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Damage assessment of lake floods: Insured damage to private property during two lake floods in Sweden 2000/2001

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ABSTRACT

This study analyses empirical data on the direct damage impact of lake floods using insurance claims for 195 private buildings. A relationship between lake water levels and insurance payments is established, but the estimated economic effects are small. Building damage also occurs in fringe areas that are not reached by surface water, which indicates a complex interplay between several factors influencing the degree of damage. Large lake floods occur over an extended time span (months). Their duration, as well as possible wind effects, should be taken into account in flood risk assessment. The slow onset of lake floods facilitates implementation of private damage-reducing measures in addition to public mitigation efforts. Private damage-reducing measures decrease the risk of structural damage to buildings, easing recovery for homeowners and society as a whole. Insurance companies can gain from investing in public flood awareness programmes and by providing information to their insurance holders on how to reduce property vulnerability in emergency situations.

1. Introduction

Northern Europe is expected to experience increasing flood implications in the future [1]. A flood is a temporary covering of land by water as a result of surface waters escaping from their normal confines or as a result of heavy precipitation [2]. Flood disasters are the result of interactions between hydrological floods and societal systems [3]. In quantitative risk assessment, risk is defined as the probability of being exposed to a flood and the expected damage [4]. Expected damage is the product of damage potential and its corresponding vulnerability, where vulnerability depends on the susceptibility of elements at risk and on property owners' ability to recognise risk and thereby to protect their property [5,4]. The degree of exposure depends on hydrological and meteorological characteristics of the water body and the weather conditions during the flood. Society's vulnerability to flood hazards has underlined the need for risk mapping and measures to mitigate the consequences of such events. Damage to buildings accounts for a considerable share of total monetary damage caused by floods [6,7]. A review of damage in the aftermath of the flooding of Elbe 2002 showed that 62% of the direct damage cost was caused by damage to buildings [8]. Knowledge about how residential areas are exposed to lake floods and their vulnerability when exposed is important in order to develop effective mitigation strategies [9].

Numerous factors are suspected to contribute to flood damage. These factors include water depth; flow velocity; duration of inundation; contamination; sediment or debris load; building construction, age, and materials; warning time and

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previous experience with flooding [10,11–13]. In addition, coastal flooding generally brings strong wave action [11]. The most frequently used approach to assess the direct costs of damage to buildings is the application of damage functions, also referred to as stage damage functions, vulnerability functions or depth damage functions [14–17,11,12,18]. Damage functions are based either upon empirical or synthetic data [19,16] and say something about the vulnerability of assets to certain flood and building characteristics [20]. Damage functions most often only consider maximum water levels as the only damage influencing factor [21]. The water level is assumed to be slow-rising, which implies that there are no hydrostatic pressure differentials between the inside and the outside of a building [22]. Extensive research on UK flood damage has resulted in several manuals (blue manual, red manual, multi-coloured manual). In addition to flood depth and land use categories, the UKs damage functions also consider flood duration. A short duration is less than 12 h, and a long duration is 12 h or more [22]. Very long flood durations (over one week) are associated with increased physical damage compared to that from a short duration [23].

The value of hazard mitigation lies in avoiding damage and loss [24]. To be able to prevent flood damage, knowledge of the potential significance of flood characteristics is needed [22]. The uncertainty in predicted flood risk to a large extent depends on the uncertainty in damage modelling and less so on the uncertainty in estimated hazard probability [25,5]. Assessment of economic consequences is constrained by limitations in available data [19]. There is no comprehensive or standardised single database for flood disasters in Europe, or a database including accurate and detailed data of the flooded areas for both recent and historical events [2]. Currently, the most comprehensive loss databases are held by insurance companies and are not publicly available [26]. Datasets of past events are a useful tool as they give an idea of possible affected areas, expected magnitude of events, their frequency and possible impacts on vulnerable elements [27].

According to a study performed by Gothmann and Reusswig [28], self-protective behaviour by residents of flood-prone urban areas can reduce monetary flood damage by 80% and reduce the need for engagement from rescue services in emergent flood risk management. Private damage-reducing measures, e.g., the building of temporary barriers, can be effective in preventing damaging water depths from reaching a building. Other measures such as moving house inventories out of the reach of the water can reduce the extent of damage even though the building may be adversely affected. Adequate and timely information distributed by authorities to inhabitants during a flood is of great importance for successful mitigation actions [29].

The objective of the study is to analyse buildings' exposure and vulnerability to lake floods using historical lake flood events and their associated insurance payments.

