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Analysis of flood damages from the 1993 and 1995 Meuse floods

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Abstract. This paper addresses uncertainties pertaining to damage assessments made for the floodings of the Meuse River in 1993 and 1995. The analysis is based on flood damage data that were collected by damage experts and consist of large sample sizes within each municipality. The most interesting aspect of these two floods is that although the volume of flooding and the inundated area were comparable in order of magnitude, the flood damage estimates in 1995 were 35% lower than in 1993. We conclude that part of the reduction in flood damage during the 1995 flood was due to a reduction in the damage to household goods. This may be explained by a marginal increase in flood warning time and experiences gained from the flood of 1993. As flood damage assessments are the cornerstone in the evaluation of flood damage mitigation schemes, empirical data of previous floods should be used to improve the foundations of the methods to assess flood damages.

1. Introduction

In 1993 the Meuse River overflowed its banks, leading to extensive flooding of the southern part of Netherlands (Figure 1). An area of over 17,000 ha was flooded, and damage to 5580 private homes was reported. The direct financial losses amounted to kDfl 253,000 (kDfl is 1000 Dutch guilders). Immediately following the flood, the Dutch government commissioned the "Meuse Flooding Committee" (Commissie Watersnood Maas) to formulate prevention measures to reduce future impacts of floods. On the basis of detailed studies reported by Delft Hydraulics in 1994 [*Delft Hydraulics*, 1994] the committee formulated a long-term strategy for flood damage reduction.

While the first phase of the project to reduce the flood impact of the Meuse River was still in progress, the Meuse flooded again in 1995. The peak discharge of this flood was 2861 $m^3\ s^{-1}$, which is comparable in magnitude to the flood discharge of 3120 $m^3\ s^{-1}$ in 1993; also, the flooded area of 15,500 ha was of the same order of magnitude as for 1993. However, the direct financial losses in 1995 amounted to kDfl 165,000, which is considerably less than the damage in 1993. In order to find an explanation for the differences in flood damages between two comparable floods, the Department of the Environment commissioned the University of Twente to study this matter with the support of a team of external experts. The research questions posed in this study were (1) What are the main causes of the differences between the 1993 and the 1995 Meuse flood damage? and (2) What are the implications for flood damage modeling? The central aim of this paper is to provide a framework for the comparison of different floods on the basis of an assessment of flood damage estimates for the 1993 and 1995 Meuse floods.

2. Framework of Analysis

2.1. Flood Damage Modeling

Flood damage mitigation schemes can be evaluated by means of a cost benefit analysis, multicriteria analysis, and "standard setting" or "target setting" [*Griffiths*, 1981]. The first method aims to compare the benefits and costs of different courses of action and, consequently, identify the alternative with the largest net benefit. For this purpose the benefits and costs are generally converted into a uniform scale of measure, for which mostly a monetary scale is chosen. In a multicriteria analysis the costs and benefits are not converted to a uniform scale; at some stage, however, the effects are normalized on a scale between, for example, 0 and 1, and weighing factors have to be attached to these effects in order to account for the preferences of the decision maker. If intangible effects predominate and trade-offs in terms of costs and benefits are difficult to make, the method of standard or target setting is applied [*Peerbolte*, 1993].

In the assessment of flood alleviation schemes by one of these methods, flood damages play an important role. *Breaden* [1973] categorized flood damages and distinguished the following types of damage: (1) direct damage, mainly to structures and public facilities; (2) indirect damage, such as the cost of lost business and production, delays, and emergency costs; (3) secondary damage, which occur beyond the parties directly or indirectly affected, such as purchasers of affected products; (4) intangible damage, including environmental effects and loss of cultural heritage; and (5) uncertainty damage, which is the damage to those living in continuous uncertainty about potential flood hazards and suffering from the associated stress. For methods of calculating immaterial damage the reader is referred to *Peerbolte* [1993], *Parker et al.* [1987], *Sugden and Williams* [1978], and *Breaden* [1973].

