Methodology for the calculation of industrial flood damage and its application to an industry in Vereeniging

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Abstract

The usual way to calculate flood damage is to use flood-damage curves. It is possible to develop standard flood-damage functions for some land uses. However, it is not possible to develop a standard flood-damage function for industries. The best option is then to complete questionnaires at every industrial plant on the flood plain and to use this information to calculate flood damage.

To calculate industrial flood damage, the damage to four components must be estimated and added to obtain the total damage to the plant. The four components are plant and equipment, raw materials, completed goods and structure. These components were combined to calculate the flood-damage potential for a plant on the Vereeniging flood plain. The mean annual damage was calculated as R0.94 m.

Introduction

From time to time nature proves that man should never become complacent and sit back thinking that his knowledge of the environment is adequate enough to understand it. The floods that caused great destruction in South Africa in late 1995 and early 1996, are a case in point. Consequently, the Water Research Commission is still financing research in this field. Since 1974, the University of the Orange Free State has been conducting flood-damage research first applying the *ex post* and later the *ex ante* approach. The calculation of potential flood damage in urban settlements forms part of this research. Urban flood-damage research is undertaken in residential, commercial, industrial and informal settlements. This article focuses on industrial flood-damage research.

Theory for the calculation of industrial flood damage

According to Penning-Rowsell and Chatterton (1977), there are two basic methods for calculating industrial flood damage. The first method is to project historic flood damage to provide standard depth/damage data. Criticism against this method is that documented historical information, which does not always exist, must be used. Another disadvantage is that damage can be over- or underestimated. If the survey is conducted just after the flood, replacement costs could be used instead of depreciated value (thus an overestimation), or cleaning-up costs and structural damage could be underestimated. The second method is to make use of the knowledge that the managers of industrial plants have of how their undertakings are affected by floods (Smith, 1993). The chief disadvantage of this method is that the damage is estimated without the occurrence of a flood, and that the information is therefore of a hypothetical nature. As early as 1965, Kates (1965) propagated the advantages of an artificial approach (using information gathered in the absence of a flood). The fact that general data provide more constant flood-damage functions and are more adaptable to the testing of flood-damage reduction options, was one of his motivations for using this method.

Kates (1965) proposes a synthesis for the calculation of industrial damage. Four sets of basic information are necessary as inputs for the artificial process:

- **Location maps** from which the location of industrial properties can be obtained.
- **Hydrological maps** that can be used to define the flood plain, and to determine flood depths and differences in flood characteristics.
- A set of **unit damage functions** which can be used for the calculation of damage to components of an industrial plant. Separate functions can be used for structural damage, damage to the contents of the plant and production damage. This damage can be expressed in terms of different unit values. Examples of such units are square metres of structure, monetary value of contents or production.
- An **adaptation option function** that reflects the adaptation of flood damage over time and space as a result of a process of training, change and the presence of more information.

The four sets of information are represented graphically in Fig. 1.

If the four basic sets of information are used, the synthesis process could be constituted as follows:

- The location maps can be used to give a description of the region's industrial complex during the period under investigation.
- A flood plain is defined by the hydrological maps that determines which parts of the industrial complex are on the flood plain.
- Each separate production unit or undertaking on the flood plain must specify the location, size and economic valuation of its structure, contents and production over a certain period of time.
- Appropriate unit damage functions are allocated to the different components of the structure, contents and production. The selection of the appropriate flood-damage function is based firstly on the hydrological maps in order to take the changes in hydrological factors into consideration, and sec-