2. Case study – lake Vänern and lake Glafsfjorden

Extensive and prolonged flooding occurred in south Sweden from autumn 2000 until spring 2001 along Lake Vänern and Lake Glafsfjorden. Lake Glafsfjorden (94 km^2) is situated in the River Byälven catchment upstream to the large Lake Vänern (Fig. 1). A prolonged period of excessive precipitation in 2000/2001, about three times normal, substantially increased water input to the lake, exceeding its outflow capacity and causing slowly rising lake levels. Lake Glafsfjorden reached its highest level on November 29, approximately 3 m above its normal level. The municipality of Arvika, which has approximately 26,000 inhabitants, was partly flooded. An extensive emergency operation, which lasted for about a month and a half, was launched to counteract the flood impact. Temporary barriers several kilometres long were built in the central part of the town, initiated by the authorities as public measures. Apart from damage to numerous private buildings along the lakeshores, several roads had to be closed and railway traffic was cancelled for more than three weeks. The costs for the flood were estimated at SEK 315 million (2009 price levels) (34 million EUR), out of which damage to buildings amounted to approximately 28% [30]. The flooding of Lake Glafsfjorden ranks as the most severe flood in Sweden in modern times.

With its 5650 km^2, Lake Vänern is the largest lake in Sweden and the largest lake within the European Union [31]. Lake Vänern has several inflows, but the river Göta Älv is the only outflow. The Göta Älv River is ca. 93 km long and flows from the lake outlet near Vänersborg to the city of Gothenburg by the North Sea. The mean discharge to the sea is 565 $m^3\,s^{-1}$ [32]. Due to water regulation, the maximum discharge from the lake is 1030 $m^3\,s^{-1}$ [31]. The outflow is limited due to landslide risks along the densely populated river valley and the flood-prone location of the city of Gothenburg. Lake Vänern and the Göta Älv River are used for hydropower production, shipping, tourism, recreation, fishing, drinking water supply, and as recipients of waste water from municipalities and industries, etc. [31]. Seven cities are located by the lake (Fig. 1) but damage occurred in both rural and urban areas. 260,000 Inhabitants live in the municipalities bordering Lake Vänern. No effort has been made, within this study, to identify the number of inhabitants living in close vicinity to the lake and thereby having exposure to flood risk. Due to the slow dynamics of Lake Vänern, the duration of a flood is likely to be long. During the flood 2000/2001, water levels remained high for several months from November 2000 to June 2001. The lake reached its peak on the 11 January 2001, 1.3 m above its normal level, which is the highest level since the lake was regulated in 1937 [33]. The return period for a level this high has been estimated by Swedish Meteorological and Hydrological Institute (SMHI) at 100–150 years. Despite public preventive measures, many locations around the lake were affected by damage to buildings, water utility systems and roads. In particular, the impact was large on recreational facilities such as campsites, boat marinas and harbours. Approximately 2000 ha of agricultural land were flooded and forestry and fishing industries suffered damage [34].

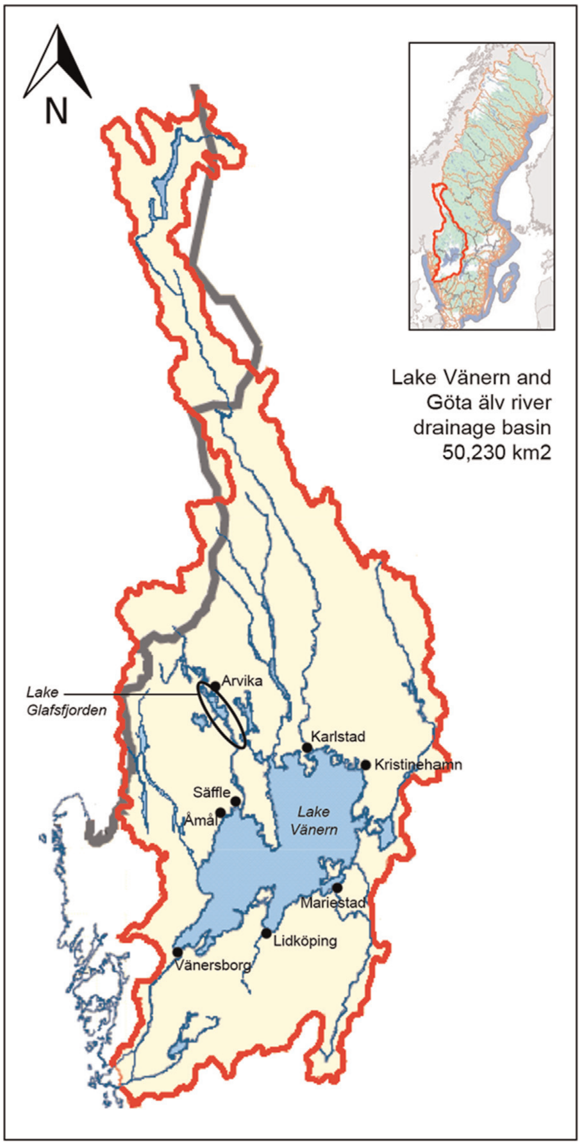

Fig. 1. Lake Vänern and Göta Älv drainage basin. Lake Glafsfjorden lies within the ellipse. The localisation of the cities exposed to flooding is shown in the map.

