VESIENTUTKIMUSLAITOKSEN JULKAISUJA
PUBLICATIONS OF THE WATER RESEARCH INSTITUTE **57**

VESIHALLITUS—NATIONAL BOARD OF WATERS, FINLAND
Helsinki 1984

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ISBN 951-46-8081-2
ISSN 0355-0982

Helsinki 1984. Valtion painatuskeskus

APPLICATION OF THE FINNECO MODEL TO LAKE PYHÄJÄRVI

Jorma Niemi & Juhani Eloranta

NIEMI, J.S. & ELORANTA, J. 1984 Application of the FINNECO model to Lake Pyhäjärvi. Publications of the Water Research Institute, National Board of Waters, Finland, No. 57.

The FINNECO lake model is a one-dimensional water quality simulation model developed in a joint project between the National Board of Waters, Finland and International Business Machines, Finland during the years 1978—1981. The model has eighteen state variables, includes the effect of wind in mixing water and simulates the freeze-up and break-up of ice on the basis of energy balance. The model was applied to the eutrophic Lake Pyhäjärvi situated in southern Finland. Calibration was carried out by a trial and error method using the data of the open water season of 1980. Using the same parameter combination and the corresponding data of 1981, the agreement between the model output and observations was poor and the model could not be considered as verified. However, reasonably good agreement was obtained with this set of data by changing the values of only five parameters. It can be concluded that the model is unable to simulate water quality accurately in a lake as eutrophic as Lake Pyhäjärvi. The sensitivity of the model to the input data was also tested. When the input data was given to the model as weekly or monthly averages instead of once every eight hours the values of most state variables, except those of phytoplankton, did not change markedly. This shows that the interval between individual input data can be longer than eight hours, which simplifies the application of the model and decreases computer costs.

Index words: Mathematical models, water quality models, ecological models, simulation models, FINNECO model, water quality prediction, Lake Pyhäjärvi

1. INTRODUCTION

In recent years the use of systems analysis in assessing environmental problems has increased considerably, in particular the use of mathematical models. Water quality models, which are one group of environmental models, have typically been used for making predictions of water quality and for carrying out research on the basic mechanisms of aquatic ecosystems.

A great number of differet water quality models have been described in the literature. They are always simplifications of natural ecosystems and therefore should be vigorously tested by applying them to different types of water bodies in order to determine their suitability for practical water management. Application of the models typically includes gathering of a large amount of information concerning the inflowing waters, such as quantity and quality of tributaries, wastewater treatment plants, diffuse loading, precipitation and in addition meteorological data and historical data concerning the water quality of the case study lake. This information must be organized in the form required by the model before calibration can be started.

The calibration process requires thorough knowledge of the structure of the model, considerable computer time, much data and a certain amount of intuition on the part of the user. Special methods such as automatic calibration for the estimation of parameters are difficult to use with such a complex model as FINNECO. The normal method of calibrating the model is therefore to use trial and error, which has many disadvantages as the criteria for evaluating the agreement between the computed and observed results are hard to define. Most of the time used in the application of complex models is spent in gathering the data and in calibration.

The FINNECO model was developed in a joint project between the National Board of Waters, Finland and Oy International Business Machines Ab, Finland during the years 1978—1981 and it was calibrated and verified to Lake Päijänne with the data of four years with good results (Kinnunen et al. 1982). Modeling was carried out with the sets of data covering the whole year, starting from May and continuing until the end of the next April. In the present application, however, simulation was carried out only with the data of the open water season.

Lake Pyhäjärvi, the case study area of this work, receives both municipal and industrial effluents. The lake is eutrophic, with high nutrient concentrations and low concentrations of dissolved oxygen, and has a short detention time. It differs therefore in many respects from Lake Päijänne, which is eutrophic only in the northern part.

The objective of this work was to determine whether the FINNECO model could be succesfully applied to this type of lake without changing its structure. In addition, the effect of the interval of submitting the input data on the computed results was tested. It was found that the model was less suitable to Lake Pyhäjärvi than to Lake Päijänne.

2. THE MODEL

The FINNECO model is a one-dimensional water quality simulation model that can be applied to lakes and reservoirs. In the model the lake basin is divided into hydraulic elements parallel to the surface of the lake. Hydraulic elements are considered to be homogeneous and therefore differences in water quality are observed only along the vertical axis of the lake. The model has eighteen state variables, namely: temperature, dissolved oxygen, biological oxygen demand, alkalinity, pH, total inorganic carbon, total dissolved solids, organic sediment, carbon dioxide, ammonia-, nitrite- and nitrate nitrogen, phosphate phosphorus, phosphorus in inorganic sediment, hygienic indicator, sodium lignosulphonate, phytoplankton (10 groups) and zooplankton. Driving variables of the model include meteorological data as well as data concerning the quantity and quality of inflowing waters. The model includes a mechanism for taking into account the effect of wind in mixing water and it simulates the annual freeze-up and break-up of ice cover on the basis of energy balance.

The structure of the model was presented in detail by Kinnunen et al. (1982). The users' manual was prepared by Kauranne (1983).

3. APPLICATION OF THE MODEL

3.1 The case study lake

Lake Pyhäjärvi, situated near the City of Tampere in southern Finland, was selected as the case study lake for the application of the model. The detention time of this lake is relatively short and it resembles to some extent a slowly flowing river. The lake receives waste waters from factories and from the City of Tampere and its surroundings. The water quality of the lake has been followed over a period of several years. These investigations have been carried out mainly by the Water District Office of Tampere and by the Water Protection Association of the river Kymijoki. In addition, special investigations have been carried out. Kuparinen (1981) investigated the inhibitive effects of various substances on bacterial activity in the lake. Virtanen et al. (1979) investigated the flow velocity of the water in lake.

Both municipal and industrial waste waters are discharged to the lake (Table 1). The waters that are discharged from Lake Näsijärvi

Table 1. The amounts of wastewater, BOD_7, total phosphorus, total nitrogen and total dissolved solids in the principal sources of nutrients discharged to Lake Pyhäjärvi in 1980.

Source of loading	Waste water discharge $10^3m^3a^{-1}$	BOD_7 t a^{-1}	Total phosphorus t a^{-1}	Total nitrogen t a^{-1}	Dissolved solids t a^{-1}
Viinikanlahti	20 500	1 300.0	21.40	589.0	484.0
Rahola	4 050	171.0	4.20	136.0	34.1
Tako	4 550	570.0	2.40	10.2	915.0
Kyösti	681	14.4	0.92	17.6	10.0
Loukonlahti	239	15.8	0.68	6.1	14.5
Suomen Trikoo	622	32.6	0.30	6.3	19.2
Σ	30 642	2 103.8	29.9	765.2	1 477.0

to Lake Pyhäjärvi through the Tammerkoski rapids are influenced by wastes of the pulp and paper industry. Because of these heavy nutrient inputs the water quality of Lake Pyhäjärvi is poor, although during recent years slight improvement has been observed. In particular, the concentrations of coliform bacteria and nutrients have decreased. For example, phosphorus concentrations in the surface water of the lake were in the winters of 1973 and 1976 200 and 77 μg 1^{-1}, respectively, while in 1979 the corresponding concentration was only 25 μg 1^{-1}. A similar decreasing trend was not observed during the same period in the hypolimnion, because this layer is at times anoxic and nutrients are released from the bottom sediment to the overlying water.

The case study area extends from the Tammerkoski rapids to the bridge of Rajasaari (Fig. 1) and forms a homogenous entity. According to the investigations of Sarkkula and Forsius (1977) the direction of flow in the lake is in practice solely towards the bridge of Rajasaari. Data of depth and surface area of the case study lake were calculated on the basis of the bathymetric map. Surface area, volume and average depth of the lake are 22.12 km^2, 192.11 · 10^6 m^3 and 8.7 m, respectively. The maximum depth is 46 m. The mean discharge of the Tammerkoski rapids was in 1961—1971 66 m^3 s^{-1}. According to Sarkkula and Forsius (1977) water does not flow equally through Lake Pyhäjärvi, but rather along certain defined routes. According to the same investigation the detention time of the case study lake is 27 days.

It was evident that this lake is not a promising case study area for any model. However, serious water pollution problems exist in the area and it was decided to test whether a water quality model of this type could be applied to the lake and perhaps later on be used in water management.

3.2 Sources of data

The data necessary for the use of the model can be divided into initialization and simulation data.

Initialization data includes the data that is needed to define the condition of the lake at the beginning of simulation and to control the computer program. This data includes morphological data of the lake, values of the parameters in the equations and information controlling the computer program, such as the length of the simulation period, the first and last day of simulation and the days when special printout is required. The initialization data is given to the model only once at the beginning of the simulation.

Simulation data includes weather data and data on the quantity and quality of the inflowing waters such as rivers, wastewater treatment plants, precipitation and diffuse loading.

