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INFLUENCE OF THE REGIME ON THE BED TOPOGRAPHY IN A RIVER

(Subject D-b)

by

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Synopsis

In scale model studies with mobile bed the dominant discharge concept is frequently used. The main advantage is that it allows an easy model operation. In reality, however, the bed of an alluvial river is changing in time due to the regime.
To obtain insight into the reliability of predictions based on mobile bed model investigations, using only one discharge, the dominant discharge concept has been tested in such a model. Results of this investigation and the scaling of the processes involved are discussed.

Resume

Aux etudes sur modèle reduit à fond mobil la méthodologie du débit dominant est appliqué fréquemment. L'avantage principale est l'operation facile du modèle. En nature, cependant, le régime d'un fleuve alluvial cause des changements du lit, comme fonction l'endroit et du temps. Afin d'etudier la confiance des prédictions basées sur des recherches en modèles réduits effectuées à l'aide d'un seul débit, on a executé des essais dans un tel modèle. Outre les results de cette étude, la présente contribution donne attention au choix d'échelles des phenomènes concernés.

1. Introduction

Schematisation of the river régime to a single discharge, the so-called "dominant discharge" is common in river engineering practice. It simplifies the correlation of river characteristics and leads to easy computations. Also for scale model studies with mobile bed the dominant discharge concept is frequently introduced. The main advantage is that it allows an easy model operation. However, it is quite evident that in this way it is only possible to reproduce a kind of average bed topography. As in reality the bed is changing in time, fair interpretation of the results may be hampered, depending on the aim of the investigation. Therefore the concept has been tested in a scale model with fixed banks and mobile bed. This has been achieved by comparing the results of runs with dominant discharge with those with varying discharge (regime).

The tests were performed in a model of the Waal River (main Rhine branch in the Netherlands) near Nijmegen in an alignment (bend rectification) which deviated strongly from the actual prototype situation (Fig. 1). Due to the character of this river it implies that the validity of the results is restricted to rivers with "slow" flood waves and predominant bed load transport. It has to be mentioned also that the influence of non-uniform conveyance of the low and high water bed was excluded because the model was provided with a constant width.

In the following sections attention is paid to the scaling of the processes involved, the schematisation of the regime and the results of the experiments.

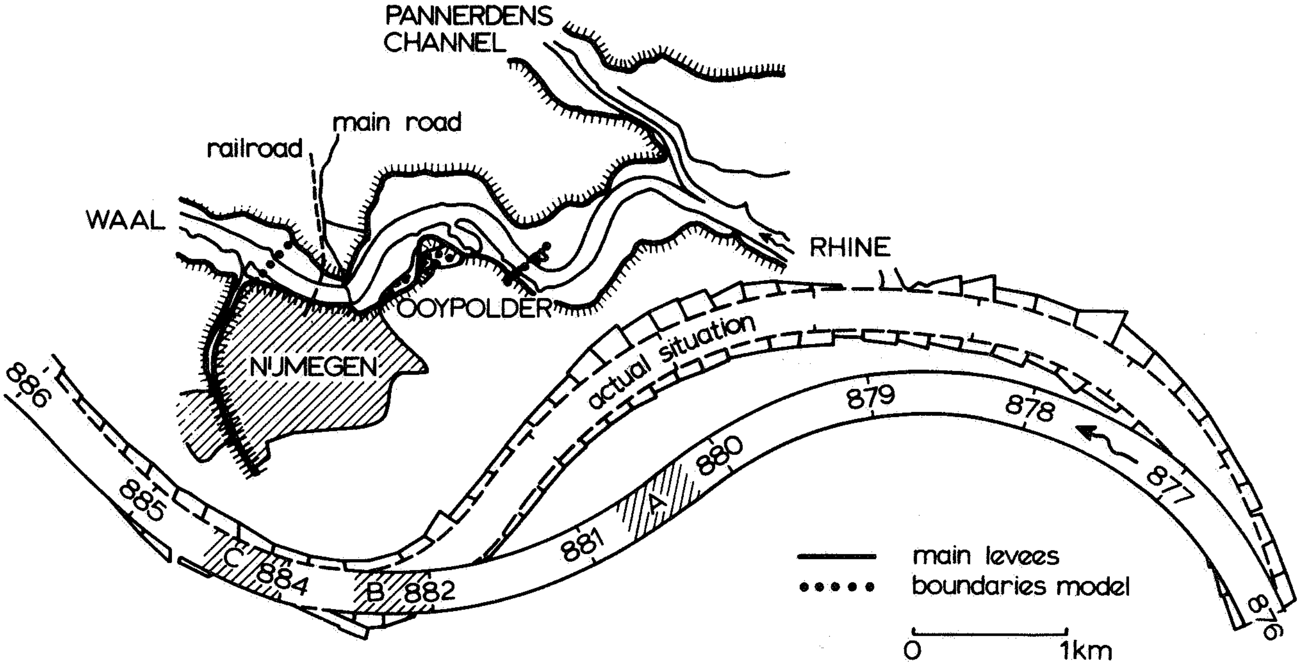
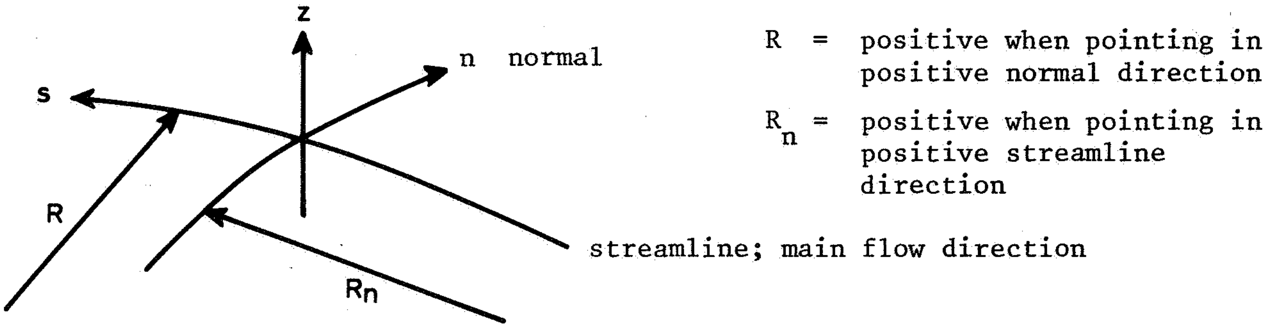


