AIMS AND EXAMPLES OF WATER QUALITY MODELING IN THE GERMAN DEMOCRATIC REPUBLIC

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GENERAL REMARKS

In all European states the annually available mean recovered water resource per inhabitant is about 2000 m^3/year or even more. In the GDR, however, it only amounts to some 900 m^3/year. Approximately half of this quantity is actually available for utilization. Thus, the natural yield of water is very limited and an extensive expansion of water supply is impossible. About 75% are taken from surface waters and 25% from the ground water. During dry months the multiple use of water increases to the factor 3 ... 4 in areas where industry and population agglomerate.

The growing demand of water by population, agriculture and industry can be met only by an intensification of the utilization of the water resources, that is by

- the installation of further reservoirs,
- the reduction of the specific water use (in relation to the unit of production) of the industry by transforming the production processes,
- incorporating the agricultural and forestry waste water utilization into the waste water treatment,
- the improvement of the quality of water in rivers and, especially, by the reduction of the degree of eutrophication in the lakes and reservoirs.

This demands further intensification of waste water treatment and effective use of fertilizers in agriculture. But we cannot hope to manage the water resources in a rational way unless we understand the relationships between the amount of water used by man, the input from man into ground and surface water and the resulting ecosystem response, especially the resulting water quality of rivers, lakes, reservoirs and aquifers.

Today, the scientific investigation of these problems is characterized by water quality modeling, i.e. by the development or improvement of mathematical models

- describing the chemical, biological and physical interactions of the components of the aquatic ecosystem,
- quantifying the changes in dispersion and decomposition of different types of waste water discharges,
- evaluating the energy fluxes and the cycling of matter within the ground water or surface water bodies,
- allowing for the control and operating of ground water resources,
- allowing for the short-term control and long-term strategy of river basins and reservoir systems.

Modeling aims at shifting attention from the symptoms to the causes, at investigating the stability of structures, at exploring some of the ecological consequences of man's impact on water resources. In spite of the fact that our knowledge of the complex mechanisms of aquatic ecosystems still is and, probably, will remain imperfect, we have to increase our level of scientific understanding and insight into these processes as quickly as possible so that those faced with making decisions about water resources control procedures always will have at hand the most up to date level of understanding of the cause-and-effect mechanisms in this complex system.

The research on water quality modeling is in full accordance with the Charter of IIASA:

a) These investigations are characterized not only by inspiring the development of scientific methodology but also by offering significant *"applied" problems*, the solution of which will contribute to the effective operation and protection of water resources.

b) Water quality modeling is the task of *interdisciplinary* teams joining together knowledge and experience from hydrochemistry, hydrobiology, hydrophysics, technology, cybernetics etc.

c) Water quality modeling demands studies which focus at the interrelationship between the components of a very complex system. Therefore, the experience and the solid base of competence of IIASA in the field of *applied systems analysis* should be used for the further development of modeling the water quality.

d) Furthermore, IIASA offers excellent possibilities for the international exchange of scientific information on water quality modeling and for international scientific cooperation in this field. The quickly growing demand for water in all countries calls for the acceleration of scientific research. We shall be successful only if we use all the possibilities of multilateral comparison and assessment of methodology and results, if we succeed in systemizing the knowledge available all over the world, if we prevent duplication of efforts in various countries, and if we take advantage of the multiplying effect of internation scientific cooperation--here at IIASA and within the frame of a collaboratory research network.

e) The water resources in many regions of the world are threatened by eutrophication and pollution as the result of

- improper use of agricultural fertilizers,
- release of waste waters from industrial enterprises,
- impact of pesticides and herbicides,
- release of municipal waste waters,
- urban refuse disposal etc.

The elaboration of methods for tackling the problem of water quality management will be of significance to practically all countries. Therefore, water quality modeling is a *"universal"* task.

f) Water quality modeling is concerned with very complicated problems connected to and generated by urbanization, development of the standard of living, spread and intensification of industry and farming. Thus, the modeling of water resources systems will involve *technical as well as social and economic components*. We shall have to ensure the cooperation of hydrologists, mathematicians and technologists and also to bridge the gap between natural and social scientists. Surely, IIASA can very efficiently contribute to the solution of these types of problems. Several Research Projects or even Research Areas of IIASA may be included.

