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ABSTRACT

The paper discusses the advantages and disadvantages of using numerical models to simulate hydraulic phenomena, in particular when they are compared to physical models. When the specific application of modelling is the design of sediment control structures, it appears that the advantages of numerical modelling then dominate. The paper outlines the development of numerical models to aid the design of (i) sluiced settling basins, and (ii) intakes and their sediment excluders. A different approach is required for each application but in both cases very good agreement is found between the numerical model's predictions and field or laboratory observations. The paper concludes that numerical modelling techniques will become more widespread in the field of design simulations for sediment control structures.

1. INTRODUCTION

Numerical modelling techniques are challenging physical modelling as the established method in many areas of hydraulics. Potentially, numerical modelling is very attractive because:

(i) it overcomes the problems of scale effects from which physical models often suffer; and
(ii) the large time and cost involved in constructing and running a physical model can be avoided. (This advantage is especially relevant in western countries where labour costs are high.)

The potential advantages of numerical models are not always realised because:

(i) numerical modelling can introduce its own inaccuracies either due to deficiencies in the numerical methods or in the assumptions used in forming a model;
(ii) computer run times or memory requirements can be large, so making the costs prohibitive; and
(iii) development costs for new numerical methods are high.

For these reasons numerical models are not universally applied to all hydraulic modelling problems. The purpose of this paper is to outline the use of numerical models in sediment control, and more particularly the use of models to aid the design of intake structures and settling basins.

2. THE USE OF NUMERICAL MODELS IN SEDIMENT CONTROL

Sediment control is an application suited to numerical modelling because the geometries of the flow boundaries are typically quite simple, for example a straight settling basin, and because the flow can usually be considered as steady or quasi-steady. Physical modelling, on the other hand, is especially difficult because it is not possible to satisfy the scaling laws in a mobile bed model unless the fluid in the model has properties which are very different from those of water, Yalin (1971).

Hydraulics Research is at present developing three numerical models for use in sediment control; two simulate the movement of water and sediment in settling basins (one models the deposition of sediment, the second models sluicing conditions). Both models can also be applied to sluice channels or "sluicing pockets" at intakes, where the channel being sluiced is sited upstream of a set of sluice gates at a diversion structure. This sediment control method has often been called "still pond regulation". The third numerical model simulates the flow of water and sediment in the vicinity of an intake structure, and so can be used to predict the proportion of the river sediment load which would be abstracted by the intake.

3. SETTLING BASIN MODELS

Settling basins have recently been designed using settling velocity criteria, for example the method due to Camp (1946) is widely used. These methods can be used to make a prediction of the settling, but not the sluicing, performance of basins. Also, as they are not based on a complete representation of the flow and sediment movement, they do not account for factors such as the changing trap efficiency of the basin as it fills.

The principal questions to be answered at the design stage are:

> What will be the size range and concentration of sediment passing into the canal and how will they vary with both the dimensions of the basin, and the rise in bed levels as the basin fills?
>
> How often will it be necessary to sluice, and for how long?

Two models have been developed to answer these and related questions.

3.1 Deposition model

The performance of a settling basin during the deposition phase is predicted using the model described by Atkinson (1986a). The basic structure of the model is similar to the many one-dimensional river models that are available and includes the key assumption that the water flow and sediment transport computations can be de-coupled, Figure 1. However, the model also includes the effects of turbulent diffusion of sediment to and from the bed. The turbulent diffusion equation is solved analytically by assuming a uniform velocity profile, and then the local distance scale is transformed to correct for the error introduced by that assumption. This procedure greatly reduces the computational time compared with a similar model described by Kerssens (1979).

Recent developments to the model include the simulation of graded sediments. The rate of deposition for each of ten equal size fractions is computed for each section in the basin, hence the size grading of the bed material in the basin is predicted. Also, the additional turbulence produced by the entry conditions to a basin or a gradual expansion down a basin can now be simulated. Finally, silt deposition is now simulated by the model, the calculations are similar to those for sand deposition but are undertaken separately.

The deposition model has been verified with field data collected at sluiced settling basins in China and Java, and in a sluice channel at an intake in Thailand.

China A data set on the Yangwu settling basin is reported by Ning et al (1983). Sediment concentration was not reported so the observed deposition pattern and that predicted by the numerical model were compared, Figure 2. Agreement between prediction and observation is very good.