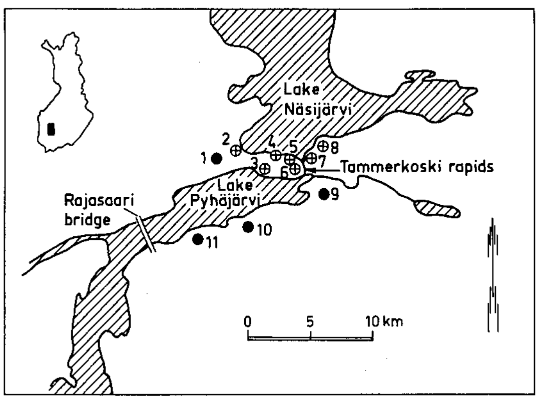

Fig. 1. Principal sources of waste water in the case study area, ● = Wastewater treatment plant, ⊕ = Factory.

1 Rahola
2 GAS Oy, Lielahti
3 Suomen Trikoo Oy
4 Näsijärvi Oy
5 YP Oy, Santalahti
6 GAS Oy, Tako
7 Oy Finlayson Ab, Tampere
8 TKS, Naistenlahden voimala
9 Viinikanlahti
10 Loukonlahti
11 Kyösti

The simulation data is given to the model once during each simulation time step, in this application once during every eight hours.

The initial values of physical and chemical state variables were obtained from the data bank of the National Board of Waters. The values of some of these variables, such as BOD, detritus and total dissolved solids, were estimated. Phytoplankton measurements were not carried out in Lake Pyhäjärvi and therefore the initial values of the two phytoplankton groups were estimated on the basis of observations carried out earlier (Lepistö et al. 1979).

Meteorological data was obtained from the Meteorological Yearbook of Finland (1981) according to observations carried out at Tampere airport. The method of obtaining the weather data for every eight hour period was identical to that used previously in applying this model (Niemi 1978, Kinnunen et al. 1982). The data on the quantity and quality of the water of the Tammerkoski rapids was obtained from the hydrological data bank of the National Board of Waters. Daily discharge data of the Tammerkoski rapids was used. The water quality data was interpolated for each time step on the basis of monthly observations.

Near Lake Pyhäjärvi there are several wastewater treatment plants, which discharge wastewater to the lake. The most important plants are the wastewater treatment plants of Viinikankoski, Rahola, Tako Oy, Kyösti, Loukonlahti and Suomen Trikoo, which were included in the model.

The loadings of these six wastewater treatment plants were added together and were treated in the model as one major source of loading. The water quality data for each plant was obtained from the regular reports of the plants. Because phosphate phosphorus and ammonia nitrogen are not analyzed from wastewater it was assumed that the concentrations of these substances were equal to the concentrations of total phosphorus and total nitrogen, respectively. The temperature of the wastewater was estimated on the basis of monthly observations carried out in the three largest plants. The following estimates of the quality of the water leaving the wastewater treatment plant were assumed: pH 7.0, total dissolved solids 200 mg l^{-1}, coliform bacteria 10^4 per 100 ml, dissolved oxygen 5.0 mg l^{-1} and alkalinity 8.0 mg l^{-1}. The data on the water quantity and quality of the wastewater treatment plant was given monthly and the daily values were interpolated on the basis of this information.

Precipitation data was obtained from measurements carried out at Tampere airport. Daily values were calculated on the basis of monthly avarage values. The data on the quality of rainwater was obtained mainly from the investigation of Järvinen and Haapala (1980). Water quality data of rainwater was assumed to be: ammonia nitrogen 15.0 mg m^{-2} $month^{-1}$, nitrate nitrogen 15.0 mg m^{-2} $month^{-1}$, pH 4.8, alkalinity 2.7 mval m^{-2} $month^{-1}$. The concentration of phosphate phosphorus was assumed to be half of the measured amount of total phosphorus. The concentrations of dissolved oxygen and total dissolved solids were assumed to be 10 mg l^{-1} and 50 mg l^{-1}, respectively. The temperature of the rain water was assumed to be the same as that of the surface water of the lake.

Investigations carried out in small hydrological basins were used in estimating the diffuse loadings entering Lake Pyhäjärvi. The drainage area of the case study area was estimated to be 159 km^2. The runoff entering the lake from the drainage area was calculated on the basis of observations made at the small research basin of Paunulanpuro. The runoff values were obtained as monthly averages from the hydrological office of the National Board of Waters. Kauppi (1979) presented the estimates of total phosphorus and total nitrogen loadings from this drainage area, expressed as average values for the years 1964—1974. According to the same investigation the annual diffuse load can be divided into three seasons: spring (April and May); summer and autumn (June-November); and winter (December-March). In this work the spring period was assumed to continue until the end of May although in Kauppi's study (1979) the spring period ended earlier, i.e. on the 19th of May. The nutrient concentrations were calculated for each of these three periods on the basis of the average loading values for the years 1964—1974 and of observed runoff values for 1980 and 1981. The nutrient concentration remained constant within each period. In calculating the nutrient concentrations it was assumed that phosphate phosphorus concentration is half of the total phosphorus concentration and ammonia and nitrate nitrogen concentrations are one third and one fourth of the total nitrogen concentration, respectively. The nutrient concentrations obtained for the

Table 2. Nutrient concentrations of the runoff waters in the drainage area of Lake Pyhäjärvi in 1980 and 1981.

Year	Season	Phosphate phosphorus $\mu g\ l^{-1}$	Ammonia nitrogen $\mu g\ l^{-1}$	Nitrate nitrogen $\mu g\ l^{-1}$
1980	Spring	37.5	398	298
	Summer and Autumn	23.0	276	207
	Winter	16.7	279	209
1981	Spring	14.9	158	118
	Summer and Autumn	3.4	58	43
	Winter	7.9	131	98

runoff are displayed in Table 2. In addition it was assumed that the dissolved oxygen concentration, pH, alkalinity and total dissolved solids concentration of the runoff waters were 11.9 mg l^{-1}, 6.0, 6.0 mg l^{-1} and 50 mg l^{-1}, respectively. The temperature of the runoff water was assumed to be the same as that of the surface water of the lake.

3.3 Calibration and verification

The model was calibrated with the data set of the open water season of 1980. The observed data of 22 May, 1980 was used as the initial data and the simulation was continued until Autumn. The initial values of some state variables, e.g. zooplankton, algae and detritus, had to be estimated because of the lack of observed data.

At the beginning of the calibration the values of the parameters were the same as those used in the simulation of Lake Päijänne. During the course of the calibration the values of the parametres were changed so that the model would respond to the observations carried out in the lake. The calibration procedure followed closely the procedure used earlier with this model (Kinnunen et al. 1982).

The calibration was carried out by trial and error, by changing the value of one or two parameters at a time and making a computer run. The computed and observed results were compared and if necessary new values were given to the parametres to improve the agreement between the simulated and observed values.

Temperature was calibrated first and after about fifteen computer runs the simulated values were in reasonably good agreement with the observed ones. After temperature simulation had been accomplished the other state variables were calibrated. Special attention was paid to the calibration of oxygen, nurients and to some extent of algae. However, the exact calibration of the two algal groups was not possible because of the lack of phytoplankton biomass observations. After about fifteen additional computer runs the model was considered to be calibrated to the case study lake.

Verification of the model was attempted with the corresponding data of 1981 using the same values for parameters as were used in the calibration. The agreement between the calculated and observed values was found to be poor and the model could not be considered verified. Therefore, values of five parameters were changed, after which the agreement was of the same order as in the calibration. The model was therefore in effect calibrated separately with the data sets of 1980 and 1981. The values of the parametres that were different in these two calibrations are presented in Table 3. This shows that the model is rather sensitive to the parameter values, because small changes in the parameters introduced considerable changes in the model output. Calibration results are presented in Figs. 2—8.

Table 3. Values of parameters having different values in the calibration runs with the data of 1980 and 1981.

Parameter	Parameter value in the calibration with the data of 1980	1981
Maximum diffusion coefficient	$3.0 \cdot 10^{-5}$	$3.0 \cdot 10^{-6}$
Phosphorus leaching coefficient	5.0	2.0
Phosphorus precipitation coefficient	0.015	0.15
Half saturation constant of phosphate phosphorus of algal group 1.	0.021	0.017
Half saturation constant of phosphate phosphorus for algal group 2.	0.021	0.017