Considering the literature on flood damages, we observe that most attention is paid to the direct material effects of flooding, although nonmaterial effects are also recognized [*Penning-Rowsell et al.*, 1992; *Peerbolte*, 1993; *Torterotot*, 1993; *Janssen*, 1991; *Pearce and Turner*, 1990; *Arnell*, 1986; *Green et al.*, 1985; *Pearce*, 1983]. These methods have in common the fact that the direct material effects are obtained from the type and number of flooded objects and the inundation depth. As the data gathered in the present study focus on the direct damage, the remaining damage categories will not be discussed any further.

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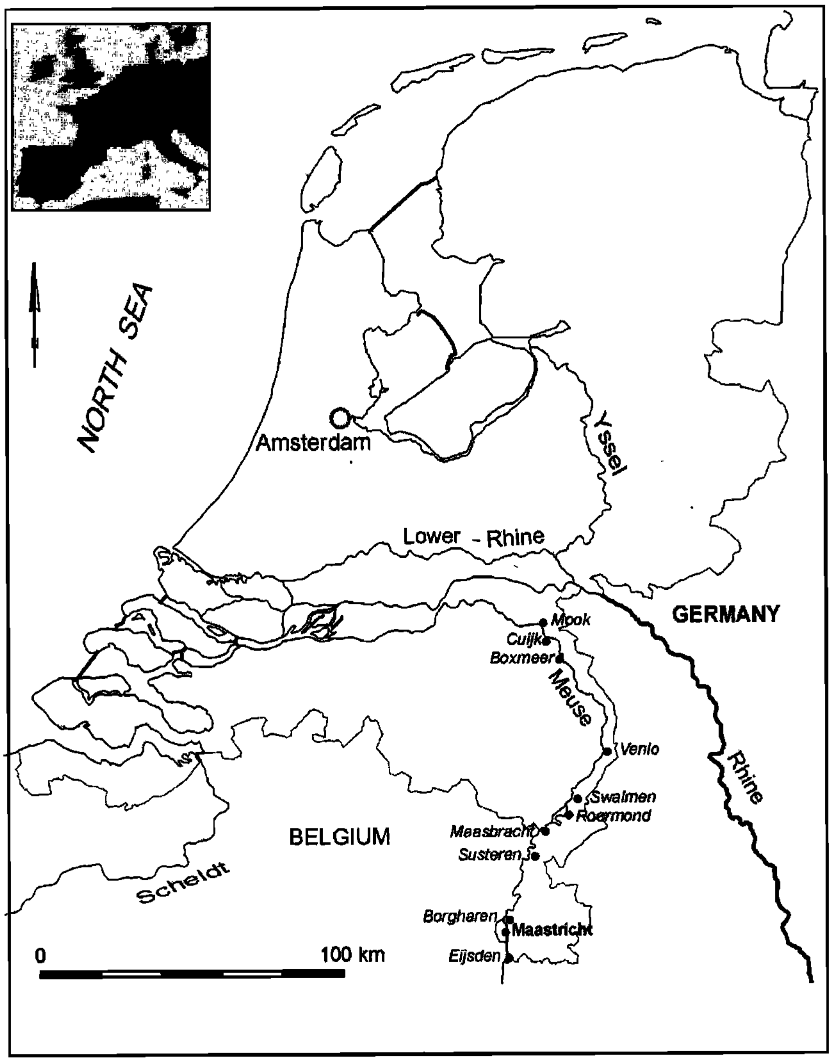

Figure 1. Location of the Dutch part of the Meuse River.

When analyzing the extensive databases pertaining to these two floods, we found some unexpected differences. For instance, one would expect that if the same areas were flooded in 1993 as in 1995, roughly the same number of objects would be flooded. Furthermore, it seems reasonable to assume that the flood damage would be approximately the same if the area and inundation depth in 1993 and in 1995 remained unchanged. This, however, was not the case. On the basis of these differences in flood damages we posed the following two hypotheses for flood damage modeling:

1. The number of damaged objects either remains the same or increases (decreases) with increasing (decreasing) flooded area.
2. The flood damage of an object is determined by the type of object and the inundation depth; hence if the inundation depth in 1993 is the same as in 1995, flood damage for the same type of object should also be the same.

