1,10)
      READ(5,10)(YAXISS(I,J),J=1,10),ORIGIN(I)
   50 CONTINUE
      DO 40 J=1,IGPP
   40 READ(5,10)(EXPLAN(L,J),L=1,5)
      DO 55 I=1,NXPLOR
      AMINI(I)=HIGH
   55 AMAXI(I)=-HIGH
      XMIN=JDAY
      XMAX=NDAY
      DO 64 I=1,IGPP
      GO TO (100,110,120,130,140,150),I
  100 READ(12)((ALGRAF(I,J,K),J=1,NXPLOR),K=1,120)
      GO TO 160
  110 READ(13)((ALGRAF(I,J,K),J=1,NXPLOR),K=1,120)
      GO TO 160
  120 READ(14)((ALGRAF(I,J,K),J=1,NXPLOR),K=1,120)
      GO TO 160
  130 READ(15)((ALGRAF(I,J,K),J=1,NXPLOR),K=1,120)
      GO TO 160
  140 READ(16)((ALGRAF(I,J,K),J=1,NXPLOR),K=1,120)
      GO TO 160
  150 READ(17)((ALGRAF(I,J,K),J=1,NXPLOR),K=1,120)
  160 CONTINUE
   64 CONTINUE
      DO 66 I=1,IGPP
      DO 66 J=1, NXPLOR
      DO 66 K=1, 120
      AMINI(J)=AMIN1(AMINI(J),ALGRAF(I,J,K))
   66 AMAXI(J)=AMAX1(AMAXI(J),ALGRAF(I,J,K))

C..........LINE GRAPHS
      DO 2110 I = 1, NXPLOR
      I2 = IGPP
      DO 2080 K =  1, I2
      YMAX = AMAXI(I)
      YMIN = AMINI(I)
      IF((ORIGIN(I).NE.ZERO).OR.((YMAX.GT.0.).AND.(YMIN.LT.0.))) GO TO      MA4710
     1 2070
      IF (YMAX) 2050,2070,2060
 2050 YMAX = 0.
      GO TO 2070
 2060 YMIN = 0.
 2070 DO 2080 J = 1, 120
 2080 FIG( K,J) = ALGRAF(K,I,J)
      DO 2090 J = 1, 10
 2090 TITLE(J) = TITLES(I,J)
      DO 2100 J = 1, 10
 2100 YTITLE(J) = YAXISS(I,J)
      CALL GRAF
 2110 CONTINUE
      STOP
      END
```

Appendix C

Listing of the Mountain Stream Data Deck

```
     TEMPLE FORK (LOGAN RIVER), LEVEL II STREAM SYSTEM
   3    6    1    1.   3    1    9    1                   1    1         4
 180 1973  540    1         0    1    1    1
                       3

   1         2    3
   1         2    3




111111111111111111111111111
      20.0
   3    3    3    3    5    5
   1    3    4
   1    3    4
   1    2    5
   1    2    5
   1    2    6    8    9
   1    2    6    8    9
GREEN ALGAE                     BLUE GREEN ALGAE
DIATOMS
STONEFLIES                      MAYFLIES
CADDISFLIES                     DIPTERANS
BROWN TROUT                     CUTTHROAT TROUT
CARBON        ENERGY       NITROGEN      PHOSPHORUS
  EGG               LARVAE              NYMPH I             NYMPH II          PUPAE
  JUVINILE          ADULT               ADULT I             ADULT II
  DETRITUS
  DECOMPOSERS
  SEDIMENT
CARBON        NITROGEN       PHOSPHORUS
  SILT
        2.        20.        .32        .02
        2.        20.        .32        .02
        3.        30.        .48        .03
                 800.       200.

       .8         8.       .0133     .00444
       .4         4.       .0067     .00022
                1000.       250.

       .21        2.1      .0035     .001169
      .75         7.5      .0125      .0041
                8000.      1000.
```

```
       2.          20.         .0333        .0111
       1.          10.         .0167        .0055
                  100.          50.

    .075          .75        .00125       .00042
     .0375        .375       .00063      .000208
                   6.           .05          .025         .02

     .0125       .125          .0021       .00069
     .05         .5            .0833       .00278
     .125        1.25          .021        .0069
     .3125       3.125       .05208       .01736
                   6.           .05          .025         .02

     .0125       .125          .0021       .00069
     .05         .5            .0833       .00278
     .125        1.25          .021        .0069
     .3125       3.125       .05208       .01736
       6.          60.           1.           .06