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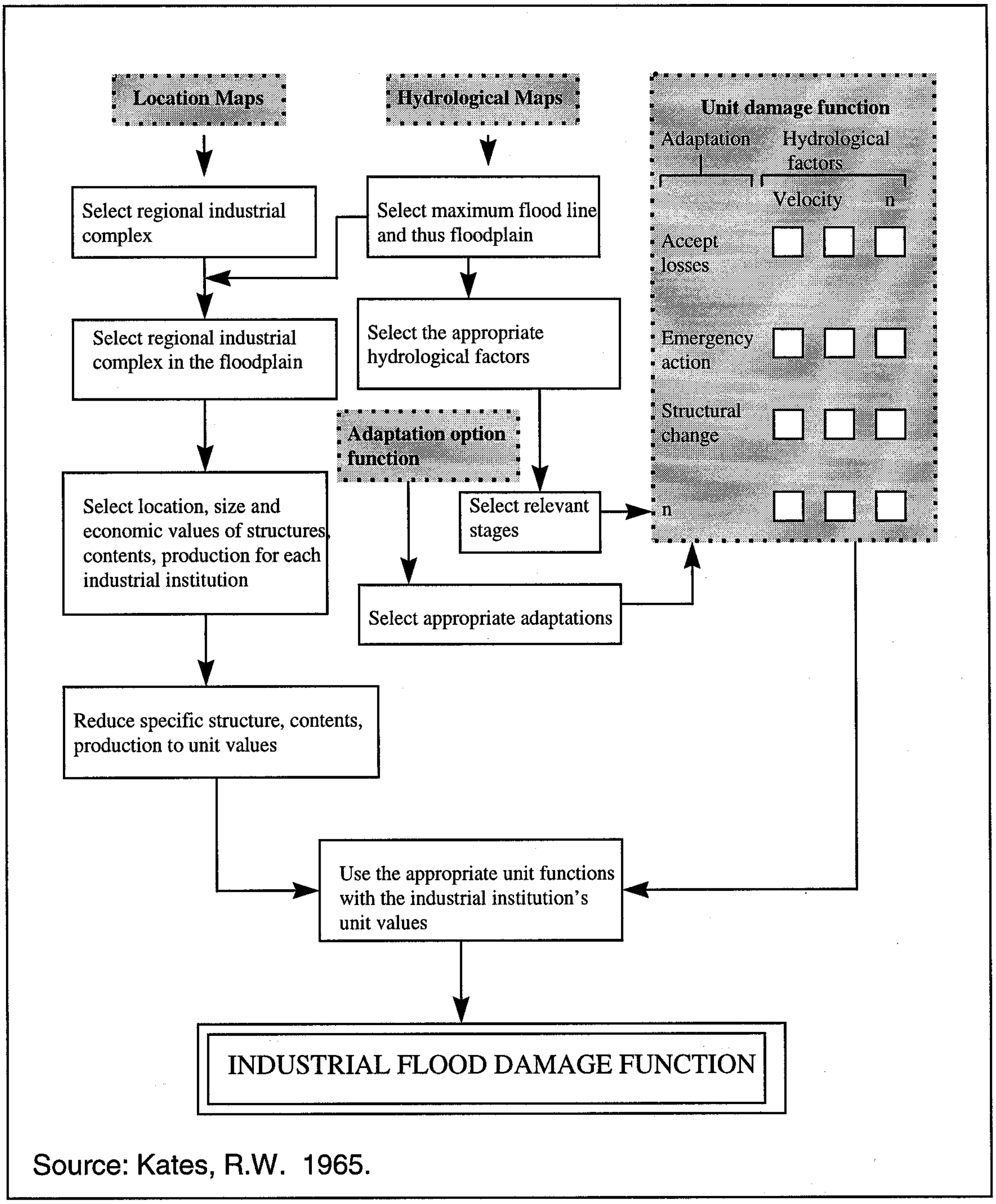

Figure 1

Four sets of basic information which serve as inputs for the artificial process to calculate industrial damage

ondly on the adaptation function to take into account the difference over time in flood-damage reduction actions.

- Damage for each institution is added up to constitute an artificial damage function for the entire flood plain, and a series of these functions indicates the change that takes place with the passage of time.

According to Kates (1965), the full application of this process is influenced by the state of technology, the cost of drawing up damage functions and the availability of useful information.

In their study of 1987, Parker et al. investigated indirect industrial damage. They referred to the approaches of Kates (1965), Smith (1979), Penning-Rowsell and Chatterton (1977) and Smith and Greenaway (1984) with regard to the calculation of indirect damage. In the Richmond River Valley study, Smith (1979) made use of a gross trade profit/turnover ratio proposed by Penning-Rowsell and Chatterton (1977). Parker et al. (1987) criticised this approach since the ripple effect on production in the economy and the disruptive effect on the transport networks had not been taken into account. Smith and Greenaway (1984) (as quoted by Parker et al., 1987), took indirect industrial damage as 70% of direct damage (Smith et al. (1990) in the Sydney study take indirect damage as 55% of direct damage). According to Parker et al. (1987), this approach would be unsuitable for England, and would amount to an overestimation of regional and national economic losses in Australia. Higgins and Robinson (1981) used loss of trade that had been converted to gross margins of the businesses as an indication of indirect losses. However, their approach did not distinguish between small business and manufacturing.

After his criticism of existing methods and his adaptation of Penning-Rowsell and Chatterton's (1977) approach, Parker et al. (1987) settled for the following approach: Loss of production was accurately measured by determining the loss of added value (the value added to the economy by the company). Additional costs caused by lower productivity because of flooding were then added to the loss of added value. Additional costs included remuneration for overtime, increase in electrical costs or the cost of the transfer of production within the undertaking.