Figure 1 Situation

2. Scaling of the processes involved

In this paper the scale n_X of any parameter X is defined as the ratio between the value of X in the prototype and in the model; $n_X = X_p/X_m$. The physical phenomena are described in a curvilinear coordinate system for the depth-averaged flow field as indicated in Fig. 2.



R = positive when pointing in positive normal direction

R_n = positive when pointing in positive streamline direction

Figure 2 Curvilinear coordinates

Taking into account the hydrological and morphological character of the river involved the scaling of the model and boundary conditions is based upon the following considerations (Jansen [1]).

Flow field. To provide sufficient reproduction of turbulence the Reynolds number has to exceed a certain value which mostly can be established easily in this type of models. The flow in the Waal River can be considered as shallow with a low Froude number and mainly friction controlled. Such a flow can be scaled correctly within acceptable limits if the so-called roughness condition is fulfilled which reads:

$$n_C^2 = n_L/n_h \qquad (1)$$

in which C is the Chézy roughness coefficient, L is a characteristic length and h is the water depth.

Because the alluvial roughness of the model will be larger than in nature ($n_C > 1$) this condition will always lead to distroted models. The importance of the Froude number F is such that it gives the freedom to choose $n_F < 1$ (exaggerated flow velocities in tilted models) provided that this does not lead to a too large Froude number in the model. Further it will be clear that only with a correct reproduction of the flow pattern a correct reproduction of the bed topography can be expected and the other way about.

Bed topography. For a scale model with mobile bed the correct reproduction of the bed topography is the main target. A correct reproduction may be expected if the sediment transport scale is invariable in space. According to Jansen [1] and

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1. JANSEN, P.Ph. (ed),
   Principles of River Engineering,
   Pitman Publishing Limited, London, 1979.

De Vries [2] this might be achieved when the so-called "ideal velocity scale" condition is fulfulled. This scale follows from the assumption that an unique function (transport formula) exists between the transport parameter $\psi = s_s / \sqrt{D^3 \Delta g}$ and the flow parameter $\Theta = \mu h\, i / \Delta D$, in which s_s is the bed load transport per unit width in main flow direction, D is the grain size (diameter), Δ is the relative submerged density of the sediment, μ is the ripple factor, and i is the water surface slope in main flow direction (downward slope is positive).

