Critical reflections on long term sediment monitoring programmes demonstrated on the Austrian Danube

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ABSTRACT Long term monitoring of the suspended sediment concentration on the Austrian Danube reaches back to the thirties. It can be shown with the available time series of daily results, that sufficient information can be reached after a relatively short time period, depending on the purpose of the data analysis as well as the data application. After a decade of monitoring, mean sediment characteristics become constant and the data contain sufficient information to perform sophisticated time series analyses. Excellent sediment rating curves can even be based on single flood events only. To determine other sediment characteristics, such as the grain size distribution of the transported or deposit material, time consuming long term monitoring is not always necessary. Appropriate information for environmental engineering applications can be gained for a variety of different parameters by flexible short term investigations, provided the objectives of the monitoring programmes are carefully defined.

THE MONITORING PROGRAMME

Due to the erection of nine hydropower plants and an almost 100% hydroelectric completion of the river, the intensity of the suspended sediment monitoring network at the Austrian Danube increased since the first measurements were taken in the late thirties. Today six gauging stations are operated permanently by the Austrian Hydrographic Service (Fig. 1). Depending on the water discharge of the Danube, one litre samples are taken several times a day. In the laboratory the water percolates through a defined fine filter, which is then dried at 100°C and weighed. This leads to the suspended sediment concentration [mg/l] of the Danube. Being aware of the remarkable uncertainties involved in this procedure, it however soon will be improved significantly by the introduction of an electrooptical turbidity measuring instrument.

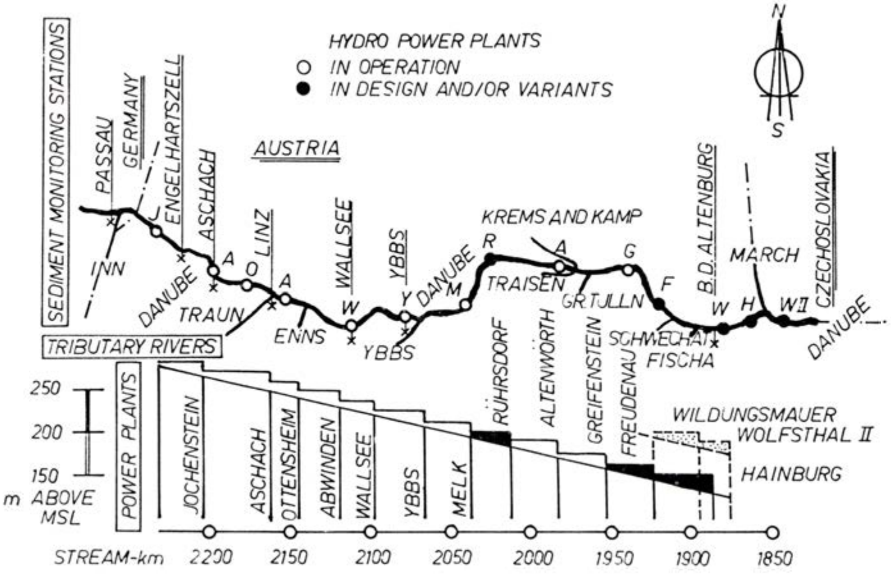

FIG. 1 Hydropower plants and sediment monitoring stations on the Danube in Austria.

Additional monitoring is arranged by the company which is in charge of the operational functioning of the hydropower plants. Their intentions are to get an overview of the sediment budget in the reservoirs of the hydropower plants. Such investigations are regularly done by echo sounding. But also the erosion tendencies downstream from the dams are determined. This is a serious problem on the eastern end of the Austrian Danube, where in geological terms the rocky substratum is overlayed by a relatively thin sediment layer. It is built up of an approximately 10m thick coarse gravel layer, local with a fine sand and silt layer of few meters at the most on the top, depending on the hydraulic conditions. An increasing erosion tendency in this section of the stream was concluded from the systematic changes in the continuous observations on the gauging station Hainburg (Fig. 2).

