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In situ measurements of particulate matter transport in rivers

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ABSTRACT In order to apply models describing mixing and transport phenomena in natural systems, data of a very specific nature are required. The programme of an investigation undertaken for more than 2 years in the River Neckar has been determined to a large extent by the concept of a model developed in parallel. Prerequisites for the collection of *in situ* data include a specially equipped boat, which permits the collection of data by means of various electrodes as well as by sampling. The continuous measuring equipment as well as the sampling device are supplied by a continuous flow of water pumped into the laboratory installed on the boat. Samples are either analysed there, in an accompanying field laboratory ashore, or in the central laboratory of the research institute. The overall geometry of river cross sections was recorded by an echograph.

Mesures *in situ* du transport de matières en particules dans les rivières

RESUME Pour la description des phénomènes de transport et mélange dans les eaux naturelles on a besoin de données de nature tout à fait spécifique. Depuis plus de deux ans on fait des expériences et des analyses dans le Neckar. Parallèlement on a mis au point un plan qui sert de base pour ces expériences. Pour recueiller des résultats sur place on a besoin d'un bateau spécial qui fournit les renseignements soit à l'aide de différentes électrodes soit par la prise d'échantillon. L'eau courante qu'on fait venir sans cesse au laboratoire du bateau approvisionne les appareils qui font des mesures sans interruption ainsi que les prises d'échantillon. C'est là ou à l'institut de recherche qu'on examine les prises d'échantillon. La géométrie de la coupe transversale des cours d'eau est enregistrée à l'aide d'un écho-sondeur.

INTRODUCTION

In order to describe concentration changes of certain constituents of natural waters it is necessary to distinguish on a conceptual basis between conservative and non-conservative substances. While the distribution of conservative substances is controlled exclusively by transport phenomena, non-conservative substances are subject to additional processes which cause an increase or a decrease in the transported load. Suspended solids belong to the group of non-conservative substances.

The concentration of such suspended solids is affected by aggregation phenomena which may be caused by an increase of the salt content of natural waters. This aggregation may lead to an increase of particle size, and in turn floc size may change the sedimentation velocity.

Käser (1980) includes such aggregation effects in a mathematical model for the description of transport and deposition of non-dissolved suspended matter. It is necessary, therefore, to understand the controlling mechanisms of the dissolved phase, in addition to the hydrodynamic characteristics of the system, in order to describe the behaviour of the suspended solids. In connection with this objective and in order to obtain input data for mathematical models, a series of *in situ* measurements of sediment transport, erosion and deposition has been made on the River Neckar.

This report concentrates on techniques of sediment sampling and analysis, and discusses only briefly the type of data obtained and their use. The latter topic has been fully considered by Käser *et al.* (1980).

ORGANIZATION OF RIVER MEASUREMENTS

The study reach

Selection of a suitable river reach for sediment measurements was confined to a stretch of river with relatively simple geometric boundary conditions, and with at least one point of effluent discharge to generate changing physicochemical conditions along the axis of flow.

These requirements were met by the regulated "Aldingen-Hofen" section of the River Neckar between river kilometres 176.0 and 172.0 (Table 1). Figure 1 shows this reach is nearly straight, and has a single effluent outfall (discharge from the Stuttgart waste water treatment plant) entering at right angles to the river axis.

The measurement programme

If river water samples are analysed only for parameters that characterize the non-dissolved solids, there will always be a lack of information with respect to diffusion, dispersion and specific physicochemical processes. In order to quantify mixing phenomena and in order to describe the transport of suspended matter, a conservative tracer (rhodamine B), in a concentration of 8×10^{-5} ml l^{-1}, was added to the discharge of the waste water treatment plant during measurements. Between the point where the tracer was added and the outfall into the river was a stretch of some 100 m which allowed complete mixing of the tracer with the discharge water.