These dimensionless parameters have to be reproduced on scale 1. If this approach holds, it implies automatically that the particle path pattern of the sediment grains along the bed is similar to that in the prototype. In other words, the sediment transport direction at any place in the model, defined with respect to main flow direction as $\tan \gamma = s_n / s_s$ is equal to that in the prototype. Hence:

$$n_{\tan \gamma} = 1 \tag{2}$$

in which s_n is the bed load transport per unit length in lateral (normal) direction.

However, based on the research of Koch [3], Struiksma [4] shows that in distorted models it is impossible to arrive at an invariable sediment transport scale. In these models the sediment transport direction scale $n_{\tan \gamma}$ will vary in space and in case of regime conditions also in time. Consequently this leads to noticeable scale effects at places where $\tan \gamma$ is relatively large or under changing flow conditions. Only in non-distorted models this conflict can be avoided but then the roughness condition will be violated. Also the conflict has a repercussion on the determination of the time scale for the morphological processes.

Time scale for the morphological processes. The character of the Waal River enables to consider the water movement as quasy-steady (Jansen [1]). This implies that the variable boundary conditions concerning discharge and water level can be introduced as a simple time step function (see Fig. 5) provided that inertial waves are suppressed during the step changes. Consequently it is sufficiently to define only the time scale for the morphological processes.

A rather common method to determine the time scale is the use of the one-dimensional continuity equation for the bed level changes:

$$\frac{\partial s_s}{\partial s} + \frac{\partial z_b}{\partial t} = 0 \tag{3}$$

in which z_b is the bed level and t is the time coordinate. This equation results in a simple expression for the time scale, which reads ($n_{z_b} = n_h$):

$$n_t = n_L \, n_h / n_{s_s} \tag{4}$$

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2. VRIES, M. de,
   Application of physical and mathematical models for river problems,
   DHL Publication No. 112, 1973.

3. KOCH, F.G.,
   Bed level computations for axisymmetric curved channels,
   DHL, TOW rivers, Report 657-IX, 1980.

4. STRUIKSMA, N.,
   Recent developments in design of river scale models with mobile bed,
   In Proc. Symposium on River Engineering, Subject D, IAHR, Belgrade, 1980.

However, this method ignores the bed level changes in lateral direction. For that reason a better approach is to start from the two-dimensional equation (see Fig. 2):

$$\frac{\partial s_s}{\partial s} + \frac{\partial s_n}{\partial n} + \frac{s_s}{R_n} + \frac{s_n}{R} + \frac{\partial z_b}{\partial t} = 0 \qquad (5)$$

After some elaboration and introducing $s_n = s_s \tan \gamma$ in Equation (5) the following time scale can be derived:

$$n_t = \frac{n_L n_h}{n_{s_s}} \left[\frac{\left(\frac{R}{s_s}\frac{\partial s_s}{\partial s} + \frac{R}{s_s}\frac{\partial s_s}{\partial n} \tan \gamma + R \frac{\partial \tan \gamma}{\partial n} + \tan \gamma + \frac{R}{R_n}\right)_m}{\left(\frac{R}{s_s}\frac{\partial s_s}{\partial s} + \frac{R}{s_s}\frac{\partial s_s}{\partial n} \tan \gamma + R \frac{\partial \tan \gamma}{\partial n} + \tan \gamma + \frac{R}{R_n}\right)_p} \right] \qquad (6)$$

In distorted models this equation does not lead to a constant value for the time scale. This is due to the already mentioned fact that the sediment transport direction scale $n_{\tan \gamma}$ will vary in space and time. There is some evidence that in distorted models the direction $|\tan \gamma|$ is larger than in the prototype (Struiksma [4]). For Equation (6) this implies that the numerator is larger than the denominator which results in a larger time scale than for the one-dimensional case (Equation (4)).

3. Schematisation of the regime

For scale model studies the dominant discharge concept is frequently introduced. For reasons of easy model operation this concept was also used for the model investigation of the Waal River near Nijmegen. Concerning the dominant discharge many definitions exist producing different results. For a discussion on this subject, reference is made to Prins [5]. To demonstrate these differences this author made computations of the dominant discharge for the Waal River near Nijmegen. By using the several definitions he arrived at a discharge range of 1,200 to 1,700 m^3/s. Comparatively in this river reach the discharge corresponding to the average water level is 1,300 m^3/s and the bankfull discharge is 1,750 m^3/s.

