Dissolved Loads of Rivers and Surface Water Quantity/Quality Relationships
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Principles underlying the development of water quality monitoring systems in Hungary

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ABSTRACT The evolution and development of observation networks on the volume and quality of water resources in Hungary, and the establishment and modernization of the national quality monitoring network are discussed. Research and development has been aimed at evaluating and improving the information content of the data base including correlation of observation parameters (characteristics), potential completion of records, trend analysis of quality changes, effect of sampling frequency, impacts of surface runoff and flood waves on water quality. Application of scientific results in order to improve methods of acquisition and evaluation of water quality data has been undertaken.

Recherches en Hongrie pour la mise au point des systèmes de contrôle de la qualité des eaux
RESUME L'étude représente l'évolution et le développement des réseaux d'observation de la quantité et de la qualité des ressources en eau en Hongrie, l'établissement et la modernisation du réseau national de contrôle de la qualité des eaux. Les activités de développement et les recherches en vue de l'évaluation et de l'accroissement du contenu en informations relatives aux données de base: étude des interdépendances des paramètres d'observation (des caractéristiques), les possibilités d'évaluation des données manquantes, évaluation des tendances de l'évolution de la qualité des eaux, analyse des effets de la variation de la fréquence de l'échantillonage, étude des matériaux polluant de surface ruisselantes, ainsi que de la qualité des eaux au cours des ondes de crues. Utilisation des résultats de recherches pour le développement des méthodes de collecte et d'évaluation des données relatives à la qualité des eaux.

HISTORY OF OBSERVATION NETWORKS IN HUNGARY

Regular observations on surface waters were started in Hungary in 1851, when the gauging network on the major streams of the country was commissioned. Hydrological data collection was extended to regular streamflow measurements in 1887. The records on underground water resources are shorter, observations on groundwater in the network of piezometer wells commenced as late as 1934 (Lászlóffy, 1974). The hydrological and hydrometeorological observation network comprises at present 501 river gauges, 1715 piezometer wells and 1404 meteorological stations. The data observed and processed are published by the Hydrological Service annually in the *Hydrographic Yearbook* series, which through the diversity of materials presented, and a long period of record extending more than 100 years, has an international reputation.

Although the observations on water quality can also be traced back almost 100 years, the socio-economic demand for regular observations arose only in the wake of rapid industrialization which started in the 1950's. One of the primary functions of VITUKI, founded in 1952, was to undertake a comprehensive survey on the water quality of streams. In the course of this exercise, 25 water quality components were determined together with the streamflow rate prevailing at the time of sampling for *c.* 1400 cross sections on 130 streams. The sampling programme was repeated annually. The establishment of hydro-analytical laboratories at the district water authorities started in 1956. In the early period their policy was to take relatively infrequent samples (normally four per year) from *c.* 800 sites.

The countrywide water quality observation network operated by the district water authorities under the professional supervision of VITUKI has been extended between 1960 and 1967 to *c.* 800 sampling sites on 290 streams in Hungary. The sampling frequency ranged from 2 to 12 times per year. It should be noted, however, that at *c.* 60% of the sampling sites samples were only taken seasonally (four per year). The samples were analysed for 15-30 water quality components (Szebellédyné & Literáthy, 1971). Primary processing revealed the necessity of increasing the frequency of sampling. For this reason, and following an initiative by VITUKI, data collection has been continued since 1968 within a *national standard water quality monitoring network* (monitoring network) extending to the 113 most important streams in Hungary. Under this improved sampling schedule the number of sites was reduced to around 300, while the annual number of samples increased to at least 12. Depending on the importance of the particular site, the sampling frequency ranged from 12 to 52 per year and at one site was 104 per year. The number of water quality components analysed ranged around 50. An important development after 1968 was the introduction of internationally approved analytical methods. The water quality data originating from the monitoring network (over 300 000 values per year) have been processed and stored by the Computer Centre of the Water Management Institute at Szentendre.