Comprehensive cross sectional velocity measurements in the discharge channel and in the river were used to quantify flow volumes, which were in the order of 24 and 2.4 m^3 s^{-1} respectively

Table 1 Characteristics of the River Neckar

MNQ	MQ ($m^3 s^{-1}$)	MHQ	S_{bottom}	n_{GMS}	b_{min} (m)	b_{max} (m)
9.8	45	412	0.0004	0.035	50	100

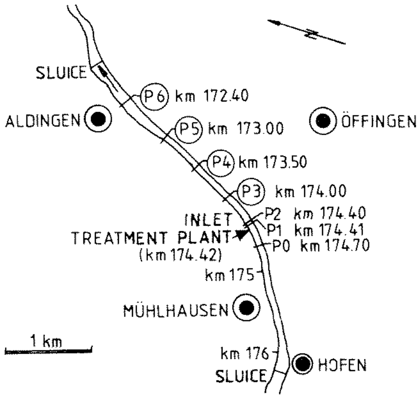

Fig. 1 Plan of the River Neckar section between Aldingen and Hofen. P0, P1, . . ., P6 are the numbers of the cross sections where the measurements took place.

for the river and the effluent discharge. The addition of tracer observations distinguishes the present series of measurements from other routine suspended solids monitoring programmes, in which only pH, conductivity, turbidity and temperature were observed *in situ* for surface samples and for samples from different depths.

Further analyses in the present study involved the assessment of total solids content, non-volatile solids and total dissolved solids. Determination of total particle concentration and particle size distribution of suspended solids, and kinetic studies of aggregation tendency were also carried out for selected samples. Table 2 summarizes the complete measurement programme.

Measuring equipment

For the particular river system and river stretch under investigation, it was necessary to use a boat for sampling and *in situ* observations. The authors used an 8.5 m boat which had an average width of 2.5 m and a cabin adequate to house the equipment. The draught of the vessel was 0.4 m. The boat was propelled by an engine of 90 kW. The cabin housed the instruments used to determine pH, conductivity, temperature, turbidity, fluorescence and average velocity, and facilities for onboard recording of all these parameters were available. The measuring electrodes and sensors were fixed to a specially designed arm, which was mounted in front of the boat (Fig. 2) and could be adjusted in depth to any preselected value. The same electrodes and sensors could also be integrated into a measuring cell which was connected to a stream of water continuously pumped from the river.

Table 2 Programme of the investigations in each cross section

	Location of measurement/analysis			
Parameters	Boat	Field lab.	Central lab.	Comment
Velocity	●			1 and 2 m below the water surface
Temperature	●			1 m below the water surface, continuously
Conductivity	●			
pH	●			
Fluorescence	●			
Collision efficiency factor		●		Important for Käser's model
Floc volume ratio		●		Samples taken from the maximum of the rhodamine plume 1 m below the water surface
Settling velocity		●		
Concentration of suspended matter			●	

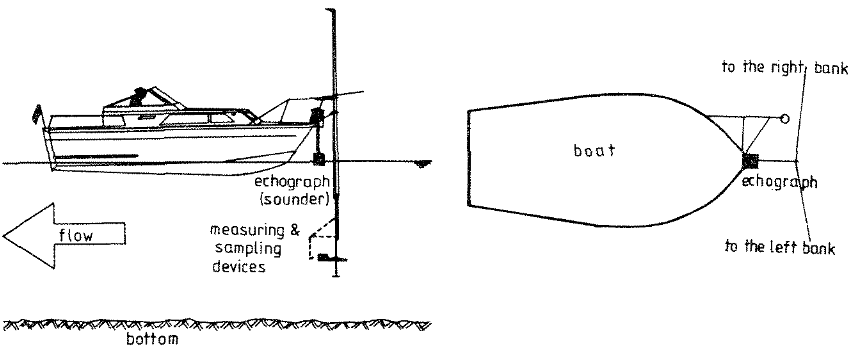

Fig. 2 Measuring and sampling equipment installed on the boat.

Propellors for velocity measurements, sensors and sampling hoses are located at a common level in the flow to ensure that water sampling and corresponding *in situ* monitoring occurred at the same depth. Collection of samples in the cabin was facilitated by a switching device which allowed the continuously pumped stream of water to be rerouted into containers of 2 litre capacity. These samples were transported very carefully to an adjacent field laboratory where further parameters were determined (Table 2).

Furthermore, the boat was equipped with an echograph unit (Fa. Fahrenholtz/Kiel) which enables correct positioning of sampling equipment and also accurate determination of the geometry of the measuring cross section.

Measuring procedure

In order to ensure quasi-stationary conditions during a complete period of measurements, it was necessary to operate at times when traffic was absent from the waterway and the sluice gates were inactive. In practice, this meant observations had to be taken between 2300 h and 0600 h.