In addition, sediment monitoring in tributary rivers as well as geographic information system assisted erosion studies in subcatchments (KLAGHOFER & SUMMER, 1990), performed with the deterministic soil erosion model EPIC - Erosion Productivity Impact Calculator (WILLIAMS et al. 1983) - belong to this sediment monitoring concept. Such studies (HAITH & SHOEMAKER, 1987; NEUFANG et al. 1989; HRISSANTHOU, 1989) consider many different erosion controlling parameters and consequently they give a good

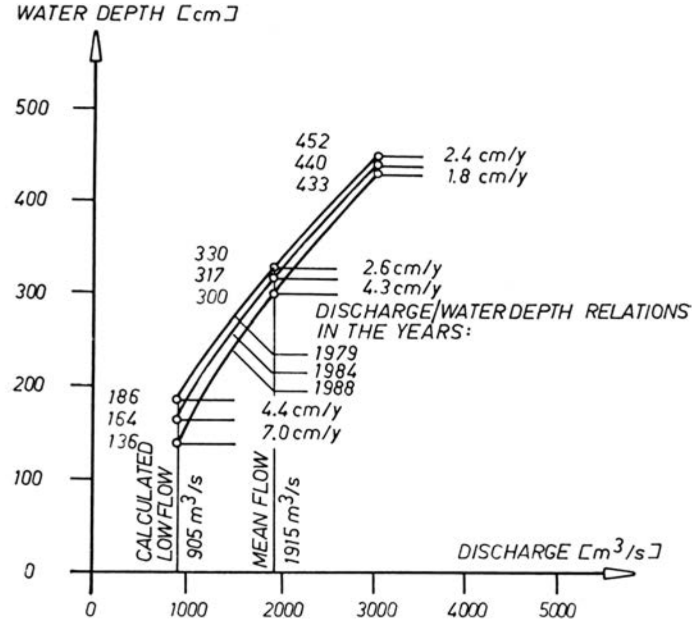

FIG. 2 Change of the discharge-water level relation in the years 1979 to 1988; gauging station Hainburg (WASSERSTRASSENDIR., 1989).

idea of the magnitude of the sediment yield of a watershed.

THE QUALITY OF LONG TERM MONITORING

The long term monitoring on the Danube covers a wide range of water discharges as well as sediment loads. These time series over a period of some decades contain information on annual and seasonal behaviour of these parameters. Regarding the temporal sediment characteristic, Figure 3 shows for two gauging stations on the Danube, that the standard error of the mean annual concentration reaches an appropriate minimum for engineering considerations after one decade as well as the percent gain in standard error for each additional year of record. Such stable conditions after a monitoring period of about ten years are also indicated by DAY (1988) for mean sediment characteristics of Canadian rivers.

Based on monthly sediment load data from 1970 to 1979 a sophisticated time series analysis was performed on these data from the gauging station Ybbs.

$$W_t = 1.48868*W_{t-12}+W_{t-1}-1.48868*W_{t-13}- -0.48868*W_{t-24}+0.48868*W_{t-25}+a_t-0.76079*a_{t-1} \quad (1)$$

$$W_t = \log X_t \quad (2)$$

$$X_t = 100*(S_t/S_a) \quad (3)$$

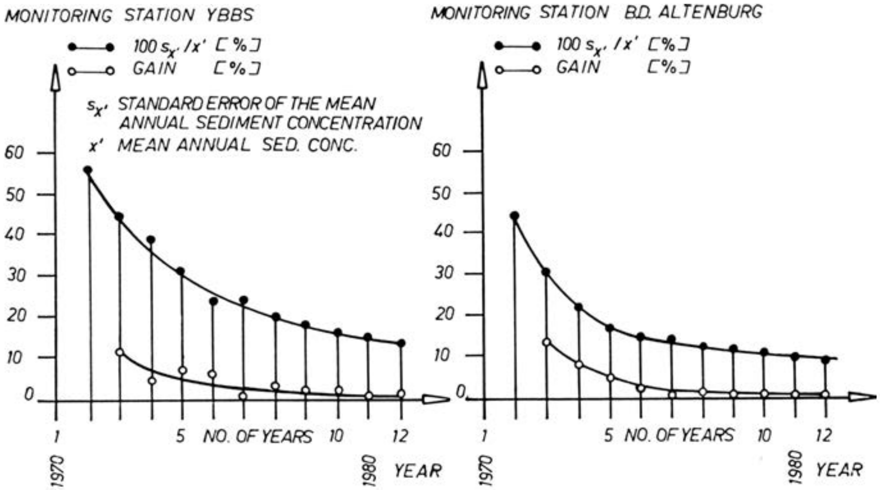

FIG. 3 Temporal development of the standard error of the mean annual sediment concentration $s_{x'}$ divided by the annual concentration mean x' as well as its gain by increasing years.