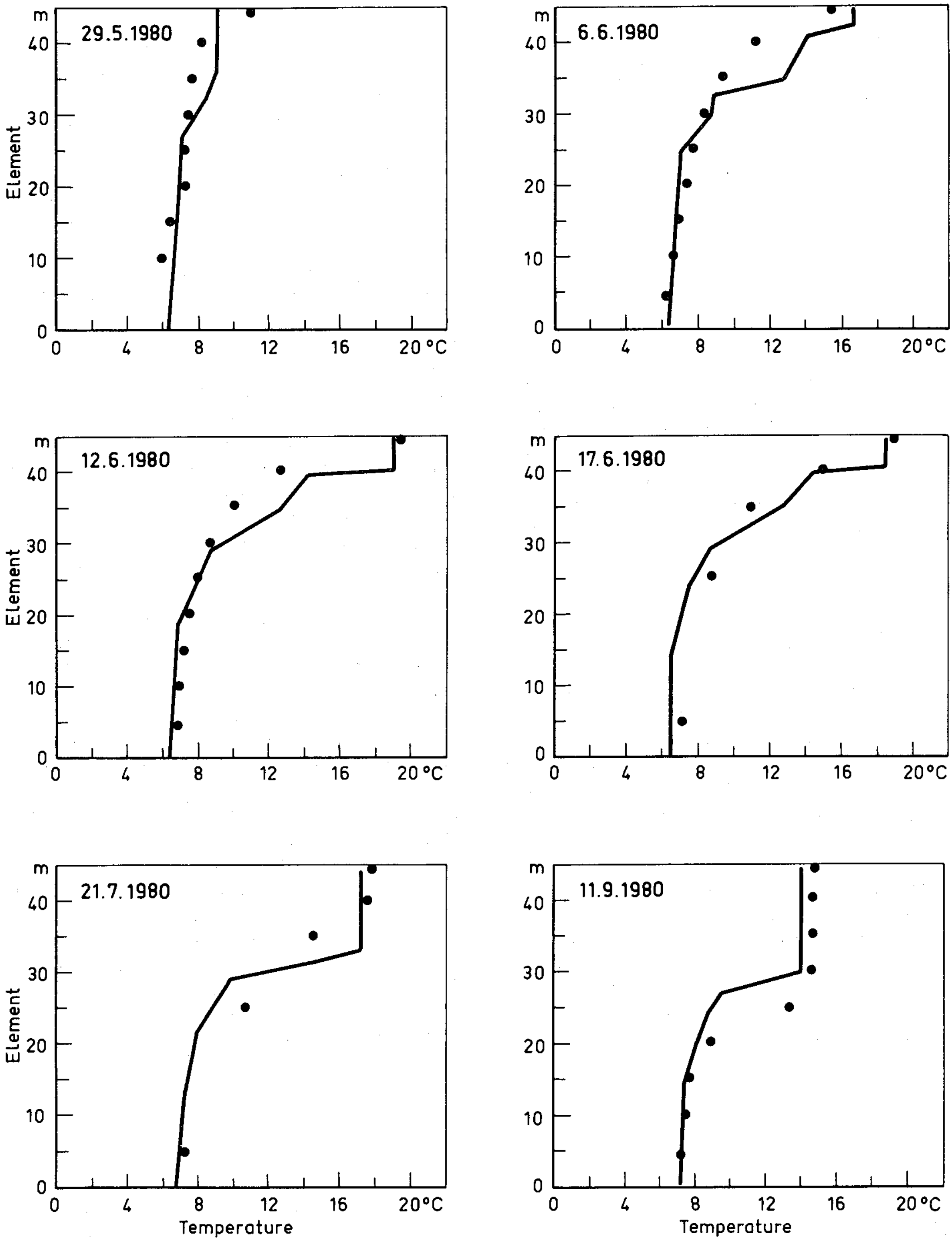

Fig. 2. Calibration results of temperature with the data of 1980.

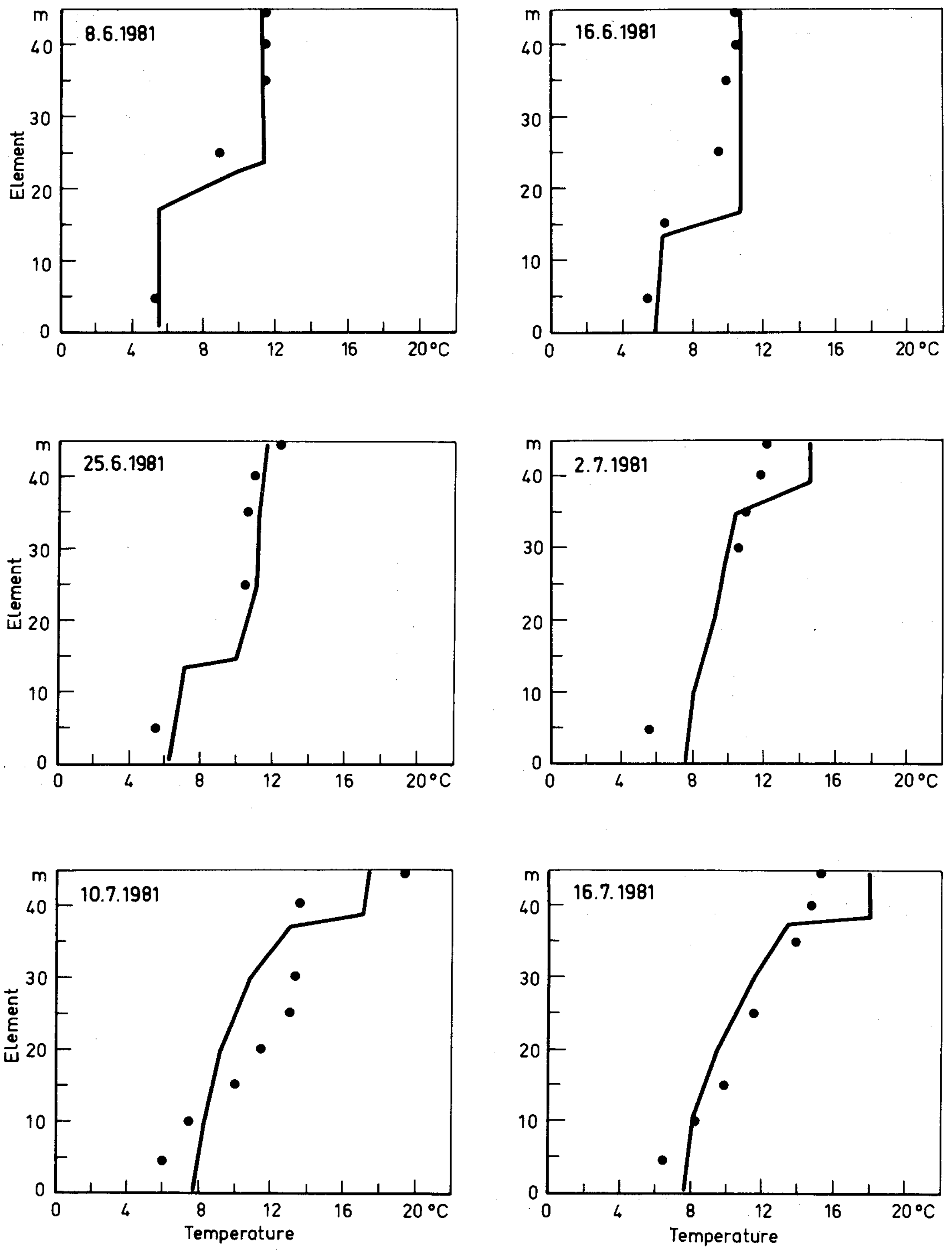

Fig. 3. Calibration results of temperature with the data of 1981.