Java Fish (1987) reports a comprehensive set of data collected by Hydraulics Research at the Karangtalun settling basin. Figure 3 presents predicted and observed sediment concentrations entering the canal at the downstream end of the basin. Again agreement is good, but the observed sediment concentrations after the 10th February sluicing showed considerable scatter, possibly due to the sediment concentration variations associated with river floods.

Thailand The Mae Tang diversion structure in northern Thailand was monitored by Hydraulics Research during 1985 (Atkinson, 1986b). An intensive set of measurements which enabled comparison with the numerical model was made in a sluice channel at the diversion in September 1985. The observed and predicted sediment concentrations in the sluice channel are compared in Figure 4, agreement is again very good.

No "calibration" of the numerical model was undertaken for any of these comparisons. "Calibration" is the adjustment of empirical factors within a model to cause it to agree with a limited data set, ("proving" the model might then be claimed by showing good agreement with a wider data set).

3.2 Sluicing model

A second model has been developed to describe the sluicing phase of settling basin operation. The model assumes that during sluicing erosion occurs from the downstream face of the sediment deposit; sluicing can then be modelled as the erosion of a series of wedges of bed material. Field observations during sluicing support this assumption, see for example Ning et al (1983). The sediment transport rate over the downstream face of each wedge is computed from bed friction and sediment transport equations. The time taken to erode the wedge can then be calculated from the volume of the wedge, the density of deposited sediment and the sediment transport rate. Summing the time for each wedge yields the time required to flush the basin.

The model has been successfully tested with data from the three sites mentioned:

Site		Observed sluicing time (hrs)	Predicted sluicing time (hrs)
Settling basin in Java	} 1st sluicing	1.3	1.6
	} 2nd sluicing	0.6	2.0
Settling basin in China		6.5	8.0
Sluicing channel in Thailand		3.0	2.5

This good agreement between a numerical model and field measurements has again been achieved without the aid of any model calibration.

4. MODEL FOR SIMULATING SEDIMENT CONTROL AT INTAKES

Both the design and siting of an intake effect the quantities of sediment that it abstracts. For example, an intake located on the outside of a river bend will abstract a relatively low sediment concentration, this is due to the lower sediment concentration and higher momentum of the near surface flow. Its momentum causes it to move towards the outer part of a bend. Siting intakes on bends, or artificially inducing curvature in the approach flow to an intake are thus well established methods of sediment control. However, the benefits are large only when most of the sediment transported in the river is moving close to the bed. If the sediment is well distributed then there may be little benefit from the cost of a large structure designed to introduce flow curvature at a diversion.

A second well tried method of controlling sediment at intakes is to separate the near bed flow, carrying its high sediment concentrations away from the canal intake. A typical structure of this type, a tunnel type sediment excluder, is shown in Figure 5.

4.1 Brief description of the model

The purpose of the model is to enable the designers of an intake to test a set of proposed designs, in each case predicting the sediment concentration abstracted by the intake.

The model uses a computational fluid dynamics computer code to solve the Navier-Stokes equations for the region close to an intake. Typically a short river reach both upstream and downstream of the intake is simulated, together with the intake and a short section of canal. The code predicts the flow field in this region and then "traces" the sediment concentrations through the flow field. Hence the sediment concentrations entering the intake can be predicted. Turbulence and its effects are simulated using the k-ε two equation turbulence model; this turbulence model has been widely applied in flow simulations in civil engineering and other fields.

Both the sediment concentration profile and the velocity profile have to be specified at the upstream boundary, these can either be measured at the site of the intake, or predicted using standard methods.

A detailed description of the numerical model is given in Atkinson (1989).

4.2 Laboratory and field verification

A comparison between predictions of the model and the results obtained from a laboratory study (Indlekoffer et al, 1975) are shown in Figure 6. The laboratory study was carried out using plastic beads of diameter 1-3mm in a small flume of width 0.25m and a depth ranging from 0.07 to 0.15m. The purpose of the study was to examine the effects of a divide wall in reducing the quantity of bedload that would enter a branch channel. Figure 6 shows both the predicted sediment abstraction with a simple 90° branch and the predicted reduction in sediment abstraction produced by adding a projection and then a divide wall to the structure. Figure 6 also shows the data measured in the experiments. Agreement between prediction and measurements is good, particularly as the computational model was again not calibrated.