       6.          60.          1.7         3.333


      10.          10.          10.
      10.          10.          10.
    5.23         .87          .29
      18.           3.           1.
$EPUT
PHW=8.,PHB=8.,LIMEXO=63,TEMPW=8.5,
$END
$PPUT
NSI=3,
NSO=3,
INFLOW=0,
NSECB=1,
NSECE=3,
XINC=10.,
XBEG=0.,
YSTART=0.,
XI=0.,10.,20.,
SI=.01,.01,.01,
BI=3*1.,
FMI= 3*2.,
FNI= 3*.06,
FLODIF=.0000001
$END
$MPUT
 CLITLO=.75,
 CLITHI=.75,
 CDRF2=1.28,
 CDRF3=6.52,
WETFAC=.6
CFAC1=.1
CFAC2=.001
ALLMAX=.98,
STRHI=5*10000.,
```

```
COAGUL=0.,
WATDAY=5.,
STRLO=5*.001,
$END
$APUT
 ANDRF2=13*.0056,4*0.,.0056,
 ANIHI=13*.583,4*0.,.589,
 ANILO=13*.6,4*0.,.6,
 ANDRF3=13*1.67,4*0.,1.67,
 NDRIFM=3,
 PREFRB=1.,
 CONTA=-1.386,
 CONTB=.1386,
CONS=60.,
 ASSIMH=.5,
 RESPM=.5,
 BACTHI=100.,
 BACTLO=0.,
 NTRANS=1,5,3,1,5,3,1,5,3,1,5,3,1,5,5,5,6,1,5,5,5,6,
 NTRANE=4,4,3,4,4,3,4,4,3,4,4,3,4,4,4,1,1,4,4,4,1,1,
 NDRIFA=2,2,2,2,2,2,2,2,2,2,2,2,2,4,4,4,4,2,4,4,4,4,
 SHELP=12*.1,10*0.,
 AMAX=1250.,.3,2165.,1250.,.3,2165.,1250.,.3,2165.,125 .,.3,2165.,
 520.,.3,4.,4.,0.,950.,.3,4.,4.,
 THRESH=800.,0.,1354.,800.,0.,1354.,800.,0.,1354.,800.,0.,1354.,400.,
 4*0.,760.,
ACCUM=0.,.0015,1354.,0.,.0015,1354.,0.,.0045,1354.,0.,.0015,1354.,0.,
 .74,4.,12.,0.,0.,.75,4.,12.,
 CONSA=6*.9,
 UPTHRE=6*10.0,
 EXOGEN=200.,100.,75.,50.,
 EGCOMP=.000001,.00000075,.00000067,.00000075,.000125,.000125,9*0.,
          .00001,.0000075,.0000067,.0000075,.00125,.00125,9*0.,
          .00000016,.00000012,.000000107,.00000012,.00002,.00002,9*0.,
          .00000001,.000000075,.000000067,.000000075,.0000125,.0000125,
 NLAY1=4*0.,285,105,
 NLAY2=4*0,345,165,
 RCONST=4*0.,.00263,.00263,
 ISFATE=22*2,
 XCRSOL=22*.2,
PREFA=
.00,.00,.00,.00,.00,.00,.00,.03,.00,.00,.03,
          .00,.00,.00,.00,.00,.00,.00,.00,.00,.00,.00,          18*0.,
.00,.00,.00,.00,.00,.00,.00,.02,.00,.00,.00,
          .00,.00,.02,.02,.02,.02,.00,.02,.02,.02,.02,          18*0.,
.00,.00,.00,.00,.00,.00,.00,.01,.00,.00,.00,
          .00,.00,.00,.02,.02,.02,.00,.02,.02,.02,.02,          18*0.,
.00,.02,.02,.00,.00,.00,.00,.02,.00,.00,.02,
          .00,.00,.01,.00,.00,.00,.00,.01,.00,.00,.00,          18*0.,
.00,.01,.02,.00,.00,.00,.00,.03,.00,.00,.00,
          .00,.00,.01,.01,.01,.01,.00,.01,.01,.01,.01,          18*0.,
.00,.00,.00,.00,.00,.00,.00,.01,.00,.00,.00,
          .00,.00,.00,.01,.01,.01,.00,.00,.01,.01,.01,          18*0.,
.00,.01,.01,.00,.00,.00,.00,.00,.00,.00,.01,
          .00,.00,.01,.00,.00,.00,.00,.01,.00,.00,.00,          18*0.,
.00,.02,.02,.00,.00,.00,.00,.00,.00,.00,.00,
          .00,.00,.00,.02,.01,.01,.00,.00,.02,.01,.01,          18*0.,
```

