Data Requirements for Sediment Transport Models of Rivers

In the following, guidelines about data requirements for sediment transport and morphological modelling are provided based on experience with MIKE21C and MIKE 11 sediment transport model applications.

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Introduction

Every sediment transport model application is different both in terms of time and space scale (extent of study area), study objectives, required accuracy, allocated resources, background of the study team etc. Often data requirements are divided between “nice to have” and “need to have”. However, as this will be different from case to case, no distinction has been made in this note. The purpose of the data is described, though, so that the model user can make his/her own judgement about the importance of the data given the actual study objectives. The equipment for field measurements is not described here.

Geometry

Maps, aerial and satellite images

It is advisable to apply maps and/or geo-referenced aerial photos or satellite images to delineate the modelling area and digitise the model boundaries for the generation of a grid (1D branches or 2D curvilinear grids). When the number of cross-sections is scarce, use of additional information from maps and images is imperative. If the study objectives include assessment of large-scale bank erosion (several tens of meters), it can be particular useful to apply (geo-referenced) aerial photos before and after the study period in consideration.

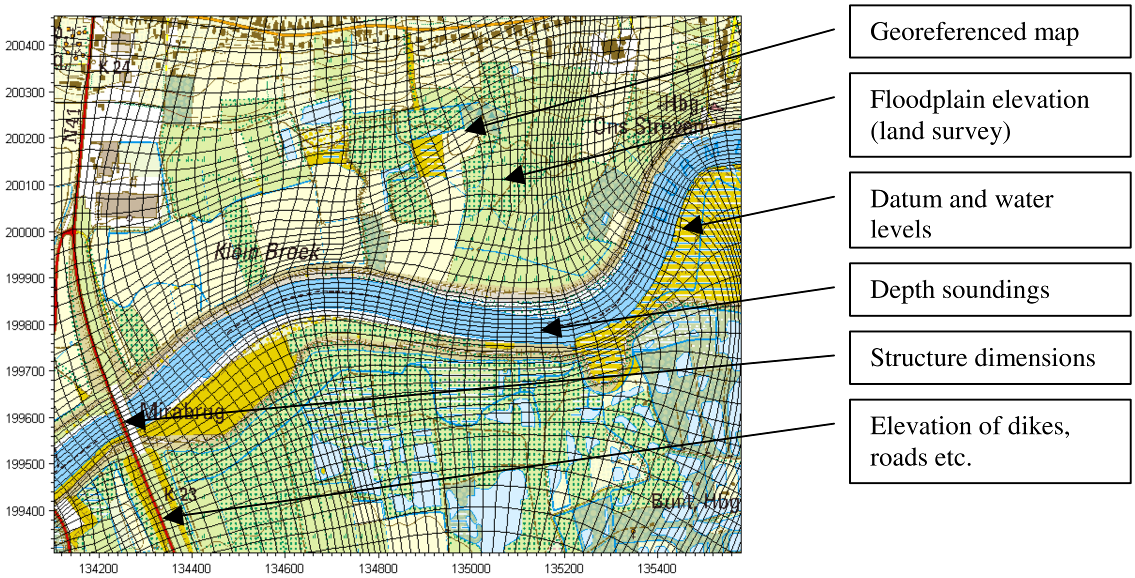


Figure 1 Data for geometric description

Depth Soundings

Establishment of the sediment transport model requires good channel bathymetry data and floodplain topography data (all together called “bathymetry” in the following).

With an echosounder, the depth is obtained along a number of transects. Obviously, they should be perpendicular to the river (cross-sections) as the cross-section shape is of particular importance. The required spacing between transects is typically 50-200m depending on the width of the river and the required grid resolution of the model. With a grid spacing of 50m in a 2D sediment model, a distance between transects of around 100-200m would typically be sufficient (i.e. interpolation in intermediate points will be done during grid preparation). A meandering reach should be covered by at least 20-30 cross-sections per wave length if the morphological changes in that river bend is of particular interest.

Specific geometric features in the river, such as a constriction, groynes, bridge, or similar, should be surveyed with higher density of survey lines.

The measured depths from echosounder are converted to bed levels by applying readings from water level gauges along the river. It is advisable, to establish a number of temporary water level stations as the lateral (and longitudinal) variations in water level can be significant, in particular in high speed and strongly curved flow. Accurate referencing (datum and horizontal position) of these stations is important and requires that the datum of each benchmark be connected. This can be a particular challenge along long reaches never surveyed before.

Land Surveys

Compared to echo sounding, land surveys of floodplains are costly, especially if the floodplains are covered by high vegetation or similar. Use of LIDAR and/or photogrametric surveys from air is useful to establish good floodplain topography. In addition, accurate level measurements of dividing lines in the floodplains such as railways, roads etc. are important. Culverts and bridges below roads, dikes, embankments must be identified and measured, as they determines the flow from one flood cell to another. The required accuracy of floodplain topography is less in connection with morphological modelling as compared to detailed flood modelling on floodplains.

Structures

In addition to survey of the bathymetry near the structures, the dimension and functionality of the structures should also be established, especially in connection with application of the structure modules in the MIKE models. The purpose is to calibrate the flow description. The structure itself is not included in the sediment transport model, as this would require a refined flow model (3D CFD code such as NS3). Any morphological changes near a structure are predicted solely based on the cross-sections up- and downstream of the structure and the predicted flow and water levels.