The model has also been applied to predict the performance of the Narora sediment excluder, India, which is shown in Figure 5. Field data at the excluder is presented in Sharma et al (date not known). The measured performance ratio, defined as the ratio of sediment concentration in the canal to that in the river, was 0.96. Predicted performance ratio was 0.93, a very encouraging result. (A physical model study had predicted a performance ratio of 0.08.)

The numerical model is to be compared with a more detailed set of field data which is at present being collected at two intakes in the Philippines. However, the initial results reported here suggest that the new approach will be capable of providing performance predictions at intakes at a fraction of the cost of physical model studies.

5. CONCLUSIONS

Numerical models now enjoy widespread use in many areas of hydraulics due to either their superior accuracy or lower cost when compared to equivalent physical models. The trend seems certain to continue as new numerical modelling techniques are developed and computers become more powerful.

In the field of sediment control three numerical models are being developed by Hydraulics Research; they simulate (i) deposition in settling basins, (ii) sluicing in settling basins, and (iii) water and sediment flow at intakes. The paper has described the physical basis for each model and has presented comparisons between the models' predictions and field or laboratory observations. In each case the agreement between prediction and observation has been very encouraging, no "calibration" was used. It appears that the trend of increased use of numerical models in hydraulics generally will also be reflected in the particular field of sediment control.

6. ACKNOWLEDGEMENTS

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FIGURES.