2.1. *Spatial and temporal incidence of flood damage*

Mainly flat areas bordering the lakes were flooded, causing damage especially on agricultural land, built areas and roads. The distribution of insurance claims for private house damage showed a concentration along the northern and northeastern parts of the lakes, in the surrounding areas of the towns of Arvika, Karlstad and Kristinehamn; however, damage was reported from the lakeshores in all areas. Areas with high relief shores or with little or no habitations lacked reported damage. A characteristic feature, especially for the Lake Vänern flood, is that there were damage costs for a large number of houses situated above the maximum flood level and thus not affected by flooding on the surface unless wind and wave effects are assumed. Damaged houses were found up to +2 m above the highest lake flood level with a few outliers on even higher ground. The long duration of the Lake Vänern event is evident from the dates for damage reports, which extend over 3 months, with some additions even several months later (Fig. 2b). Damage reports began coming in to the insurance company when the water level in the lake began rising by only small amounts; the main damage occurred before the lake reached its peak level on 11 January.

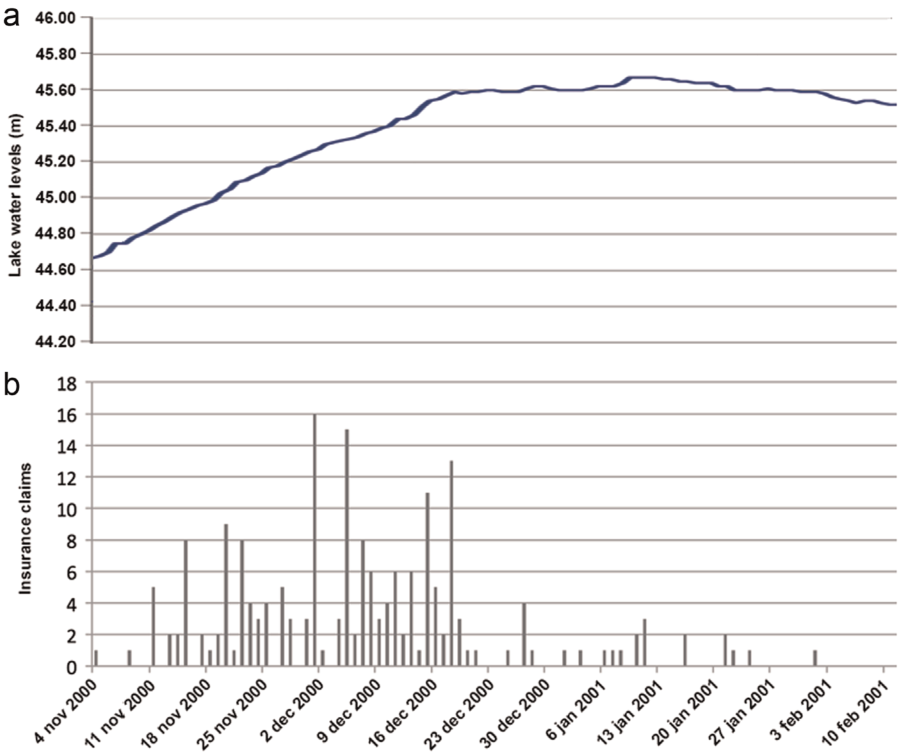

Fig. 2. The upper part of the figure (a) shows the water level rise of Lake Vänern between 4 November 2000 and 10 February 2001. The lower part of figure (b) shows the timing of damage claims from 4 November 2000 to 10 February 2001. The peak in number of claims during November is due to the Lake Glafsfjorden flood, which preceded the Lake Vänern flood.

