A risk based approach to the development of evacuation plans in the mine subsidence area along the Meuse

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Abstract

The "Mijnverzakkingsgebied" (mine subsidence area) is located in the eastern part of Belgium along the river Meuse and is affected by subsidence up to seven meters due to historical mining activities. The subsidence is so large that during high flood stages in the river Meuse the area is under severe risk of flooding if one of the surrounding dikes would break. In such a case water depth in the area could locally reach 7 meters. This would lead to great damage to the houses and economic activities in the region. To minimise the victims and the damage in the event of a dike failure, different evacuation plans were set up, which were based on two-dimensional inundation maps of the study area. These flooding scenarios were simulated assuming dike breaches at various locations. Application of calibrated one-dimensional and two-dimensional hydraulic models of the river Meuse and the mine subsidence area enabled analysing maximum water depth, the time-to-flooding and local water depth fluctuations during an inundation. Both applied hydraulic models were fed with recent and accurate bathymetry and topographical data from a detailed DEM monitored via laserscanning. The input data was of high quality which enabled one to carry out the analysis on a resolution of 25 meters. A combination of the different inundation maps and the local streetmaps gives an insight into the optimal evacuation direction for the inhabitants of the different villages. The different scenarios show also that certain regions can be flooded with inundation depths of more than 5 meters. In these regions, people have to be evacuated immediately by helicopter.

Keywords: inundations, hydraulic modelling, dike breach, evacuation plans, mine subsidence area.
1 Meuse

The Meuse originates in France near Pouilly-en-Bassigny at the Plateau of Langres (France) at ca. 400 m. asl. and is approximately 935 km long from its source to the Haringvliet (the Netherlands). The catchment area of the Meuse is about 36000 km$^2$, of which 10000 km$^2$ is situated in France, 13000 km$^2$ in Belgium, 9000 km$^2$ in the Netherlands and 4000 km$^2$ in Germany. The catchment area is shown in Figure 1 (Peeters [1]).

The Meuse is a lowland river. Flows are dominantly rain fed. Within the catchment of the Meuse, no glaciers or snow accumulations feed the river. As far as the hydrological and geographic features are concerned the Meuse can be roughly split into three zones. Zone 1, from Pouilly-en-Bassigny to Sedan (France), has a long and narrow catchment in a wide, permeable river valley. Zone 2, from Sedan to Lanaken (Belgium), transects rocky impermeable stone, resulting in a narrow river valley and a large slope. Zone 3, from Lanaken to Haringvliet (the Netherlands), has a wide river valley with permeable soils.

The river Meuse has several main tributaries, which are the Chiers (Zone 1), the Viroin, Semois, Lesse, Sambre and Ourthe (Zone 2) and the Jeker, Geul, Roer, Niers and Dieze (Zone 3).

Figure 1: Catchment area of the river Meuse (© WHM).
The Ardennes area (eastern part zone 2) forms the highest part of the Meuse catchment. Before the elevation of Ardennes massif, the Meuse had already a northern direction. The Meuse kept up with the elevation by cutting its way through. That’s why the Meuse valley and the valley of the tributaries are small and steep in this section, except for some parts of the Lesse and Ourthe. North of Lanaken (Belgium) the Meuse is a typical lowland river.

Precipitation in the Meuse catchment is distributed rather uniform over the year, but because of the higher evaporation in summer, the discharge pattern of the Meuse shows generally clear peaks in winter. Within the catchment area the amount of precipitation varies significantly. The year average precipitation varies from about 800-900 mm in zone 1 to 1000 mm with peaks of 1500 mm (high parts Ardennes) in zone 2. In zone 3 the yearly average is less and amounts 700-800 mm (Berger [2]). The catchment area of the Meuse is relatively small, so the chance that precipitation occurs simultaneously in the catchment is large.