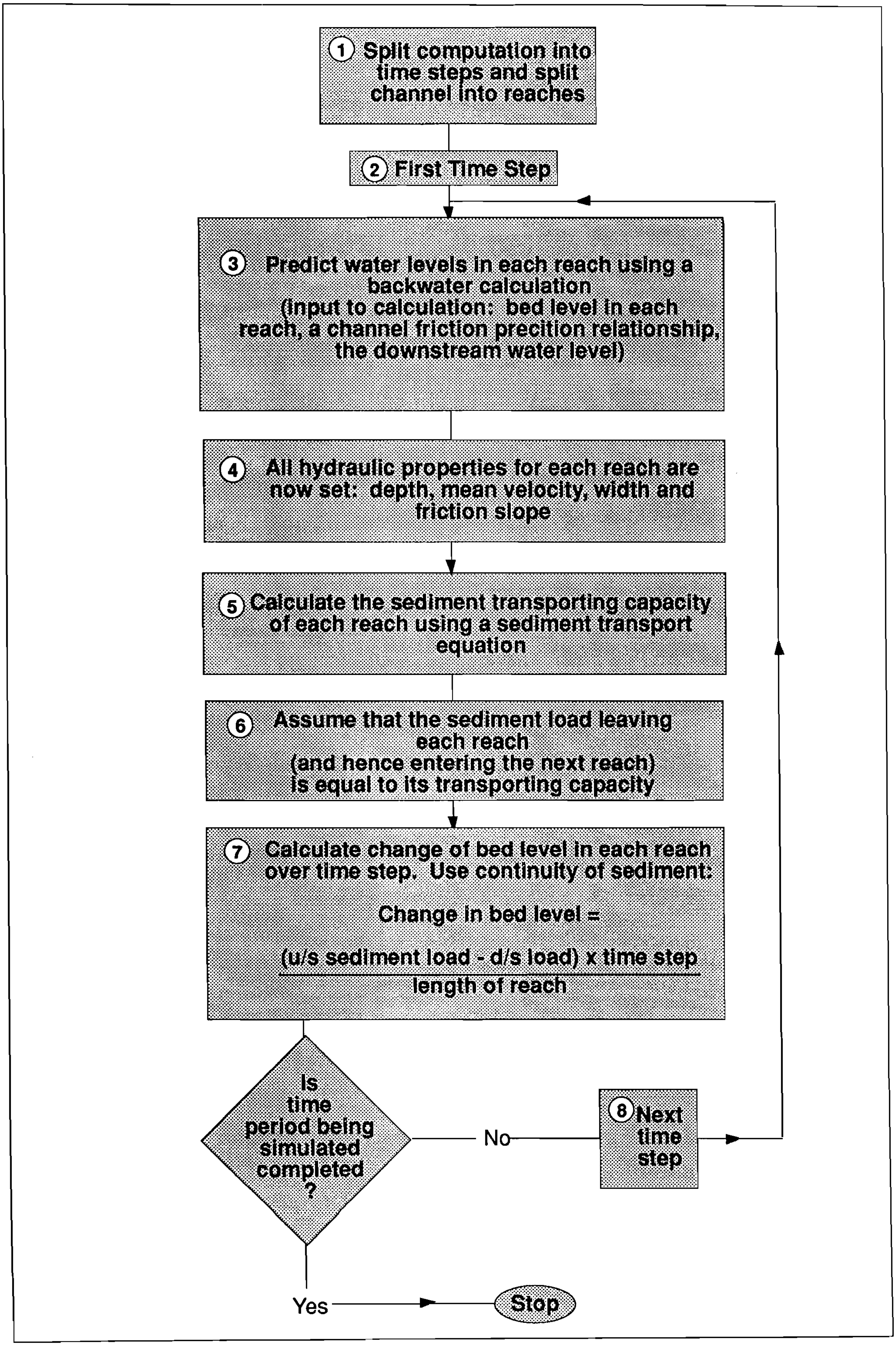

Fig 1 Computational steps for a standard 1-dimensional river model

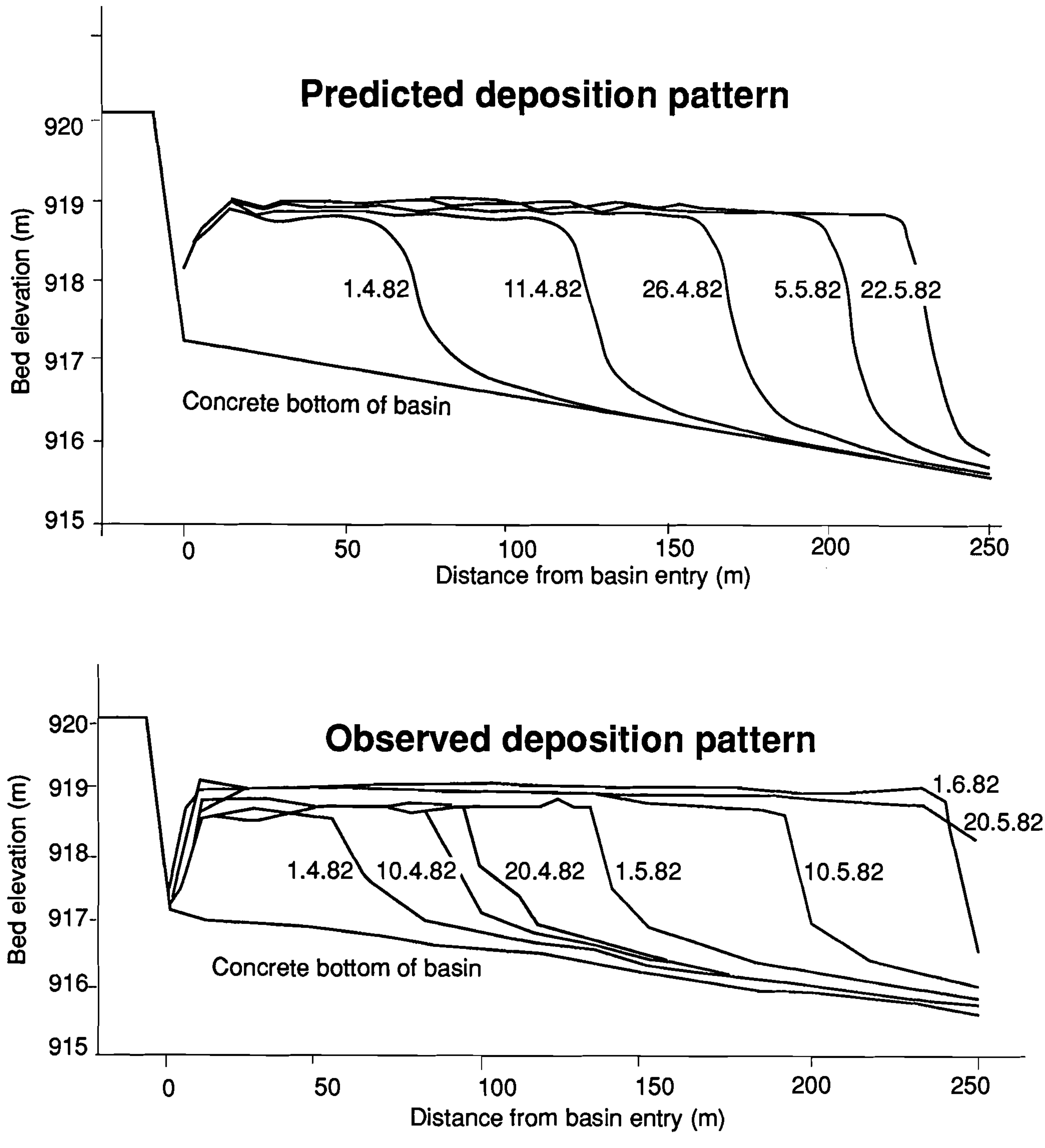