WATER QUALITY MODELING

Control of the Salt Load of Rivers

The hydrochemical conditions prevailing in surface waters are the result of processes taking place in the catchment areas. We have to distinguish physiogenic processes (e.g. salt immigration) and anthropogenic processes (e.g. salty sewage water influx). Since the continuous production of potassium is of great importance for the national economy of the G.D.R., the potash industry located in the "Südharz" potash district has been permitted to pass about 48.5 million m^3/year of salty sewage waters into the rivers Wipper/Unstrut. To ensure a maximum value of 40^o dH total hardness at a draw-off cross-section of the Saale-River (Figure 1), the industrial salt load in the Unstrut-Saale region has been systematically controlled since 1963 by

- precalculating the possible flow rate of salty sewage water in CaO (kg s^{-1}) as a function of the rate of streamflow in the rivers,

- precalculation of the diluting water ($m^3\ s^{-1}$) required from the Saale storage reservoir system to avoid a total hardness greater than 40° dH at the draw-off station.

System theory (convolution operation) is used to model the processes inclusive of the salt immigration (incontrollable salt/ sewage water influx, underground infiltration, subsurface chemical flow, base flow). The model has been developed and is used by the Institute of Water Management and the Water Board, Halle.

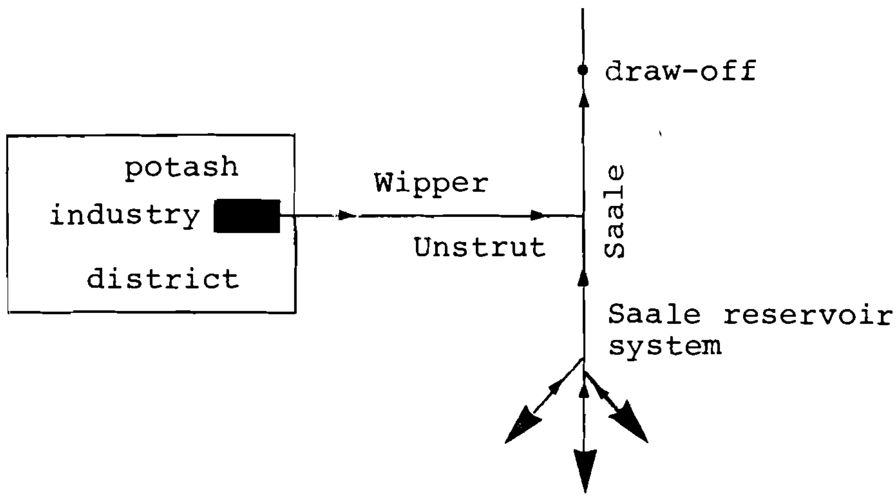

Figure 1.

Thermic Load on a Lake System

The use of surface water for cooling in a nuclear power station interferes with the natural balances of heat, water and matter by the rise in temperature, evaporation and biological productivity. The most thorough investigations in the G.D.R. have been carried out on the Stechlinsee system (Fig.2). The lakes, Stechlinsee and Nehmitzsee, were tested under natural conditions (1957-1965) and after a 70 MW nuclear power station had been started (1966). Water is drawn from the Nehmitzsee, used for cooling in the nuclear power station, and rechanneled into the western basin of the Stechlinsee, from which place it flows back to Nehmitzsee.