Reviewing the data produced by regular water quality sampling, which has been introduced much more recently than hydrological data collection, it is concluded that the most characteristic feature of the past decades was an increase in sampling frequency. However, limitations in laboratory capacity has inevitably led to a reduction in the number of sampling sites. Due to the combined effects of changes in analytical methods, sampling sites and frequency, a water quality data base that may be considered uniform and suitable for comprehensive appraisal essentially has only become available since 1970 (Hock, 1983). For setting research objectives and for compiling preparation or decision-making studies in the domain of water pollution control, the data base from the monitoring network is supplemented by the data series obtained from special water quality investigations of different type and scope.

Continuous modernization of the observation and data collection networks for the volume and quality of water resources has been prompted both by engineering and economic considerations (Kovács, 1979). The engineering requirements have been controlled by the primary information demands of the users at different levels (research, decision making, state water administration, planning). The economic requirements, on the other hand, call for the development of data collection systems which produce the desired information with the lowest expenditure (WHO, 1977). These requirements cannot be satisfied unless the basic parameters of the data collection networks (representative sampling sites, sampling frequency, components to be analysed, etc.) are identified by scientific studies. Some intermediate results of selected research projects, which have substantially contributed to modernizing water quality data collection in principle and in practice, are presented in this paper.

DETERMINATION OF WATER QUALITY CHARACTERISTICS

The relationships between several water quality components, and also between hydrological and water quality data have been studied at four cross sections on streams considered representative. The objective was to obtain a better understanding of the fundamental phenomena affecting water quality, in order to reduce the burden on laboratory capacity by the practical application of the results. In the course of this work a comparative analysis has been undertaken of multivariate linear regression functions, determined from the complete, unbiased data series available from weekly sampling, and of the suggested functions, involving parameters derived from observations of high frequency. No appreciable loss of information was observed, as long as only the types of function suggested were used for component estimation. By evaluating the data series obtained from actual observations and from application of the functions, the extent to which the suggested relationships are suitable for replacing observed data for specific chemical parameters has been studied. A measure of the relative standard deviation of error ($\sigma_{\Delta\%}$) is employed to assess the agreement between different data series.

From these studies it was concluded that a regression function can be used for estimating a particular water quality component, if the relative standard deviation of error of the residuals from function calibration ($R_{s\%}$) is less than 10% and in the *parallel* test $\sigma_{\Delta\%} \leq 10$. An additional condition is that the number of reference points must exceed 30 and these must scatter in a random manner about the angle bisector representing complete fitting (Fehér, 1982). The results of the study at the Baja cross section on the Danube using the natural component Ca^{2+}_{eq} are presented in Fig.1.

ANALYSIS OF TREND IN WATER QUALITY

The water quality data obtained at weekly intervals from the monitoring network served as the basis for analysing the trend of changes in water quality over time. For this purpose a simulation

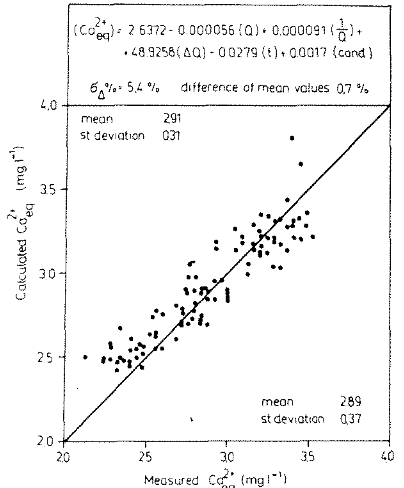

FIG.1 Comparison of calculated and measured values of Ca^{2+}_{eq} *for the Danube at Baja, 1980.*

model has been developed by Hock (1983) to describe the correlation between streamflow, dilution, water temperature, time and one of the water quality components. In order to determine the coefficients of the relationship, Hock used repeated linear regression analysis based on the principle of least squares. The method developed has been used to analyse the average trend of water quality changes over a 10-year period. On the basis of practical experience the limit below which a change is not considered a trend has been set at 3% $year^{-1}$. A rate of change similar to this limit means that the value of the particular component will double in about 25 years.