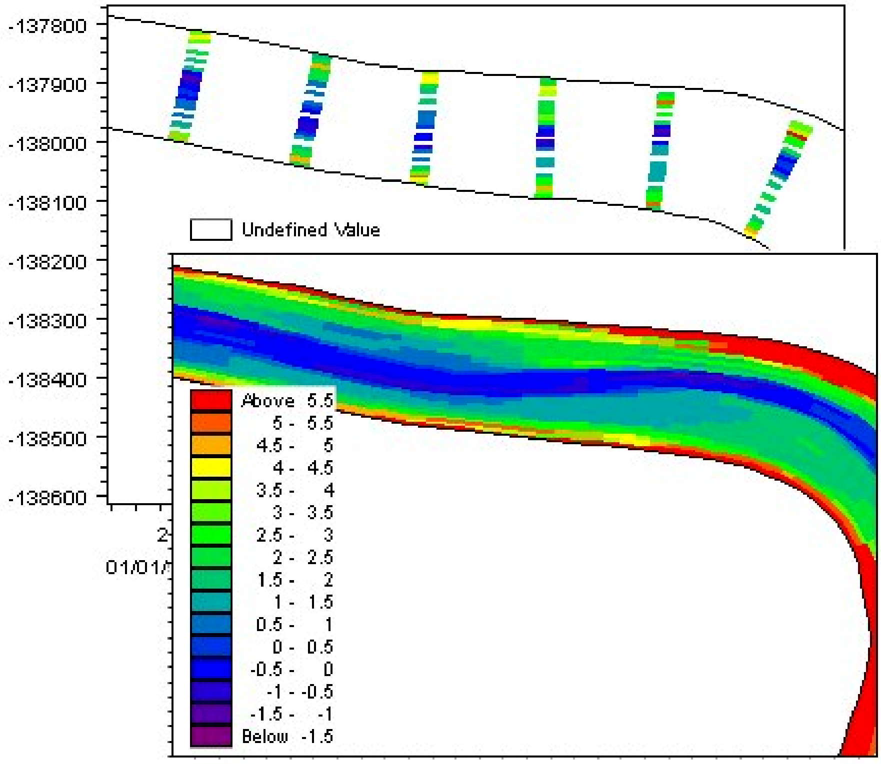


Figure 2 Example of interpolation of cross-section data from a river survey into a MIKE21C grid

Hydrographs

In most applications, morphological models (1D as well as 2D) require an upstream discharge boundary condition and a downstream water level boundary condition. In addition, some parts of the channel system may be described as "closed boundaries", in which case this will simply be defined with a zero discharge boundary condition. In addition, discharge data is required in the interior of the model area to establish the right water balance in case there is a substantial exchange of flow between channel and floodplains (and ground infiltration, evaporation, precipitation etc.).

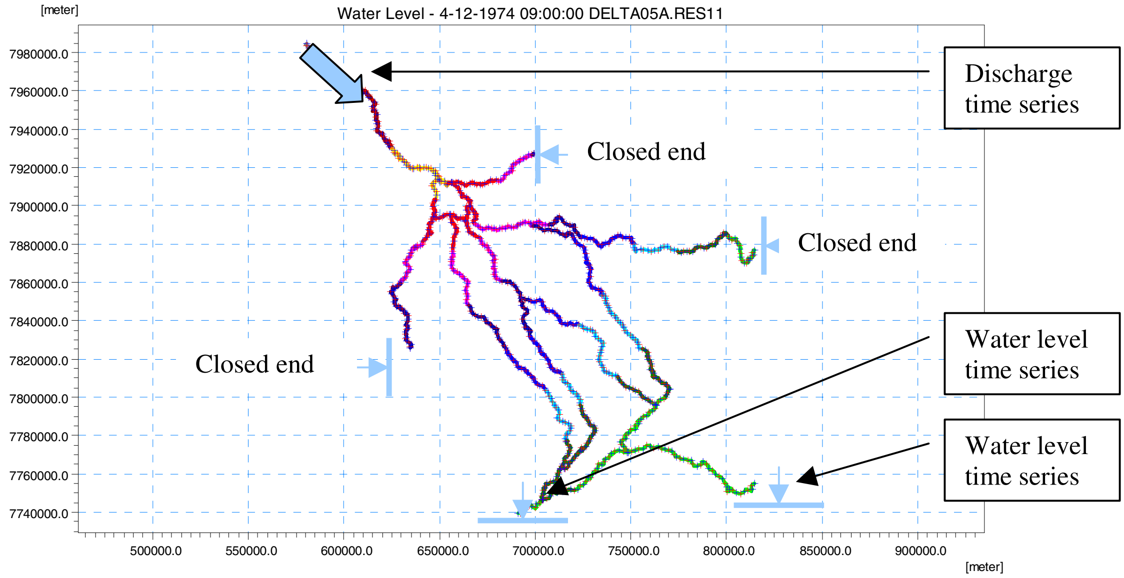


Figure 3 Data for boundary conditions

Boundary conditions for morphological modelling often cover very long time periods (decades). Old data of water level and discharges from different stations must be collected. Discharge time series are usually based on rating curves, which relate a continuously measured water level with discharge measurements with different intervals. It is advisable to review and if necessary to revise such rating curves. In particular extreme discharges can be associated with considerable uncertainty if such rated discharges are based on extrapolations from measurements at a much lower stage.