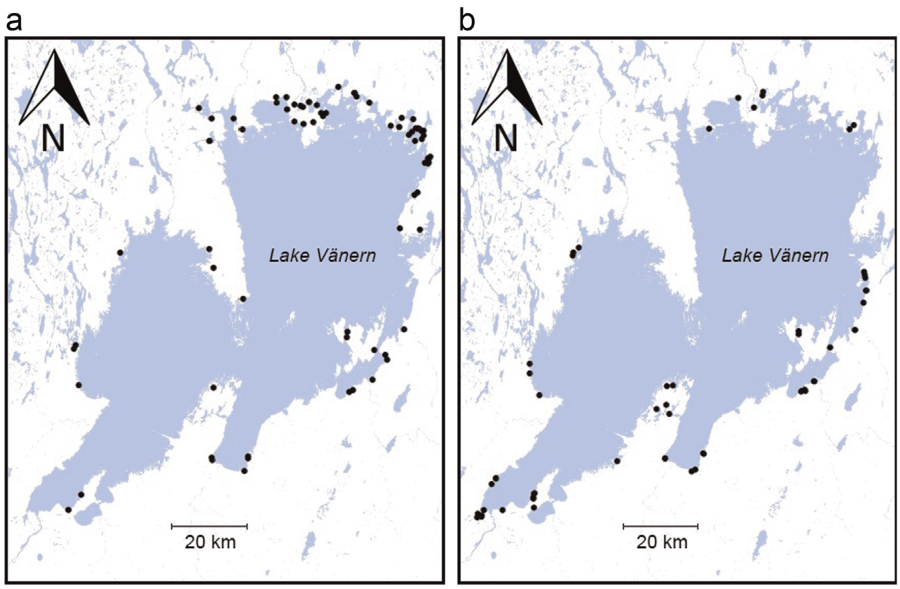

Fig. 3. Damage claims reported before (a) and after (b) 13 December 2000. The flood damage shifted from north to south along the lake during the prolonged event and was possibly dependent on shifts in wind direction.

2.2. Meteorological (wind) incidence of flood damage

Prevailing southerly winds that characterised the early, rising phase of the flood of Lake Vänern were associated with damage, especially along the northern shores (Fig. 3a). In late December 2000, and later in the winter months of 2001, winds changed to more northerly directions, and damage was then reported mainly from the southern part of the lake basin

Table 1
Description of the factors used in the regression analysis of lake flood damage impact (SEK 2001 year price level).

Variable	Description	Obs	Mean	Std. Dev.	Min	Max
Insurance payments (SEK) total	The amount paid to insurance holders	195	53,100	97,188	125	580,668
Insurance payment Detached houses	The amount paid to insurance holders	57	28,203	34,869	143	140,360
Insurance payments Holiday houses	The amount paid to insurance holders	69	89,409	146,373	1000	580,668
Water level (cm) (water depth)	Estimated max water above ground at damaged object	195	27	39	0	140
Distance to water front (m)	Estimated distance between damaged object and lake at max levels	195	11.2	26.1	0	200
Pre-war building	0=After 1945 1=1945 or earlier	132	.36	.48	0	1
Floors	0=One floor 1=More than one floor	195	.16	.37	0	1
Damage-reducing measures	0=No private measures 1=Private measures	195	.43	.50	0	1
Duration (w)	Estimated duration in weeks	195	3.04	6.02	0	27
Building damage	0=No building damage 1=Building damage	195	.6	.49	0	1

Table 2
Regression analysis using a Probit model. Dependent variable: structural damage to buildings. Standard errors in brackets.

Water level	Distance to water front	Estimated duration	Number of floors	Damage-reducing measures	Intercept	*N*
.013*** (.004)	−.002 (.004)	−.003 (.017)	−.212 (.279)	−1.043***(.202)	.503** (.179)	*195*

*** $P<0.001$.
** $P<0.01$.

Table 3
Linear multiple regression analysis. Dependent variable: insurance payments, robust standard errors in brackets.

Explanatory variable	Full sample (1A)	Detached houses (1B)	Holiday houses (1C)	Full sample (2A)	Detached houses (2B)	Holiday houses (2C)
Intercept	8.024*** (.246)	8.004*** (.384)	7.665*** (.290)	8.447*** (.23)	8.737*** (.636)	7.917*** (.373)
Water level	.006* (.003)	−.013 (.012)	.011** (.005)	.005 (.003)	−.004 (.013)	.009 (.006)
Distance	−.019*** (.004)	−.024*** (.005)	−.006 (.005)	−.024*** (.005)	−.026*** (.005)	.422 (.012)
Duration	.03 (.018)	.156* (.070)	−.000 (.028)	.014 (.026)	.114 (.072)	−.016 (.04)
Damage to buildings	1.983*** (.228)	2.216*** (.367)	2.505*** (.344)	1.795*** (.277)	1.786** (.489)	2.541*** (.444)
Pre-war				−.736** (.259)	−.728* (.348)	−.565 (.612)
Floors	.567* (.251)	.705* (.34)	.452 (.635)	.785** (.288)	.897* (.423)	.118 (.468)
Damage reduction	.773*** (.213)	.91* (.36)	1.34*** (.295)	.875*** (.253)	.576 (.536)	1.396*** (.313)
N	195	57	69	132	39	47
Adjusted R^2	.3890	.5518	.5297	.4402	.5474	.4795

*** $P<0.001$.
** $P<0.01$.
* $P<0.05$.

(Fig. 3b). The concentration of damage claims in the northern part of Lake Vänern is partly a consequence of this area being the most populated, with a higher number of recreational buildings in exposed locations along the shores. There was a low occurrence of westerly winds during the flood event and just a few damage cases along the eastern shore were reported for winds from this direction. Strong wind speeds occurred only during brief periods, mainly northerly winds exceeding 10 m/s. In particular, a local high water level associated with northerly winds was recorded in the southern part of the lake on February 1, 2001, temporarily topping the recorded maximum level of the lake by approximately 0.3 m [33]. On that occasion, strong wave impact may have contributed to increased flood damage.