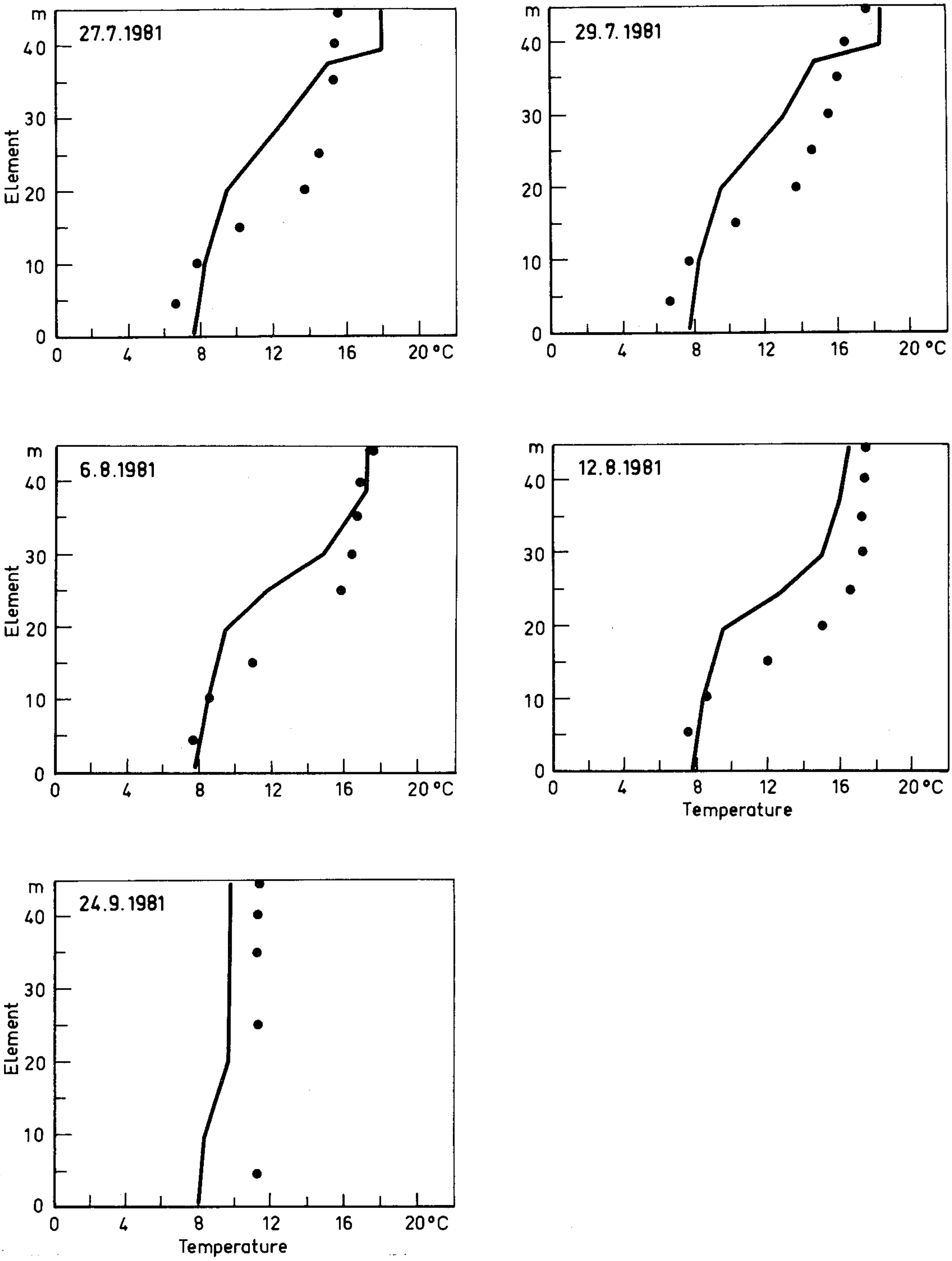

Fig. 3. Continued

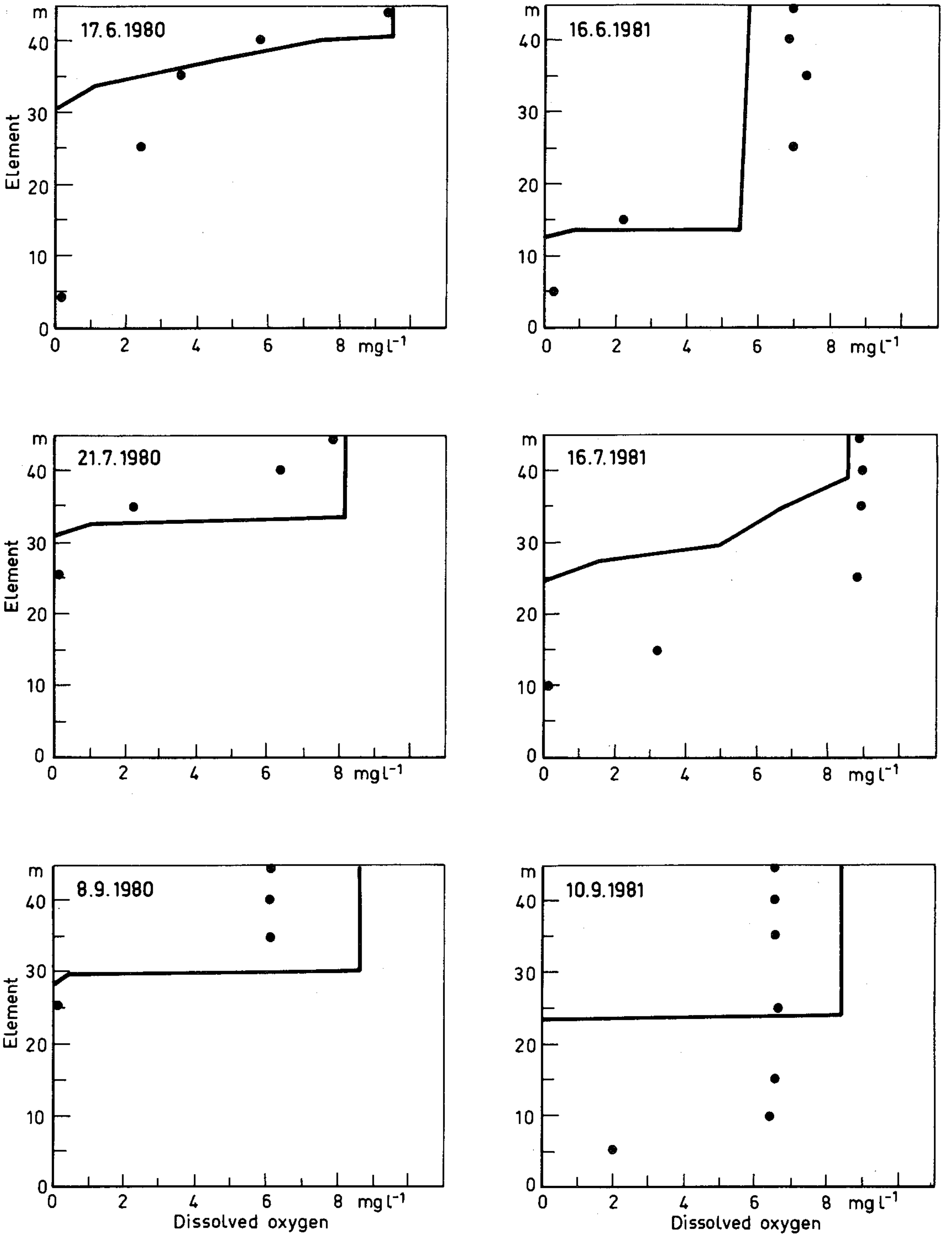

Fig. 4. Calibration results of dissolved oxygen with the data of 1980 and 1981.

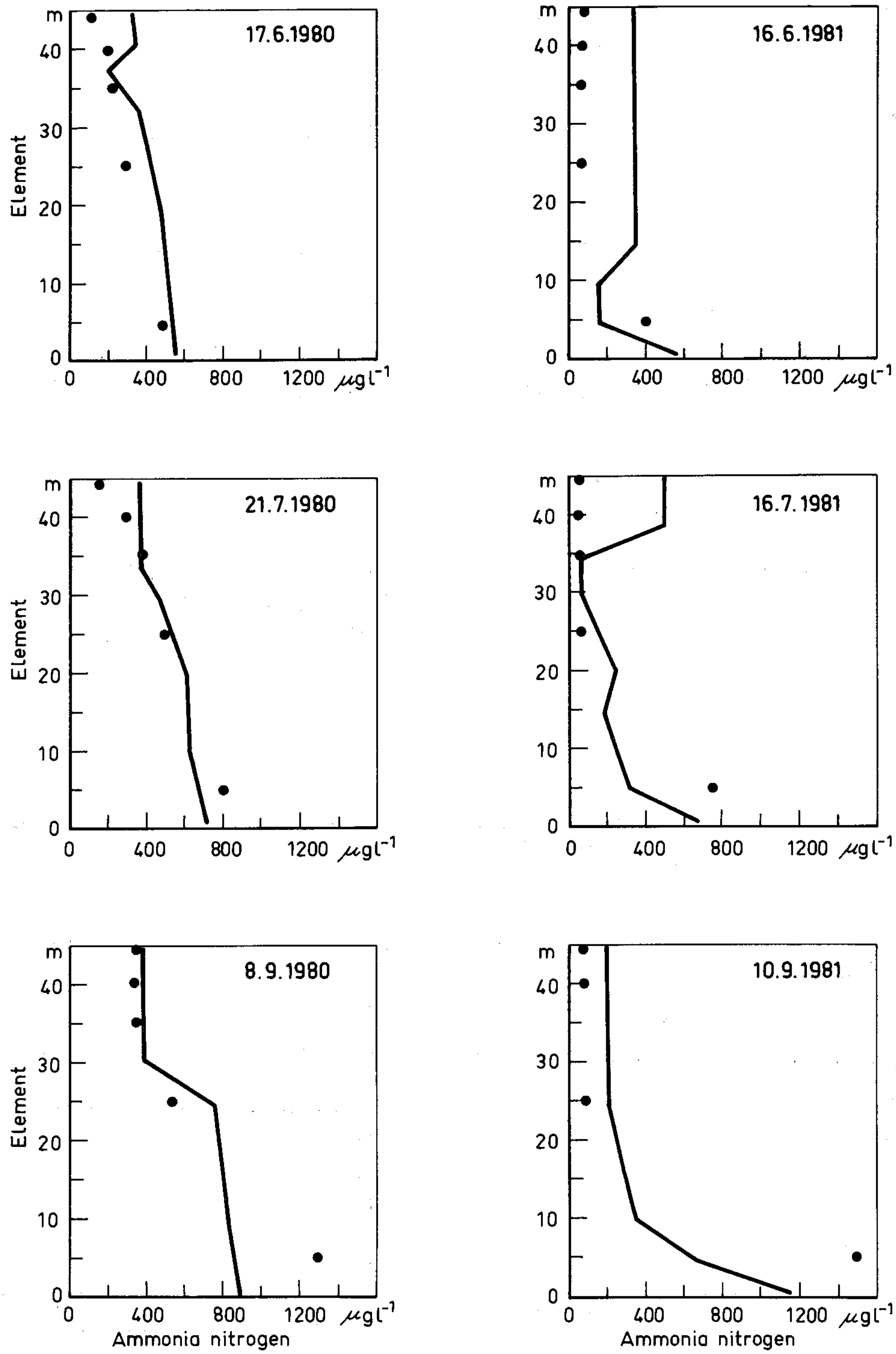

Fig. 5. Calibration results of ammonia nitrogen with the data of 1980 and 1981.

