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Dispersion and dynamically one-dimensional modelling of salt transport in estuaries

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Introduction

An estuary forms the transition between the ocean/sea and a river and within its boundaries fresh and salt water mix. Fresh water intake points may be located within the reach of salt intrusion. In order to justify political and managerial decisions it is thus necessary to understand and be able to predict the process of salt intrusion in estuaries.

For one-dimensional dynamic simulation of the hydrodynamics and salinity intrusion the modelling suite SOBEK is available. In the Netherlands this software is used to evaluate the impact of for example measures and climate change on salinity intrusion in the Dutch Rhine Meuse Delta (RMD). Recent validations of SOBEK have mainly focused on water levels and discharges, while less attention was paid to its capability to describe salt transport. Therefore the objective of this research is to obtain a better understanding of dynamic one-dimensional modelling of salt transport and improve the governing formulations with the newest scientific insights.

Advection and dispersion

The water in the estuary is rocked up and down by the tide and salt and fresh water mix. In one-dimension this is described by advection (main current) and dispersion (three-dimensional mixing processes). Many scientists like Thatcher and Harleman (1972), Savenije (2012), Kuijper and van Rijn (2011) and Gisen (2015) have studied this phenomenon and based on the underlying physics they derived dispersion formulations.

The dispersion coefficients described by those authors all have in common that they depend on the maximum flood velocity, a stratification parameter, and the relative salinity. In this research various dispersion formulations have been implemented in SOBEK and their performances have been compared with measurements.

Method

In this research a tidal flume experiment conducted by Rigter (1973) and measurements in real estuaries by Savenije (2016) are used to

get a better understanding of the process of salt intrusion and to validate SOBEK. By systematically changing characteristics of the system Rigter was able to investigate the response of salt intrusion. This way he investigated the effect of changing tidal amplitude, bed roughness, water depth, flume length, river discharge and density differences. Savenije did field work in many estuaries worldwide during which he obtained salt intrusion curves in the estuaries along with the corresponding hydrodynamics.

In a first step the Thatcher-Harleman dispersion formulation was evaluated by a comparison with the data from the tidal flume experiment and the real estuaries. Based on the results and recent scientific insights (Savenije, KvR, Gisen) adjustments to the dispersion formula were proposed and implemented in SOBEK. This newly implemented dispersion formula allowed to validate a wider range of dispersion formulations, including the ones referred to before. In a last step the most promising formulation has been tested for the Dutch Rhine Meuse Delta, by simulating the year 2003 and evaluating the salinity concentration at various locations.

Results

Below the simulation results for the tidal flume experiment (representative of a prismatic estuary), the convergent estuaries and the Dutch delta are elaborated. The dispersion formulations used are the originally implemented formulation based on Thatcher and Harleman (1972), more recent formulations based on the work of Savenije (2012), Kuijper and van Rijn (2011), Gisen (2015) and the formulation derived by Gisen adjusted for wide estuaries (Daniels, 2016).

Tidal flume test

For the tidal flume test the simulation results using the formulation based on Thatcher and Harleman (1972) and the dispersion formulation for prismatic channels of Kuijper and van Rijn (2011) are included. As immediately can be seen from Fig. 1 the

results using Kuijper and van Rijn give an improved resemblance with the data. This can be attributed to certain mixing phenomena which are included in the KvR formula.

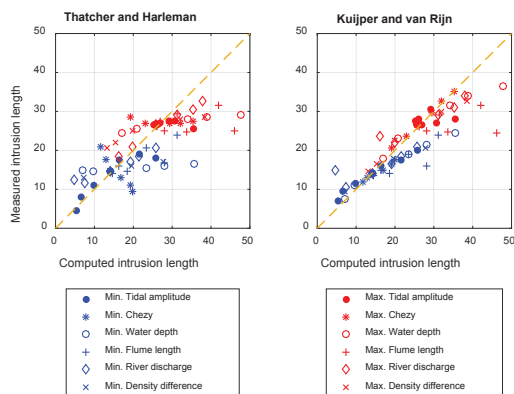


Figure 1. Maximum and minimum intrusions simulated with TH and KvR-Dispersion formulations

Real convergent estuaries

For the simulations considering salt intrusion in the real estuaries Table 1. shows the coefficient of determination (R^2) for the maximum intrusion length, RMSE and standard deviation of the relative error for the maximum intrusion length, the bias of the salt intrusion curve and the standard deviation of the salt intrusion curves (for more details see Daniels (2016)). As one can see from those numbers there is not a dispersion formulation performing significantly better than the others.

Table 2. Quantified model results for dispersion based on Thatcher-Harleman (a), Savenije (b), Gisen (c), Gisen for wide estuaries (d) and Kuijper and van Rijn (e).

	a	b	c	d	e
R^2	0.87	0.86	0.85	0.88	0.83
RMSE	0.23	0.30	0.21	0.19	0.35
σ_L	0.20	0.27	0.21	0.19	0.26
B_e	0.01	-1.50	0.35	1.34	-2.62
σ_p	3.33	3.12	2.94	3.23	3.64

The Rhine Meuse Delta (RMD)

After the theoretical research on the dispersion coefficient in the tidal flume and convergent estuaries the dispersion formulation derived for prismatic channels by Kuijper and van Rijn (2011) is selected to be tested on the Dutch Delta. This is a more complex system consisting of multiple branches and side harbours. In Fig. 2 one can see that using this formulation (without calibration) the observed trend in salinity is

simulated, but that the magnitude of the variance over a tidal cycle is underestimated and peaks in salinity are not always captured.

Conclusions

The dispersion formulation derived for prismatic channels by Kuijper and van Rijn (2011) performed best for the tidal flume tests. For real convergent estuaries it is more difficult to select a dispersion formula which is superior to the others. This raises the question why one would need a different formula for convergent and prismatic channels.

Applying the model to the RMD it is seen that, without calibration of the coefficients, the right trends are simulated. However, the magnitude of the variance over a tidal cycle is underestimated and peaks in salinity are not always captured.

Future work and acknowledgements

Research in this subject should be extended using more real cases to validate the model, considering both convergent and prismatic channels. The difference between prismatic and convergence channels should be investigated, and one should find out if the tidal flume experiments are actually representative for real prismatic channels. This research was part of a thesis for the degree of Master of Science at Delft University of Technology and was carried out in collaboration with Deltares and Rijkswaterstaat.

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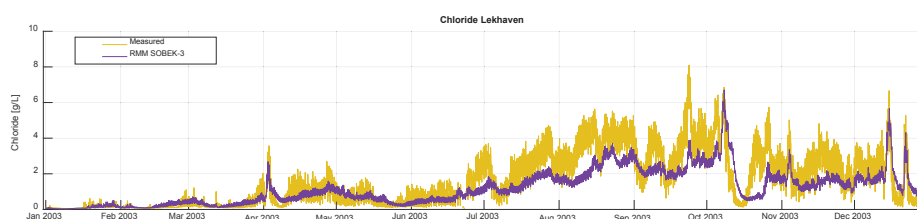


Figure 2. Chloride concentrations at Lekhaven.