2.2. Measuring Flood Damages

Flood damages from the 1993 and 1995 floods were assessed by damage experts commissioned by the Dutch government. For private residences, flood damage was assessed on the basis of reconstruction costs. For industries, institutions, and infrastructure, damages were assessed on the basis of the hypothetical costs of reconstruction to achieve the state prior to the flood. Data on the costs of cleanup, assistance, and the damage to infrastructure were compiled by the government agencies concerned. All costs were given in kDfl, or 1000 Dutch guilders, and included 17.5% value added tax (VAT). These damage estimates are considered to be of high reliability, since the damage assessments were carried out by experts and constituted the basis for compensation by the government. If private parties disagreed with their estimates, a protest could be submitted.

The extent of the flooded area per municipality was determined from aerial photographs. The inundation depth per flooded object was not known precisely but could be inferred from water level registrations. Finally, it was known for each municipality which remedial actions against flooding were taken, such as levees, evacuation, etc. [*Nierop*, 1996].

3. Hydrology of the 1993 and 1995 Meuse Floods

3.1. Discharge Distribution and Water Level

The maximum discharge during the 1993 flood at Borgharen, near the border between Belgium and Nether-

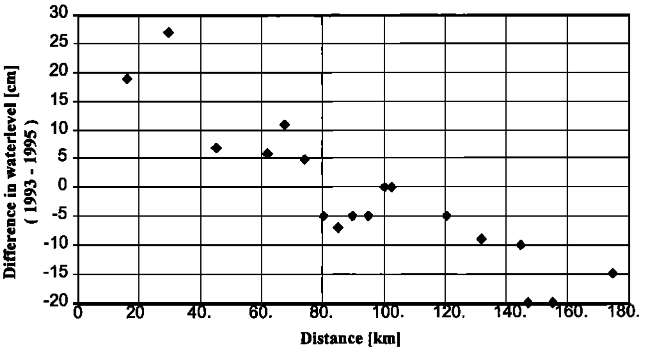

Figure 2. Difference in depth of inundation along the Meuse River between the floods of 1993 and 1995 measured from the Belgian border.

lands, was 3120 m^3 s^{-1}, which was 8% higher than the maximum discharge in 1995 (2861 m^3 s^{-1}). The 1993 flood occurred in December and lasted for 3 days; the 1995 flood occurred in January–February 1995 and lasted for 5 days. Because of the longer duration of the 1995 discharge the storage capacity in the upper part of the Meuse filled up. This explains why, in 1995, the maximum inundation depth in the upstream part of the Meuse was 0.20 m lower and in the downstream part was 0.20 m higher than in 1993 [*Bleichrodt and Ensinck*, 1994; *Goudriaan*, 1995]. Figure 2 shows the difference between the extreme water levels in 1993 and 1995 at 13 locations along the Meuse. The evolution of the water level in Borgharen is shown in Figure 3.

3.2. Inundated Area

The inundated area in 1995 was 10% less than the inundated area in 1993 (17,000 ha). Because of remedial action this reduction in inundated area was not evenly distributed over the five damage categories. In the private sector the flooded area was reduced by 39%, while in the agricultural sector it was reduced by 15%.

3.3. Role of Water Level Prediction and Flood Warning

On December 14, 1993 (Figure 3), an early warning signal about the rising water level of the Meuse was issued by the Department of Public Works and Water Management. Since rising water levels are a regular phenomenon in this region, the local population was not concerned. This attitude seemed justified because the early warning was withdrawn on December 16. However, because of continuous rainfall in Belgium and France, the water level of the Meuse became perilously high on December 20. Nevertheless, many people still underestimated the risk of flooding and postponed the moment of evacuation as long as possible [*Rosenthal*, 1998]. The local authorities were caught by surprise by the rapid rise of the water level, so they had insufficient time to warn the public. Hence the majority of the population at the upstream and downstream parts of the river later complained that they were not informed in time.