```
.00,.00,.00,.00,.00,.00,.00,.00,.00,.00,.00,
         .00,.00,.00,.01,.01,.01,.00,.00,.01,.01,.01,            18*0.,
.00,.01,.01,.00,.00,.00,.00,.02,.00,.00,.00,
         .00,.00,.00,.00,.00,.00,.00,.00,.00,.00,.00,            18*0.,
.00,.02,.02,.00,.00,.00,.00,.02,.00,.00,.00,
         .00,.00,.02,.01,.01,.01,.00,.02,.01,.01,.01,            18*0.,
.00,.00,.00,.00,.00,.00,.00,.00,.00,.00,.00,
         .00,.00,.00,.01,.01,.01,.00,.00,.01,.01,.01,            18*0.,
.00,.00,.00,.00,.00,.00,.00,.00,.00,.00,.00,
         .00,.00,.00,.00,.02,.02,.00,.00,.00,.02,.02,            18*0.,
.00,.00,.00,.00,.00,.00,.00,.00,.00,.00,.00,
         .00,.00,.00,.00,.01,.01,.00,.00,.00,.01,.01,            18*0.,
.00,.00,.00,.00,.00,.00,.00,.00,.00,.00,.00,
         .00,.00,.00,.00,.00,.00,.00,.00,.00,.00,.00,            18*0.,
.00,.00,.00,.00,.00,.00,.00,.00,.00,.00,.00,
         .00,.00,.00,.00,.00,.00,.00,.00,.00,.00,.00,            18*0.,
.00,.00,.00,.00,.00,.00,.00,.00,.00,.00,.00,
         .00,.00,.00,.00,.00,.00,.00,.00,.00,.00,.00,            18*0.,
.00,.00,.00,.00,.00,.00,.00,.00,.00,.00,.00,
         .00,.00,.00,.00,.02,.02,.00,.00,.00,.02,.02,            18*0.,
.00,.00,.00,.00,.00,.00,.00,.00,.00,.00,.00,
         .00,.00,.00,.00,.01,.01,.00,.00,.00,.01,.01,            18*0.,
PREFV=
.00,.00,.00,.00,.20,.20,.00,.05,.00,.00,.00,
         .00,.00,.00,.00,.00,.00,.00,.00,.00,.00,.00,            18*0.,
.00,.00,.00,.00,.20,.20,.00,.05,.00,.00,.00,
         .00,.00,.00,.00,.00,.00,.00,.00,.00,.00,.00,            18*0.,
.00,.00,.00,.00,.20,.20,.00,.05,.00,.00,.00,
PREFM=
.00,.04,.04,.00,.02,.02,.00,.02,.00,.00,.02,
PREFO=
.00,.10,.10,.00,.10,.05,.00,.02,.00,.00,.10,
TAKE= 0.,3.,2.,0.,2.,2.,0.,2.,0.,0.,2.,0.,0.,
       1.,.5,.25,.1,0.,1.,.5,.25,.1,
 CURVE=0.,.15,.10,0.,.014,.014,0.,.07,0.,0.,1.,0.,0.,1.2,1.0,2.,3.,
       0.,1.2,1.0,2.,3.,
ASSIM=0.,.25,.25,0.,.25,.25,0.,.25,0.,0.,.25,0.,0.,.7,.7,.7,.7,0,4*.7
WMIN= .0001,.0001,.002,.0001,.0001,.002,.0001,.0001,.005,.0001,.0001,
      .002,.001,.001,1.,5.,15.,.001,.001,1.,5.,15.
WMAX= .00011,.002,.005,.00011,.002,.005,.0001,.006,.01,.00011,.002,
      .005,.0011,1.,5.,15.,50.,.0011,1.,5.,15.,50.
TOPT= 22*10.
TMAX= 22*15.
SLOPE=0.,-.16,-.16,0.,-.16,-.16,.0,-.16,.0,.0,-.16,0.,0.,4*-.2,0.,4*-.2
CONST=0.,.016,.01,0.,.012,.008,0.,.017,0.,0.,.025,0.,0.,.007,.015,.017,
      .02,0.,.007,.015,.017,.02,
BEFAC3=40*.0001,
BEFAC4=40*.0,
AMORTA=22*0.,
ALLMAX=.98,
IXFATE=22*2.,
IAFATE=22*2,
*END
$VPUT
EXTINS=.07
EXTINP=.06
EXTINW=.69,
```