Conditions in a series of selected river cross sections, at increasing distance downstream from the point of effluent discharge, were measured during each observation period. At each profile, a cable was fixed perpendicularly across the river. The boat was attached to this cable, but movement across the river was still possible (Fig. 2). The cable was marked to allow relatively fast and precise positioning of the boat without causing too much turbulence from the engine. In each cross section, pH, conductivity, fluorescence and temperature were determined at points 1 m below water surface and at 5 m across the river. Where possible, corresponding measurements of flow velocity were made at depths of 1 and 2 m. A sample was taken from the centre of the effluent plume for subsequent analysis of suspended solids content and aggregation tendency. In addition, volume equivalent particle size distribution and sedimentation equivalent particle size distribution of sampled suspended sediment were determined by Coulter counter (Neis *et al.*, 1975) and by sedimentation velocity studies respectively.

The geometry of each cross section was determined by means of the echograph. The boat was moved between profiles in a downstream direction and close to the right bank of the river in order to minimize disturbance of the discharge pattern. Measurements with all of the sensors and electrodes were integrated over 60 s to obtain representative average values.

The series of samples taken from the plume was completed by one sample from the river upstream of the effluent discharge and one sample from the discharge itself, so that boundary conditions could be quantified.

EVALUATION OF THE MEASUREMENTS

Favourable meteorological and hydrographic conditions were encountered during the measurements in the present study but it should be noted that the techniques used are particularly suited to certain conditions of river discharge. The low velocities of flow during measurements, which did not exceed 0.2 m s^{-1} (recorded at a discharge of 26.4 m^3 s^{-1}), allowed very exact positioning of the boat along the cable. The procedure of fixing a cable across the river is only suitable for channels of limited width and restricted flow velocities. High flow velocities and very wide rivers will certainly present difficulties, and problems would arise in the study reach at flow velocities of greater than 0.5 m s^{-1}, which occur at a discharge of 70 m^3 s^{-1} or above. Despite the relatively low velocities of flow during measurements, all preliminary analyses showed that the River Neckar was completely mixed in a vertical direction. This permitted a significant reduction in the number of sampling and observation points required to define variations, and in consequence the depth of the measuring arm was kept constant at 1 m.

Nevertheless, the overall assessment of one cross section, including fixing of the cable, and about 10 points of observation, took between 30 and 40 min. This relatively long period of time required at each cross section inevitably led to some downstream drifting of the boat. Although not a difficulty in the present study, an increase in time taken for measuring or in flow velocity would accentuate drifting and would prevent satisfactory completion of observations of each profile. This potential problem needs to be considered in all programmes which undertake *in situ* river measurements.

Further specific difficulties in the present measurement programme were encountered in the immediate vicinity of the effluent discharge because of back-flow affects in the area between plume and the outfall side of the river. These back-flow phenomena were identified by means of floats, but could not be accurately monitored in the cross section surveys because of disturbance to the flow patterns caused by the boat.

Meaningful analysis of river samples also has to take into consideration the potentially large number of disturbances which may occur during transport to the field and the central laboratories. For example, aggregation will be enhanced through the motion resulting from transport, and organic substances contained within a sample may be subject to decomposition. In order to minimize such disturbances, careful attention should be given to sample fixation, to sample preparation and to the time span between sampling and analysis.

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REFERENCES

Käser, F. (1980) Ein Rechenverfahren zur Beschreibung von Ausbreitungs-, Aggregations- und Sedimentationsvorgängen suspendierter Feststoffe in natürlichen Fließgewässern (A computational routine describing processes of expansion, aggregation and sedimentation of suspended particulate matter in natural streams). Dissertation, University of Karlsruhe.

Käser, F., Tödten, H., Hahn, H. H. & Küpper, L. (1980) Naturmessungen über die Konzentrationsverteilung von konservativen und suspendierten Wasserinhaltsstoffen unterhalb der Einleitung in einem Fluß (Field investigations relating to the distribution of the concentration of conservative and suspended matter downstream from an inlet). *Sonderforschungsbereich 80, SFB 80/ME/157, University of Karlsruhe.*

Neis, U., Eppler, B. & Hahn, H. H. (1975) Quantitative analysis of coagulation processes in aqueous systems: an application of the Coulter counter technique. *Progr. in Wat. Techn.* 7 (2).