In 1995, memories of the 1993 flood were still quite fresh, and people were not willing to take risks again. On January 23, 1995 (Figure 3), villages along the Meuse began to prepare for another flood. Because of this attitude the public and the authorities had more time in 1995 to undertake preventive action and evacuation. On January 25 the Department of Public Works predicted that the water level of 1993 might be exceeded. The percentage of respondents who were satisfied about the time of advance warning increased to over 90% as compared to 30–40% in northern and southern Limburg in 1993 [*Rosenthal*, 1998].

Predicting water levels along the Meuse is hampered by the fact that it is impossible to predict precisely the amount of precipitation in the Meuse basin. Since water levels in the Meuse can change as quickly as from 1 to 3 m d^{-1}, this uncertainty sometimes results in flood warnings which have to be recalled later. In 1993 the population living along the Meuse anticipated such a withdrawal and ignored the warning. However, after a flood had occurred, precautionary measures were taken even before a formal warning was given.

4. Analysis of Flood Damages at Municipal Level

The flood damages of the 1993 and the 1995 Meuse floods (Table 1) are divided into five damage categories: private property, agriculture and horticulture, trade and industry, institutions, and government. Damage data for the flood of 1993 were taken from the reports of the Meuse Flood Committee. Data on the 1995 Meuse flood were derived in the course of our present study. The flood damage in 1993 amounted to kDfl 253,000, which is kDfl 88,800, or 35%, higher than the damages resulting from the flood of 1995 (kDfl 165,000). As can be seen from Table 1, the largest contribution to the reduction in flood losses in 1995 was due to the reduction in damage to private property. The 50% reduction in losses is more than can be expected on the basis of the 39% reduction in flooded area within this subcategory.

Government expenditure on reconstruction and aid amounted to kDfl 22,200. From Table 1 we see that this reduction was due mainly to a reduction in the costs of cleaning up, aid, and repairs to the river infrastructure; the costs of repairing damages to the land infrastructure were higher. Since discharges from both floods were similar, one would expect

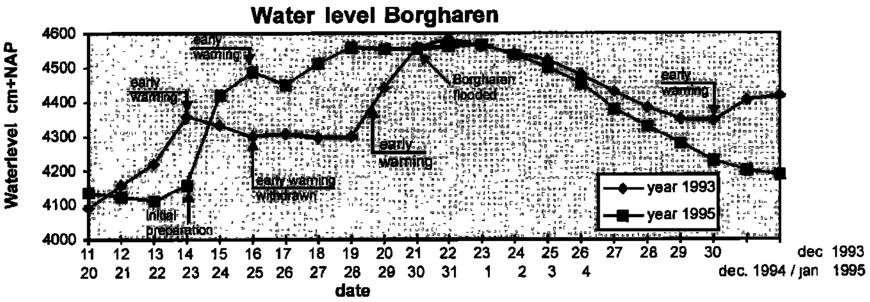

Figure 3. Water level prediction and flood warning at Borgharen.

Table 1. Damage Data of the 1993 and the 1995 Meuse Floods

Damage Category	1993 Damage, Millions of Dfl	Percent	1995 Damage, Millions of Dfl	Percent
Private	96.5	38	40.7	25
Houses	80.8		40.0	
Cars	1.0		*	
Caravans	13.5		0.7†	
Gardens	1.2		*	
Agriculture and horticulture	19.4	8	20.9	13
Trade and industry	74.0	29	62.2	38
Trade and industry	71.3		62.2	
Gravel extraction	2.7		*	
Institutions	2.6	1	2.1	1
Government	61.3	24	39.1	24
Buildings and sites	6.6		0.5	
River infrastructure	21.9		1.5	
Land infrastructure	15.5		18.0	
Public utilities	7.3		*	
Clear away and assistance	10.0		19.1	
Total	253.8	100	165.0	100

*Data not available.
†Only holiday houses.

government expenditure to be similar as well. Whether the government learned from the previous inundation is an issue that merits further investigation. It is difficult to explain the increase in 1995 of damages in the agricultural sector, since the flooded area in this sector was reduced by 15%, while the duration of flooding was comparable. This point will be discussed below.