If the station of the rating curve is located at a channel constriction (often the case at a bridge), particular caution must be exercised as the constriction is subject to scour during extreme flow events and subsequent sedimentation during low flow periods. Furthermore, a measurement station can be subject to substantial morphological changes over the time period in consideration. If the rating curve is based on only one set of discharge measurements, it may not be representative for the entire simulation period. Thus, the variation in the bed elevation at the measuring station can be necessary to consider for accurate prediction of the upstream hydrograph.

In absence of reliable discharge time series, a synthetic discharge time series can be generated as a last option by assuming for instance natural slope conditions at the station, and use the water level slope, water level and cross-section data to calculate the corresponding natural discharge.

If the required morphological model is only covering the main channel and floodplains are excluded (but still important in terms of the water balance due to exchange of flow between channel and floodplain), one way to establish reliable discharge boundaries for the main channel is to establish a model (for instance a 1D model) covering the entire floodplain-channel system, and to use this model to calculate discharges in the main channel. This extracted discharge time series can subsequently be applied as upstream boundary condition (plus possibly additional lateral inflow boundaries further downstream) in the detailed model (e.g. 2D model) covering only the main channel.

Downstream discharge boundaries can be applied also, but they may be source of instability and should be avoided: If the imposed discharge outflow boundary condition is higher than the actual conveyance capacity of the channel at the downstream location, the boundary will be “drained”. The imbalance between the river models conveyance and the actual boundary condition can be caused by for instance 1) inaccurate representation of the channel bathymetry at low flow (too coarse grid), 2) inaccurate calibration of the bed resistance, 3) morphological changes during the simulation which alters the models conveyance at the boundary location. Therefore, it is recommended always to apply upstream discharge boundaries and downstream water level boundaries.

Water levels

Accurate simulation of the water level and energy slope in the morphological models requires calibration of the bed resistance number. With an upstream discharge and downstream water level boundary, the main target parameter is the water level at various locations along the river. Therefore, a number of water level measurements along the river is required, and as a minimum at the upstream boundary. The water level time series do not have to be continuos or to cover the entire time period. However, they should preferably cover both low flow and high flow conditions in order to provide a representative calibration parameter.

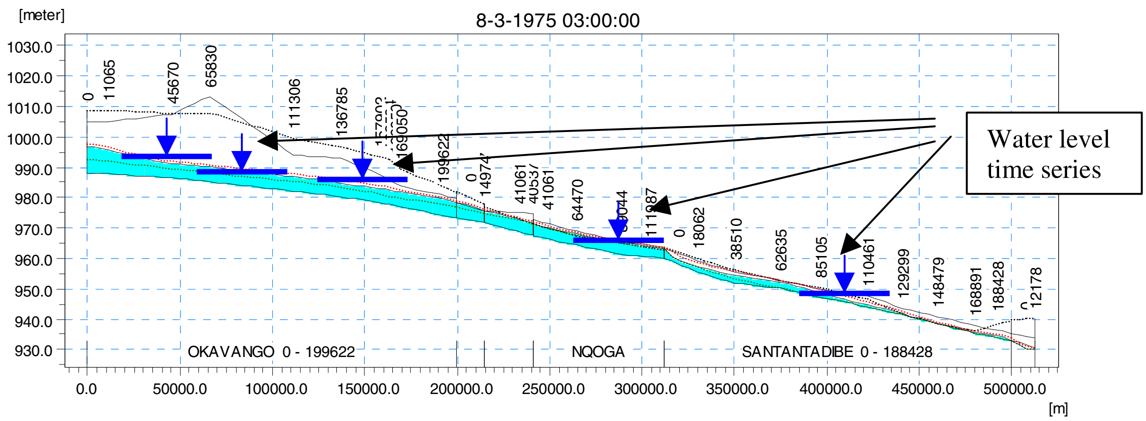


Figure 4 Data for calibration of bed resistance

It should be noted that simulated water levels at low flow are very sensitive to the accuracy of the model bathymetry. One single cross-section and/or grid point may cause backwater effect, which effects the water level in a longer reach upstream of this point. On the other hand, the simulated water level at high flow is more insensitive to local inaccuracies in the bathymetry. For morphological simulations, usually the high flow events are most important.

Velocity

Velocity measurements are required to obtain information about the flow distribution across the river channel and flow patterns in bifurcations and confluences. The traditional equipment is a mechanical propeller. More efficient equipment for velocity measurements is ADCP, as this provides a continuos line of velocity measurements and at various depths. Cross-sections of flow velocity are particular interesting for calibration and validation of the hydrodynamic model in three lines: before, in the middle and after a river bend. In addition, the distribution of flow between main channel and adjacent floodplain is important.