For the model study the dominant discharge was determined experimentally. A discharge was selected during the calibration of the model which gave the best result with respect to the reproduction of the bed topography. The results of this calibration are briefly discussed by Struiksma [4]. The selected discharge corresponded with a prototype value of 1,250 m^3/s, which is within the range computed by Prins [5].

To test the reliability of the dominant discharge concept it is not necessary to reproduce the prototype regime in a similar way. This implies that deviations from the prototype regime characteristics are acceptable to a certain extent. This freedom facilitated the design of the discharge-time function. The result was a compromise between a realistic regime and practical limitations in relation to the model operations. The most important limitations were the maximum discharge (corresponding with 2,000 m^3/s in the prototype) and the manual adjustment of the changes in discharge and corresponding water level. Three times a day such an adjustment could be realised at most.

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5. PRINS, A.,
Dominant discharge,
DHL, Research Report S 78-III, 1969.

In view of the foregoing paragraph deviations were accepted concerning the hydrological cycle and the duration curve. The time scale of the bed level changes in the model was estimated at $n_t = 600$ (Equation (6)), which implies that one year in the prototype (hydrological cycle) agrees with 15 hours in the model. This is a very impractical measure for the model operations and for that reason the hydrological cycle was modelled on day basis (24 hours). In Fig. 3 the discharge duration curve of the introduced regime is compared with that of the prototype. It can be seen that differences were accepted especially for the discharges exceeding 1,250 m^3/s.

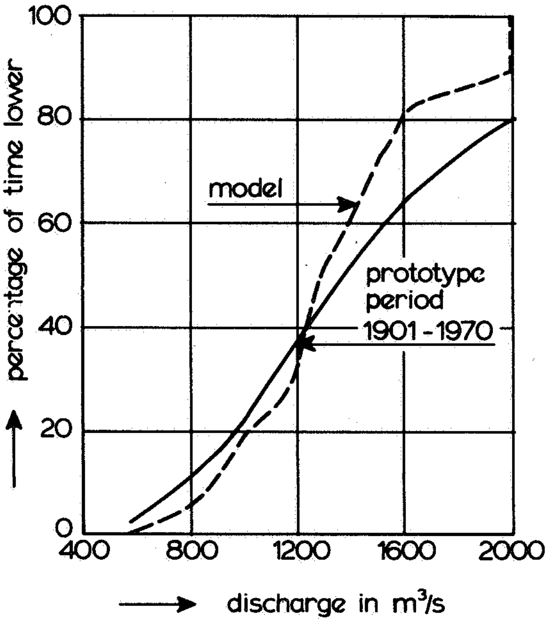

Figure 3 Duration curves

In Fig. 5 the introduced discharge-time step function is shown. Besides the variations within the hydrological cycle it consists also of long term variations. It starts with a dry period, is followed by a wet period and is concluded with again a dry period. The occurence of long dry and wet periods is a phenomenon which is frequently observed in nature.

4. Results of the investigation

Before starting with the discussion of the results of the investigation some general information is given in the next two paragraphs about the applied scales, prototype data and the impact of the regime on the sand transport processes.

The applied scales were: length $n_L = 100$, depth $n_h = 40$, velocity $n_v = 2.58$, grain size $n_D = 4$, relative submerged density $n_\Delta = 1$ and geometrical standard deviation of the gradation $n_\sigma = 1$. Some relevant prototype data are: $h_p = 2.92$, 4.88 and 6.48 m corresponding with $Q_p = 600$, 1,250 and 2,000 m^3/s respectively, $\bar{D}_p = 4$ mm and $\sigma_p = 2.3$.

In Fig. 4A the results of the sand transport measurements in the model are shown as a function of the corresponding prototype discharges. Also the grain size distribution of the transported sediment has been measured. These results are depicted in Fig. 4B, again related the corresponding prototype discharges, and compared with the grain size distribution of the bed material used in the model. From this figure it can be seen that during the lower discharges the transported material became substantally finer than during the higher discharges. The low flows were not fully able to transport the coarser fractions. Consequently armouring of the bed in the beginning of the inner bends could be observed due to phase lag effects in the lateral grain sorting.