2 Mine subsidence area

In the eastern part of Belgium along the western bank of the river Meuse (zone 3), coal extraction was executed from the beginning of the 19th century until 1980. In many of the now abandoned mines instability problems have arisen, several large-scale collapses have occurred and a large part of that area has subsided up to 7 meters. In this area, between the river Meuse and the Zuid-Willemsvaart, 6 villages (Vucht, Eijsden, Mazenhoven, Leut, Meeswijk and Lanklaar) are situated with more than 10,000 inhabitants.

The mine subsidence area is protected against inundations by the winter dikes along the river Meuse. A discharge of more than 3000 m³/s, which is 10 times the average discharge of the river, can be evacuated without serious inundations. However, failure of the winter dike can never be excluded.

Along the western bank of the river Meuse, the mine subsidence is so large that during high flood stages in the river Meuse the area is under severe risk of flooding if one of the surrounding winter dikes would fail. In such a case water depth in the area could locally reach 7 meters (figure 2) (Agtersloot [3]).

Also, due to the large hydraulic gradient between the high water levels in the river Meuse and the topography of the subsidence area, the expected flow velocities in the case of a failure of the winter dike will be very high and the time between the start of the failure of the winter dike and the inundation of the mine subsidence area will be very short. This would lead to great damages to houses and economic activities in the region, and also risk of people killed by drowning. Finally, also the drinking water supply of 300,000 people would be seriously hampered.

3 Objective of the study project

When a failure of the winter dike occurs, due to the large hydraulic gradient between the high water levels in the river Meuse and the topography of the mine
subsidence area, very high inundation depths and a very short time to evacuate the inhabitants of the area are expected.

In order to minimise the victims and the damage in the event of a failure of the winter dikes the local river authority asked Flanders Hydraulics Research for a detailed hydraulic analysis of the potential inundation event, which is the input for the set up of evacuation plans. Due to the serious consequences, these evacuation plans must be very accurate and should be based on two-dimensional inundation maps of the study area.

4 Inundation maps of the study area

4.1 Set up of the hydraulic models

The project studied the effects of an inundation during flood stages in the river Meuse in combination with a dike failure of the winter dike. For this purpose a one dimensional hydraulic model of the river Meuse and a two-dimensional hydraulic model of the entire mine subsidence area were set up. The one dimensional model of the river Meuse calculates the river discharges and the local waterlevels at several nodes along the river and the discharge through the breach during a flood period. This result is the boundary condition for the two dimensional model which calculates the inundations in the mine subsidence area. The two-dimensional model is thus nested in the one dimensional hydraulic model of the river Meuse.

The set up of a one dimensional hydraulic model of the river Meuse was the first step of the study. The hydraulic simulation software MIKE11 (Danish Hydraulic Institute) simulates the flood routing in rivers and estuaries by solving numerically the non-linear equations of open channel flow (Saint Venant equations) between the grid points in one direction. The computational scheme
is applicable to vertically homogeneous flow conditions ranging from steep river flows to tidally influenced estuaries. Both subcritical and supercritical flow can be described by means of a numerical scheme, which adapts according to the local flow conditions.

A MIKE11 hydraulic model was set up from Lanaken, 20 kilometres upstream from the mine subsidence area, to Maaseik, 15 kilometres downstream. Recent topographical data of the river bed of the river Meuse was used. This model was calibrated and validated by comparing the calculated and measured waterlevels and discharges at three different monitoring stations for 4 historical high water periods. The average error between calculated and measured waterlevels was 10 cm, so the model was well calibrated. The one dimensional model needs an upstream boundary condition, the discharge \( Q(t) \) at Lanaken, and a downstream boundary condition, the \( q/h \) relation at Maaseik (D'Haeseleer et al [4]).

The dike failure was simulated in the one dimensional hydraulic model by adding an artificial opening in the winter dike of the Meuse connected with a large reservoir which has the same volume \( (V) \) / stage \( (h) \) relation as the mine subsidence area. In this way, the discharge through the breach \( Q(t) \) and the effect of the breach on the waterlevels in the river Meuse were well simulated. The discharge through the dike breach \( Q(t) \) is then given to the two dimensional model of the mine subsidence area as an upstream boundary condition.

