Flood modeling for risk evaluation – a MIKE FLOOD vs. SOBEK 1D2D benchmark study

P. Vanderkimpen  
_Flanders Hydraulics Research, Flemish Government, Antwerp, Belgium_  
_Soresma, Antwerp, Belgium_

E. Melger  
_Deltares/Delft Hydraulics, Delft, Netherlands_

P. Peeters  
_Flanders Hydraulics Research, Flemish Government, Antwerp, Belgium_

**ABSTRACT:** The flood risk for a section of the Belgian coastal plain was evaluated by means of two similar flood modeling packages: MIKE FLOOD and SOBEK 1D2D. The submodels and processes available in both packages were matched as closely as possible. Subsequently, the impact of the software package on hydraulics, flood damage and flood risk was quantified. The results from both packages agree well. Some differences occur, but these can easily be explained as a result of unavoidable minor differences in concepts and implementation. The uncertainty associated with the selection of either software package is insignificant compared to other sources of uncertainty.

1 **INTRODUCTION**

Floods resulting from the failure of a coastal defense can be studied by a combination of 1D and 2D modeling techniques. A 1D approach is used to describe breach growth and breach flow and a 2D approach is used to predict flood propagation in the inundated areas. As breach flow may be influenced by backwater effects, breach flow and flood propagation should be evaluated simultaneously.

The flood modeling packages MIKE FLOOD (Danish Hydraulic Institute) and SOBEK 1D2D (Deltares | Delft Hydraulics) both offer the possibility to dynamically link a 1D breach model to a 2D flood plain model. Both packages were compared with each other as part of an effort to estimate the contribution of software uncertainty to model uncertainty and overall flood risk uncertainty. “Software uncertainty” refers to the uncertainty that may result from slightly different implementations of similar concepts. Other sources of uncertainty are treated in a companion paper (Vanderkimpen & Peeters 2008).

2 **SOFTWARE**

2.1 **MIKE FLOOD**

MIKE FLOOD dynamically links two independent software packages: MIKE 11 (1D) and MIKE 21 (2D).

MIKE 11 solves the Saint-Venant equations by means of a finite difference scheme. Breaches can be modeled by means of a “dam break” structure. Breach growth can be described by time series for breach width, crest level and side slope. An erosion model based on the Engelund-Hansen sediment transport equation is also available. Breach flow can be computed by means of two sets of equations: the standard set is based on the equations for flow through a generic structure (Borda losses) and the alternative set was obtained from the NWS DAMBRK model.

The “classic” version of MIKE 21 uses a rectangular grid and solves the shallow water equations by means of a finite difference scheme. It is capable of handling flooding and drying, spatially varying surface roughness, eddy viscosity, Coriolis forces and wind friction.
2.2 **SOBEK 1D2D**

SOBEK 1D2D is an integrated software package which enables the construction of complex models by dynamically integrating 1D components from SOBEK-Rural, SOBEK-Urban and SOBEK-River and 2D components from SOBEK Overland Flow (formerly known as Delft-FLS).

SOBEK 1D (Rural, Urban and River) solves the Saint-Venant equations by means of a finite difference scheme. Breaches can be modeled by means of a complex “river weir” with time dependent properties. Breach growth can be described by time series for crest width and crest level. Breach flow is obtained from weir flow equations.

SOBEK 2D (Overland Flow) uses a rectangular grid and solves the shallow water equations by means of a finite difference scheme, identical to the one used by SOBEK 1D. SOBEK 2D is capable of handling flooding and drying, spatially varying surface roughness and wind friction. It also contains a “dam break” link, capable of describing breach growth by means of empirical breach growth equations ((Verheij-)vanderKnaap).

3 **MODELS**

3.1 **Study area**

The study area (shown in Figure 1) covers the eastern part of the Belgian coastal plain, between Zeebrugge and the Dutch border. It is bordered by the sea to the north, canal embankments to the west and south and old sea dikes bordering a former tidal inlet ("Zwin") to the east. It occupies an area of 75 km².