Fig 2 Predicted and observed deposition pattern in Yangwu Settling Basin, China

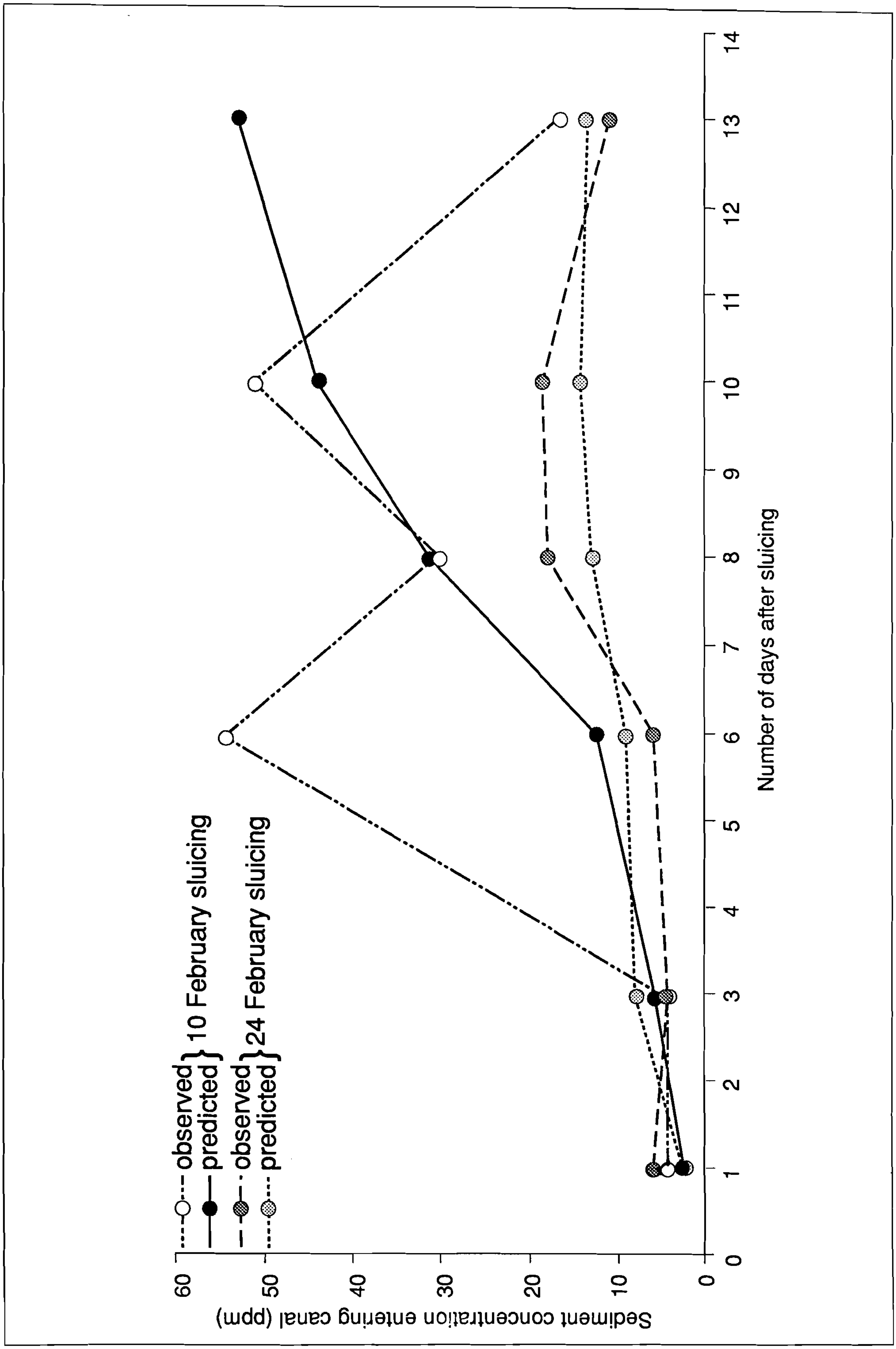

Fig 3 Predicted and observed performance of Karangtalun Settling Basin, Java