Then, a two dimensional hydraulic model of the mine subsidence area was set up. The software DELFT1D2D (WL|Delft Hydraulics) was applied. This program is especially suited to simulate the dynamic behaviour of overland flow over initially dry land, as well as flooding and drying processes on every kind of geometry, including lowlands or mountain areas. It simulates very well the influence of the existing or planned infrastructure on flooding processes. Land use, vegetation characteristics and urban areas are also included.

DELFT1D2D simulates unsteady hydrodynamic flow in two dimensions. It computes the river flow using the full shallow water equations on a rectilinear grid, based on a robust finite difference scheme able to tackle both subcritical and supercritical flow.

The two dimensional hydraulic model was fed with recent topographical data from a detailed digital elevation model (DEM) monitored via laserscanning. The DEM gives the local altitude on a grid of 4 by 4 meters. The average error of the topographical data was 0.07 m in the z-direction. For data of line elements, such as levees and roads classical topographical monitoring was used. These elements were added to the DEM. All this data was imported in the two-dimensional model. The input data was of high quality which enabled to carry out the analysis on a resolution of 25 meters.

The land use map of the study area was used for the determination of the friction coefficients of each cell. The land use map is based on interpretations of several satellite images: Corine Land Cover (based on Landsat) and the Small Scale Land Use Map of Flanders and Brussels (based on Spot).

In the study the following assumptions were made:
the dike failure occurs at the moment of maximum waterlevels in the river Meuse
- the width of the breach was 50 m.
- the flood of December 1993 was simulated. This flood had a maximum discharge at Lanaken of 3125 m³/s, with a probability of 1/65 year.

4.2 Hydraulic simulations

The winterdike between the river Meuse and the mine subsidence area has a length of 9 kilometres. Over this stretch 8 different simulations were calculated, with each time a different location of the dike failure.

The location of each breach was first built in in the MIKE11 model, to calculate accurately the discharge Q(t) through the breach. The discharge through the breach Q(t) was then applied to the two dimensional model of the mine subsidence area as an upstream boundary condition.

Each simulation enabled to analyse not only maximum water depth associated with different boundary conditions but also the time-to-flooding, local water depth fluctuations during an inundation and local flow velocities. The real objective of the study was to give a good insight in the inundation course, so the time-to-flooding and the water depth fluctuations during an inundation are the most important results. For each hour after the breach an inundation map, including the local waterdepth, was set up. Figure 3 shows the inundation maps at different moments after the dike failure. The different colours show the inundation depth. All inundation maps of one scenario are combined into a inundation movie, which gives a good overview of the expected inundations.

Table 1 shows for the different locations of the breach the time-to-flooding of the different villages in the mine subsidence area.

Several villages are inundated very fast after the breach. If such a breach occurs, there is very little time to evacuate people. A good evacuation plan has to be set up and communicated to the local public.

A combination of the different inundation maps and the local streetmaps gives insight in the optimal evacuation direction for the inhabitants of the different villages. Table 2 shows the optimal evacuation direction in the case of a dike failure at Villain XIV (scenario 4).

The direction indicated in table 2 offers different evacuation roads. The determination of the optimal road depends on

- the capacity of the road
- the length of the road
- the condition of the road
- the presence of street furniture, such as flower boxes, roundabouts,…
- the inhabitants of the different villages
- the familiarity of the people with the road
- …
Figure 3: Inundation maps at different moments after the dike breach at Villain XIV – scenario 4 (1 hour after the breach, 2 hours after the breach, 3 hours after the breach, 6 hours after the breach, 12 hours after the breach, 24 hours after the breach (background: Topographic Map 1:100,000, ©NGI Belgium).

