MONITORING SEDIMENT TRANSPORT IN A SMALL HARBOUR

Sedimentation Estimation from ADCP Measurements

Many harbours in tide-dominated areas silt up as a consequence of asymmetric tides. To understand the process of harbour sedimentation at tidal rivers, it is important to know the amount of transport of suspended sediment. In a small and shallow harbour along a tidal river, simultaneous ADC, OBS, CTD and water sample measurements are done for observations of suspended sediment transport. ADCP backscatter is converted to suspended sediment concentration by means of calibration with OBS, CTD and water sample data. Sediment fluxes are calculated by multiplication of SSC by ADCP discharge data for a total of more than three hundred validated moving boat measurements. The residual value of adding up these fluxes over a tidal period corresponds with the net tidal sedimentation mass.

The harbour of Hitland is situated along Hollandâ€™s River IJssel near Rotterdam in the Netherlands. The harbour suffers from sedimentation as a result of asymmetric tides. To quantify the sedimentation rate, the transport of suspended sediment is observed using a combination of optical and acoustic measuring techniques.

Measurement Techniques
Regarding measurements of Suspended Sediment Concentration (SSC), both optical and acoustical devices are generally used. Estimates of SSC from an optical instrument such as an Optical Backscatter Sensor (OBS), however, has to be regarded as a point measurement, which restricts either the spatial or temporal resolution of SSC observations. Moreover, optical devices are intrusive; they disturb the local flow field. Acoustic Doppler Current Profilers (ADCPs) are capable of yielding SSC estimates over the depth range ensonified at a high temporal and spatial resolution. They are non-intrusive, as the sediment suspension is being monitored at distance. The disadvantage of the acoustic approach is the dependence on sediment properties. Optical backscatter intensity is comparatively insensitive to changes in sediment properties. Simultaneous ADCP and OBS measurements are used for observations of suspended matter in the harbour of Hitland.

Measurements
Over a period of two tide cycles, suspended sediment is monitored using a 1,200 kHz ADCP (from RD Instruments), an OBS and a CTD sensor. The OBS is calibrated in advance for the sediment suspensions in the harbour. On five fixed transects in the harbour, a total of more than three hundred moving boat measurements are done. The ADCP acoustic backscatter is converted to SSC by means of OBS and CTD data. All instruments have been configured to measure at a corresponding time and place. Water samples are taken for calibration purposes using a Nisken bottle. A certified laboratory analysed the water samples on SSC and grain-size distribution. Besides the moving boat measurements, water-level is measured by a digital water level meter of the Zuid-Holland Directorate of the Ministry of Transport, Public Works and Water Management (Rijkswaterstaat).

Data Processing
Real-time calibration is validated during post-processing using the lab results on the water samples. Both ADCP discharge and backscatter data are validated. For each ADCP measurement the sediment flux is calculated by multiplication of SSC values by discharge data. The five fixed transects mark out five sedimentation areas within the harbour. The sedimentation flux through transects is calculated by adding together all sediment fluxes over a tidal period. The residual value of adding up the fluxes through transects corresponds with the net tidal sedimentation in the sedimentation areas. To estimate sedimentation volume, the mass concentration is converted using an estimation of the dry density of the sediment; to estimate sedimentation rate, the sedimentation volume is divided by harbour area.

Sedimentation
Corresponding to the harbourâ€™s bathymetry, the sediment accumulates for the greater part at a shoal in the entrance of the harbour. Riverwards, this shoal changes into a steep slope into the 13 metre deep river. Towards the back, the harbour first deepens and then gets shallower again. During flood periods SSC values of more than 50 mg/l are present in the harbour. Ebb currents are too weak to re-suspend and transport the sediment from the harbour. Yearly, a total maximum of 265 tons of sediment accumulates in a water/sediment layer near the bottom of the harbour. The density of this layer is a function of the residence time of the sediment in the layer. Because of continuous sedimentation, no sure density can be determined. Assuming a minimum density of 300 kg/m3 the maximum sedimentation volume in the harbour is nearly 900 m3/year. This corresponds with a sedimentation rate of about 3 cm/year.

Software
For monitoring of suspended sediment we used our Plume Detection Toolbox. This software tool converts ADCP echo intensity in real time to SSC (fluxes) by means of simultaneous OBS and CTD measurements. The conversion method takes into account the influence on

sound absorption of variable sediment concentrations in different layers. The sediment attenuation is calculated using an iterative process. During post-processing the real time calibration can be optimised using water sample lab results, such as suspended sediment concentration and grain-size distribution.

Discussion

As stated earlier, both optical and acoustical devices have their pros and cons. Optical devices such as OBS sensors have proven to be successful in many applications focusing on fine-grained suspended sediments. Because of the restricted resolution of optical SSC measurements, a combination of optical and backscattering is chosen to measure SSC. One consequence of using an ADCP is the disadvantage of the dependence of acoustic backscatter on sediment properties. In particular, irregularities in grain-size distribution restrict the accuracy of acoustic SSC measurements. In order to overcome this problem, grain-size distribution is taken into account by iterative calculation of the sound attenuation and SSC. During post-processing, lab results on water samples (SSC and grain-size distribution) are used to validate the real time calibration and refine the results. Because of the unknown density of the accumulation layer the calculated sedimentation volume has to be regarded as a rough approximation.

Conclusion

It is possible to quantify the mass sedimentation by means of ADCP and OBS measurements. The dependence of acoustic backscatter on grain-size distribution is taken into account by iterative calculation of the attenuation of the backscatter and SSC. Sedimentation rates are calculated more accurately using the lab results of water samples. Estimations of the sedimentation volume are difficult because of the unknown dry density of the sediment in the accumulation layer. In general, the ADCP has proven the ability to measure sediment fluxes. However, it is always necessary to calibrate the SSC calculations. For ground truth, water samples of SSC have to be taken; for calculation of water and sediment absorption measurements of, respectively, CTD and grain-size distribution are needed.

Applicability in Ports and Harbours

This study of suspended sediment transport was performed in a small and shallow harbour. However, the presented method is also applicable to larger and deeper harbours and ports. The ADCP range is limited by the frequency used. For instance a depth of more than 20 metres exceeds the range of a 1,200 kHz ADCP. In this case, a lower frequency system may be used. Moreover, for continuous monitoring of sediment transport at one depth it is possible to install a Horizontal ADCP at the entrance of a harbour. These monitoring results can be extrapolated over the entire depth range by means of a model. This model has to be calibrated, for instance by means of moving boat measurements. Next to monitoring suspended sediment, the Horizontal ADCP can be used for monitoring of current velocities, discharges and ship traffic.