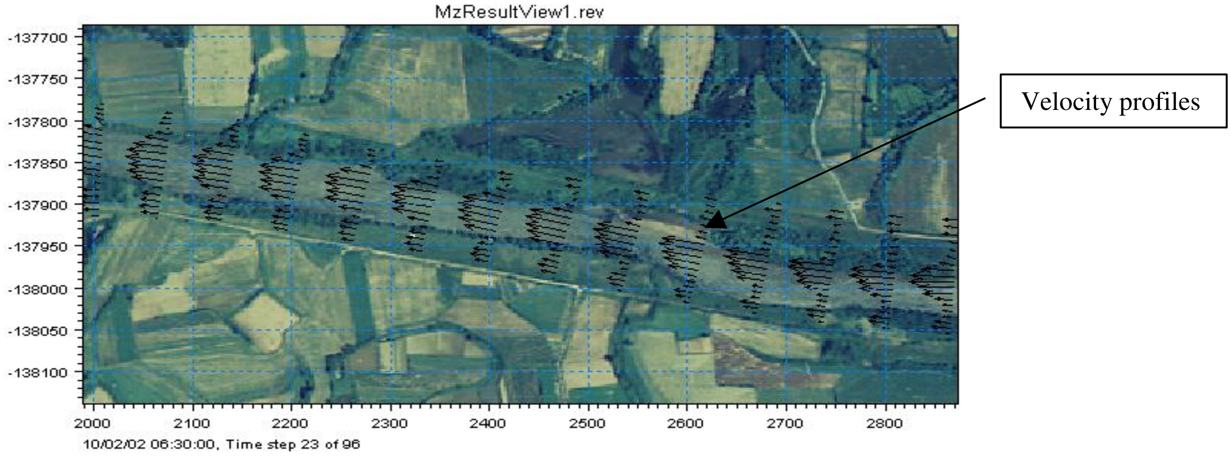


Figure 5 Example of simulated flow distribution in the main channel and the adjacent floodplains inside the summer dikes

Furthermore, in large braided rivers, it is important to cover the transition from deeper parts of the cross-section to the shallow bars. Measurements of velocity should preferably be carried out during high flow, Ideally, measurements are carried out during rising stage, maximum stage and falling stage.

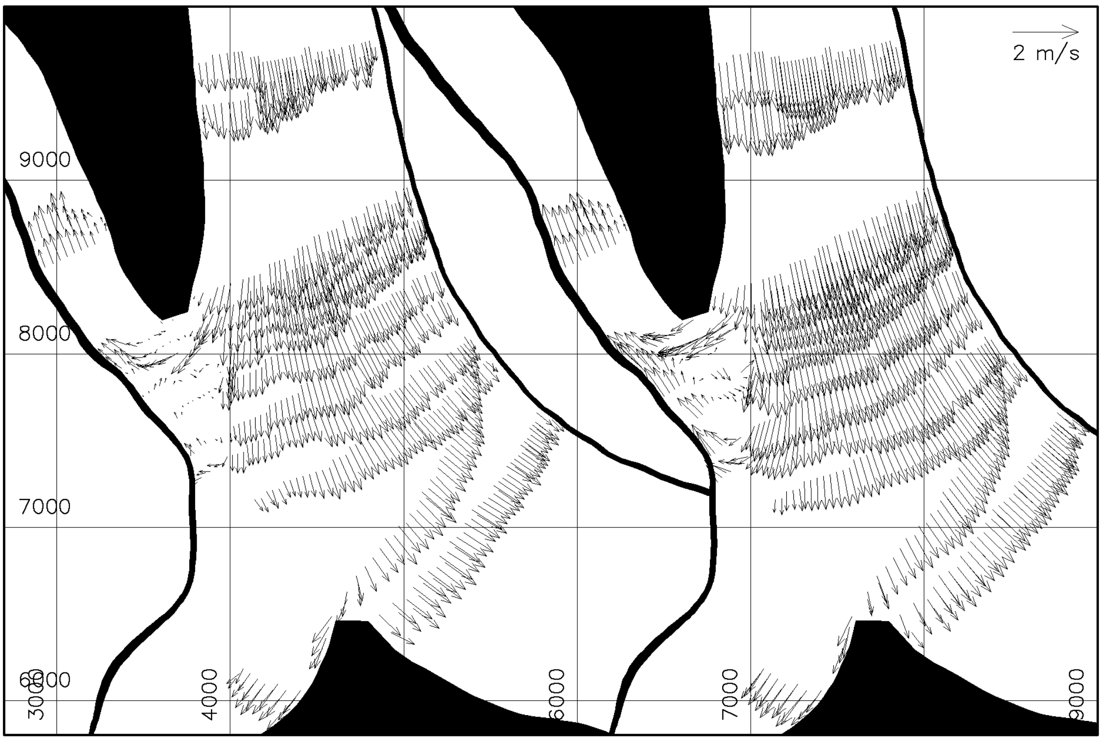


Figure 6 Data for calibration of bed resistance and eddy viscosity (flow velocity, left: observed, right: simulated in the model)

In addition to ADCP (or mechanical propeller) measurements, a continuous flow-meter mounted in the river bed or on a bridge pier can measure the flow during the entire survey campaign period (but only at one particular point, which is often selected where the flow velocity is critical).

Sediment Transport

Bed samples

For sediment transport modelling, it is necessary to know the characteristics of the sediment in the river bed. Therefore it is recommended to collect a number of bed sediment grap samples. These samples should be analysed (sieve analyses) in terms of grain size distribution. A typical level of detail is 5 grap samples from each cross-section in say 4 cross-sections in a study reach. In case the sediment is graded, more samples are required. In addition, samples from different depths below the surface of the riverbed may be required. Often, this will reveal armoured layers, sand layers on top of gravel layers etc.

