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Optimization of 2D flood models by semi-automated incorporation of flood diverting landscape elements

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ABSTRACT: A simple GIS procedure was used for restoring narrow linear flood diverting landscape elements in rectangular grid digital elevation models. Subsequently, four different DEM's (fine and coarse grid, with and without linear elements) were incorporated in 2D flood models. Finally, the various flood models were used to compute flood risk in the eastern part of the Belgian coastal plain. The results obtained with fine and coarse grids were quite different, but when linear elements were restored in both grids, they agreed remarkably well. The application of this GIS procedure allows model run times to be reduced by an order of magnitude, while still preserving flood risk accuracy.

1 INTRODUCTION

The study reported in this paper aimed at quantifying the flood risk in a coastal plain, associated with failure of the coastal defenses during extreme storm events.

Flood patterns can be affected by the presence of flood diverting linear landscape elements (e.g. dikes, road or railroad embankments) in the floodplain. When using a two-dimensional rectangular grid flood model, the representation of these elements requires the use of a very fine elevation model grid. This often results in very large data sets and, as a consequence, very long simulation times. When elevation data are aggregated into a coarse grid, narrow linear landscape elements are frequently flattened or filtered out. Manually restoring these elements becomes impracticable when large areas are being studied. Therefore, a simple GIS procedure was developed for restoring these elements in a semi-automated way.

2 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 km^2.

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

3 APPROACH

3.1 *Digital elevation model*

Linear landscape elements were identified and restored by combining raster (elevation) and vector (linear elements) data.

First, linear landscape elements that may affect flood patterns (mainly dikes and (rail)road embankments) were selected from an existing national vector database. These elements are shown in Figure 2.

Subsequently, crest levels were estimated from an existing high resolution (5 × 5 m) raster elevation model. As the position of the vector elements rarely coincides exactly with the highest point in the elevation model, a 10 m wide buffer was drawn around the line elements. The buffers were converted to a raster format and the high resolution elevation data inside these buffer areas were stored in a separate crest level model.

Next, two lower resolution elevation models (20 × 20 m and 40 × 40 m) were generated through aggregation of the high resolution elevation data. Each low resolution raster cell was assigned a value corresponding to the average of the underlying high resolution raster cells. This procedure inevitably results in the flattening or even disappearance of narrow linear elements.

In parallel, two lower resolution crest level models were generated through aggregation of the high resolution crest level data. In this case, however, each low resolution raster cell was assigned a value corresponding to the maximum of the underlying high resolution cells, thereby preserving the correct crest levels.

Finally, the linear elements in the low resolution elevation model were automatically restored by simply merging the low resolution elevation model and the low resolution crest level model, giving prevalence to the crest level model.

Figure 2. Linear landscape elements (source: National Geographic Institute).

Four different elevation models were constructed in this way: fine (20 × 20 m), coarse (40 × 40 m), fine with linear elements restored and coarse with linear elements restored.

3.2 *Flood model*

The elevation models were incorporated in a set of flood models, constructed by means of the software package MIKE FLOOD (Danish Hydraulic Institute). This package offers the possibility to dynamically link 1D breach models (MIKE 11) to a 2D floodplain model (MIKE 21). For a full description of these models, reference is made to the software manuals (DHI 2007).

The flood models were used to predict floods resulting from breaches in the coastal defense, caused by a series of extreme events with return periods of 4000, 10000 and 40000 years.

The hydraulic boundary conditions (astronomical tide and storm surge) and the characteristics of the breaches (number, location, dimensions and time of breaching) were obtained from an earlier analysis, carried out within the framework of the EU-funded Interreg IIIb project Comrisk (Anonymous 2005). For a detailed description, the reader is referred to the original study or a companion paper (Vanderkimpen et al. 2008).

3.3 *Flood damage and casualties*

The results from the flood models were used to estimate flood damage and number of casualties 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 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.

The number of casualties was estimated by means of an empirical function, based on the maximum water depth and the maximum hourly rise.

3.4 *Flood risk*

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

4 RESULTS

4.1 *Digital elevation model*

The four different elevation models are shown in Figure 3. Elevations range from sea level (black) to 15 m above sea level (white).

The figures show how a number of narrow dikes in the northeastern part of the study area have been filtered out in the coarse model (Figure 3c) and restored in the coarse model with linear elements (Figure 3d).