The results obtained on the basis of 10-year data series over the period 1970-1979 in the 11 border cross sections of the Tisza River basin are illustrated in Fig.2. The tabulations in the upper part of the drawing display the mean values of the 10-year data records, which can be compared with the new set of COMECON limit values shown in the right-hand lower corner. The trends of water quality changes can be found in the lower part of the tabulations. The average annual rate of change in BOD_5, NH_4^+-N, NO_3^--N and PO_4^{3-} exceeds 7% $year^{-1}$ at respectively one, six, three and seven of the 11 cross sections studies. The rate of change in PO_4^{3-} was higher than 15% $year^{-1}$ in two cross sections, but this rate is considered extraordinary. The annual average change in BOD_5, O_2, NH_4^+-N, PO_4^{3-} and total dissolved solids was significant at the 5% risk level for three, seven, nine, ten and eight cross sections, respectively.

DETERMINATION OF SAMPLING FREQUENCY

Within the complex research project concerned with eutrophication in Lake Balaton (Somlyódy, 1982) considerable attention has been devoted to improving the collection of water quality data in the basin. The studies have included an analysis of sampling frequency and its impact on the relative error of the nutrient load estimate.

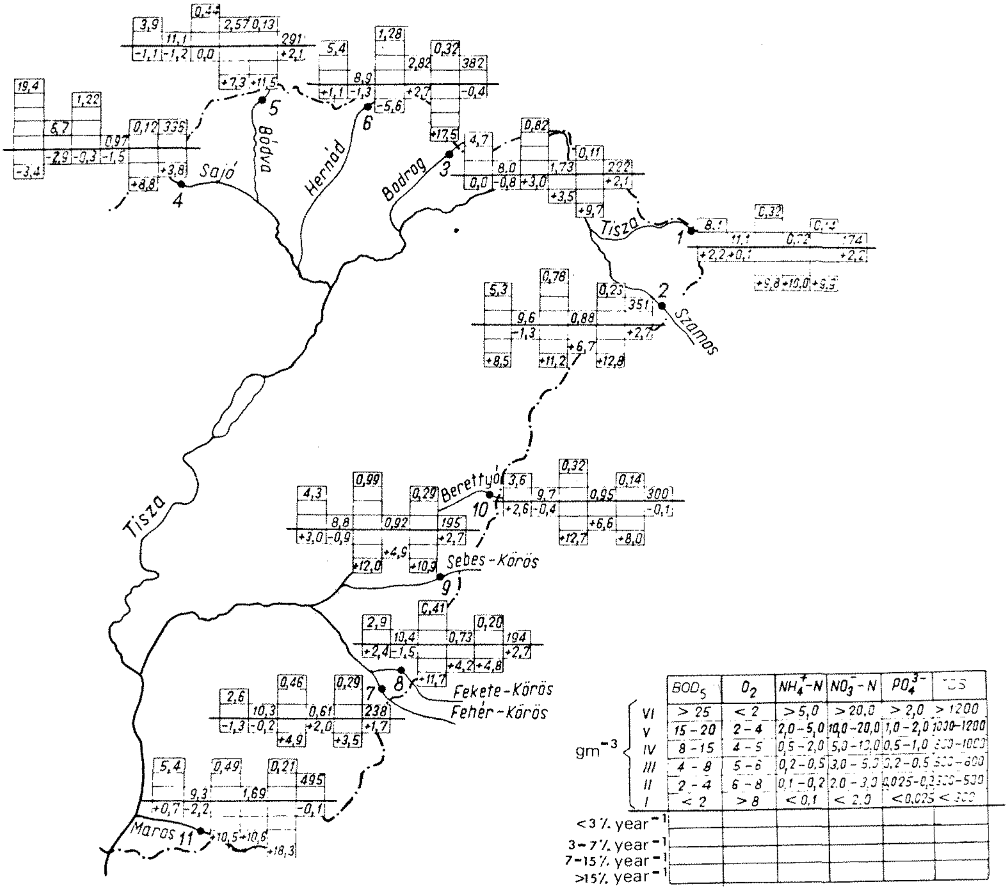

FIG.2 Trend analysis of water quality in the border sections of the Hungarian part of the Tisza River basin.