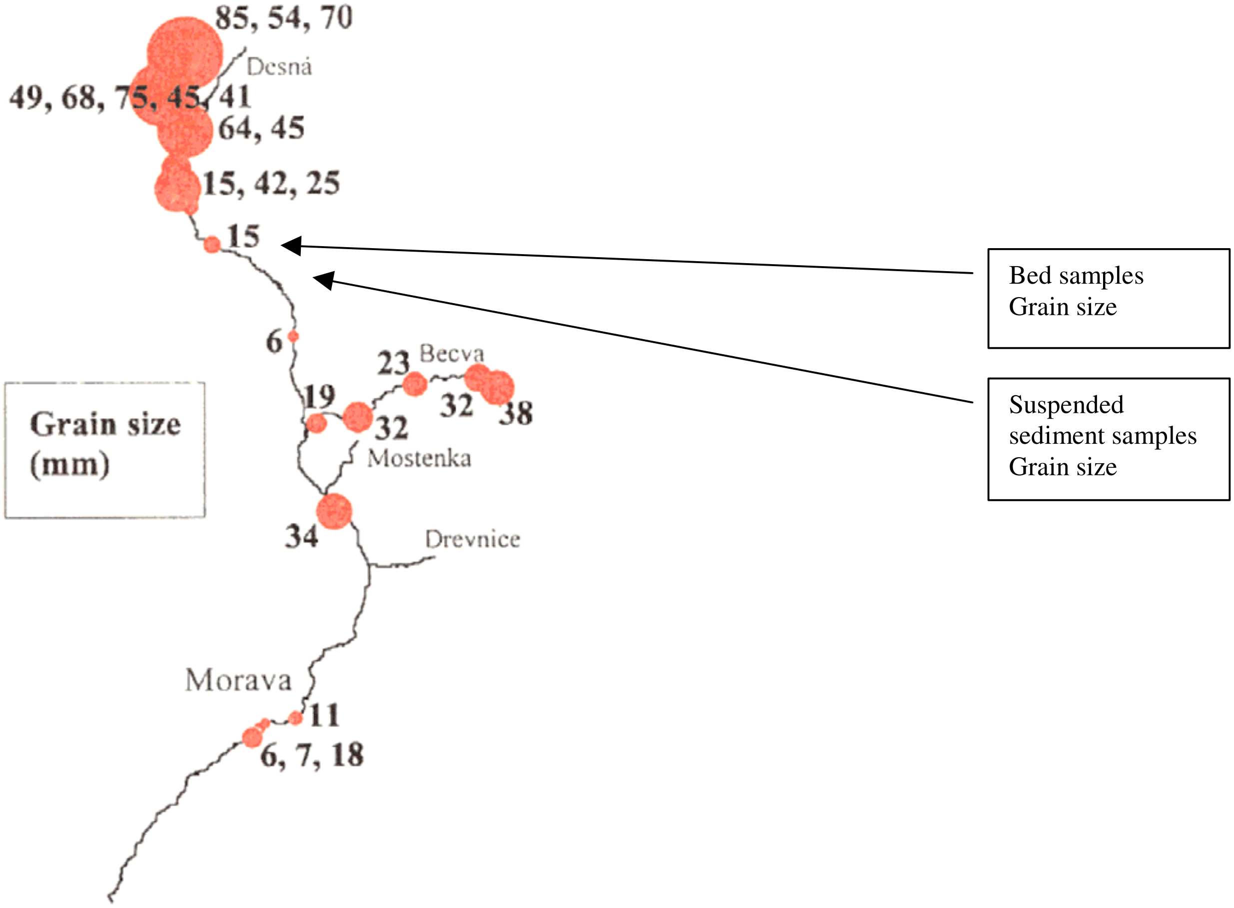


Figure 7 Example of the result of bed samples along a river. The d50 grain size diameter is depicted.

Figure 8 Example of a river where there may be some differences in the sediment grain size from the gravel bar (in the foreground) to the main channel (in the background).

Suspended samples

During the velocity measurement campaign, suspended sediment samples (in case of sandy river) should preferably be carried out at the same time. One approach is to apply depth integrated bottle samples, which is filled while being lowered and heaved. Point samples (at different depths) should be done with pumping, where a larger water sampler can be collected over a certain period of time and thereby minimising the uncertainty (time integrated sample). The water samples should be brought to laboratory and analysed with respect to concentration of suspended sediment, percentage of fine sediment (washload), and with respect to grain size distribution of the remaining coarser suspended sediment.