4.2 *Inundations*

The inundations are shown in Figures 4–6. They were characterized by means of the total volume of water and the maximum flooded area. The results are

Figure 3a. Digital elevation model (fine grid).

Figure 3b. Digital elevation model (fine grid with linear elements).

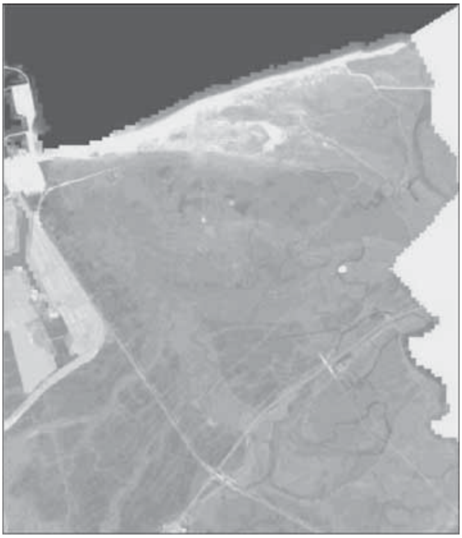

Figure 3c. Digital elevation model (coarse grid).

Figure 3d. Digital elevation model (coarse grid with linear elements).

Figure 4a. Flooding caused by a storm with a return period of 4000 years (fine grid).

Figure 4b. Flooding caused by a storm with a return period of 4000 years (fine grid with linear elements).

Figure 4c. Flooding caused by a storm with a return period of 4000 years (coarse grid).

Figure 4d. Flooding caused by a storm with a return period of 4000 years (coarse grid with linear elements).

Table 1a. Relative change of flooding for a storm with a return period of 4000 years.

Grid	Volume %	Area %
Fine	–	–
Coarse	10	29
Fine with linear elements	–1	–39
Coarse with linear elements	3	–40

Table 1b. Relative change of damage and casualties for a storm with a return period of 4000 years.

Grid	Damage %	Casualties %
Fine	–	–
Coarse	46	–38
Fine with linear elements	–20	38
Coarse with linear elements	21	38

Figure 5a. Flooding caused by a storm with a return period of 10000 years (fine grid).

Figure 5b. Flooding caused by a storm with a return period of 10000 years (fine grid with linear elements).

Figure 5c. Flooding caused by a storm with a return period of 10000 years (coarse grid).

Figure 5d. Flooding caused by a storm with a return period of 10000 years (coarse grid with linear elements).

Table 2a. Relative change of flooding for a storm with a return period of 10000 years.

Grid	Volume %	Area %
Fine	–	–
Coarse	7	14
Fine with linear elements	–10	–26
Coarse with linear elements	–12	–22

Table 2b. Relative change of damage and casualties for a storm with a return period of 10000 years.

Grid	Damage %	Casualties %
Fine	–	–
Coarse	3	–7
Fine with linear elements	–30	30
Coarse with linear elements	–28	–40

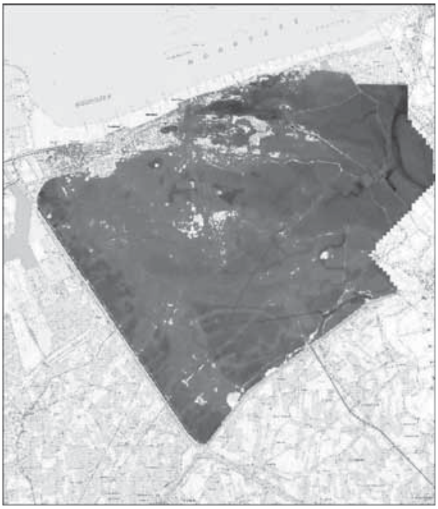

Figure 6a. Flooding caused by a storm with a return period of 40000 years (fine grid).

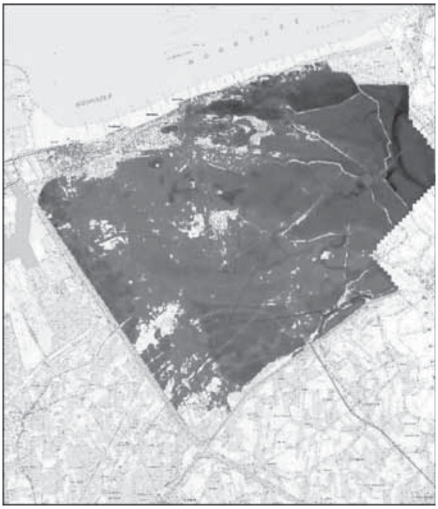

Figure 6b. Flooding caused by a storm with a return period of 40000 years (fine grid with linear elements).