```
PLDEP=3*1.,
 CONTE2=.008333,.0055,.033333,
 CONTE3=-.0002083,-.0000925,-.003333,
RESPE=3*-.001,
RESPC=3*.001,
RESPD=3*.166666
UPCON1=16*0.,3*.34,5*0.,3*.113,
UPCON2=16*0.,3*-231050.,5*0.,3*-639150.,
UPCON =16*0.,3*.75,5*0.,3*.75,
CONNIT=16*0.,3*7.,5*0.,3*35.,
VTDEDY=8*  10.,
VTDEDS=8*.001,
NDRIFV=3*2,
CONRAD=165.,65.,35.,
ENERGY=10.,
IVFATE=3*1,
NGOV=3*1,
NGOA=22*1,
NGONRP=3*1,
NGOL=3*1,
 VDRF2=1.1,1.1,1.0375,
 VDRF3=.299,.299,.21557,
$END
```

8.	9.	10.	11.	12.	13.	13.	12.
11.	10.	9.	8.				
175.	300.	425.	575.	665.	700.	685.	610.
475.	385.	230.	160.				
.330	.330	.329	.329	.328	.328	.327	.327
.327	.327	.326	.326	.325	.325	.325	.325
.325	.325	.325	.325	.325	.325	.325	.325

	.325	.325	.325	.325	.325	.325	.325	.325
	.325	.325	.325	.325	.325	.325	.325	.325
	.325	.325	.325	.325	.325	.325	.325	.325
	.325	.325	.326	.327	.328	.329	.330	.330
	.330	.330	.331	.332	.333	.334	.335	.336
	.337	.338	.339	.340	.340	.340	.340	.341
	.342	.343	.344	.345	.345	.345	.346	.348
	.350	.351	.353	.355	.357	.359	.361	.363
	.365	.367	.370	.380	.390	.400	.410	.420
	.430	.440	.450	.460	.470	.480	.495	.500
	.520	.540	.560	.580	.600	.620	.640	.660
	.680	.700	.720	.740	.760	.780	.800	.835
	.870	.905	.940	.975	1.010	1.050	1.080	1.100
	1.120	1.140	1.160	1.180	1.200	1.180	1.160	1.140
	1.120	1.100	1.080	1.050	1.040	1.030	1.020	1.010
	1.000	.990	.975	.965	.950	.940	.930	.920
	.910	.900	.885	.870	.855	.840	.825	.810
	.800	.790	.780	.770	.760	.750	.740	.730
	.715	.700	.685	.670	.655	.640	.625	.615
	.605	.595	.585	.575	.565	.555	.542	.529
	.515	.503	.490	.477	.464	.450	.446	.442
	.438	.434	.430	.426	.422	.418	.414	.410
	.406	.402	.400	.400	.400	.400	.400	.400
	.400	.400	.400	.400	.400	.400	.400	.400
	.400	.400	.399	.397	.395	.393	.391	.389
	.387	.385	.385	.385	.385	.385	.385	.385
	.386	.386	.386	.386	.386	.386	.386	.387
	.387	.387	.387	.387	.387	.387	.388	.388
	.389	.388	.388	.388	.389	.388	.389	.388
	.388	.388	.387	.386	.385	.384	.384	.384
	.383	.383	.383	.383	.383	.383	.383	.383
	.383	.383	.383	.383	.382	.382	.382	.382
	.381	.380	.380	.380	.379	.378	.377	.376
	.375	.372	.369	.363	.360	.357	.354	.350
	.348	.347	.346	.344	.342	.341	.340	.340
	.339	.339	.338	.337	.336	.335	.336	.337
	.338	.339	.339	.340	.340	.341	.341	.342
	.343	.344	.344	.345	.345	.346	.347	.347
	.348	.349	.350	.350	.351	.351	.352	.352
	.353	.353	.355	.354	.352	.350	.349	.346
	.344	.340	.339	.337	.335	.333	.332	.330
	.330	.330	.331	.332	.333	.334	.335	.330
	.328	.326	.325	.327	.327			
30	2							
	.9	9.	.144	.009				

9.8	8.0		
8.3			
18.	3.	1.	
30 4			
.9	9.	.144	.009

9.7	8.0		
5.8			
18.	3.	1.	
30 4			
1.85	18.5	.296	.019

8.1 8.0
5.6
18. 3. 1.
30 4

2.8 28. .448 .028

6.1 8.0
5.0
18. 3. 1.

30	4			
	1.95	18.5	.296	.019

	4.1	8.0		
	5.0			
	18.	3.	1.	
30	4			
	.9	9.	.144	.009

3.2 8.0
5.0
18. 3. 1.
30 4

.9 9. .144 .009

3.1 8.0
4.7
18. 3. 1.
30 4

.9 9. .144 .009

	3.2	8.0		
	4.7			
	18.	3.	1.	
30	4			
	.9	9.	.144	.009

	4.5	8.0		
	5.3			
	18.	3.	1.	
30	4			
	.9	9.	.144	.009

5.9	8.0		
16.0			
18.	3.	1.	
30 4			
.9	9.	.144	.009

7.2	8.0		
11.0			
18.	3.	1.	
30 4			
.9	9.	.144	.009

	8.2	8.0		
	8.3			
	18.	3.	1.	
30	3			
	.9	9.	.144	.009

9.8	8.0	
8.3		
18.	3.	1.

Appendix D

Description of the General Stream Model