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Institute for Water and River Basin Management
o. Prof. Dr.-Ing. Dr. h.c. mult. Franz Nestmann
Department for Hydraulic and Rural Engineering with Theodor-Rehbock-Laboratory
76131 Karlsruhe

3D numerical studies on stratification and mixing processes affecting fine sediment transport in the pre-dam of the Dhünn reservoir in Germany

Wendy Gonzalez*, Irina Klassen, Anne Jakobs and Frank Seidel
Sponsored by the Federal Ministry of Education and Research in frame of the GRoW Programm
***E-Mail: wendy.otero@kit.edu**

Research background

Reservoirs have become indispensable on a large part of the earth due to the storage of drinking water and power generation. As a result, the prediction of processes that take place within reservoirs is becoming increasingly important for example, for the operation and management of these water bodies.
Due to the deposition of fine sediments, the storage capacity of a reservoir is reduced, which can often lead to severe ecological and economic consequences. The fine sediment transport and deposition depend largely on the flow processes in the water body. These in turn are influenced by stratification and mixing processes. Numerical modelling is an indispensable tool with regard to the simulation and prediction of deposition patterns and deposition volume.
The main focus of the present study is the 3D-numerical analysis of the effect of stratification and mixing processes on the fine sediment transport caused by temperature differences within a reservoir.

Study area

Fig. 1 shows the big pre-dam of the Dhünn reservoir in Germany which was the study case for the sensitivity analysis performed. This figure also shows the curvilinear grid used to discretize the study area. The resolution of the grid cells varies between 6 and 78 m. The water depth in the reservoir varies between 0,7 m (at the main Inflow) and 25 m at the dam.

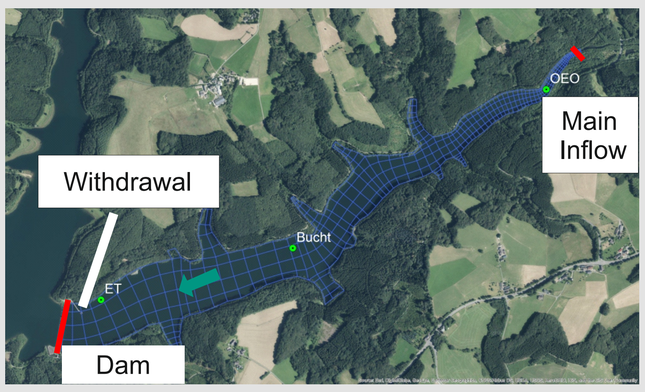

Fig. 1. Big pre-dam of the Dhünn Reservoir. Three stations for comparision of results are represented with green points. Source: modified after ESRI world imagery[1].

Study results

For the numerical modelling a curvilinear grid with Z-layer vertical discretization was adopted. The sediment transport was modelled taking into account water temperature using the softwar Delft3D[2].
The ocean model[3] was used to simulate the heat flux accros the reservoir surface. The relative air humidity, the air temperature, the cloud coverage and the solar radiation are inputs parameters for this model. In order to study the influence of each of them on the water column temperature, the vertical distribution of suspended sediment concentrations and the deposition volume, a change of +/- 10 % in each mentioned variable was introduced with respect to a reference simulation which not included wind effects.
Also the effect of a reduction of the number of vertical layers (from 15 to 10 layers), the inclusion of wind and an increase in the horizontal background diffusivity (from 0 to 0.001 m²/s) on the modeling results was investigated.
A summary of the results are shown in Table 1

Table 1. Influence of studied parameters on the temperature of the water surface and sediment deposition volume.

Simulation	Change in the water temperature at the surface (%)	Change in the sediment volume deposition (%)
Reference	0,00	0,00
relative humidity +10%	1,87	0,00
relative humidity -10%	-1,87	0,06
air temperature +10%	0,93	-0,02
air temperature -10%	-0,93	0,04
cloud coverage +10%	4,67	0,10
cloud coverage -10%	-2,80	0,05
solar radiation +10%	5,61	0,08
solar radiation +10%	-4,67	0,03
reduction vertical layers	0,00	-0,40
including wind	2,80	-4,38
background vertical diffusivity	-1,87	-1,70

Since the inclusion of wind caused the largest variations on the sediment deposition volume (highlighted in Table 1), in the following some comparisons with the reference simulation are shown.