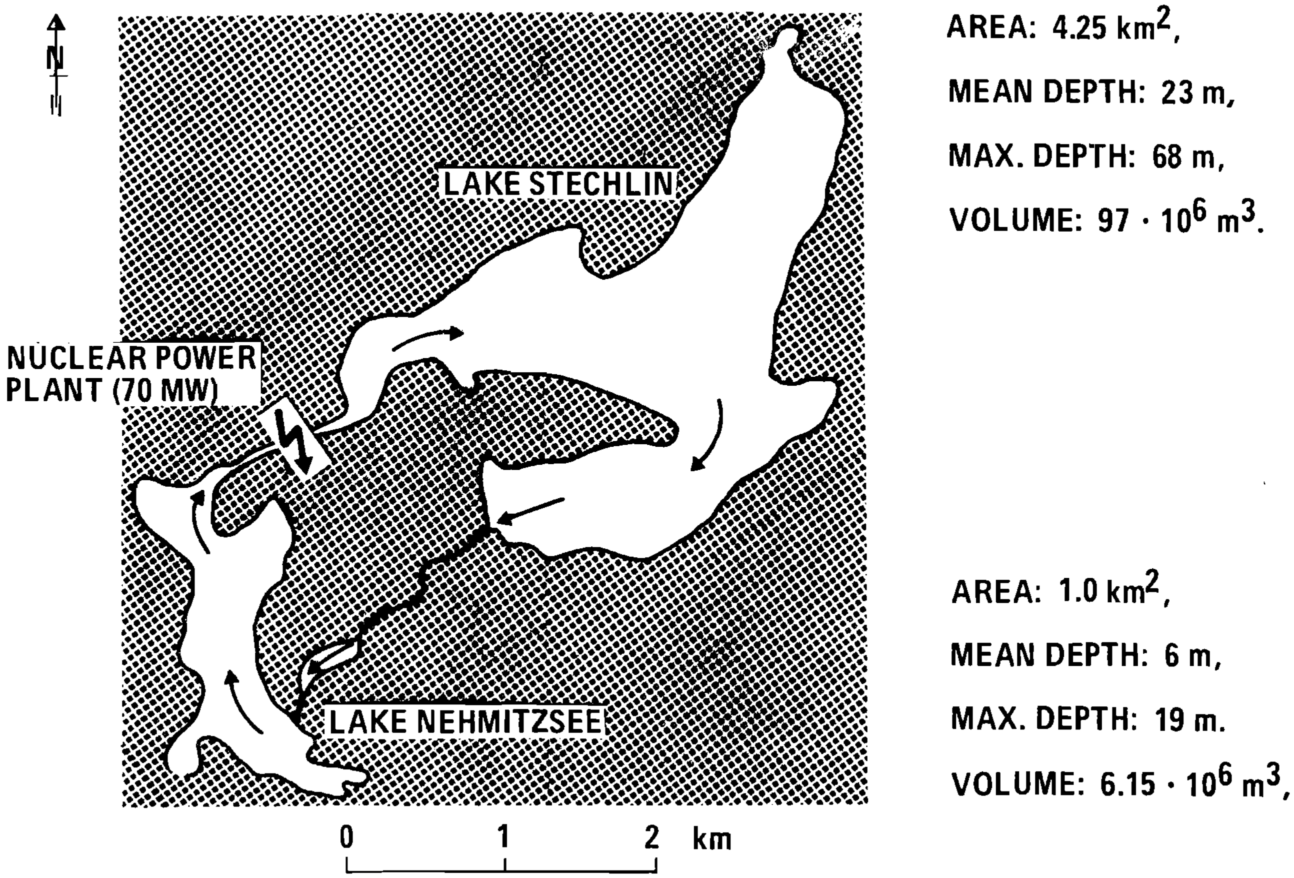

Figure 2. The Stechlinsee System

The average flow intensity is 350,000 m^3/day. The difference between the inflow and outflow temperatures is about 10 K. Most of the heat is released into the atmosphere. The average anthropogenic heating of Lake Stechlin is in the order of 2 K, in the hypolimnion 0.6 K. The biological productivity increased considerably. The quality and the quantity of the phytoplankton and benthos communities changed. In spite of definite signs of eutrophication Lake Stechlin has kept its oligotrophic character.

The following hydrophysical and limnological investigations have been performed (partly by the Research Institute of Hydrometeorology of the Meteorological Service of the GDR, partly by the Academy of Sciences of the GDR):

- Heat balance of the Lake Stechlin, temperature field, vertical exchange between epi- and hypolimnion,
- change of the optical conditions (transparency),
- the decrease of the ice cover of the lakes,
- the hypolimnion oxygen content,
- the phosphate storage capacity of the sediments in the lakes,
- the change of the dynamic regime of the primary production processess, especially the intensification of the phytoplankton growth in the upper layers, the spring bloom of phytoplankton and the appearance of new species,
- the zooplankton and zoobenthos,
- the qualitative and quantitative shifts of the macrophythe community, etc.

The construction of a comprehensive model taking into account the temperature, the water circulation, the nutrient-phytoplankton interactions, etc., would provide a solid basis for the deeper understanding and for the management of systems of this type.

Darß-Zingst Bodden Chain

The Darß-Zingst bodden chain is seperated from the Baltic Sea by a narrow strip of land (Fischland, Darß, Zingst) in the north of the GDR. The chain consists of distinct basins (Saaler Bodden, Bodstedter Bodden, Barther Bodden, Grabow) and opens into the Baltic Sea at Pramont. Its length amounts to 55 km, its area to 197 km^2. The average depth is 1.7 m, the mean total water volume 342.10^6 m^3. In accordance with the definition of the term "estuary" by Bowden (1962), the chain of boddens may be considered as an example of an estuary. Tides do not play an important role (Fig. 3).