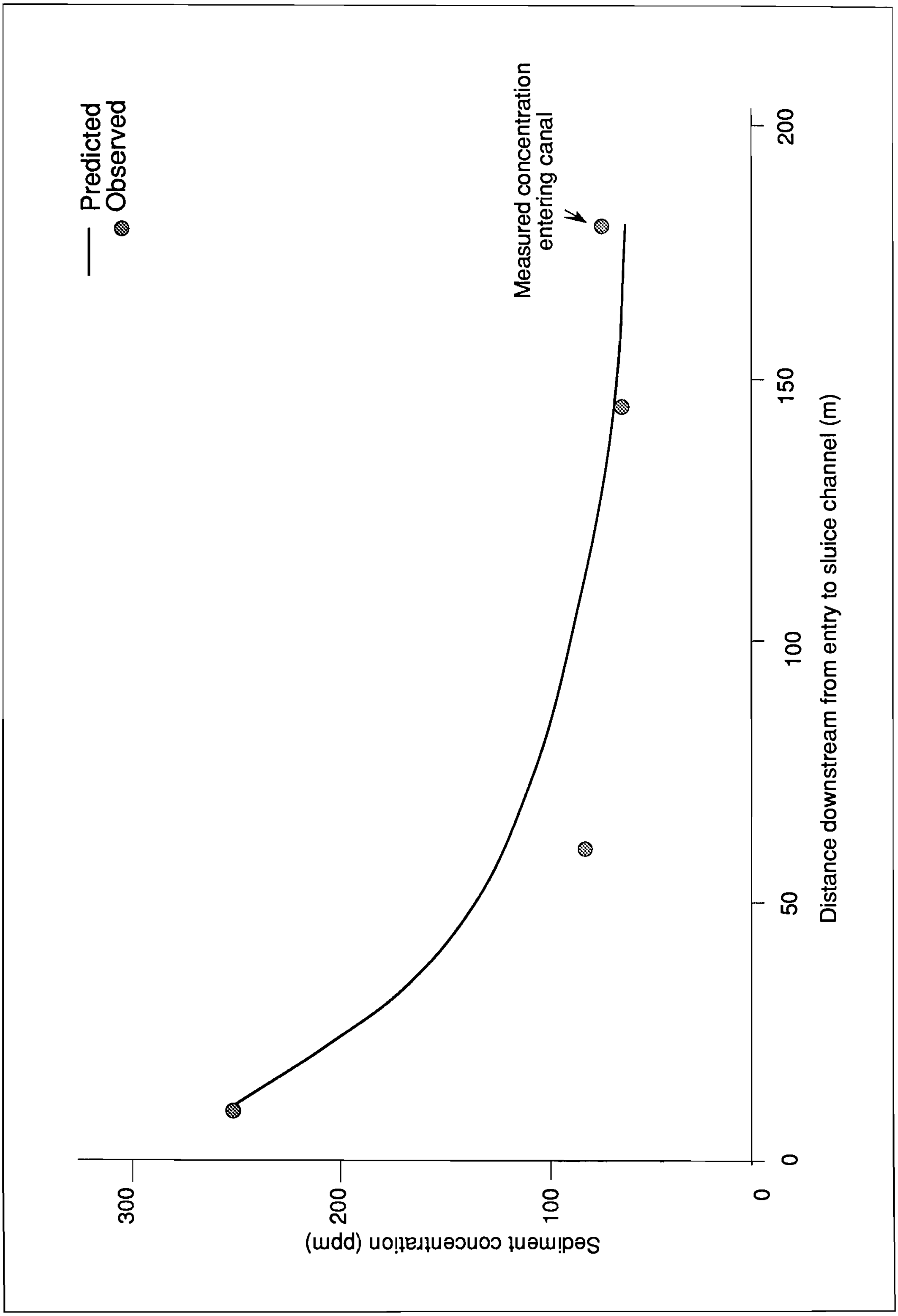

Fig 4 Predicted and observed sediment trapping in the sluice channel at Mae Tang Diversion, Thailand