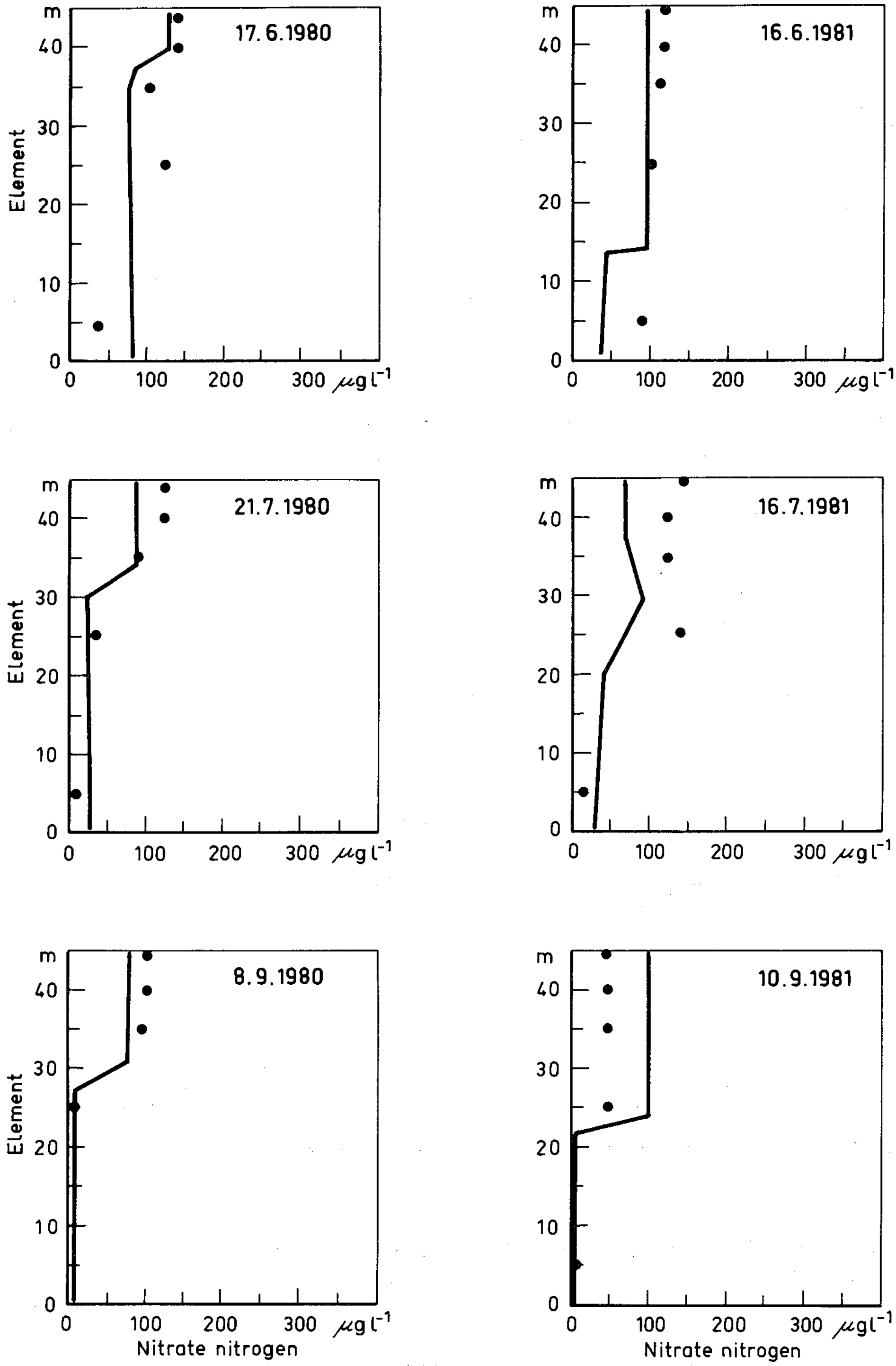

Fig. 6. Calibration results of nitrate nitrogen with the data of 1980 and 1981.

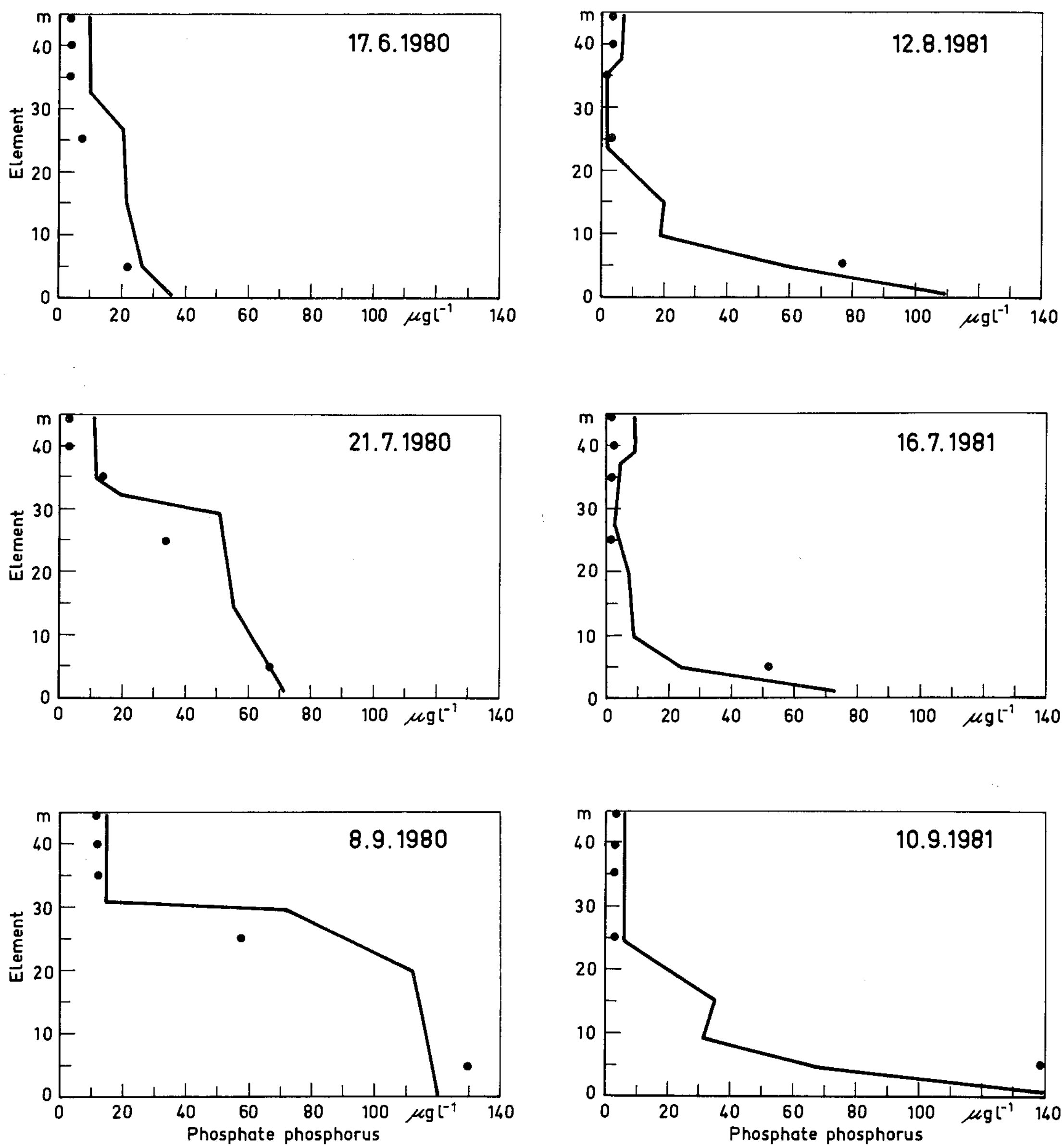

Fig. 7. Calibration results of phosphate phosphorus with the data of 1980 and 1981.

4. SENSITIVITY OF THE MODEL TO THE INPUT DATA

The values of the forcing functions must be given to the model once during every simulation time step, the length of which can be selected. In this application the length of the simulation time step was eight hours. The observations of the water quality and quantity of the tributary, wastewater treatment plants, diffuse loading and loading entering the lake through precipitation are carried out at much longer time intervals and interpolation of the observations is necessary in order to obtain data for each eight hour time step. In preparing the input data from observations, various computer programs other that that of the model must be used. This increases considerably the time and computer resources necessary for obtaining the data. If the time inter-

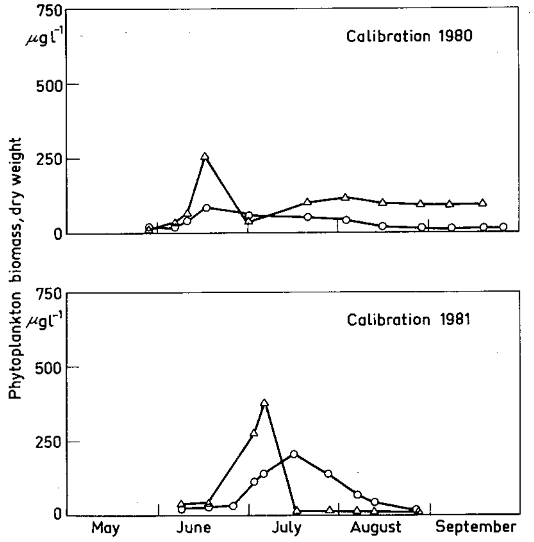

Fig. 8. Calibration results of phytoplankton biomass with the data of 1980 and 1981.