4.1. Number of Damage Reports and Flooded Area

As indicated earlier, one of the assumptions made in flood damage modeling is that the number of flooded objects will either remain the same or increase in proportion to the increase in flooded area. To test this assumption, the data on the number of flooded objects as derived from the damage reports and the flooded area are shown in Table 2. For private housing and industry the reduction in the flooded area in 1995 led to a comparable reduction in the number of damage reports. This is not the case for agriculture: The flooded area in 1995 was reduced while the number of damage reports increased. Further analysis of the data reveals that this increase in damage reports was not caused by the flooding of new areas in 1995 which were not flooded in 1993. It appears that the increase in flood damage reports in 1995 resulted from the fact that the farmers were unable or unwilling to bear more of the flood damage themselves. In 1993 the Department of Agriculture proposed a settlement which would compensate farmers for 65% of the incurred damages. In 1995 farmers protested strongly against a similar settlement, which eventually resulted in a better settlement [*Rosenthal*, 1998]. The increase in the costs of cleanup and repairs to the land infrastructure in 1995 may be due to a similar change in attitude on the part of the local authorities by making the costs of flood damages more explicit.

We conclude that the flooded area can serve as a reasonable substitute for estimating the quantity and type of flooded objects. However, whether all objects within this flooded area will indeed experience damage and whether damage is reported depends on individual action, attitude, and experience with previous floods. This introduces a margin of uncertainty into the number of flood damage reports, which, according to Table 2, is of the order of 20% or more.

4.2. Average Flood Damage Per Damage Report

The actual flood damage to an object depends on the type of the object, e.g., residential, shops, general stores, and services, and the depth of inundation [*Penning-Rowsell et al.*, 1992]. This implies that if the same objects in a municipality were flooded in 1993 as in 1995 and the depth of inundation was the same, one would expect the average extent of flood damage per object in this municipality to be the same as well. This hypothesis can be tested by plotting the 1993 average flood damages per object for each municipality against the 1995 average flood damages per object for each municipality. If the assumptions made in section 1 are valid, the damages for all the municipal-

Table 2. Number of Damaged Objects and Flooded Area

Damage Category	Flooded Area in 1993, ha	Flooded Area in 1995, ha	Area 1993 Minus 1995, %	Number of Damage Reports in 1993*	Number of Damage Reports in 1995*	Damage Reports 1993 Minus 1995, %
Private housing	345	209	−39%	5580	4424	−21%
Agriculture	8614	7318	−15%	473	664	+40%
Industry	157	99	−37%	84	57	−32%
Cleaning	see private housing	see private housing	−39%	10,000 kDfl	19,100 kDfl	+91%
Land infrastructure	see private housing	see private housing	−39%	15,500 kDfl	18,000 kDfl	+16%

*For the first three damage categories, private owners are approached. This led to the indicated number of damage reports. The last two categories refer to government agencies, which resulted in the total amount of damage in kDfl (kDfl is 1000 Dutch guilders).