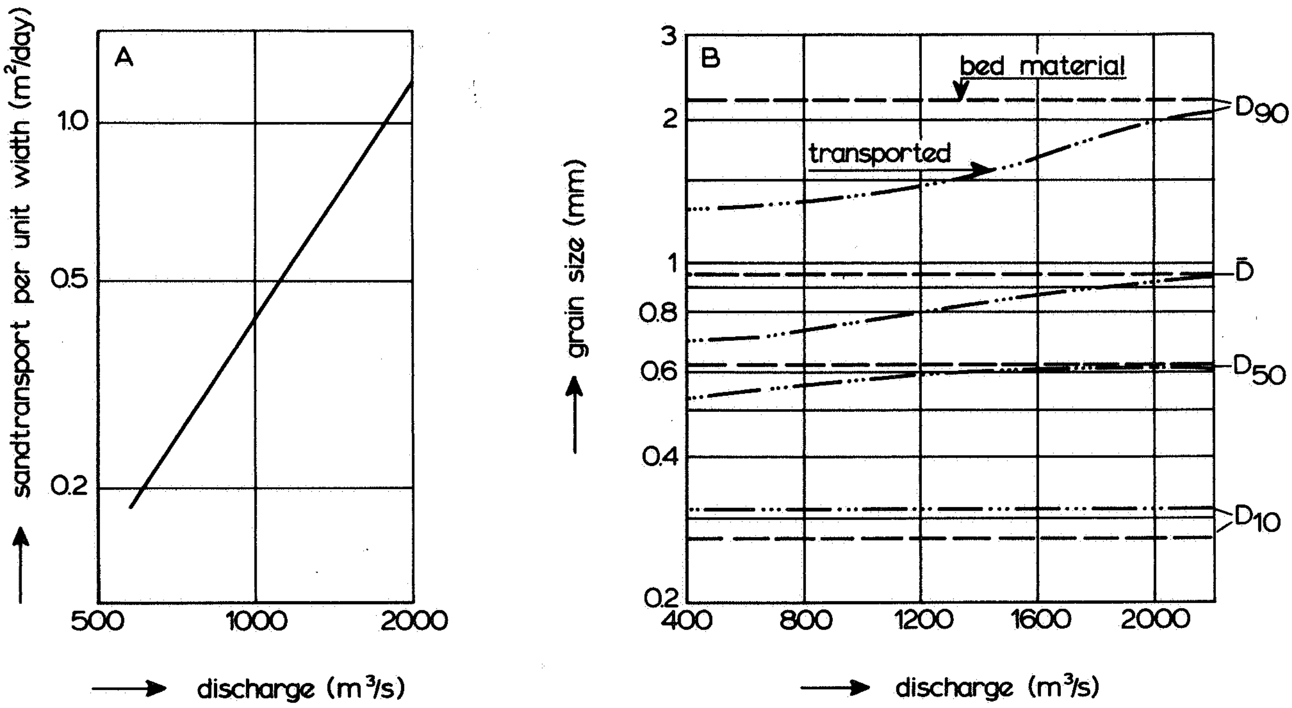

Figure 4 Sediment transport

In Fig. 1 is indicated with A, B and C which reaches have been sounded. These reaches are typical: i.e. a crossing (A), a beginning (B) and a downstream part (C) of a bend characterised by undefined, steep and moderate cross-sectional bed slopes respectively. Each reach was also subdivided in three areas in lateral direction to study the changes of the cross-sectional profiles (marked with left, axis and right). Before the discharge-time step function was introduced first the model bed was shaped under dominant discharge conditions untill an equilibrium was reached. At that moment soundings were carried out to establish this initial condition as a reference.

To obtain a fair impression of the influence of the regime on the bed topography the natural "noise" of the bed forms was smoothed by averaging the soundings in space and time. In Fig. 5 the results of the soundings (prototype levels) as a function of time (model) are shown. The initial condition is indicated with the thin horizontal lines (dominant discharge concept).

Concerning the total mean bed level in the reaches A, B and C slight time dependency can be observed. This is due to the fact that the model has been provided with a constant width of 2.6 m. Note that the bed level in reach C is higher than in the more upstream reaches. This is caused by the presence of groynes as a bank protection in this reach (Fig. 1) which results in a somewhat larger effective width. The time dependency in lateral direction is more interesting. Reach A and C show clearly relatively large changes in the steepness of the cross-sectional bed slope. However, these differences do not appear before the long wet period starts. So it seems that the long term variations of the regime has more influence than the variations during one hydrological cycle modelled on day basis. It can also been seen that in reach C the cross-sectional bed slope remains steeper after the wet period. More time is needed to arrive again at the conditions during the first dry period. It is striking that negligible time dependency is observed in reach B. This reach is stable even during the long term variations. Apparently the dominant discharge concept leads to consistent predictions with respect to the bed topography only in this reach.