The determination of the optimal road can be investigated via a bi-directional network analysis, which takes the different aspects, as mentioned above, into account. Due to the fact that in some scenario’s the time-to-flooding is very short (maximum some hours, see table 1) and the fact that the inundation depth
Table 1: Time to flooding (hours) of the different villages.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Breach location</th>
<th>Vucht (hours)</th>
<th>Eisden (hours)</th>
<th>Leut (hours)</th>
<th>Meeswijk (hours)</th>
<th>Lanklaar (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>no breach</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1</td>
<td>Vucht</td>
<td>1</td>
<td>2</td>
<td>8</td>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td>2</td>
<td>Mazenhoven</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>8</td>
<td>24</td>
</tr>
<tr>
<td>3</td>
<td>Kraaienbos</td>
<td>32</td>
<td>30</td>
<td>2</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>4</td>
<td>Villain XIV</td>
<td>22</td>
<td>14</td>
<td>5</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>veerpont</td>
<td>-</td>
<td>44</td>
<td>10</td>
<td>6</td>
<td>26</td>
</tr>
<tr>
<td>6</td>
<td>Molenveld</td>
<td>-</td>
<td>27</td>
<td>7</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>7</td>
<td>Genootsbeek</td>
<td>-</td>
<td>-</td>
<td>17</td>
<td>10</td>
<td>44</td>
</tr>
<tr>
<td>8</td>
<td>Stokkem</td>
<td>-</td>
<td>-</td>
<td>21</td>
<td>4</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 2: Optimal evacuation directions for a breach at Villain XIV (scenario 4).

<table>
<thead>
<tr>
<th>Hours after the breach</th>
<th>Vucht</th>
<th>Eisden</th>
<th>Leut</th>
<th>Mazenhoven</th>
<th>Meeswijk</th>
<th>Lanklaar</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>west</td>
<td>west</td>
<td>west</td>
<td>west</td>
<td>west</td>
<td>north</td>
</tr>
<tr>
<td>6</td>
<td>west</td>
<td>west</td>
<td>-</td>
<td>south</td>
<td>-</td>
<td>north</td>
</tr>
<tr>
<td>12</td>
<td>west</td>
<td>west</td>
<td>-</td>
<td>south</td>
<td>-</td>
<td>north</td>
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<td>west</td>
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<td>-</td>
<td>south</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>24</td>
<td>west</td>
<td>-</td>
<td>-</td>
<td>south</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Figure 4: Areas with inundation depths of more than 5 and more than 7 meters – breach at Villain XIV (6 hours after the breach, 12 hours after the breach, 24 hours after the breach) (background: Topographic Map 1:100.000, ©NGI Belgium).
can be very large (several meters, see figure 3), the best evacuation direction is sometimes the stair to the highest floor of one's own house.

The different scenario’s show however that certain regions can be flooded with inundation depths of more than 5 meters in a very short period of time. In this regions, people have to be evacuated immediately by helicopter. Figure 4 shows the regions of the mine subsidence area with inundation depths of more than 5 and more than 7 meters. The local community authorities will evacuate people out of these regions by highest priority.

5 Conclusions

The mine subsidence area is located in the eastern part of Belgium along the river Meuse and is affected by mine subsidence up to seven meters. The area is protected against inundations by a winterdike.

When a breach of the winterdike occurs, due to the large hydraulic gradient between the high water levels in the river Meuse and the topography of the subsidence area, very high inundation depths and a very short time to evacuate the inhabitants of the area are expected.

In order to minimise the victims and the damage in the event of a failure of the winterdikes the local river authority asked Flanders Hydraulics Research for a detailed hydraulic analyses of the inundation event, which is the input for the set up of evacuation plans.

For different locations of the dike failure, inundation maps were set up and optimal evacuation directions were derived. Also, the most vulnerable regions in the mine subsidence area were determined.

The applied combination of one and two-dimensional hydraulic models showed to be a good research instrument for the accurate determination of the inundation areas and the most vulnerable zones. This determination is the first step towards the set up of optimal evacuation plans.

References