3. Material and methods

3.1. Available data and data compilation

Information on lake levels was compiled in GIS using data obtained from Arvika municipality regarding Lake Glafsfjorden and from the Swedish Meteorological and Hydrological Institute (SMHI) for Lake Vänern. The data from SMHI also contained data on wind conditions. Elevation data for affected shore areas were extracted from the Swedish National Elevation Database. The data consisted of a grid of 2 m cell size with a vertical accuracy of approximately 5–20 cm. No consideration was made for the possible influence of minor depressions, dikes, and road culverts that were not already represented in the elevation data. Damage data were provided by Länsförsäkringar, Sweden's largest insurance group holding approximately 30% of the national home insurance market. There can be regional differences deviating from this rate, for example in Arvika, where Länsförsäkringar holds approximately 40% of the home insurance market. In Sweden, flood damage to residential property is covered by basic home insurance. The insurance covers damage inflicted upon building structures, inventory and other movables, damage inspection, cost of cleaning and drying out buildings, costs of private damage-reducing measures and under special circumstances non-structural damage to property, e.g., damage to lawns and gardens caused by damage-reducing measures. At present there are no special demands on policyholders related to risk reducing efforts that can affect the conditions for receiving refunds, other than the general request for carefulness and to following guidelines concerning water utility systems. No active choice has to be made to include flood insurance in a person's home insurance and, at present, the price of the policy is not connected to the actual flood risk in a specific area and no insurance holder is refused inclusion of flood insurance in their home insurance. The initial insurance data that were available cover 30–40% of the market, suggesting that flood impact upon property is more extensive than revealed by these data. To validate the representativeness of the collected insurance information, the estimated aggregated insurance payments were used to estimate the insurance amount paid by another Swedish insurance company and then compared to the sum of actual insurance claims paid by that company. Estimated aggregated cost corresponded very well to actual aggregated cost, which leads us to accept that data from the company Länsförsäkringar is representative for the Swedish home insurance market.

The damage data from the insurance company contain information about the individual insurance amounts paid to insurance holders, the date the damage occurred, if the damage concerned residential or holiday property and if the claim concerned private measures, damage to buildings, inventories or a combination of these. Concerning spatial resolution the insurance company provided information concerning municipality within which damage occurred but did not have information on the exact location of the flood damaged property. There was also large diversion on the detail level of the flood damage documentation in the insurance reports which could be back traced to the effort of the individual insurance adjuster.

Object characteristics, in this case, building characteristics, can influence objects' vulnerability to flooding. As the objective of the study is to analyse lake flooding exposure and the vulnerability of private property to lake flooding, data on micro level are needed. An accurate geographic location and the presence of private measures potentially affecting exposure (water level) or vulnerability (damage) is essential to know. Due to incomplete information on exact location, damage-reducing measures, age of building and the number of floors, telephone interviews were carried out directly with the afflicted policyholders. Because of the time elapsed since the event (12 years), some house owners had only vague recollections of specific characteristics of the flood and the flood damage. Some insurance holders could not be reached due to lack of current contact information and some had passed away. The step to link the reported insurance payments with the GIS layer for buildings was not as straightforward as anticipated and some cases could not be localised with certainty. Out of the 427 observations on individual insurance claims initially provided by the insurance company, a dataset of 195 observations contained enough information to undertake further analysis of property exposure and vulnerability to lake floods. A hypothesis to be tested is that private damage-reducing measures, lake water levels, flood duration, distance to lake water, number of floors and a building coming from the pre-war era affect the probability of buildings experiencing structural damage. To test weather lake water levels further, flood duration, distance to lake water, number of floors in buildings, buildings coming from the pre-war era and structural damage affect the size of insurance payments.

3.2. Methods

Beyond GIS analysis, econometric methods are used to analyse private property's exposure and vulnerability to lake flooding. Regression analyses are used to test the statistical significance of suspected explanatory variables with regard to the marginal changes in insurance payments and occurrence of structural building damage. The criterion of the sample is that the included observations were subject to high water levels in one of the two lakes Vänern and Glafsfjorden in 2000 and 2001. The analysis is conditional upon flood damage occurring and payment being made from the insurance company to insurance holders.