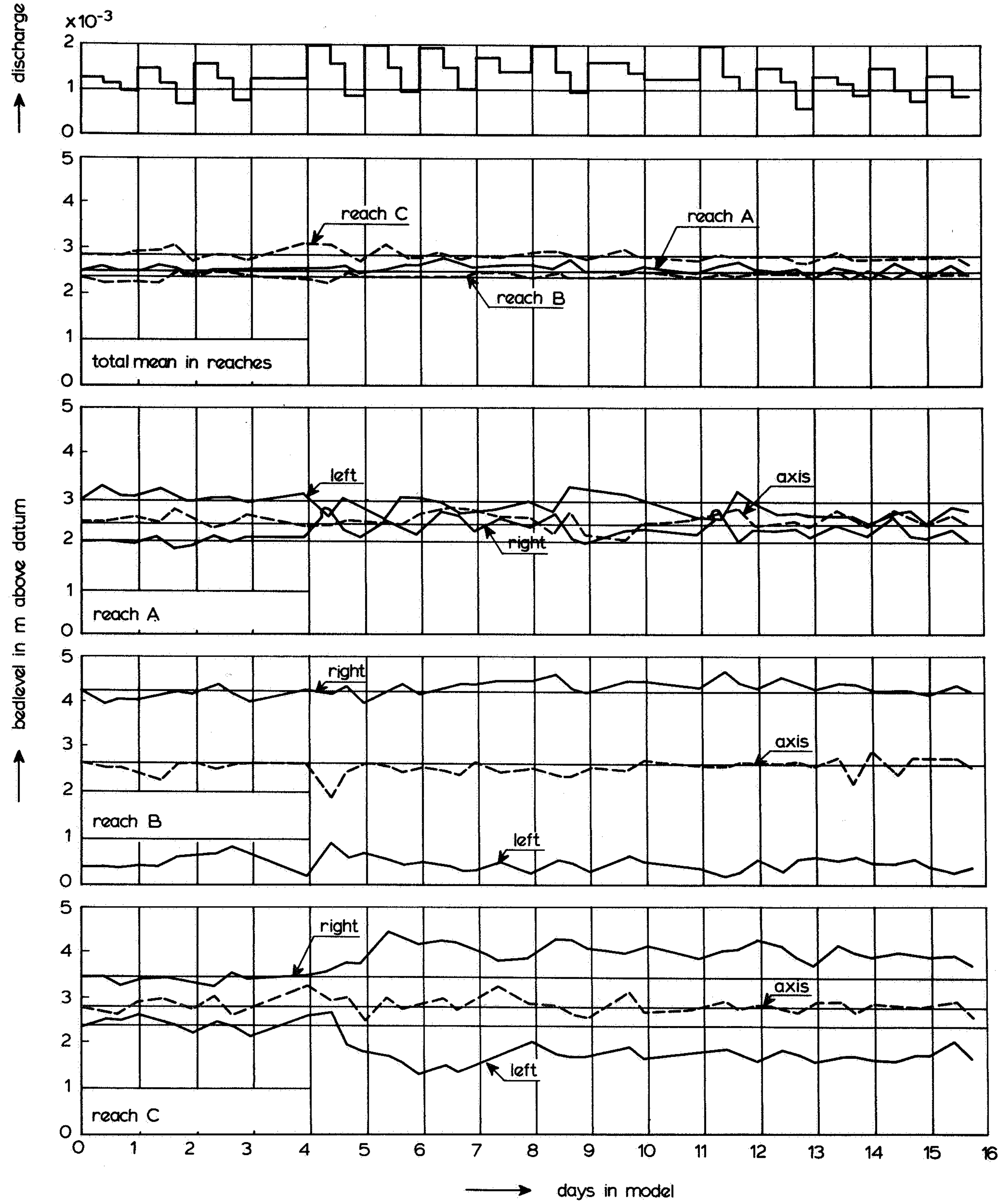

Figure 5 Results of soundings

In conclusion it can be said that the dominant discharge concept can lead to wrong predictions in new situations depending on the aim of the investigation. For instance when the navigable width of the channel is studied, which depends o.a. on the steepness of the cross-sectional bed profiles, the dominant discharge concept would give too optimistic figures for the reach C. In such cases a regime investigation has to be applied. However, in connection with the effort which is required it is recommended to introduce a regime only during the calibration and the most promising new situation.

Acknowledgement

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