The water balance is influenced by the exchange of water with the Baltic Sea and by the inflow of water from the mainland. The brackish water in this chain is of the type oligohaline to mesohaline as the salinity increases from 1‰ up to 7‰ towards the Baltic Sea (off-shore value 9...12‰). The bodden chain

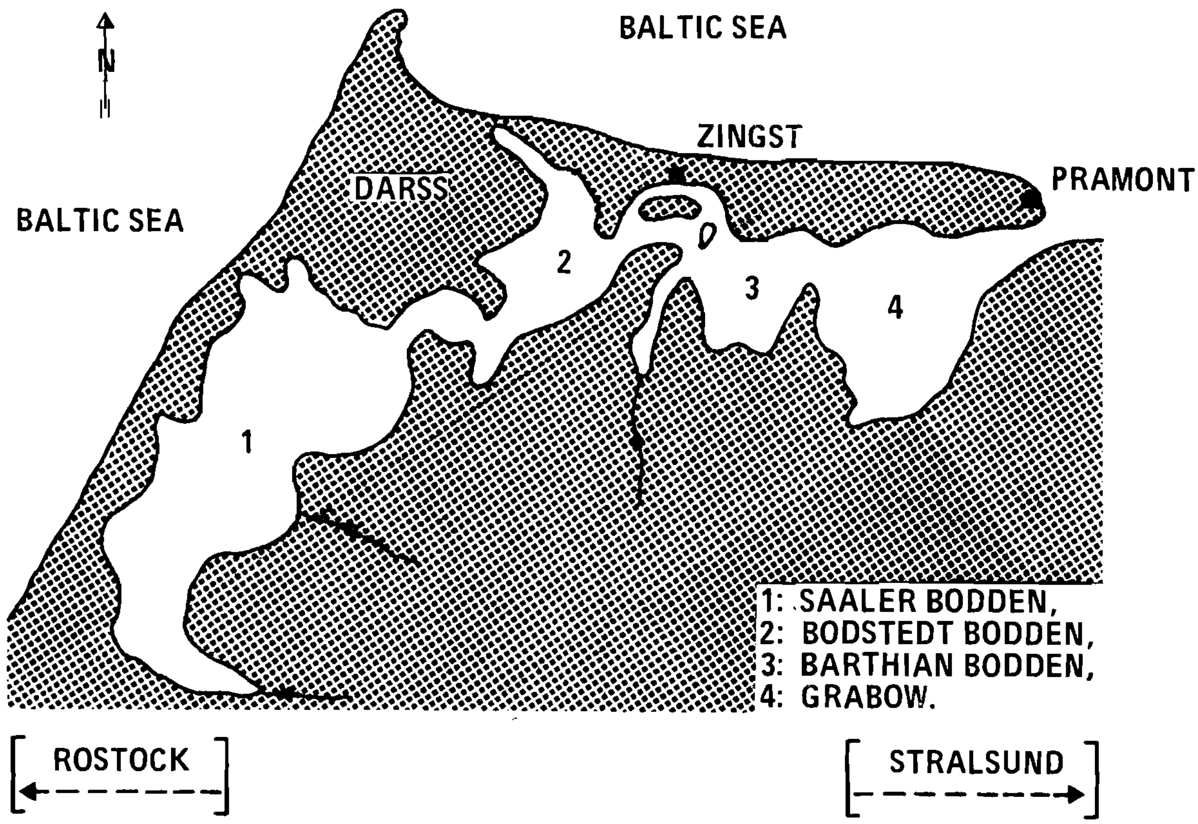

Figure 3. The Darß-Zingst Bodden Chain

annually receives about 1.7 g phosphorus and 6.8 g nitrogen per square meter of surface. The main part of these nutrients enters with the "fresh waters" from the mainland into the "inner" part of the chain. Thus, the nutrient concentrations and the annual production of phytoplankton decreases from the inner part of the chain (7300 g m^{-2}) to the open sea (800 g m^{-2}). Also the gradient of the organic content of the bodden sediments (determined by measuring the weight loss by burning at 550 °C) points in this direction. (Dry weight 30 percent in the inner part, 4 percent at Pramont.) In all parts of the bodden chain the sediments can be categorized into a "mineral complex" (dry weight $\leq$ 5 percent) and into a "mud complex", within which the organic matter content is greater than 5 percent and may exceed 40 percent of the dry weight. The binding and mobilization of nutrients in the sediments play an important role in the cycling of matter and in the bioproduction.

The following aspects have been the subject of extensive investigations of the Department of Biology of the Wilhelm-Pieck-University of Rostock, the Department of Biology of the Ernst-Moritz-Arndt-University of Greifswald and the Water Board of the Coast (GDR):

- Micro- and macrophytobenthos, zoobenthos, microbiology,
- inorganic and organic components of the sediments,
- P/Fe ratio in the water and in the sediments etc.