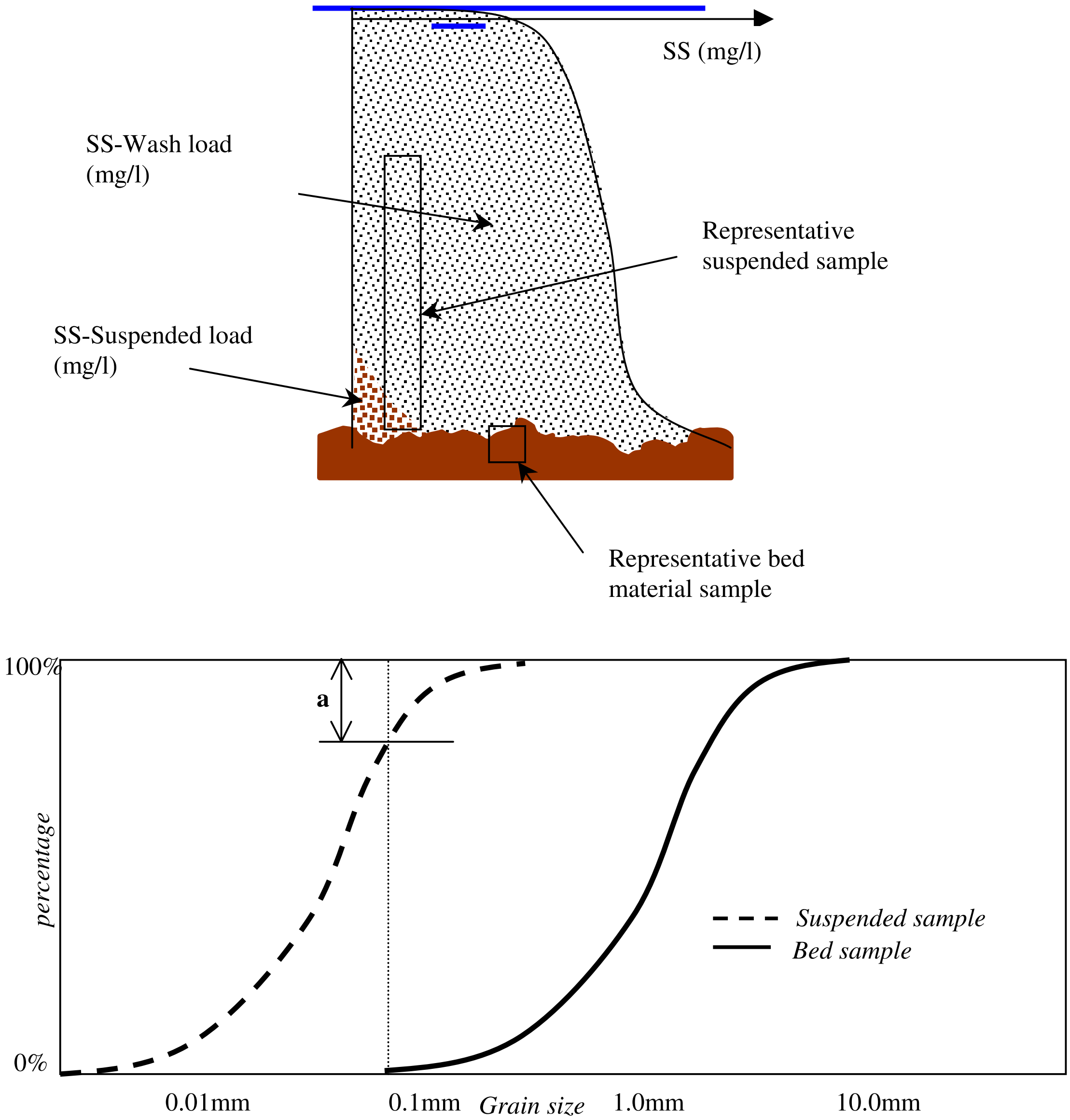
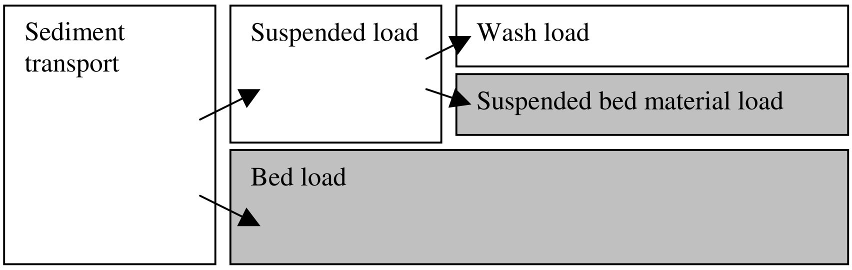


Figure 9 A grain size distribution curve for the suspended sample (dashed line) and bed sample (full line) is compared in order to find the scaling factor "*a*" which divides between wash load and suspended bed material.

The concentration of suspended sediment must be divided into wash load (which is disregarded in morphological modelling) and suspended bed load. A method to do so is as illustrated in the figure above to compare the grain size distribution of suspended and bed samples, respectivly.

Sediment transport rates

Sediment transport is divided into different categories. The transport modes of particular relevance in morphological modelling, where the interaction between river bed and water column is considered, are suspended bed material load and bed load. Wash load is by definition not interacting with the sediment on the river bed (however, in the floodplain, the wash load may be transformed into suspended bed material load, as deposition *can* take place here).



Measurements of sediment transport rates at different locations along the river are useful for calibration of the sediment transport model. Equipment of this is bed load meters (e.g. Helley-Smith) and suspended sediment samples (concentration) combined with velocity and depth measurements.