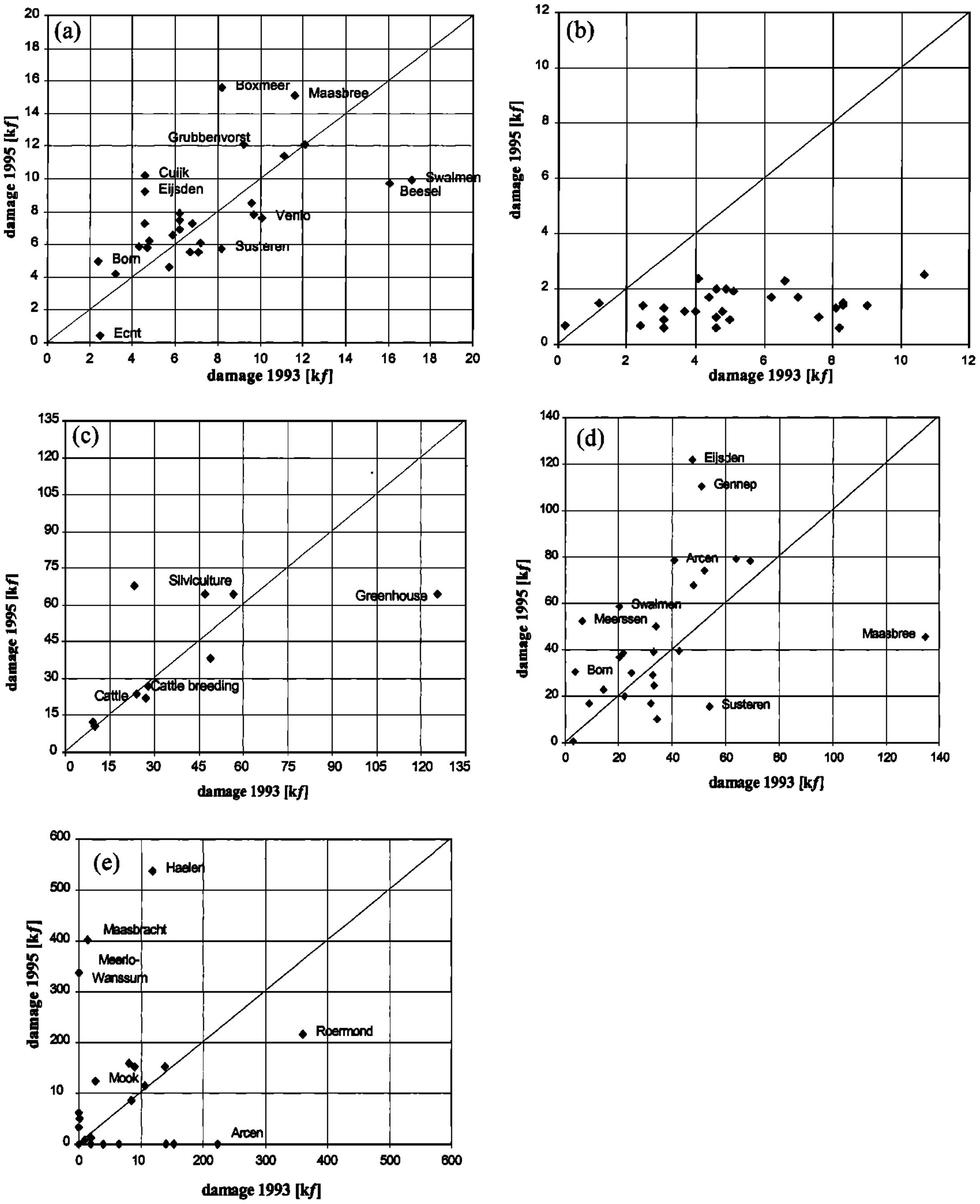

Figure 4. Average damage per damage category and per municipality for the Meuse floods of 1993 and 1995: (a) building fabric, (b) household inventory items, (c) agriculture and horticulture, (d) trade and recreation, and (e) industry.

ities should lie along the diagonal for each damage category. Any differences in the average flood damage per municipality for the same category of objects must be due to differences in inundation depth per municipality.

Here we define the "average flood damage per object for each municipality" as the value obtained if the flood damage per damage category in a certain municipality is divided by the number of flood reports per damage category in that municipality. The flood damage categories are the same as the ones given in Table 1. The average flood damage per damage category and per municipality is presented in Figures 4a–4e, with the exception of Figure 4c where the damage to agriculture is subdivided into damage subcategories. In section 4.3 the variation in the flood damage data shown in Figures 4a–4e is examined in more detail.