Furthermore, Penning-Rowsell and Chatterton (1977) mentioned that indirect flood damage (loss of income) had two variables that determined the extent of the damage, namely the turnover of the undertaking and the duration of the disruption. Disruption could be caused in two ways, namely:

- the undertaking itself could be flooded, and/or
- the access routes of the undertaking could be cut off.

After studying the available literature, it was decided to adapt the approach of Parker et al. (1987), and the following method was used in Vereeniging to calculate the indirect flood damage:

$$V = Gm \times D$$

where:

V = Loss of profit
Gm = Gross margin per day
D = Days of disruption

$$Gm = NP \times T$$

where:

NP = Net production value per day
T = part of the net production value that has been added by the undertaking

The loss of profit is calculated by multiplying the gross margin by the number of days for which the undertaking could not do business. Gross margin is gross income minus variable costs such as inputs, electricity, water and transport. Fixed costs are not taken into account. Gross margin in this case is calculated by multiplying the net production value per day by the percentage of value added.

Determination of industrial damage in Vereeniging

For the calculation of damage, the four steps proposed by Kates (1965) were followed. The flood plain was defined with the assistance of the Department of Water Affairs and Forestry (DWAF). Then all the industries on the flood plain were identified, plotted on a map and questionnaires were completed at a number of industries. In this article, the focus is on one industry. The methodology applied can, however, be extrapolated to other industries.

Calculation of direct potential industrial damage to Industry 1

One industrial complex (31.9 ha) with three separate units was identified. The works engineer of the industrial complex was interviewed and the potential flood damage was calculated based on the information supplied by the engineer.

The first step was to determine to what depth the three sites would be flooded (Table 1). To determine the depth of flooding for different sized floods, the ground-floor height of the buildings were subtracted from the flood water height, (m a.s.l.). The flood heights were obtained from cross-sections that were provided by the DWAF. Ground heights were determined by means of orthophotos.

It can be deduced from the table that a flood with a recurrence interval of 200 years will cause Unit 1 to be flooded by 2.8 m.

TABLE 1
DEPTH OF INUNDATION OF THE DIFFERENT UNITS OF INDUSTRIAL COMPLEX 1, VEREENIGING

Floodfrequency		Unit 1		Unit 2		Unit 3	
Frequency	Elevation*	Elevation**	Depth***	Elevation**	Depth ***	Elevation**	Depth ***
1:2	1420.5	-	-	-	-	-	-
1:5	1425	-	-	-	-	-	-
1:10	1426.5	-	-	-	-	-	-
1:20	1428	-	-	-	-	-	-
1:50	1429.5	1429.152	0.348	-	-	-	-
1:100	1430.5	1429.152	1.348	-	-	-	-
1:200	1432	1429.152	2.848	-	-	-	-
1:500	1433.5	1429.152	4.348	1432	1.5	-	-
1:1000	1435	1429.152	5.848	1432	3	-	-

* Metres above sea level (m a.s.l.)
** Ground-floor elevation (ground height + floor height) m a.s.l (floor height = 0.152 m)
****Depth of flooding = flood height - ground-floor elevation*

TABLE 2
TOTAL POTENTIAL DIRECT DAMAGE TO UNIT 1, 1993
(DAMAGE IN RAND, MILLION)

Components	Flood frequency in years				
	1:50	1:100	1:200	1:500	1:1000
Plant and equipment	0.0	21.0	36.8	56.0	56.0
Raw material and unfinished goods	0.0	0.3	0.5	0.5	0.5
Finished goods	0.0	0.4	0.7	0.7	0.7
Structural	0.4	1.1	1.4	3.5	3.5
Total	0.4	22.8	39.4	60.7	60.7

TABLE 3
TOTAL POTENTIAL DIRECT DAMAGE TO UNIT 2, 1993
(DAMAGE IN RAND, MILLION)

Components	Flood frequency in years				
	1:50	1:100	1:200	1:500	1:1000
Plant and equipment	0	0	0	21.0	36.8
Raw material and unfinished goods	0	0	0	0.3	0.5
Finished goods	0	0	0	0.4	0.7
Structural	0	0	0	1.1	1.4
Total	0	0	0	22.8	39.4

TABLE 4
TOTAL POTENTIAL DIRECT DAMAGE TO INDUSTRY 1 IN VEREENIGING, 1993

Flood frequency in years	Damage in Rand (million)
1:50	0.4
1:100	22.8
1:200	39.4
1:500	83.5
1:1000	100.1