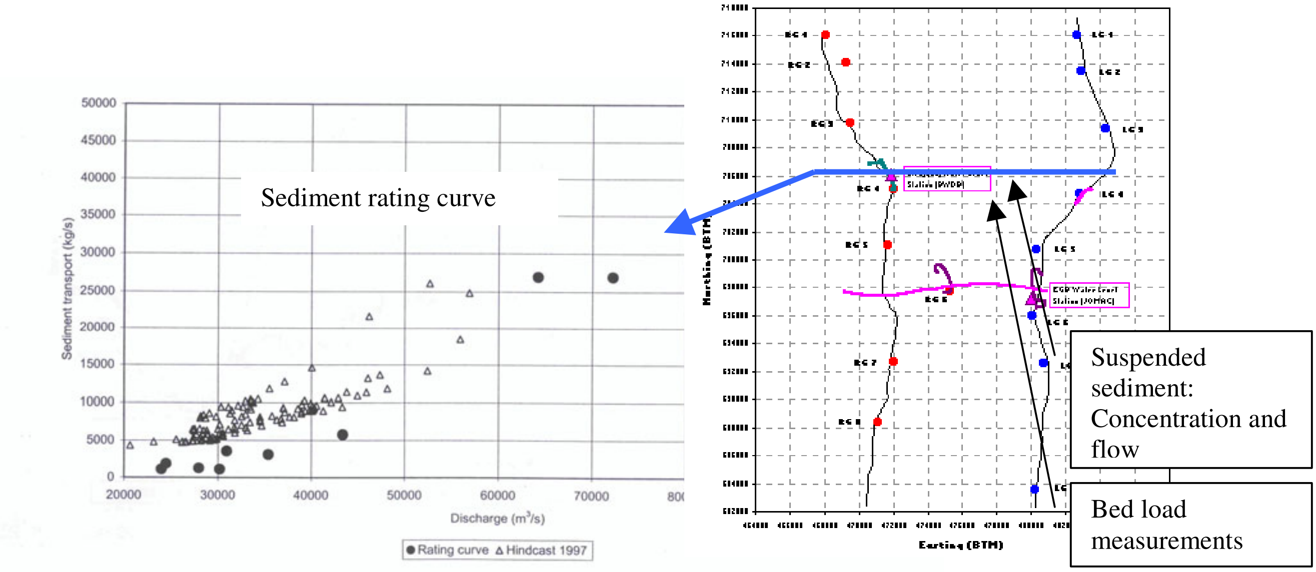


Figure 10 Establishment of sediment rating curves (sediment transport against discharge).

Such data can be difficult to establish and associated with significant uncertainty. Indirect data sources are backfilling rates in dredged trenches and navigation channels, differences in scour depths in well-defined constrictions (bridges) between low flow and high flow, mobility of sand bars etc. Analyses of such indicators are useful to validate/establish sediment transport rates. Measured and simulated sediment transport rates can be compared as *time series* or as *rating curves* (transport rate against flow discharge). A sediment rating curve is good because it integrates all measurements in time and depict the average. On the other hand, hysteresis effects are not revealed. Often, the sediment transport rate can be different during a rising limb of the hydrograph as compared to the falling stage. Other effects such as a submerged sand bar propagating through the measurement station may have other impact on the sediment rating curves.

Cohesive sediment samples

If the sediment is cohesive, a number of extra samples are required. Undisturbed core samples should be collected and analysed with respect to dry density, content of organic material, shear strength. Preferably, a profile of density is established. In a sediment laboratory, erosion and consolidation tests can be performed. In-situ erosion tests are recommended, as this will eliminate the (large) uncertainties in reproducing natural conditions in a laboratory. SPT tests may be useful to elaborate different sediment characteristics at different layers. In-situ fall velocity tests (e.g. Owen tubes) are useful for establish settling properties. Mobility and thickness of mud layers must be surveyed.

Morphology

Bathymetry

Calibration of the morphological model is based on calibration of the hydrodynamics, and the sediment transport model, respectively. The validation of the morphological model is to compare simulated and observed bed level changes. Thus, bathymetry measurements at different times are required, for instance before and after large flood events. Often, it is sufficient to carry out a full bathymetry covering the entire study area from for instance before the time period to be simulated, and to supplement this with additional cross-section surveys in just a few transect lines at different times. There should be cross-section information before the flood event (or time period in consideration), during maximum flow, and after the flood event.