A Probit regression model is a regression model for binary dependent variables using the normal distribution to estimate the probability of a certain outcome and what effect individual predictive variables have on that probability. In this study, the Probit model is used to analyse the dependency of building damage upon flood characteristics, geographical factors and structural building characteristics. The dependent variable *building damage* is a binary variable, taking on the value 1 if the insurance payments include a refund for structural building damage and 0 if there is no presence of building damage.

The relationship between insurance payments and the variables possibly affecting the size of insurance payment on buildings is estimated using a linear multiple regression model. The dependent variable, insurance payment, is non-linear and has therefore been transformed to linearity by using the natural logarithm (ln). In samples where there are large differences in size among observations, which is the case for this sample, heteroscedasticity can occur. Heteroscedasticity means that observations within a random sample do not have the same variance. In the presence of heteroscedasticity, the regression analysis produces unbiased estimates but biased standard error (SE), which further can lead to biased inference. Standard errors in a regression analysis are an estimate of how far the sample mean is likely to deviate from the population mean and the size of standard errors affect whether a hypothesis is rejected. To compensate for heteroscedasticity, Whites heteroscedasticity-consistent standard errors (HCE) are used in the linear regression analysis. Using HCE, the point estimates of the coefficients are exactly the same as in ordinary least squares (OLS), but the standard errors take into account issues concerning heteroscedasticity [35].

Insurance payments are tested for differences in mean values using a two-sided *t*-test (using *t*-distribution) with regard to whether the claims concern compensation for detached houses or holiday houses. To be able to conclude upon estimations of individual coefficients the explanatory variables must be independent of each other. Multicollinearity is when two or more explanatory variables are highly correlated. To check for multicollinearity in the multiple regression analysis, the variance inflation factor (VIF) is used. VIF shows how the variance of an estimator is inflated by the presence of multicollinearity and is a measure of how strong the linear relationships are between the explanatory variables [35]. Low values indicate low interdependencies. Values higher than 10 require further investigation.

Two models are tested. Model (1) includes the estimated water level at the location of occurred damage, distance to surface water, duration time for the flood at the location of damage, whether the building has more than one floor, structural damage to the building and whether the property owner took any damage-reducing measures. Model (2) includes the same predictive variables as model (1) but also includes a dummy variable for pre-war buildings. Information on the age of buildings is not complete for the full sample. Due to the small number of observations in the sample the regression function is estimated both with (model1) and without (model 2) the pre-war variable. The models are first run on the full sample (A), including detached houses, holiday houses, garages and other outbuildings. The model is then run on two sub-samples, (B) including only detached houses or (C) including only holiday houses. The distributions of the predictive variables are presented in Table 2.

Adjusted R2 values are used as a measure of goodness of fit to quantify how much of the total variation in insurance payments can be explained by the model. Adjusted R2 values take into account the number of predictors in the model and are seen by many as the appropriate measure when the sample is considered to be small in relation to the number of explanatory variables included in the model [35].

4. Results

Descriptive statistics of variables are displayed in Table 2. 60 Per cent of the insurance claims in the study concerned structural damage to buildings. Private damage-reducing measures were carried out for 43% of all property in the case study area. In Table 1, the result of the Probit regression is shown. Changes in spatial, temporal or building characteristics do not have statistically significant effects on the probability of suffering structural building damage. Changes in water level increase the probability of damage while private damage-reducing actions decrease the probability of damage. Calculating the individual marginal effects of water level and damage-reducing measures, using the mean values of other variables, shows that a marginal change in the water level increases the probability by 0.4% and that private damage-reducing actions decrease the probability by 38.5%. Despite both variables being highly statistically significant, only damage-reducing measures have a highly significant practical effect. Damage-reducing measures in this study are the private initiative of property owners to build barriers, hire or buy water pumps, hire transport and storage for movable inventory, artificial elevation of buildings or a combination of two or more of the these measures. Some insurance reports explicitly state that private initiatives such as construction of barriers and other measures managed to avoid flooding of afflicted buildings.

The descriptive statistics in Table 2 show suspiciously differentiated mean values for insurance payments whether it concerns the full sample, detached houses or holiday houses. A test of the mean values shows that holiday houses and detached houses might not belong to the same population. To take this into account and to further improve the regression model, the sample insurance payments are also analysed in two subgroups, insurance payments for detached houses and insurance payments for holiday houses. Adjusted R^2 values for the subsample are higher than for the full sample, indicating a better fit of the regression model; however, it also results in small samples giving high impact to every individual observation in the sample (see Table 3). 43 Per cent of the observations in the sample occurred in a fringe area never reached by surface water. Damage costs in fringe areas were lower than in exposed flooded locations, but contributed to raising the overall costs of the events, not so much in the case of Lake Glafsfjorden which has comparatively steep shores, but with about one fourth of the total costs of the Lake Vänern flood.