4.3. Analysis of Variation in Flood Damage Data

The damage data given in Figure 4 tend to cluster around the diagonal, indicating that damage per flooded object was roughly the same in 1993 as it was in 1995. Exceptions to this generalization occur with respect to damage to household inventory items (Figure 4b) and damage to industry (Figure 4e). Since household inventory items are used daily, most of the objects damaged by the 1993 flood are likely to have been

Table 3. Coefficients for Systematic and Statistical Error and Maximum Relative Error in Damage at Municipal Level

Damage Category	Systematic Error a	Statistical Error b	Maximum Relative Error $\|a\| + b$
Building fabric	−0.03	0.07	0.10
Agriculture and horticulture	−0.04	0.14	0.18
Industry	−0.04	0.12	0.16
Trade and recreation	0.27	0.08	0.35

replaced in 1995. The reduction in damage to household inventory items can be explained by increased public awareness resulting from the 1993 flood, which led to more appropriate actions to reduce flood damage as well as more timely evacuation. This aspect of human behavior in reducing damage to household inventory items is not accounted for in the depth-damage relations. A similar observation can be made in the case of damage to industry. In 1993 the 29 flooded municipalities reported a total of 84 cases of industrial flood damage, while in 1995 there were 57 damage reports. If in a municipality flooding of only one or two industries could be avoided due to local actions or evacuation, the average industrial flood damage per municipality changed considerably. Hence the scatter in Figure 4e is the result of the small number of flood damages per municipality and the effect of local actions. The industrial flood damage is modeled under the assumption that if an industrial area is flooded, all industries in this area will experience flood damage. The Meuse data show that in practice this is only partly true.

To analyze the uncertainty in the flood damage data in Figures 4a–4e, it is useful to make a distinction between systematic and statistical errors. The systematic error in the data for both floods stems from factors such as the differences in the insurance claims and anticipation of the second flood. The statistical error is a result of random variations in the damage estimated due to sampling errors and temporal local measures. On the basis of Figures 4a–4e we assume that both the systematic and statistical error are proportional to the flood damage D, or

$$\varepsilon(D) = aD + bD, \tag{1}$$

where the coefficients a and b pertain to the systematic and statistical error, respectively. The uncertainties in the number of flooded objects and the flood damage per object can be used to analyze alternative flood protection schemes. This may mean that the benefits of these schemes overlap and cannot be distinguished anymore. Furthermore, the uncertainty determines the type of processes, selection of damage categories, and the spatial resolution in flood damage assessment models. A first estimate of a was obtained from the slope of the linear regression curve

$$D_{95} = (1 + a)D_{93}. \tag{2}$$

Data points with D_{95} outside the range $[0.5\, D_{93}, 2D_{93}]$ were treated as outliers and omitted from the analysis. With the exception of the damage caused to household inventory (Figure 4b), already discussed previously, the systematic error is 10–20%. The value of the statistical error b was estimated from the standard deviation of a. The values obtained for a and b for the different damage categories are listed in Table 3. Note that the sign of the systematic error may be different. Therefore the maximum relative error in the municipal flood damage is defined as $|a| + b$ and listed in Table 3.

The next step is to obtain an order of magnitude estimate of the error in the flood damage caused to individual objects D_i present within a community. We assume that the error at the object level is proportional to the damage as well:

$$\varepsilon(D_i) = (a' + b')D_i, \tag{3}$$

where a' and b' are identical for all the communities. As no data are available for the damage incurred by individual objects, the question arises whether an estimate of a' can be obtained. A general expression for the maximum relative error in the object damage can be derived, provided a number of assumptions are made. We assume the object damages have a uniform correlation coefficient $\rho(D_i, D_j) = p$ for $i \neq j$ where $0 \leq p \leq 1$. Using (3) and the standard error propagation formula [*Bevington and Robinson*, 1992], one obtains

$$\varepsilon(D) = (a' + b')\left(\sum_i D_i^2 + p \sum_{i,j} D_iD_j\bigg|_{i \neq j}\right)^{1/2}. \tag{4}$$