$$S_t = (S_1+S_2+S_3+...+S_i+...S_n)/n \quad (4)$$
$$S_a = (S_1+S_2+S_3+...+S_t+...S_m)/m \quad (5)$$
$$S_i = C_i*Q_i \quad (5)$$

C_i ... daily observed sediment concentration [g/m^3]
Q_i ... daily observed water discharge [m^3/s]
S_i ... daily sediment load [g/s]
S_t ... monthly sediment load [g/s]
S_a ... average sediment load [g/s] - period 1970/81
X_t ... average monthly sediment load [%]
m ... total number of month - period 1970/81
n ... total number of days in the respective month t

The results show that the observed monthly sediment load during this only ten year period contain sufficient information to define properly an ARIMA model of the form $(0,1,1)x(1,1,0)_{12}$. The applicability of this model, which follows equation (1) to evaluate the sediment load W_t at the time t, was used to predict the observations for a two year period from 1980 to 1981. The good agreement between the calculated values and the actually monitored values can be seen in Figure 4.

A COMPARISON OF SHORT AND LONG TERM MONITORING RESULTS

Today, for the different sections of the Danube, sediment rating curves (SRC) are available which are based on the data of the six previous mentioned gauging stations. GRUBER (1973) evaluated them for the period 1960 to 1966 by fitting an exponential function of the form

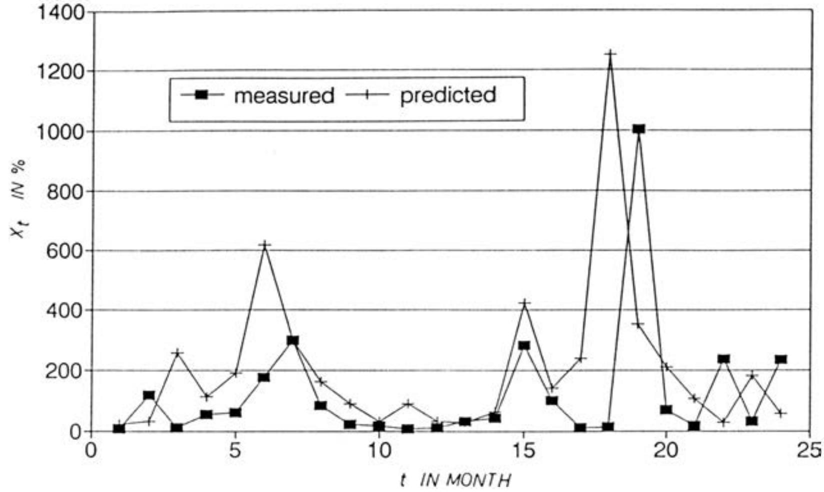

FIG. 4 Comparison of the simulated monthly sediment load values with the in situ values.

$$C = aQ^b \tag{3}$$

through the x-y relation of the daily concentration and discharge measurements, wherein C stands for the suspended sediment concentration [g/m^3], Q for the discharge [m^3/s] and a as well as b are coefficients.

TABLE 1 Comparison of the observed annual sediment loads (= 100%) during the period between 1970 to 1981 with the calculated values based on different sediment rating curves (SRC).

	Long Term Monitoring		Single Flood Observations		
Year	GRUBER (1973)	1.1.1970 to 31.12.1981	8.8.1970 to 20.9.1970	23.6.1973 to 28.7.1973	30.5.1976 to 8.6.1976
1970	103%	46%	109%	110%	120%
1971	101%	47%	100%	95%	105%
1972	98%	47%	93%	84%	95%
1973	105%	51%	97%	85%	97%
1974	116%	56%	108%	96%	109%
1975	119%	56%	112%	105%	116%
1976	120%	57%	111%	101%	113%
1977	118%	57%	109%	98%	111%
1978	117%	56%	107%	94%	106%
1979	116%	56%	106%	94%	106%
1980	121%	58%	111%	97%	111%
1981	121%	58%	112%	100%	113%

For example, his SRC which was developed for the station Ybbs was compared with a similar gained SRC, but this time based on the daily data from 1970 to 1981. Applying both curves to determine the annual sediment load over this period and comparing their results with the actually observed values, Table 1 shows clearly the enormous differences in the results.