Table 4. Combinations of tributary data and meteorological data used to test the sensitivity of the model to the input data.

Run No	Data	Frequency of giving of input data		
		Once every 8 hours	Weekly average	Monthly average
1.	Tributary data	+		
	Meteorological data		+	
2.	Tributary data	+		
	Meteorological data			+
3.	Tributary data		+	
	Meteorological data	+		
4.	Tributary data	+		
	Meteorological data			+
5.	Tributary data		+	
	Meteorological data		+	
6.	Tributary data			+
	Meteorological data			+
Calibration run	Tributary data	+		
	Meteorological data	+		

val of giving the input data could be increased e.g. to weekly or monthly average values the application of the model would become easier.

The sensitivity of the model to variations in the input data was tested by making six computer runs with different sets of input data. In these runs the tributary data (including the water quality and quantity of the tributary, wastewater treatment plants, diffuse load and precipitation load) and meteorological data were given to the model in various combinations of weekly or monthly averages (Table 4).

The results of these six computer runs were compared with the results of the calibration run, in which the input data was given to the model every eight hours. It was found that the results of the runs 1,2,3 and 4 were approximately equal to those of the calibration run. The results of the runs 5 and 6 presented in Figs. 9—14, were also close to the results of the calibration run.

5. DISCUSSION

Water bodies are complex ecological systems affected by a great number of interacting processes. Models, which are mathematical representations of such systems, are abstract and imperfect in comparison with the real ecosystems which they are intended to represent. Even the most complex of models can include only a fraction of all the important reactions of a water body. Therefore at the present stage of model development a model can never simulate a water body accurately in all conditions.

Models are often evaluated according to three basic properties, namely realism, precision and generality (Walters 1971). By realism is understood how well the mathematical equations of the model correspond to the reactions occurring in nature. Precision implies how accurately the model produces the data on which it is based, while generality is the range of applicability of the model. Consequently, a model cannot include these three properties to an equal extent. Typically, models can be built by paying attention to some of these properties. For example if the objective of modeling is to attain understanding of the aquatic system it is more important that the model is capable of showing the direction of research than that its numerical precision should be high. On the other hand if the objective of the model is to develop a tool for water management, precision is generally the goal and the same attention is not given to realism and generality.

In the present application the objective was to apply a model in order to assess its suit-

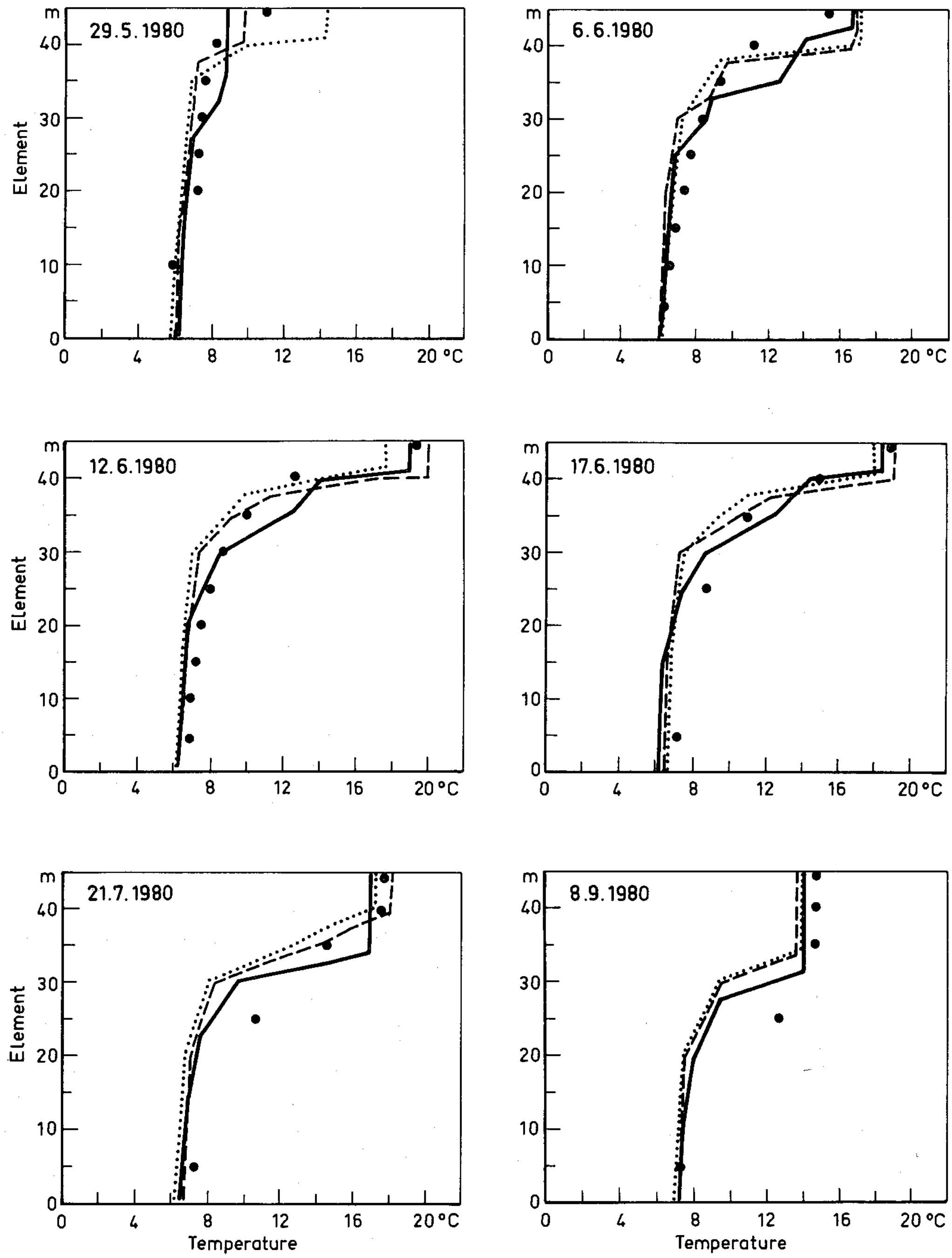

Fig. 9. The effect of input data on simulated temperature results.
● = observations
—— = calibration run of 1980, input data given once every eight hours
– – – = input data given as weekly averages
• • • = input data given as monthly averages

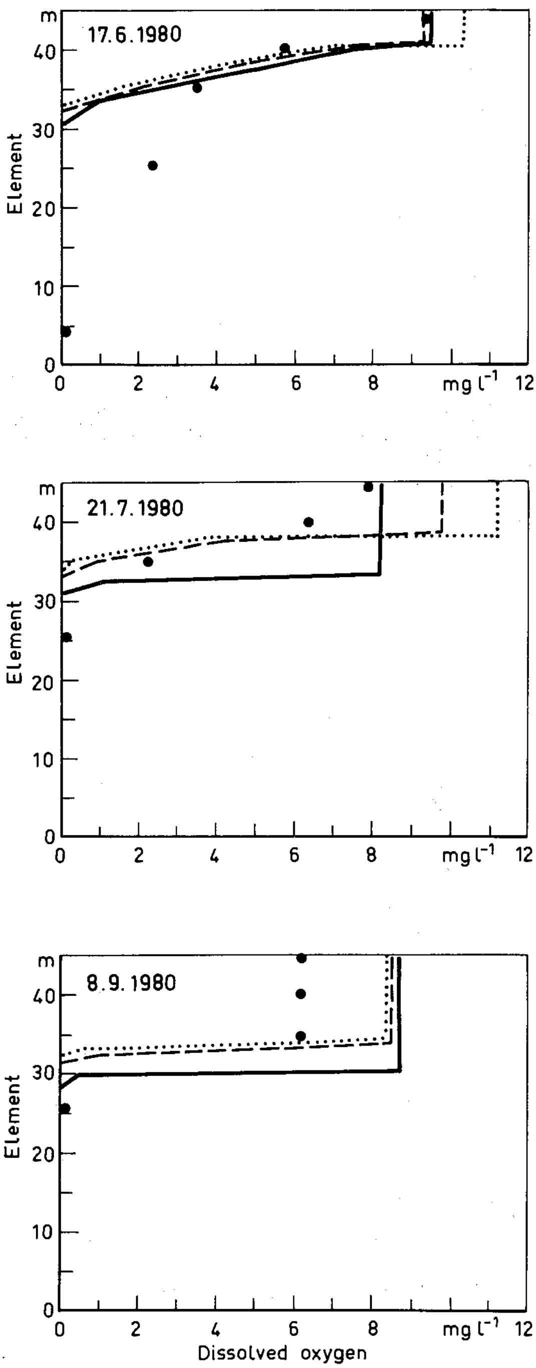

Fig. 10. The effect of input data on simulated dissolved oxygen results
- ● = observations
- —— = calibration run of 1980, input data given once every eight hours
- - - -= input data given as weekly averages
- . . . . = input data given as monthly averages