Assuming that the D_i are distributed with mean μ and standard deviation σ, it follows that the maximum relative error in the object damage is given by

$$(a' + b')|_{\max} = (|a| + b)\sqrt{\frac{N}{(1 - p)[1 + (\sigma/\mu)^2] + pN}}$$

$$\approx \frac{|a| + b}{\sqrt{p}}, \tag{5}$$

provided $p > 0$ and $(\sigma/\mu)^2$ is small compared to pN, where N is the number of damaged objects per community. The average number of flooded objects per community and the maximum relative error in the object flood damage for different values of the correlation coefficient are shown in Table 4. According to Table 4, $pN \gg 1$ with the exception of industry where $pN \approx 1$. In general, σ/μ will be smaller than 1, hence we assume that the condition $(\sigma/\mu)^2 \ll pN$ is satisfied for all the damage categories. Furthermore, it seems reasonable to assume that the object damages within a community are correlated due to the spatial proximity. In addition, we note that the maximum error in the object flood damage corresponding to correlation coefficients in the range 0.5–1.0 are 20–40% of the object flood damage.

5. Conclusions and Discussion

In this paper we have looked at the reasons why damages for the 1995 flood of the Meuse were so much lower than for the Meuse flood of 1993. In addition, some of the consequences for flood damage modeling were studied.

The maximum discharge of 1995 Meuse flood was 8% lower than for the 1993 Meuse flood. However, the duration of the 1995 flood was much greater than that of the 1993 flood. These

Table 4. Average Number N of Flood Objects and Maximum Relative Error $(|a'| + b')|_{max}$ in the Damage at Object Level for Different Values of the Correlation Coefficient p

Damage Category	N_{93}	N_{95}	$p = 0.25$	$p = 0.50$	$p = 0.75$	$p = 1.0$
Building fabric	192	152	0.20	0.14	0.12	0.10
Agriculture and horticulture	47	66	0.36	0.25	0.21	0.18
Industry	3.5	2.5	0.32	0.23	0.18	0.16
Trade and recreation	40	34	0.70	0.49	0.40	0.35
Average	···	···	0.40	0.28	0.23	0.20

differences in the flood wave resulted in a maximum inundation depth which was 20 cm lower in the upstream region and 20 cm higher in the downstream region of the Meuse.

The difference in flooding damage of 89 million Dfl between the 1993 and the 1995 Meuse flood can partially be explained on the basis of a 50% reduction in damages to household items. This reduction can in turn be attributed to a marginal increase in flood warning time and to the experiences gained by the population during the 1993 flood. The remainder of the difference in flood damages can largely be attributed to a reduction in government spending on repairs and aid and to a reduction in damages to trade and industry.

The analysis of the flood damage data raises some questions about the accuracy of a basic element of flood damage modeling. It was found that in some cases the number of damage reports increased, even though the flooded area was smaller. Our conclusion is that the flooded area is a reasonable basis for estimating the number and type of flooded objects. However, whether all the objects in the flooded area are indeed likely to experience damage and result in flood damage reports depends on individual precautionary measures and on the attitude and experience of the public and authorities with previous floods. This introduces an additional margin of uncertainty in the number of flood damage reports, which, as shown in section 4.1, can be 20% or more.

On the basis of the available data a first approximation of the uncertainty in the flood damage at the level of objects was derived. We found that the uncertainty in the damage per flooded object was 20–40% of the damage per object. The estimation of the uncertainty in the flood damage data in this study was rendered more difficult because the data were mainly available at the municipal level. An analysis on a local level may reduce some of the observed uncertainties.

Since flood damage modeling now and in the future will form an important basis for the selection of appropriate countermeasures and the evaluation of flood damage mitigation strategies, the theoretical foundations of these damage models should be further improved. The recent floods provide a wealth of data which should be used for this aim. For the time being, uncertainties in the number of flooded objects and additional uncertainties in the depth-damage relation as outlined in this paper should be used to identify the uncertainty ranges needed for the evaluation of different strategies on the basis of flood damage models. Furthermore, these uncertainties should be taken into account during the construction of models for the assessment of these flood damages [*Wind et al.*, 1996].

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