TABLE 5
ESTIMATED INDIRECT DAMAGE TO INDUSTRY 1 FOR DIFFERENT PERIODS OF DISRUPTION, 1993

Period of disruption: Months	Damage in Rand (million)
1	2.8
2	5.7
3	8.5
4	11.3
5	14.2
6	**17.0**
12	34.0

Direct damage per unit

Direct damage to the components plant and equipment, raw materials, completed goods and structure was calculated for two units of the industry. After the depth of flooding had been determined, the data collected by means of the questionnaire were processed to calculate the damage for each unit. In Tables 2 and 3, damage to Units 1 and 2 is indicated for plant and equipment, raw materials and unfinished goods, finished goods and structure.

Since it was established that there would be no damage to Unit 3, within the stated frequency regime the table for Unit 3 is not shown. In order to determine total damage per flood frequency to the whole complex, the damage to the two units was added (Table 4).

It is evident from the table that a flood with a frequency of 1:100 years will cause direct damage amounting to R23 m. at 1993 prices.

Calculation of indirect damage

To place the extent of the whole complex's potential for indirect damage in perspective, it is necessary to understand the following discussion of the specific industry's markets. The industry's market consists of a 70% high-speciality segment and 30% ordinary national and international segment. The industry's share in the South African market is 50% (1993). Fifty per cent of the national and international market share can be lost if a flood disrupts the complex. This possible reduction in the market share is caused by the fact that it will take more than six months to get back into production after a flood.

Parker et al. (1987) suggest that it will take a maximum of two weeks for general clean-up, one day to one year for total machinery replacement and a few hours to six months for stock replacements. It is therefore highly likely that the figure of six months given by the respondent is reasonable. However, management found it difficult to agree on this figure, since they had no flood experience. In order to estimate the indirect damage, it was decided to calculate damage for various periods of disruption and combined it with the different flood lines.

Parker et al. (1987) recommended that loss in added value be taken as indirect damage. According to Botha (1991), added value is final demand minus imports. Industry 1 is an iron and steel industry. In this category, added value constitutes 60% of intermediary inputs (Percentage of added value as calculated from input-output table for agriculture according to subregions, Department of Regional and Land Affairs, September 1992). The value 0.60 was then taken as added value ratio for Industry 1. The turnover of Industry 1 was multiplied by 0.60, and the result then multiplied by the period of disruption in order to calculate indirect damage to Industry 1. In Table 5, the indirect damage is indicated in million Rand for different periods of disruption.

Because there is uncertainty about the time that the industry would be out of operation the following assumptions are made to estimate the indirect damage:

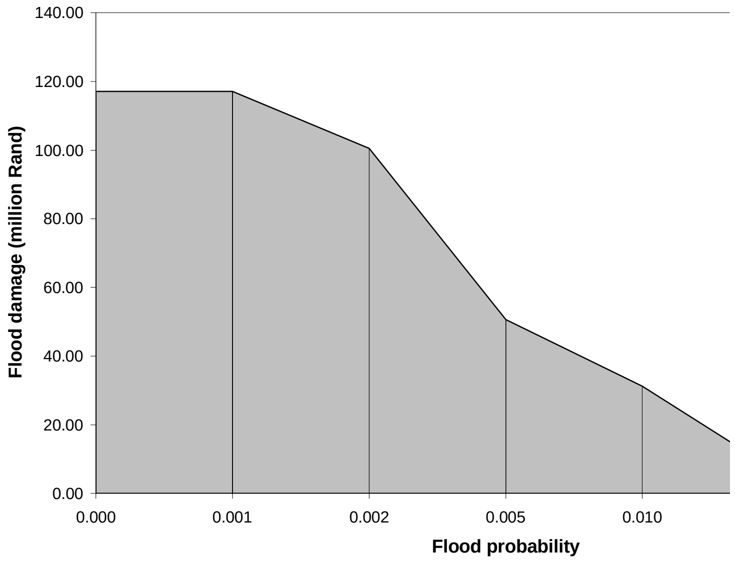

Figure 2
Estimated damage to a industry on the Vereeniging flood plain (1993)

- six months out of business when flooded by the 1:1 000 and 1:500 year floods;
- four months out of business when flooded by the 1:200 year floods;
- three months out of business when flooded by the 1:100 year floods; and
- two months out of business when flooded by the 1:50 year floods.