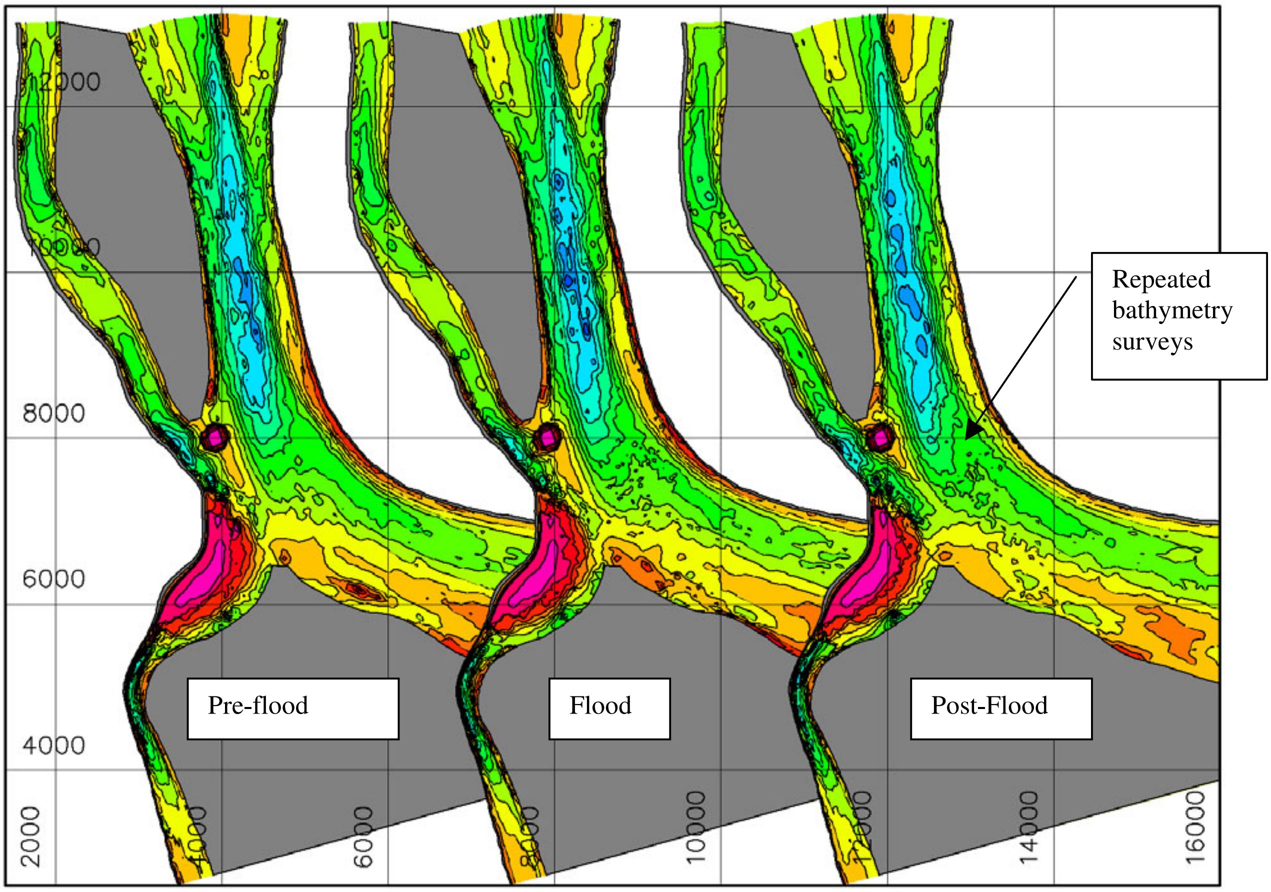


Figure 11 Examples of channel bathymetries before, during and after a major flood.

Historic information about the river bathymetry (from maps and historic surveys) further supplements this information. If the bank erosion rate is very high, it is necessary to make separate measurements of the bank retreat.

Sediment boundaries

In a morphological model with dynamic feedback between the hydrodynamics, sediment transport and bed level and planform changes, the upstream sediment transport boundary condition is important. The longer the simulation period is, the more important the boundary condition is. Basically, two types of boundaries can be imposed: Bed levels or sediment transport rates at the boundary. The former is often applied, if it can be assumed with good approximation, that the bed level remains the same at the upstream boundary. The latter is applied, if specification of sediment transport (e.g. a zero transport) can be done accurately. This could for instance be as a sediment rating curve.

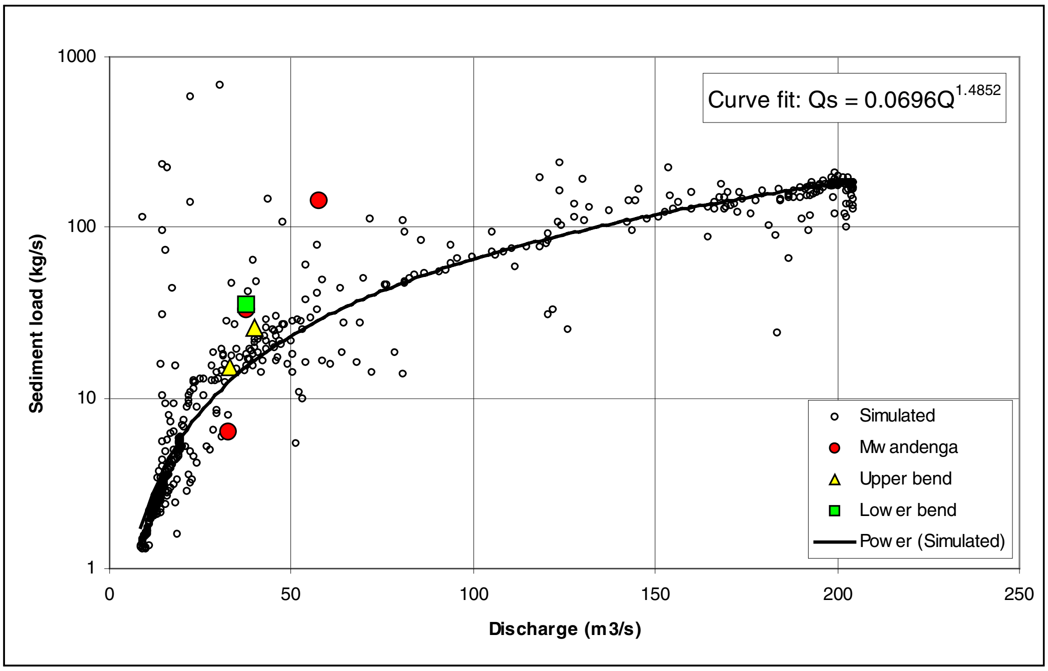


Figure 12 Example of simulated and measured sediment rating curve.

More information

More information about DHI's sediment transport models for rivers may be found on the internet www.dhisoftware.com/mike21c or www.dhisoftware.com/mike11 or by contacting DHI.