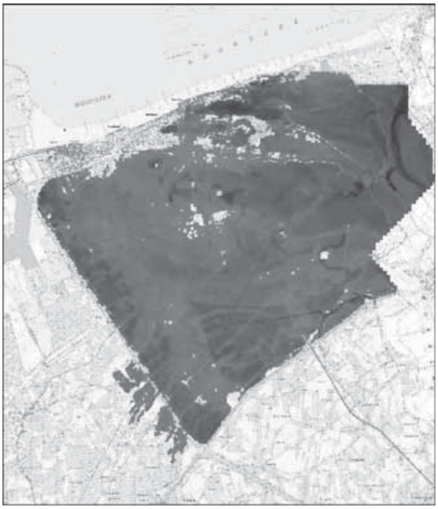

Figure 6c. Flooding caused by a storm with a return period of 40000 years (coarse grid).

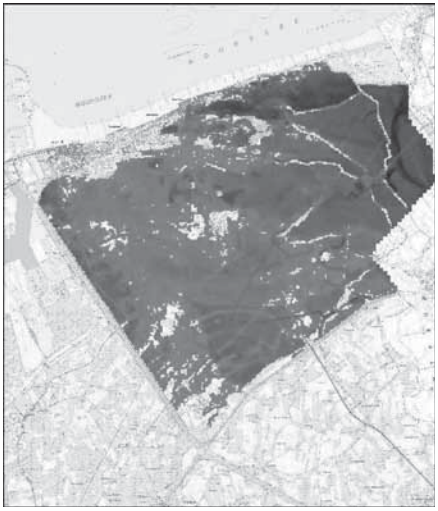

Figure 6d. Flooding caused by a storm with a return period of 40000 years (coarse grid with linear elements).

Table 3a. Relative change of flooding for a storm with a return period of 40000 years.

Grid	Volume %	Area %
Fine	–	–
Coarse	5	4
Fine with linear elements	–18	–7
Coarse with linear elements	–20	–7

Table 3b. Relative change of damage and casualties for a storm with a return period of 40000 years.

Grid	Damage %	Casualties %
Fine	–	–
Coarse	1	–29
Fine with linear elements	–5	36
Coarse with linear elements	–5	33

summarized in Tables 1a–3a. For each variable, the relative deviation from the reference situation (fine grid without linear elements) is shown.

The use of a coarse elevation model leads to worse flooding (larger volume and larger area). The incorporation of linear elements has an opposite effect (smaller volume and smaller area). When linear elements are restored, the impact of mesh size decreases significantly.

4.3 *Damage and casualties*

The results from the damage and casualty calculations are summarized in Tables 1b–3b. Here too, relative deviations from the reference situation are shown.

The use of a coarse elevation model leads to an increase of damage and a decrease of casualties. The restoration of linear elements has the opposite effect. These trends are most probably influenced by the spatial variation of land use (damage) and population density (casualties) in the study area and may not apply to other areas.

4.4 *Flood risk*

The flood risk (total damage and casualties) has been summarized in Table 4. Once again, relative deviations have been used.

The results obtained with fine and coarse models are quite different (flood risk and casualty risk differ by 30%), but when linear elements are restored, they agree remarkably well (flood risk and casualty risk differ by less than 1%).

4.5 *Model run time*

The coarse flood models contain four times less computational points and therefore run nearly four times faster than the fine models. In MIKE FLOOD, the link between the 1D and 2D models is explicit and the maximum allowable simulation time step is limited by the Courant condition. Therefore, an increase of the 2D model mesh size also allows for a proportional increase of the model time step. As a result, the coarse models may run up to eight times faster than their fine counterparts.

Table 4. Relative change of damage risk and casualty risk.

Grid	Damage %	Casualties %
Fine	–	–
Coarse	32	–32
Fine with linear elements	–19	–37
Coarse with linear elements	–19	–37

5 CONCLUSION

When using a two-dimensional rectangular grid flood model for flood risk evaluation, model performance can be improved considerably by means of a simple GIS-procedure for semi-automated incorporation of flood diverting landscape elements into the elevation model. Model run times can be reduced by an order of magnitude, while still preserving flood risk accuracy.

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