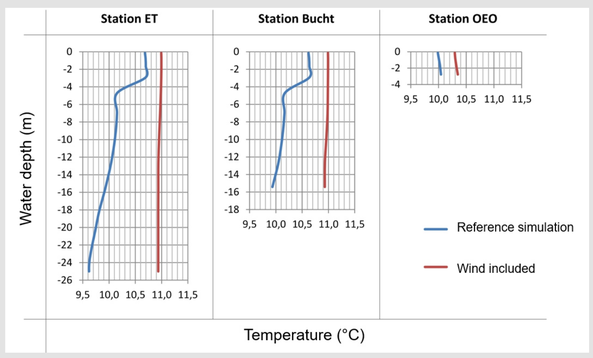

Fig. 2. Simulated temperature profiles at three stations in the study area for the reference simulation and another including wind.

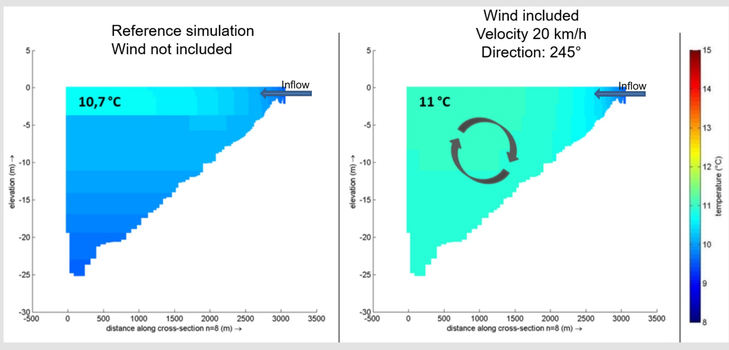

Fig. 3. Longitudinal profile (from Inflow to Dam) showing the temperatures along the reservoir.

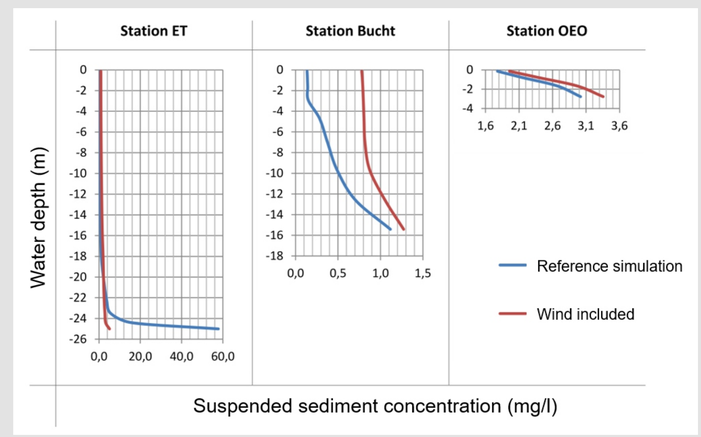

Fig. 4. Vertical suspended sediment concentration profiles at three stations.

The deposition pattern was qualitatively similar for both simulations.
A good agreement between measured and simulated water levels and temperatures profiles was found in the simulated hydrodynamics of the reservoir for a period of 15 days.

Conclusions

The following conclusions can be derived from this study, taking into account of course the range of values considered for each parameter:

- The input parameters for the heat flux model showed effects on the water temperature in the area of the water surface, but the sediment transport was only very slightly affected by them (< 0.1 %).
- The variation of the vertical layers resulted in smaller deviations from the reference simulation. The variation of the background vertical diffusivity had an impact on both the temperatures and the sediment transport.
- For fine sediment transport under the influence of temperature and wind, it was found that wind has a considerable influence on the flow processes in the reservoir and consequently on sediment transport.

References:
1. Esri, World Imagery. ArcGiS Version number 10.3.0.4322.
2. Deltares (2016): User manual Delft3D FLOW. Delft.
3. Gill, A. E., 1982. Atmosphere-Ocean dynamics, vol. 30 of International Geophysics Series. Academic Press. 243, 246, 252, 254