In order to allow for prediction and control of the water quality of the bodden chain a mathematical model of the ecosystem has been set up (by the Academy of Sciences of the GDR, Institute of Geography and Geoecology). Energy balance equations are written for about 15 variables. The structure of the boddens is described by a cascade model of completely mixed water bodies. The model covers the energy fluxes through the system, the cycling of phosphorus and nitrogen, the recycling due to the excretion of nutrients by zooplankton and the mineralization of organic material due to bacterial action, the external regulatory factors such as solar radiation and water temperature, external nutrient input, transport processes within the chain and in exchange with the Baltic Sea. The model allows for the prediction of annual fluctuations of different biological and chemical components and shows the high degree in which the bioproductivity in summer depends on the internal nutrient circulation, on the release of nutrients from the sediments and on the water exchange with the Baltic.

Reservoirs and Rivers

The main features of the aquatic ecosystems of reservoirs and rivers are investigated (by the Technical University of Dresden, Section of Water Management, the Institute of Water Management, etc.) aiming at the improvement of our knowledge about these ecosystems and at the further development of ecosystem modeling. These investigations cover

- field measurements in reservoirs of different states of eutrophication,
- laboratory models for the simulation of the most significant processes (growth rates, yield coefficients, grazing rates, heterotrophic decomposition, etc.),
- development of mathematical models of the following types:

  a) Statistical evaluation of available data and subsequent incorporation into statistical models. Recursive models for obtaining parameter estimations from given time series. (Example: Oxygen content of the Saidenbach reservoir if the following input variables are given: water temperature, BOD, seston, chlorophyll a, nitrate nitrogen, chemical oxygen demand, orthophosphate and transparency.)

  b) Deterministic models of phytoplankton--nutrient interaction aiming at the promotion of our understanding of the kinetics of these processes. Two-layer reservoir model taking into account phosphate, several types of phytoplankton, zooplankton and physical factors.

  c) Combinations of both statistical and deterministic models for instance for the prognosis of the water quality in a reservoir which is still under construction. (The slowly proceeding impounding process beginning after the spring flood is expected to result in much more favorable oxygen conditions as compared with a fast rate filling of the reservoir beginning during the spring flood.)

  d) Combination of laboratory models (showing the response of the laboratory ecosystem to the change of special parameters) with field experiments in reservoirs (e.g. by the use of large transparent plastic hoses or bags) in order to examine the conditions of similarity.

These types of investigations are performed within reservoirs with different states of eutrophication and for rivers loaded with organic wastes.

CONCLUSIONS AND SUMMARY

This presentation gives an overview of the problems and results of water quality modelling, especially in the GDR. Some conclusions are the following:

a) Water quality modeling in the GDR covers:
   - Control of the salt load of rivers,
   - Investigation of the influence of the thermic load caused by a nuclear power plant on a lake system,
   - Estuary modeling (Darß-Zingst bodden chain),
   - Modeling of the water quality of reservoirs and rivers, etc.

b) The research on water quality modeling is in full accordance with the Charter of IIASA.

c) Modeling an aquatic ecosystem, the following stages can be distinguished:
   - Measurement of the most important hydrographical data;
   - Quantitative and qualitative analysis of the biocoenosis;
   - Determination of the main components which must be taken into account by the model;
   - Mathematical description of the relations between these components on the basis of our knowledge about ecophysiological processes, trophic relations, etc.;
   - Construction of the model, calibration and verification (using the computer);
   - Concentration of field and laboratory investigations on subjects permitting the improvement of the model.

d) Aquatic ecosystems are non-linear ones: small variations in one parameter (e.g. nutrient import, global radiation) can cause non-linear variations of other parameters.

Often the variations of the "input parameters" are of stochastic character. But the statistical approach to water quality modeling is not without difficulties: usually there are considerable interactions between several input variables (e.g. between water temperature, nitrate nitrogen, phosphorus, chlorophyll and transparency). It is very difficult to obtain further insight and understanding into the underlying dependency between the variables only by statistics. Secondly, man-made effects mostly are reasonably handled by deterministic models.

e) Efficient water quality models only can be constructed if

- hydrophysical, chemical and biological factors adequately are taken into account as far as possible by deterministic equations.
- the coefficients, incorporated into the model, are well defined biological, biochemical, chemical or physical quantities,
- the close cooperation between the modeler and the investigations in the laboratory and in the field is maintained,
- the theoretical basis of water quality modelling is improved by the use of the thermodynamics of irreversible processes,
- the verification of the model is carried out very carefully.

f) Water quality modeling calls for international cooperation beginning with the improvement of the exchange of data, reports and models.

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