The critical sampling interval from which the original continuous time series can be reconstructed without appreciable loss of information has been derived theoretically by introducing certain constraints (Szöllősi-Nagy, 1976). From an analysis of the measurement data obtained at the mouth of the Zala River, this interval was found to be slightly longer than one day for phosphorus and nitrogen, but between one-half and one day in the case of suspended solids. When estimating pollution load, the studies have revealed that a sampling frequency of once per week is necessary, for instance to reduce the relative error in the annual average total phosphorus load to below 25%. Approximately two samples must be taken per week if it is desired to estimate the monthly load with similar accuracy. At a sampling frequency of once per month, the error in the annual load will be as great as 60%.

Simulation by Monte-Carlo methods will produce more accurate estimates of the pollution load than the foregoing considerations. The data are selected from the existing data series in a random manner, observing a particular sampling strategy, and then the average loads are determined. The distribution and statistical parameters of the load estimates are obtained by repeating the procedure a sufficient number of times. An example of the monthly means and the extreme values produced for a period of four years, based on n = 1, 2, 5 and 12 samples per month and on 1000 simulation runs, is presented in Fig.3(a). The width of the uncertainty band is diminished by about 40% on average by increasing the number of samples per month from one to two. Figure 3(b) illustrates the nature of the distributions. It

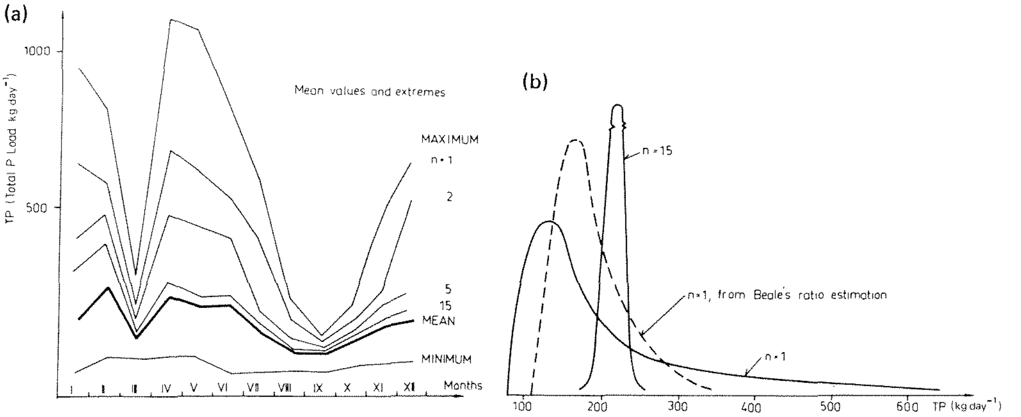

FIG.3 Effect of infrequent sampling on the estimation of monthly mean loads, Zala River at Fenékpuszta, 1976-1980.

is of interest to note that the uncertainty of the mean can be reduced, even for the same number of samples, by employing a proper method of estimation (Beale's approach).

STUDY OF NON-POINT POLLUTION SOURCES

The runoff from minor catchments triggered by violent storms may produce high pollutant loads from nonpoint sources. With the aim of determining this load, extensive investigations are under way on the minor streams discharging to Lake Balaton and in the Rakaca basin. The results clearly emphasize the importance of frequent sampling at times of floods on such streams. The bulk of the annual pollutant load, especially the plant nutrients from intensively farmed catchments, is contributed by the flood waves. This is demonstrated in Fig.4. in which pollutant load *vs.* streamflow relationships have been plotted for a small tributary to Lake Balaton. The low position of the curve based on a 5-year time series of monthly samples, derived from the results of regular sampling in the monitoring network, clearly indicates that no reliable estimate of the annual load is possible, unless detailed quality responses during floods can be observed (Jolánkay, 1982).

A portion of the detailed records from a similar special study is illustrated in Fig.5. The early summer floods in the Rakaca Creek, which drains a contoured catchment, reflect the impact of surface runoff and have a strong influence on the transport of plant nutrients.