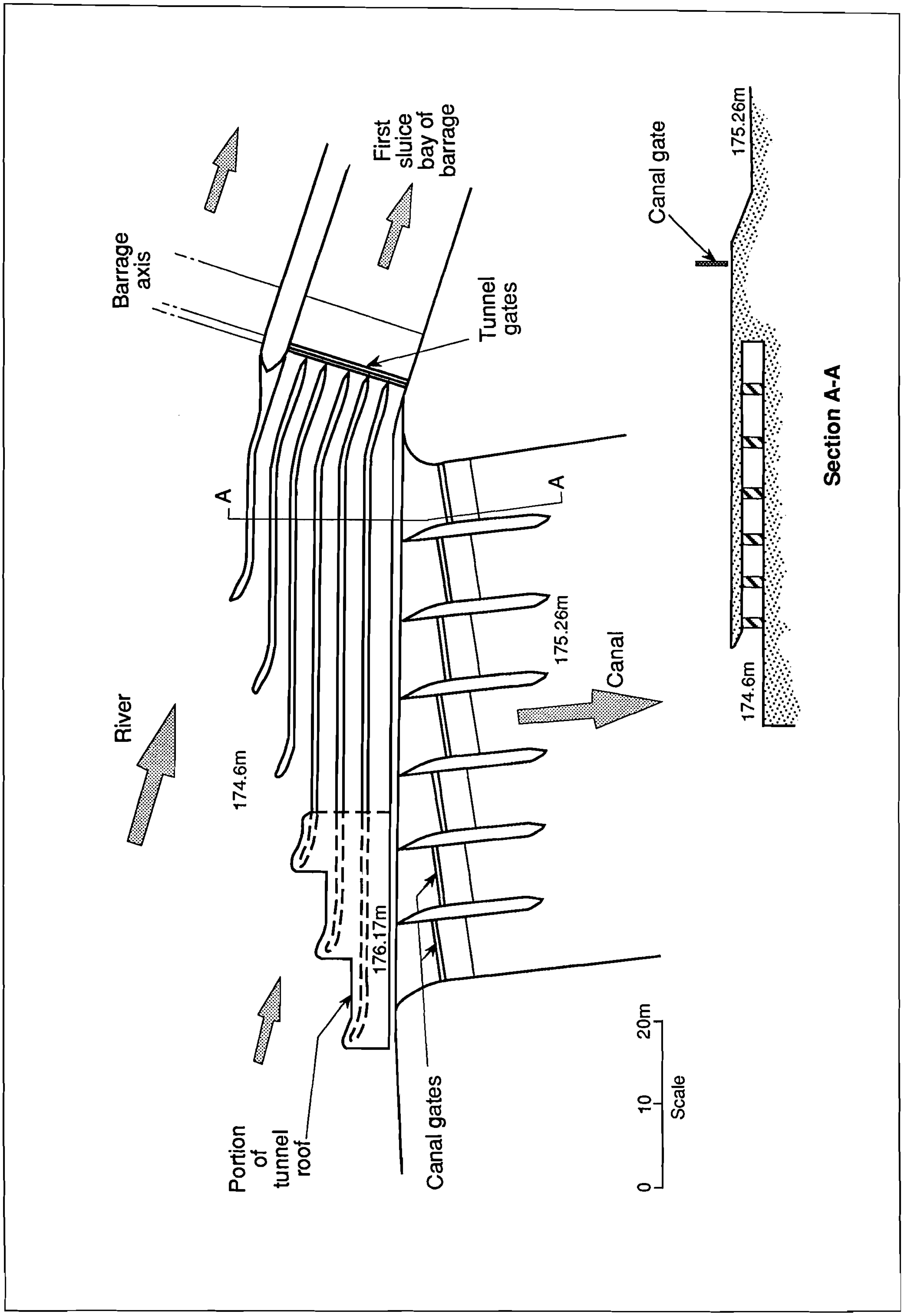

Fig 5 Plan view of Narora sediment excluder

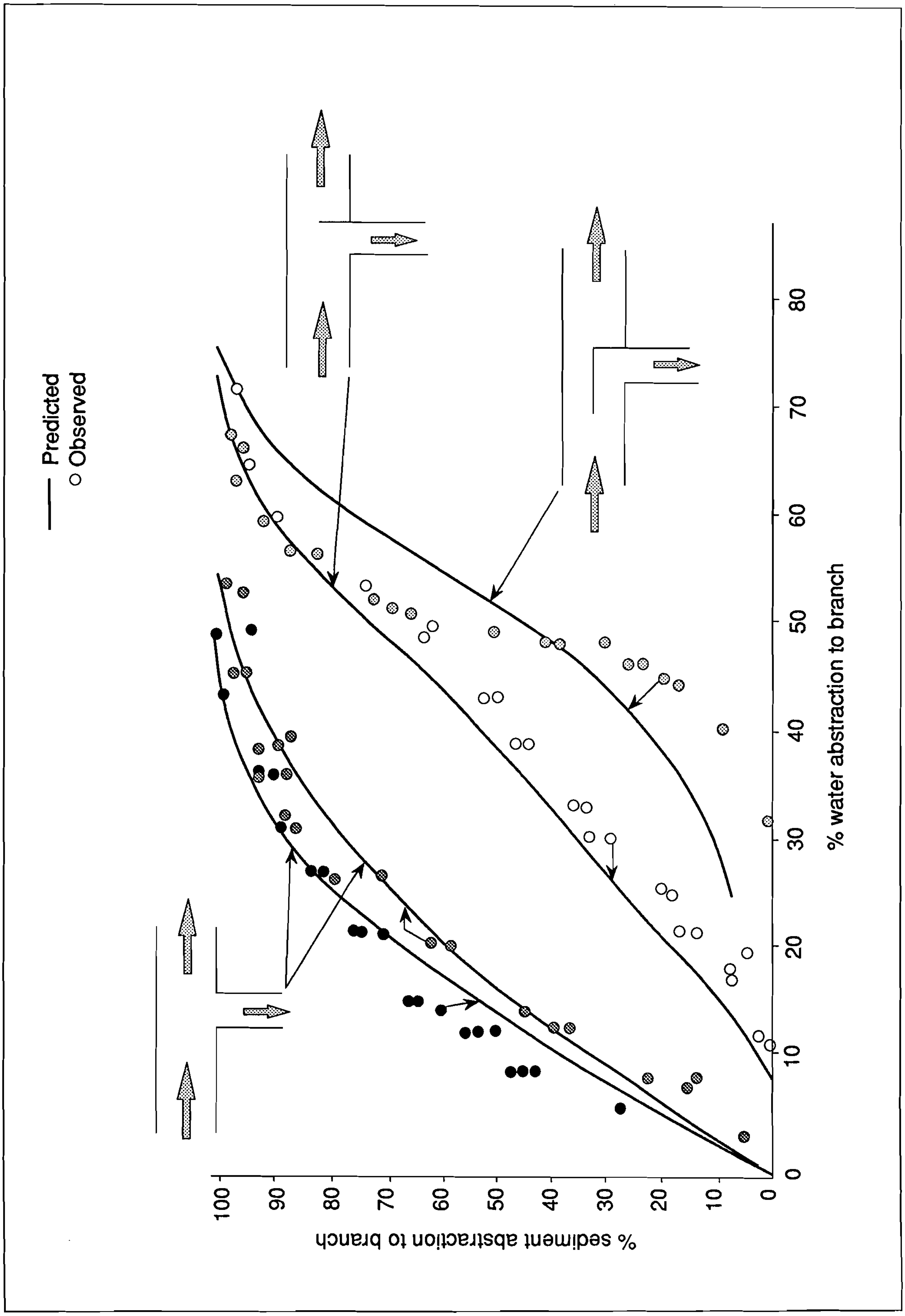

Fig 6 Comparison between predicted and observed sediment abstraction to the branch, Indlekoffer et al experiments