3.2 **Model versions**

Two almost identical models were constructed: one in MIKE FLOOD and one in SOBEK 1D2D. In order to match both models as closely as possible, only features available in both packages were used. Breach growth was described by means of time series and flood propagation was made to depend on surface friction only. Eddy viscosity, Coriolis forces and wind friction were not taken into account.

3.3 **Boundary conditions**

Hydraulic boundary conditions (astronomical tide and storm surge) were obtained from an earlier analysis, carried out within the framework of the EU-funded Interreg IIIb project Comrisk (Anonymous 2005). Three different return periods (4000 years, 10000 years and 40000 years) were considered. The studied storm surge lasts for 45 hours and is superimposed on three tidal cycles. Figure 2 shows the resulting storm water levels.

Figure 1. Study area (source: National Geographic Institute).

![Figure 1](image1.png)

Figure 2. Storm water level (HT \( n = \) nth high tide).

3.4 **Breaches**

The number of breaches, breach locations and time of breaching were obtained from the coastal defense failure analysis performed as part of the Comrisk project. The location of the breaches is shown in Figure 3 and the time of breaching is summarized in Table 1.

![Figure 3](image2.png)

Figure 3. Location of breaches.

Breaches were modeled by embedding a dam break (MIKE 11) or a river weir (SOBEK 1D) in a short channel. The channels were given a large width (300 m) and a low roughness (Manning’s \( n = 0.03 \) s/m\(^{1/3}\)).

Breach growth was described by means of time series for crest level and width. The initial depth equals 0 m for all breaches. The lowest crest level equals 6 m AD at Knokke (233–236), 5 m AD at Het...
Zoutse (241–243) and 4 m AD at Zwin. Vertical growth takes place in less than 15 minutes for the breaches at Knokke and slightly more than 1 hour for those at Het Zoute and Zwin. Initial width equals 90 m at Knokke, 60 m at Het Zoute and 20 m at Zwin. Breaches at Knokke do not grow horizontally; whereas those at Het Zoute and Zwin were assigned a horizontal growth rate of 30 m/h. Maximum width equals 150 m at Het Zoute and 200 m at Zwin.

For the calculation of breach flow default values for head loss coefficients and discharge coefficients were used. In SOBEK 1D the weir was assumed to be broad crested. In MIKE 11 both the standard (Borda losses) and the alternative (NWS DAMBRK) flow equations were evaluated.

### 3.5 Coastal plain

The ground elevation in the coastal plain is shown in Figure 4. It ranges from sea level (black) to 15 m above sea level (white).

The coastal plain was modeled by means of a rectangular grid with a grid cell size of 20 × 20 m. The dominant land use being agriculture, the surface roughness was described by a low and uniform Manning coefficient (0.03 s/m¹/³).

### 4 RESULTS

#### 4.1 Breach flows

The breach flows are shown in Figures 5–10. In the first set (Figs 5–7) the flows computed by MIKE11 are based on the standard flow equations (Borda losses) and in the second set (Figs 8–10) they are based on the alternative flow equations (NWS DAMBRK). The corresponding volumes are summarized in Tables 2–5.

The figures show that at the end of each tidal cycle, small return flows occur.

In general, breach flows obtained from both packages are in good agreement. The observed differences can be explained by conceptual differences between the flow equations.

The flow equations in MIKE 11 automatically take contraction losses into account. The calculation is based on the width of the channel in which the breaches are embedded (standard equations) or a user specified reservoir width (alternative equations).

All breaches were embedded in 300 m wide channels and the reservoir width was set to 200 m for all breaches. As a result, contraction losses were applied to all breaches, especially during the early stages of breach growth. SOBEK 1D offers the possibility to specify a user-defined contraction coefficient. This coefficient was left at its default value, namely 1. Hence no contraction losses were taken into account.

The criterion for transition from free flow to submerged flow is also different in both packages. In MIKE 11 the standard flow equations switch from a...
The alternative flow equations provide a better match with SOBEK 1D than the standard equations. The largest differences are observed for breaches 242 and 243. These breaches are located upstream of large flat areas in the coastal plain. As a result of backwater effects, breach flow tends to become submerged very quickly and peak flows are strongly influenced by the submerged flow criterion.