Mean annual damage (MAD)

In order to make choices between alternative strategies for flood-plain management, it is necessary to compare the economic and social influences of each option. For this mean annual damage was *inter alia* used. Mean annual damage is in mathematical terms the integral of the damage calculated over the study interval of flood frequency (Smith and Handmer, 1986). Hydrological data showed that only floods larger than the 1:20 year will cause flood damage and with this in mind the MAD has been calculated. Mean annual damage is estimated by calculating the area beneath the line in Fig. 2. In Fig. 2, total damage is represented against probability of flood occurrence.

The area below the line in Fig. 2 was calculated to have a value of 0.94 m., which means that the MAD for the complex amounts to R0.94 m.

Industrial flood-damage mitigation for Vereeniging

During the survey in 1993, no specific provision was made for a flood. However, sandbags were stacked during the 1974 flood and after the flood the equipment that could be raised was raised by 800 mm.

Evacuation

According to Van Vuuren (plant engineer at the site, 1993), 3% of plant value, equipment, raw materials and completed products can be removed within three days. If the industry receives a flood warning and it is decided that the completed products must be removed, this can be done at 0.44 t/h. The industry can turn out 90 t of manufactured products per week if it is functioning at 100% capacity. In 1993, the plant produced at 65% capacity. The production rate was therefore 0.65 x 90 = 58.5 t per week. This means that, if the plant contains a week's completed products, it can be removed in 5.5 d. In view of Vereeniging's warning time of 12 h, it will not be possible to remove much of the products.

Since the railway lines, on which the industry depends for transport, function on time schedules, trains may only be used at certain times. In the case of a flood warning the railway lines might be required by management for evacuation purposes, and arrangements will have to be made to use the railway line, which will delay the process further. Evacuation takes place in the following order:

- completed products and vehicles;
- semi-completed products;
- raw materials;
- machinery; and
- movable equipment.

Cleaning up

Additional labour will not be necessary for cleaning up after a flood. The plant will reschedule the labour in such a way that own labour can do the cleaning up. However, expert labour will be required to reset the acid baths (among other things, the acid content in the baths must be checked) used in the construction process. The cost involved amounts to R280 000 (1993) [35 000 x 4 x 2 (4 mills and 2 baths)].

Insurance

Whereas the government did not render any assistance during a cloudburst in 1984 at Vereeniging, insurance companies made large pay-outs. Continued insurance was granted under certain conditions. One of these conditions is that the drainage line that runs through the premises, must be inspected by the insurance company every three months, to ascertain that the stream is free of any obstructions.

Best option

In view of the high potential for damage and the extent of disruption, permanent structural flood-damage reduction meas-ures may be the best course of action to take. Two structural measures that can be considered, are flood proofing or the building of flood levees. The erection of 1m high flood proofing or the building of a 1m high flood levee can reduce the mean annual direct damage from R653 000 to R338 000. This is a reduction of R315 000 per year. In this example, costs for the erection of flood proofing were not taken into account, and further investigation is therefore necessary to determine the potential benefit-cost ratio.

Several other options for protection can also be tested. Benefits and costs of different heights of flood proofing or walls can i.e. be compared in order to determine the optimal height and composition.

Summary and conclusion

Various steps (Fig. 1) must be followed in order to determine the potential for flood-damage to industries. This includes identifying industries that are exposed to the risk of flooding, consulting hydrological maps to determine whether industries are situated on a flood plain or not and preparing a hydrological report to determine the flood elevation, and thus the depth of flooding.

For the damage component, four sets of basic information were necessary. Damage to the plant and equipment, to raw materials and unfinished goods, to finished goods and to the structure of buildings is added to determine the total damage to the undertaking. Direct as well as indirect damage was calculated for different floods. Mean annual damage was then calculated for the industry. It is evident from the MAD that as much as R0.94 m. per year could be used for flood-damage reduction options.

The research indicated that it is extremely problematic and thus not practical to draw up standard flood-damage functions for industries. Even if industries could be classified, too many differences still exist, for example, the level of technology and condition of equipment could differ within the same class. For a full investigation, it is therefore important to complete questionnaires at each industry on a flood plain. The method of processing collected data that was recommended by this article is simple, yet reliable. Procuring accurate data from questionnaires is most important.

When the MAD of the industry (R0.94 m.) is compared to an MAD of R124 000 for the flood plain of the residential area in Vereeniging (Booysen and Viljoen, 1996), it is evident that the potential for flood damage to an industrial plant is very high. For this reason, it is important that research on flood-damage prevention measures is not neglected - particularly the creation of an optimal package, which could include flood proofing of different extents, flood walls and possible insurance options. Also very important, is the most sensible pre-emptive flood management approach, viz. the need to keep industrial development out of low-lying areas.

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