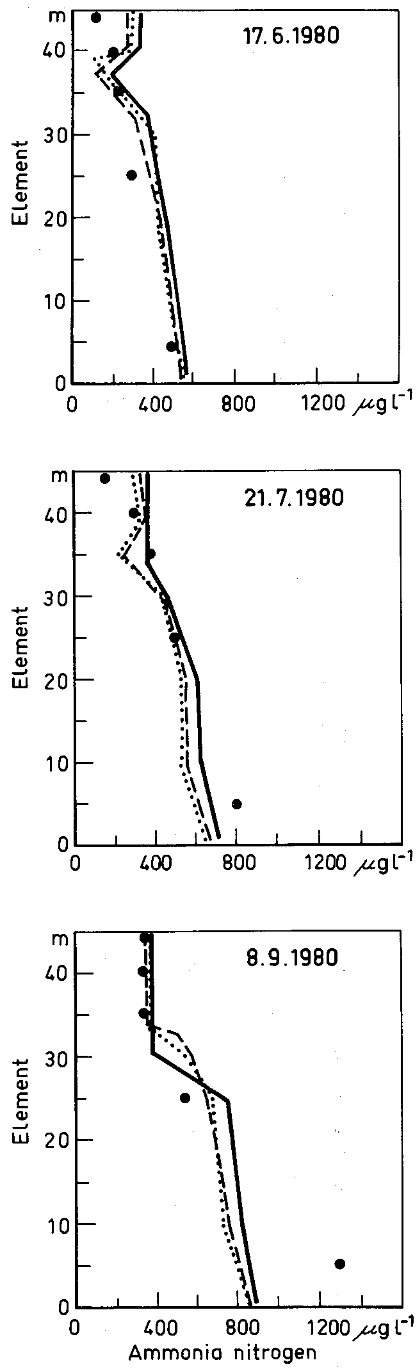

Fig. 11. The effect on input data on simulated ammonia nitrogen results.
- ● = observations
- —— = calibration run of 1980, input data given once every eight hours
- - - - = input data given as weekly averages
- . . . . = input data given as monthly averages

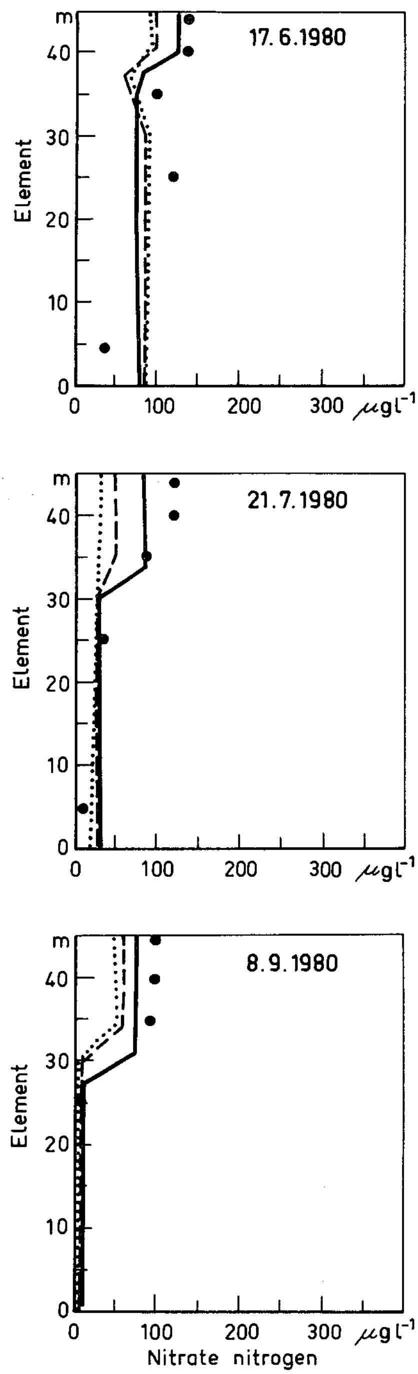

Fig. 12. The effect of input data on simulated nitrogen results
● = observations
—— = calibration run of 1980, input data given once every eight hours
- - - = input data given as weekly averages
· · · · = input data given as monthly averages

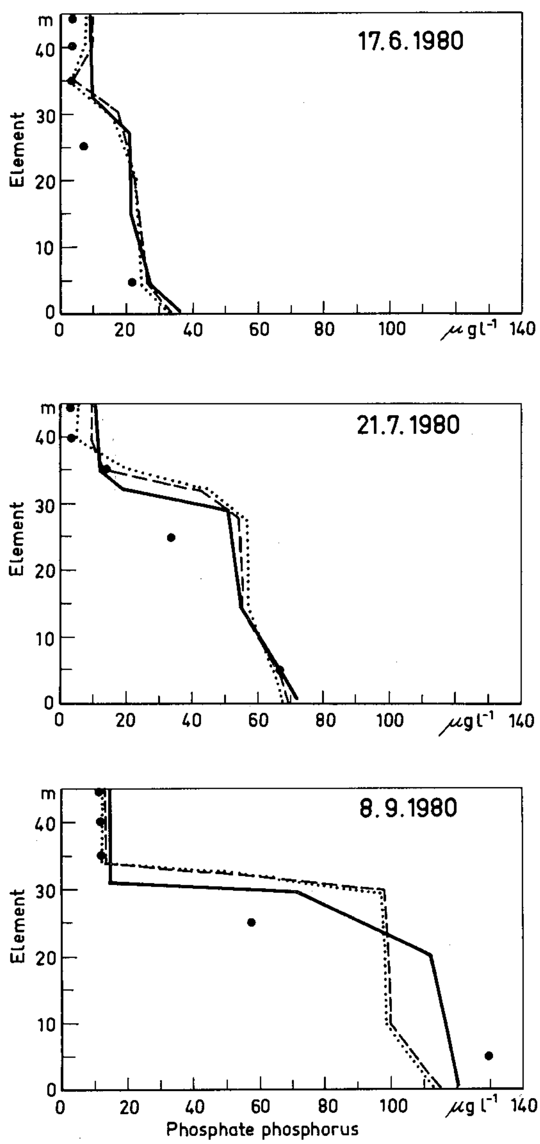

Fig. 13. The effect of input data on simulated phosphate phosphorus results
● = observations
—— = calibration run of 1980, input data given once every eight hours
- - - = input data given as weekly averages
· · · · = input data given as monthly averages

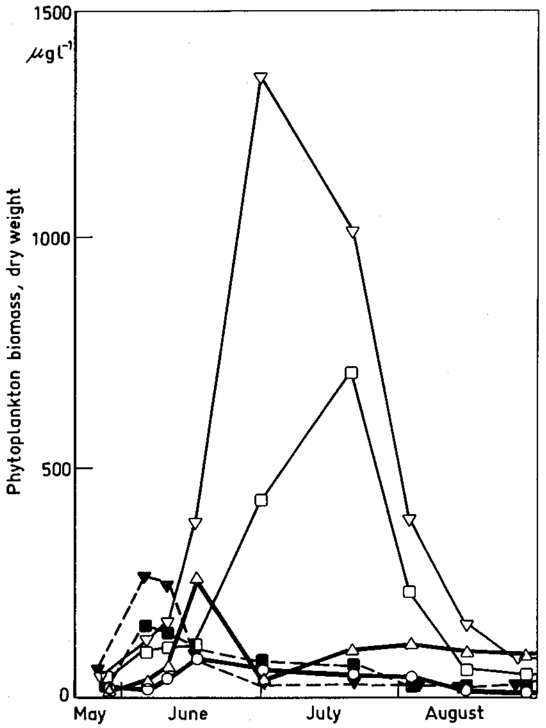

Fig. 14. The effect of input data on simulated phytoplankton results
○—○ = algal group 1, calibration run of 1980 input data given once every eight hours
△ – △ = algal group 2, calibration run of 1980, input data given once every eight hours
□ –□ = algal group 1, input data given as weekly averages
△ ▬ △ = algal group 2, input data given as weekly averages
▽ – ▽ = algal group 1, input data given as monthly averages
▼ – ▼ = algal group 2, input data given as monthly averages

ability for predictive purposes. Therefore, the main emphasis was placed on the numerical precision of the model, and calibration was continued until the model gave the best overall agreement with the observations.

Finnish watercourses typically consist of chains of lakes which are in contact with each other through straits or rivers. In lake modeling it is therefore sometimes difficult to specify the case study area and the natural boundaries of the lake. This problem was also encountered in the present study. Specification of the case study area was carried out on the basis of morphological characteristics of the lake as well as of flow measurements. No measurements of the output discharge from the case study area were available, and the discharge had to be calculated. The main features of the case study area are rapid flow through the lake, i.e. short detention time and consequently weak temperature stratification, high input of nutrients through tributaries and wastewater treatment plants, high nutrient concentrations and anaerobic hypolimnion. The effect of bottom sediments on water quality is considerable, particulary during the anoxic period which lasts typically from June to August. Occurrence of unequally distributed flows can cause considerable horizontal variations in water quality. All these features make this lake difficult for modeling work.

The data for running the model, especially the values concerning some state variables should ideally have been observed more frequently, i.e. the biomass values of phytoplankton were totally missing from the calibration and verification years. In preparing the data concerning meteorology, hydrology, tributaries and wastewater treatment plants, interpolation had to be used. Frequent use of interpolation introduces an error, but is inavoidable in this type of work. Estimation of the diffuse loading data was based on the investigation of Kauppi (1979). This method is an efficient of means of calculating diffuse load but requires measurements of field percentages of the drainage basin, which had to be estimated.