MIKE 11’s alternative flow equations provide a better match with SOBEK 1D than the standard equations. The largest differences are observed for breaches 242 and 243. These breaches are located upstream of large flat areas in the coastal plain. As a result of backwater effects, breach flow tends to become submerged very quickly and peak flows are strongly influenced by the submerged flow criterion.

Free flow expression to a submerged flow expression when the downstream energy head exceeds the water level at the breach crest. The alternative equations use a single expression for both flow regimes and apply an empirical reduction coefficient as soon as the submergence factor (downstream water level above crest level divided by upstream water level above crest level) exceeds 0.67. In SOBEK 1D a single equation in combination with an empirical reduction factor is applied too. For a broad crested weir, the reduction factor is not applied until the submergence factor exceeds 0.82.
4.2 Inundations

The extent of the inundations is shown in Figures 11–16. The results for MIKE 21 (Figs 11–13) are those obtained with the standard breach flow equations. The corresponding inundated areas are summarized in Table 6.

The calculation of damage requires the knowledge of spatially distributed values for the maximum water depth and the maximum flow velocity. The spatially averaged values within the inundated areas are listed in Tables 7 and 8.

For the largest return period, the extent of the inundations is clearly limited by the presence of canal embankments.

The extents of the inundations obtained with both packages are in very good agreement. Upon visual inspection of the figures, hardly any differences can be detected.

The inundated areas and the maximum water depth are also in good agreement. The observed differences are partially caused by differences between breach flow volumes.

The maximum flow velocities show larger differences. These are caused by differences in computation of flood wave celerity over dry bed and wet bed and differences in simulation of 2D sub- and supercritical flows over vertical objects schematized by only one grid cell (i.e. roads, dikes, etc). Additional information on these topics can be found in McCowan et al. (2001) and Stelling and Duinmeijer (2003).

Furthermore, the differences in maximum flow velocities are caused by the way in which these maxima were computed. SOBEK 1D2D is capable of storing the maximum values for water depth and flow velocity that occurred during the computations. MIKE FLOOD, on the other hand, stores the maximum values of water depth and flux. Maximum velocities can’t be computed from these data. As an alternative, maximum velocities were obtained by post-processing the instantaneous velocities that were saved at regular intervals during the simulation. As the output interval (10 minutes) was much larger than the computational time step (2 seconds), these estimated maxima are undoubtedly an underestimation of the true maxima.

4.3 Flood damage

Flood damage was computed by means of the procedures described in Vanneuville et al. (2006) and Verwaest et al. (2007). The calculations were limited to the Belgian part of the study area.

A distinction was made between “basic damage” and “additional damage”. Basic damage refers to the damage caused by temporary inundation. It was
Figure 11. Inundations, return period 4000 years. MIKE 21.

Figure 12. Inundations, return period 10000 years. MIKE 21.

Figure 13. Inundations, return period 40000 years. MIKE 21.

Figure 14. Inundations, return period 4000 years. SOBEK 2D.

Figure 15. Inundations, return period 10000 years. SOBEK 2D.

Figure 16. Inundations, return period 40000 years. SOBEK 2D.
Table 6. Inundated area.

<table>
<thead>
<tr>
<th>Software</th>
<th>4000 years</th>
<th>10000 years</th>
<th>40000 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIKE 11, std</td>
<td>8.96</td>
<td>18.27</td>
<td>69.37</td>
</tr>
<tr>
<td>MIKE 11, alt</td>
<td>9.32</td>
<td>19.35</td>
<td>71.30</td>
</tr>
<tr>
<td>SOBEK 1D2D</td>
<td>8.92</td>
<td>18.46</td>
<td>72.66</td>
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Table 7. Maximum water depth.

<table>
<thead>
<tr>
<th>Software</th>
<th>4000 years</th>
<th>10000 years</th>
<th>40000 years</th>
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</thead>
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<tr>
<td>MIKE 11, std</td>
<td>0.55</td>
<td>0.66</td>
<td>0.89</td>
</tr>
<tr>
<td>MIKE 11, alt</td>
<td>0.57</td>
<td>0.67</td>
<td>0.94</td>
</tr>
<tr>
<td>SOBEK 1D2D</td>
<td>0.56</td>
<td>0.67</td>
<td>0.97</td>
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</table>

Table 8. Maximum flow velocity.