The results of the multiple linear regressions are summarised in Table 3. Estimated water depths at the location of damaged objects range between 0 cm and 140 cm. The mean value of water depth was 27 cm. The low mean value can partly be explained by 43% of the objects never being reached by surface water. Lake water levels are statistically significant only in 1A (full sample) and 1C (only holiday houses). A one-unit increase in lake water level (cm) will lead to an increase in insurance payments of 0.6% and 1.1% for the full sample and for holiday hoses, respectively, keeping all other variables constant.

The distance between objects and the water front ranges from 0 m to 200 m. The mean distance for objects where 11 m. Distance has a significant effect in all groups except for 1C and 2C (holiday houses). The size of insurances claims decreases with 1.9–2.6% when distance to lake water increases with one unit (m). The effect is highest for detached houses.

The duration of the floods ranged from 0 weeks up to 27 weeks, with a mean duration at 3 weeks. Duration is statistically significant only in subgroup 1B (detached houses). When the duration of the flood increases by one unit (week) the size of the mean insurance payment increases by 16.9%.

36 Per cent of the damaged objects where built in 1945 or earlier and are henceforth referred to as pre-war buildings. The pre-war variable is significant in the full sample and for detached houses but not for holiday houses. Buildings built prior to the end of World War II cause 52% lower mean insurance payments compared to that of post-war buildings.

Out of 63 detached houses, 31 had basements, 15 had no basement and for 17 houses information was lacking. Overall, only 16% of the buildings in the sample consisted of more than one floor. Having more than one floor is statistically significant for all groups except for those containing only holiday houses. The holiday houses in the samples generally consist of only one floor. Having more than one floor is related to increasing insurance payments between 76% and 145%, keeping all other variables constant, with the largest effects in the sub-samples containing only detached houses (1B, 2B)

Of all of the predictors in the regression analyses, the presence of structural building damage is the strongest driver for the size of insurance payments and highly positively significant in all groups, increasing mean insurance payments between 626% and 1124%, depending on sub-group, keeping all other variables constant. Damage-reducing measure also has significant effects in all groups except 2B. Because costs related to these measures are refundable by the insurance company, they affect the mean insurance payments positively. The effect is not nearly as large as for building damage and damage-reducing measures lower the probability of suffering building damage. Overall, 43% of the objects were subject to one or several private damage-reducing measures and 60% of all afflicted objects experienced structural building damage.

5. Discussion

To our knowledge, the underlying factors explaining the cost of insured damage to buildings have never been statistically tested based on observations of lake floods. As previously mentioned, damage functions used to estimate costs of damage to buildings caused by flooding are mostly depth damage functions [11,16,10]. These functions presume a dependency of the magnitude of damage costs upon water levels inside a building. Data presented in the previous section reveal only a weak economic relationship between damage costs and lake water levels, which can be explained by the fact that many buildings with topographic locations implying deep inundation depths had surprisingly small insurance payments. The large extent of a fringe area, with damage to buildings located up to at least 2 m above the peak flood water level, was obvious during the lake floods, particularly for Lake Vänern.

Damage may increase due to longer duration of inundation, influencing building structures and materials, which are resistant to a more short-lived inundation. In established UK flood research, long duration is considered to be more than 12 h [22]. In the work of Green et al. [23], long duration is more than one week. In contrast, large lake floods can last for months but at the same time, the gradual rise of lake water levels allows for damage-reducing measures to be taken. In this study, the duration of the floods had an effect on insurance payments only for detached houses, which indicates that prolonged exposure to water causes more severe damage than floods with a shorter time span. Floods in large lakes are characterised by long duration, soaking the ground, making buildings vulnerable to water penetration through ground and pipes and more sensitive to rainfall during flooding because the ground is already saturated and not able to absorb more water. Detached houses are to a larger extent situated in fringe areas. This can be a possible explanation as to why the duration of a flood has more effect on detached houses than for other buildings in the sample.

In large lakes, wind can cause a wave effect which can lead to temporary flooding of objects that are not reached by documented lake water levels. The importance of wind and wave action was mentioned in some of the insurance reports. Wind effects may potentially raise the water surface of Lake Vänern by slightly less than 1 m [36]. No statistical analysis of wind occurrence or the effect of wind direction was made, partly because the sub-samples would become very small.