Despite the shortcomings in observation frequency discussed above, the data can in general be considered adequate for this type of application and is seldom more accurate in ecological modeling. This implies therefore that the applicability of the model for this case study lake is not primarily a question of the adaquacy of available data.

Calibration of the model was carried out using a trial and error method, i.e. by making a computer run and comparing the simulated and observed results, changing the values of one or two parameters at a time and making a new run. Altogether 46 runs were needed to produce the presented results. The observation of the sensitivity of the model made during its earlier application (Kinnunen et al. 1982) was verified in this application. The sensitivity of the model to various parameters e.g. half saturation constants, decay rates of nutrients, growth rates and temperature correction rates is obvious. It is also evident that it is difficult to obtain laboratory or field measurements of the correct values of parameters. The number of parameters that can be calibrated in the model is about one hundred for only some of which are recommended values available in the literature. Consequently the number of parameters that has to be mainly estimated by calibration remains large and the correct combination of parameters for producing the best fit with the observations, if such a combiantion exists, is hard to find. Seeking this combination requires several computer runs and considerable computer resources as well as some intuition on the part of the user.

In every model there are certain parameters which have a paramount effect on the behaviour of the model. In this model these are the parameters affecting advection and diffusion. If these parameters are not at the correct level the model does not produce the observed results with any combination of the remainder of the parameters. Therefore in the calibration of the FINNECO model it is important first to calibrate the temperature stratification and water stage of the lake. After this has been accomplished attention can be directed to the calibration of the other state variables. Strict division of the order of calibrating the other state variables cannot be given. The concentrations of nutrients and phytoplankton biomass are closely interrelated and they must be calibrated simultaneously, while the calibration of some other state variables such as coliforms, sodiumlignosulphonate and total dissolved solids can be calibrated separately because other state variables are not affected by them.

Calibration by the trial and error method is not rewarding because there are no definite limits or criteria according to which the calibration should be finished. The user tends to think that the next parameter combination may give even better results, as is sometimes the case, and calibration continues, leading sometimes to better agreement but sometimes giving poorer results. It is therefore important to recognize the stage at which the agreement between the model output and observations is reasonably good and to stop modeling.

In this work the model was calibrated with the data of 1980 and gave reasonably good results. However, verification could not be obtained with the calibrated model using the data of 1981. After changing the values of five parameters the agreement between the simulated and observed results was as good as in calibration. This shows that the model is not capable of accurately simulating such a dynamic system as the present case study lake. On the other hand it also shows that the structure of the model is quite good in representing the real lake because only five parameters out of about one hundred had to be changed.

Methods for estimating parameters in ecological models have been presented e.g. by Lewis and Nir (1978), Benson (1979 and Jørgensen et al. (1981). Evaluation of the problems encountered in modeling complex aquatic systems has been presented e.g. by the Canada Center for Inland Waters (1979), by Simons and Lam (1980) and by Fedra et al. (1981).

The test in which the effect of input data on the simulated results was investigated yielded important information. It was found that giving the meteorological data and the quantity and quality of all inflowing waters such as tributaries, wastewater treatment plants, diffuse loading and precipitation as weekly or monthly averages gave nearly as good results for most of the state variables, except for phytoplankton biomass as were obtained by giving these data once during every eight hours. This implies that gathering the input data for the model becomes easier and does not require as much computer time as was needed erlier. The slight difference between the simulated results with these two sets of input data could be decreased by calibration. However in the present work the model was not calibrated using weekly or monthly input data.

It must be pointed out that part of the tributary input data for every eight hour time step was obtained by interpolation on the basis of measured weekly or monthly averages. Therefore the precision of this set of input data does not correspond to the data input frequency. Meteorological data, on the other hand, was originally obtained as hourly or daily averages. However, this experiment shows that the lenght of the time step could be increased from eight hours. This should decrease the time needed for preparing the input data and reduce computer costs.

Is the FINNECO model suitable for making prognoses of the water quality of the modeled lake? This application shows that at present it is not suitable for this purpose in this lake. However, application of the model to this lake with complex hydrology and high nutrient concentrations gives valuable information concerning the suitability of the complex model to the simulation of water quality and introduces some of the problems that are encountered. In an earlier application of the FINNECO model better results were obtained (Kinnunen et al. 1982). In that study, however, the area investigated was more stable, with only minor variations in water quality and therefore the model gave better numerical accurracy. Additional case studies are needed in order to again more information concerning the suitability of the FINNECO model to various types of lakes.

ACKNOWLEDGEMENTS

Jorma Niemi gathered the necessary data for running the model, calibrated it and wrote this paper. Juhani Eloranta operated the computer program of the model and wrote various programs for preparing the required data sets.

We would like to thank the personnel of the Tampere Water District Office, especially limnologists Jaakko Keränen and Kirsti Krogerus, for carring out special field investigations for obtaining the necessary data for the application of the model. Further, we would like to thank the head of the Tampere Water District Office, Altti Luoma, for encouragement during the course of this work. We are grateful to Mr Michael Bailey for revising the English of the manuscript.

Helsinki, February 1983

Jorma Niemi, Juhani Eloranta

LOPPUTIIVISTELMÄ

FINNECO malli on yksidimensioinen veden laatua simuloiva malli, joka kehitettiin vesihallituksen ja Oy Suomen International Business Machines Ab:n välisessä yhteisprojektissa vuosina 1978—1981. Malli soveltuu järvien ja tekoaltaiden veden laadun simulointiin. Järvi tai tekoallas oletetaan mallissa horisontaalisuunnassa homogeeniseksi, joten ero veden laadussa ilmenee ainoastaan vertikaalisuunnassa. Mallin simuloimat tilamuuttujat ovat: lämpötila, liuennut happi, biologinen hapenkulutus, alkaliniteetti, pH, epäorgaaninen hiili, epäorgaaninen sedimentti, hiilidioksidi, ammonium-, nitriitti- ja nitraattityppi, fosfaattifosfori, epäorgaanisen sedimentin fosfori, hygieniaindikaattori, natriumlignosulfonaatti, kasviplankton ja eläinplankton. Mallin ulkoisia muuttujia ovat säätiedot sekä simuloitavaan järveen laskevien vesien kuten jokien, jätevedenpuhdistamoiden, sateen ja hajakuormituksen määrä- ja laatutiedot. Mallissa otetaan huomioon tuulen vettä sekoittava vaikutus ja se soveltuu myös talvikauden simulointiin. Mallia sovellettiin Tampereen Pyhäjärveen avovesikausina 1980 ja 1981. Pyhäjärvi on läpivirtausjärvi, johon kohdistuu eri tyyppistä jätevesikuormitusta. Kuormituksesta johtuen veden laatu on heikko, ravinnepitoisuudet ovat korkeita ja alusvedessä vallitsevat ajoittain hapettomat olosuhteet. Kohdealue asettaa suuret vaatimukset sovellettavalle mallille.

Malli kalibroitiin vuoden 1980 tiedoilla. Noin 30 tietokoneajon jälkeen lasketut ja havaitut tulokset vastasivat toisiaan tyydyttävästi. Malli yritettiin verifioida kalibrointiajon parametrikombinaatiolla ja vuoden 1981 vastaavilla tiedoilla, mutta malli ei verifioitunut tyydyttävästi. Muutettaessa viiden parametrin arvoa saatiin myös tällä aineistolla kohtuullisen hyvä yhteensopivuus laskettujen ja havaittujen arvojen välille. Tämä viittaa siihen, että mallin rakenne jäljittelee tyydyttävästi ekosysteemin toimintaa, sillä mallissa on kaikkiaan kalibroitavia parametrejä noin 100. Mallia voidaan tällä hetkellä pitää kalibroituna Pyhäjärveen kahden eri vuoden aineistolla, mutta ei verifioituna. Kaikkiaan mallilla tehtiin tässä työssä 46 tietokoneajoa.

Lisäksi tutkittiin mallin herkkyyttä ulkoisille muuttujille, antamalla niiden arvot mallille kahdeksan tunnin välein, viikkokeskiarvoina ja kuukausikeskiarvoina. Havaittiin, että mallilla saadaan käytännössä lähes yhtä tarkat tulokset antamalla ulkoiset muuttujat kuukausikeskiarvoina, lukuunottamatta kasviplanktontuloksia. Jos ulkoisten muuttujien arvot annetaan mallille harvemmin kuin kerran kahdeksassa tunnissa se helpottaa mallin vaatimien tietojen muokkausta ja säästää tietokoneaikaa.

Pyhäjärvi osoittautui vaikeaksi soveltamiskohteeksi mallille, eikä malli toiminut siinä niin hyvin kuin Päijännesovellutuksessa (Kinnunen et al. 1982). Tulokseen vaikuttavat mm. järven virtausolosuhteet, hapellisten ja hapettomien vesimassojen vaihtelu, heikko lämpötilakerrostuneisuus sekä altaasta pois virtaavan vesimäärän arvioiminen. Sovellutus osoitti, että malli jäljittelee tyydyttävästi luonnon ekosysteemin toimintaa, mutta että sen numeerinen tarkkuus ei ole riittävä tällä kohdealueella.

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