<table>
<thead>
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<th>40000 years</th>
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<tr>
<td>MIKE 11, std</td>
<td>0.31</td>
<td>0.34</td>
<td>0.35</td>
</tr>
<tr>
<td>MIKE 11, alt</td>
<td>0.32</td>
<td>0.35</td>
<td>0.37</td>
</tr>
<tr>
<td>SOBEK 1D2D</td>
<td>0.41</td>
<td>0.42</td>
<td>0.42</td>
</tr>
</tbody>
</table>

Table 9. Basic damage.

<table>
<thead>
<tr>
<th>Software</th>
<th>4000 years</th>
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<th>40000 years</th>
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</thead>
<tbody>
<tr>
<td>MIKE 11, std</td>
<td>131</td>
<td>378</td>
<td>863</td>
</tr>
<tr>
<td>MIKE 11, alt</td>
<td>158</td>
<td>412</td>
<td>926</td>
</tr>
<tr>
<td>SOBEK 1D2D</td>
<td>133</td>
<td>400</td>
<td>977</td>
</tr>
</tbody>
</table>

Table 10. Additional damage.

<table>
<thead>
<tr>
<th>Software</th>
<th>4000 years</th>
<th>10000 years</th>
<th>40000 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIKE 11, std</td>
<td>22</td>
<td>52</td>
<td>112</td>
</tr>
<tr>
<td>MIKE 11, alt</td>
<td>25</td>
<td>57</td>
<td>145</td>
</tr>
<tr>
<td>SOBEK 1D2D</td>
<td>36</td>
<td>81</td>
<td>207</td>
</tr>
</tbody>
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Table 11. Total damage.

<table>
<thead>
<tr>
<th>Software</th>
<th>4000 years</th>
<th>10000 years</th>
<th>40000 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIKE 11, std</td>
<td>153</td>
<td>430</td>
<td>975</td>
</tr>
<tr>
<td>MIKE 11, alt</td>
<td>183</td>
<td>469</td>
<td>1071</td>
</tr>
<tr>
<td>SOBEK 1D2D</td>
<td>169</td>
<td>481</td>
<td>1184</td>
</tr>
</tbody>
</table>

Table 12. Annual flood risk.

<table>
<thead>
<tr>
<th>Software</th>
<th>Basic $10^3$</th>
<th>Additional $10^4$</th>
<th>Total $10^4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mike 11, std</td>
<td>351</td>
<td>57</td>
<td>408</td>
</tr>
<tr>
<td>Mike 11, alt</td>
<td>413</td>
<td>63</td>
<td>476</td>
</tr>
<tr>
<td>Sobek 1D2D</td>
<td>361</td>
<td>92</td>
<td>453</td>
</tr>
</tbody>
</table>

Estimated from the maximum water depth and a series of land use dependent empirical damage functions. Additional damage refers to the damage caused by high flow velocities and mainly occurs in the vicinity of breaches. It was estimated by means of an empirical function, incorporating maximum water depth and maximum flow velocity.

Values for basic damage, additional damage and total damage are listed in Tables 9–11.

As expected, the values for basic damage are in good agreement, whereas the values for additional damage show larger differences. As basic damage largely outweighs additional damage, the values for total damage show better agreement.

4.4 Flood risk

The annual flood risk was estimated from the damage associated with return periods of 4000, 10000 and 40000 years, following the weighing procedure described in Vanneuville et al. (2002). The results are shown in Table 12.

As flood risk is a linear function of damage, the values for flood risk show the same tendencies as those for damage: values for basic risk are in good agreement (difference less than 20%), those for additional risk do not agree very well (difference more than 50%) and total risk is in good agreement (difference less than 20%).

5 CONCLUSION

The contribution of model uncertainty or parameter uncertainty to overall flood risk uncertainty can be considerable, but the software uncertainty resulting from the choice of a software package in which the selected models and parameters are implemented becomes insignificant when both packages provide similar possibilities. As a result, it can be stated that the choice of the modeling package is in no way predominant in flood risk evaluation.
ACKNOWLEDGEMENT

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REFERENCES