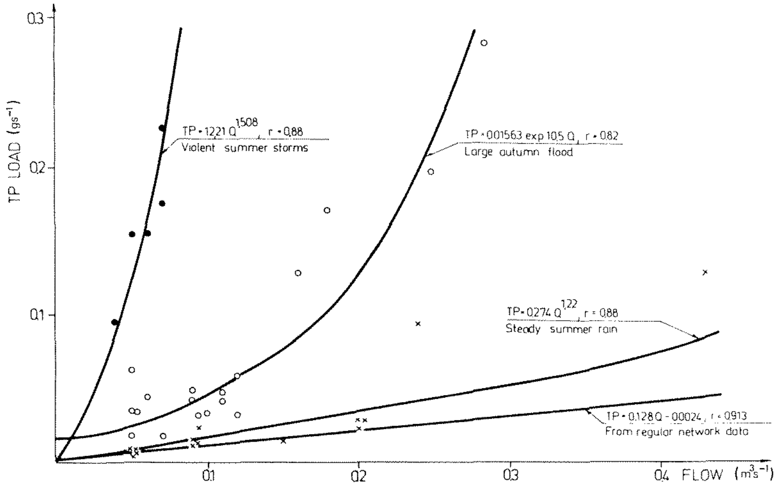

FIG.4 Relationship between TP load and flow based on regular sampling and flood measurements, Örvényesi Séd Creek.

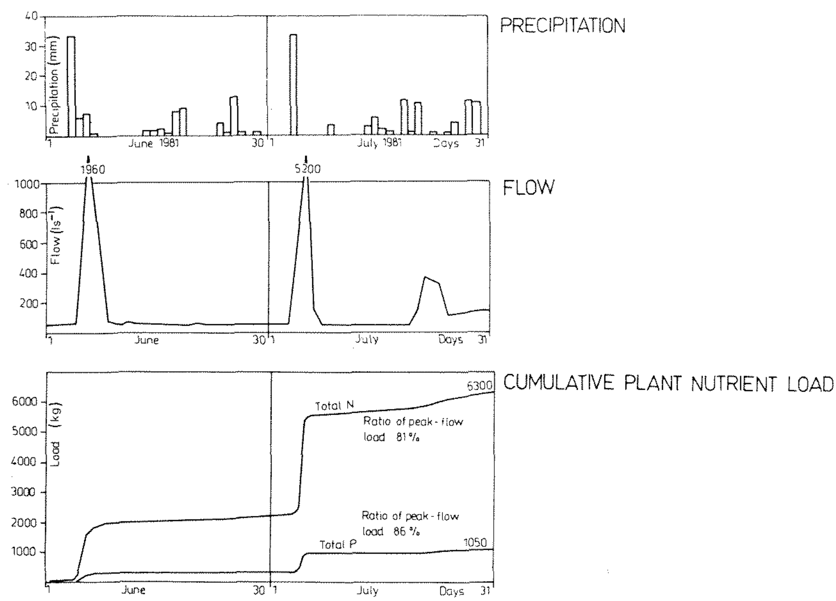

FIG.5 Rakaca project on monitoring surface runoff quality at the measuring station of Meszes (basin area of 207 km²).

At the Meszes gauging station floods contributed 79% of the total annual nitrogen load, which comprised 48 900 kg, and 71% of the total annual phosphorus load, which comprised 5480 kg (Pintér, 1982).

PRACTICAL APPLICATION OF SCIENTIFIC RESULTS

Work in modernizing the water quality data acquisition, evaluation and classification system is in progress under the guidance of the National Water Authority, OVH. The scientific results outlined in the foregoing sections represent a substantial contribution to the formulation of the principles and methods for improving the system of data acquisition and evaluation. Under the improved sampling schedule it is anticipated that the number of sampling sites in the national monitoring network will be further reduced, while the frequency will be increased to at least 26 per year.

The principles and methods of the evaluation and classification system for water quality have been summarized in the Code of Practice, which is to be introduced in 1983 (OVH, 1983). A number of scientific results, including the method of trend analysis described above, have been incorporated in this code.

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