Table 1 contains also results calculated in the same manner as GRUBER (1973) but on the bases of SRC evaluated from typical single flood events only. Considering the following assumptions these SRC chosen as example from a variety of similar SRC give as good, if not even better results as the time consuming and expensive long term observations:

(a) No time delay between the flood wave and the concentration wave.
(b) The same duration of the flood wave as well as the concentration wave.
(c) A direct relation between the ranked concentration values and the ranked discharge data.

As it can be concluded, in this case long term monitoring does not necessarily mean better results.

THE APPLICATION OF SHORT TERM INVESTIGATIONS

SUMMER (1990) introduced a model to describe the selective transportation and deposition of suspended sediments on a daily basis, in the reservoir of the Altenwörth hydropower plant on the Austrian Danube. Besides the hydraulic characteristics of the reservoir (GODINA, 1987), the sediment characteristics of the model input were based on a long term SRC as well as on single measurements describing the relation between the discharge and the grain size distribution of the transported material. The applicability of this model was tested on the results of investigations such as

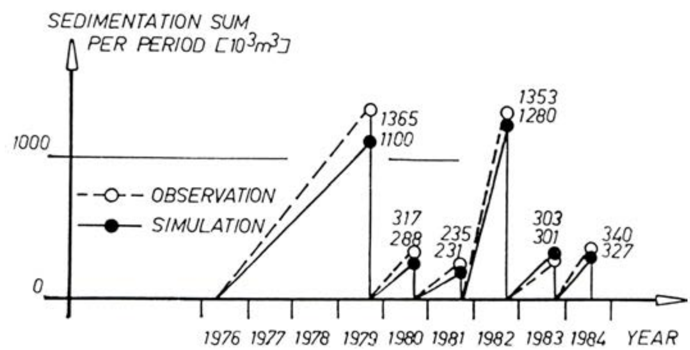

FIG. 5 Comparison of the calculated and observed sedimentation in the reservoir Altenwörth, period May 1976 to June 1984.

(a) the deposited volume of sediments (Fig. 5) which were annually monitored by echo sounding to estimate the sedimentation rate in equidistant cross sections all over the reservoir.
(b) the longitudinal and vertical grainsize distribution in the reservoir which was determined due to cores, taken over the whole sediment layer.

KLAGHOFER and SUMMER (1990) used sediment concentration measurements, as based on the observations of two typical floods of the tributary Ybbs-river to determine the sediment delivery ratio (SDR) of an approximately 100km^2 lower alpine subcatchment of the Austrian Danube. The calculated erosion rates for these few days were compared with the average concentration values in the river. But only a fair agreement with the SDR curve by VANONI (1977) could be seen. The determined values in the erosion study were often smaller than that of VANONI, probably due to the two facts that:
(a) the study took place during the summer period when a protective plant coverage of the surface was already developed.
(b) only sheet erosion and no rill erosion occured on the agricultural used land.

CONCLUSIONS

An increased number of environmental studies are based on parameter intensive deterministic models. The verifications of their results often fail due to a lack of data. Investigating single events rather than long term monitoring and observing different related hydrological events over a short time period, results in specific data sets related to these model parameters.

For example to learn about the influence of floods on the siltation and erosion process in a reservoir, a comparison of the reservoir's shape before and after an event leads to different conclusions than annual surveying. Sediment concentration measurements during the rise and fall of a flood contain more information than daily sampling at exactly the same time of the day, without considering the hydrological environment. Or during single rain storms, the soil erosion is influenced by different parameters than looking at it in a period of days, weeks, month or years.

As it can be seen, the decision for sampling strategies has to contain considerations about their objectives. But they also depend on the chosen simulation model - e.g. deterministic or stochastic - and its parameters. Finally, the significance of the controlling parameters, their relation to each other as well as their variability in time and space play a major role in the correct decision for the most suitable monitoring procedure as well.

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