Building characteristics were problematic to analyse. The categories ‘buildings with basement’ and ‘buildings with furnished basement’ were of interest to analyse but left out due to incomplete information. Buildings with basements can be more susceptible to water penetration through ground and pipes and furnished basements may hold high insurable values. Furnished basements are known to have higher damage than unfurnished basements, which are known to have higher damage than buildings with no basement [37]. It was not possible to explicitly analyse damage costs for these categories, instead they are included in the dummy variable “more than one floor”. The presence of basement should, in an applied risk analysis, be taken into account.

The variable of having more than one floor increases the mean insurance payment. This indicates that buildings having more than one floor are more vulnerable than single-storey houses to lake flooding. The expected result was that buildings with more than one floor would have lower damage costs due to the opportunity of moving inventories at risk away from the flooded parts of the house [38]. Interviews and insurance records document that property owners in some cases moved their inventory to safe places, e.g., external warehouses if a location on the own property was not an option. If there exists an advantage of having more than one storey, it could not be detected within this study. A possibility is that the advantage is outweighed by the cost of restoring damage to a possibly larger house with higher loss potential.

Repeating the analysis, by using a dummy variable for pre-war buildings, leads to smaller samples, which affect estimated coefficients and significance levels somewhat. This is an indication of how sensitive the estimates are to the further reduction of observations with large variance in small sample sizes. The fact that pre-war buildings are less susceptible to flooding than buildings constructed later may be explained by differences in construction styles and methods concerning location, building material, floor levels and presence of basements for pre-war versus post-war buildings. The era of construction being significant is supported by a Norwegian study, Hydra [37], which finds that mean damage cost for post-war houses are higher.

Concerning building characteristics, more information on building type, i.e., whether a building has a timber frame or whether it is a concrete building, would have been desirable, but this information was not available. Detailed information on the circumstances at each damaged building would do much to enhance research possibilities on factors involved in flood damage [39,12]. Restrictions in data availability have been a great difficulty within these studies and have limited the possibilities of otherwise promising, valuable and rare insights into a private insurance company's records.

Insurance payments where a building with structural damage needed restoring are considerably higher than for other damage. Other costs are compensation for damaged inventories, for drying and cleaning up during and after the flood, damage inspection and for private damage-reducing measures. Private measures are refundable by the insurance companies and despite reducing the risk of substantial damage, they do add to the insurance payment. Measures are sometimes not sufficiently effective in avoiding damage, leading to an insurance refund both for structural damage and for damage-reducing actions. The insurance payments were higher for houses where measures had been taken but where structural damage still occurred than for houses with no measures taken. This can be explained by a location effect because damage-reducing measures are more likely for the most threatened houses. Compensation for measures is lower than payments concerning structural damage where no measures were taken. This should incite insurance companies to educate their insurance adjusters on the importance of giving advice on private damage-reducing measures according to local conditions. To further promote private measures, the insurance company can offer favourable insurance solutions to customers who on their own initiative implement precautionary measures that decreases flood risk. The benefits of avoiding structural damage are higher than what can be detected by the insurance payments. Structural damage implies a burden to the property owner not only in terms of restoration costs, but the strain put upon the property owner by the perceived stress during a crisis situation and in the aftermath due to the effort, time and economic worries related to restoration, which infringes upon leisure time and everyday life.

6. Conclusions

The GIS analysis implied that wind effects can affect the timing and magnitude of damage. Whereas wind effects can normally be omitted from river flood models, they should not be ignored for damage modelling of large lake floods. The use of wind climate data could be a possible approach to improve the estimation of flood risk for wind-exposed shores.

Forty-three per cent of all damaged objects were located in fringe areas of the lakes. In these areas, damage might depend on a different set of predictors than for buildings in the near vicinity of the lake. Based on the results of this study, lake water levels are not recommended as a proxy for in-house water levels and should not be used in depth damage functions derived with in-house water levels. Buildings located in the immediate vicinity of the lakes, holiday houses and, to some extent, outbuildings are more directly affected by marginal changes in lake levels but even here lake water levels in predictive purposes should be used with caution.

The lake floods in Sweden in 2000/2001 lasted for several months. The duration of a flood was found to increase the size of insurance payments for detached houses, which to a large extent are located in fringe areas. At the same time, slow rising water levels enabled implementation of private damage-reducing measures, which lowers the probability of extensive building damage.

Apart from water depth, damage assessment of lake floods needs to especially consider flood duration, wind and wave impact and the size of a potential fringe damage zone. The vulnerability of buildings in the fringe area should be more thoroughly analysed. Research efforts are also needed to derive more detailed and reliable information on building characteristics, damage and meteorological and geographical data that are needed to explain variability in damage costs and further on how to integrate private damage-reducing measures into risk analysis and damage assessments.

Insurance companies can gain from investing in public flood awareness programmes and by providing information to their insurance holders on how to reduce property vulnerability in emergency situations.

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