Estimates of Regional Losses in Case of a Repeat of the 1356 Basel Earthquake

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Summary

The losses we estimated are defined as average damage to buildings for all settlements affected (intensity equal to and larger than V on the modified Mercalli scale), number of injured and number of fatalities. These estimates are approximate and preliminary. The newest information on the resistance of the building stock to shaking has not been included. The results in which we have most confidence are the ratio of human losses within the city of Basel to that outside of it, because any errors in the absolute values of the loss estimates tend to cancel. For a repeat of the 1356 earthquake with assumed magnitude of 6.9 and three possible epicenters (distances 6, 10, and 15 km from Basel), we calculated that the countryside would sustain 2 to 4 times the number of human losses than the city itself. In cases of smaller earthquakes (M6.5 and 6.0), at the same distances from Basel, the countryside will sustain 2 to 16 times the losses of the city. With the current population, the number of fatalities is expected to lie in the range of 6,000 to 22,000 for M6.9, 1,700 to 8,400 for an M6.5, and 160 to 1,400 for an M6.0. However, these values should be taken as preliminary, pending recalculation with recent information on building stock properties. Our preliminary estimates suggest that the number of persons requiring hospitalization may range from 6,000 to 8,000 in case of an M6.9, from 2,300 to 4,500 in case of an M6.5, and from 350 to 1,000, in case of an M6.0 earthquake. The portion of losses sustained by the neighboring countries, France and Germany are estimated to range from 0% to 5% of the total losses, strongly depending on the selected epicenter and magnitude.

Introduction

In this report, the expression "loss estimates" means approximate calculations of average building damage, number of fatalities and injured, by community. We were asked to estimate losses for the case of a repeat of the 1356 Basel earthquake [*Lambert, et al.*, 2005; *Mayer-Rosa and Cadiot*, 1979]. We agreed to undertake this work, although we are ill prepared for it. Our experience centers on loss estimates in developing countries, and our method is approximate: In daily practice of loss estimates immediately after earthquakes worldwide [*Wyss*, 2004], we simply need to determine whether or not an earthquake has caused a disaster. This is a less ambitious aim than to estimate the approximate extent of a future disaster.

In the case of the Kashmir M7.6 earthquake of October 2005, the prediction of losses to be expected in that region published six months earlier [*Wyss*, 2005] was correct within a factor of 2, approximately [*Wyss*, 2006]. This accuracy is sufficient for preparing for future disasters and for triggering rescue operations. This example shows that attempts of predicting future losses can be useful.

The most significant contribution we may be able to make in the present case is to compare the extent of the regional losses, to those in the city of Basel. There is a strong need for a regional loss analysis because, to our knowledge, no one has done this. Other efforts to estimate the risk due to a repeat of the 1356 earthquake [*Faeh, et al.*, 2001; *Oprsal, et al.*, 2005], or of a similar event in the region, have concentrated with good reason on the largest city to be affected: Basel. However, in densely populated Switzerland, the sum of the losses in medium-size and small settlements may not be neglected. We are uniquely prepared to estimate the sum of the regional losses because this is the approach we use in case of large earthquakes in developing countries.

Negative aspects of the loss-estimating tool for this job, QUAKELOSS, are the following. (1) The tool is calibrated for regions where large earthquakes are frequent. Switzerland had no recent earthquakes that might serve as calibration events of comparable magnitude. The 1356 event is of limited use for calibration, as epicenter location and magnitude are uncertain, and a good description of the effects is available only for the city of Basel. (2) We do not use information on site amplification in our current database. Microzonation and site amplification maps are available for parts of the region, but they are derived from theoretical models or earthquakes with much smaller magnitudes [*Faeh, et al.*, 1997; *Kind*, 2002; *Noack, et al.*, 1997]. (3) The information on the quality of the building stock is approximate. (4) A community is modeled as located in one point at the center of it.

Positive aspects of QUAKELOSS for the job at hand are the following. (A) It calculates losses approximately correctly for Italy, a neighboring country in which building stock characteristics vary moderately from those in Switzerland, and where recent events provide calibration. (B) QUAKELOSS calculates the strong shaking and the losses at all settlements in the vicinity of the earthquake, allowing an estimate of the regional losses, and an estimate of the relative importance of the major city, Basel.

Several paleoseismic studies have identified seismically active faults to the SW of Basel and determined their approximate time of activity [*Becker, et al.*, 2002; *Ferry, et al.*, 2005; *Lacave, et al.*, 2004; *Lemeille, et al.*, 1999; *Meghraoui, et al.*, 2001; *Schuerch and Becker*, 2005]. In addition, in geomorphologic studies the amount of strong ground motion in the region surrounding Basel was estimated for past centuries and millennia [*Becker and Davenport*, 2003; *Becker, et al.*, 2002; *Lacave, et al.*, 2004; *Schuerch and Becker*, 2005]. The consensus is that the 1356 earthquake occurred somewhere south or south-west of Basel. For this reason, we place our scenario epicenter in this area.

Input parameters

The source parameters of the hypothetical repeat earthquakes were taken from the website of the Swiss Seismological Service: Latitude 47.47N, longitude 7.6E, depth 12 km and M 6.9. This epicenter is located 10 km from the center of Basel. Because the historic epicenter, as well as the extent of the rupture, is not accurately known, we also estimated losses using two additional possible epicenters: 47.5N/7.6E (at 6 km distance), and 47.42N/7.56E (at 15 km distance) (Table 1).

Scenario	M	Lat. (deg)	Lon. (deg)	Depth (km)	Distance (km)	Hour	Settl. (V)	Settl (VII)
1	6.9	47.50	7.60	12	6	21	1100	320
2	6.9	47.47	7.60	12	10	21	1150	380
3	6.9	47.42	7.56	12	15	21	1200	400
4	6.5	47.50	7.60	12	6	21	680	170
5	6.5	47.42	7.56	12	15	21	733	230
6	6.0	47.50	7.60	12	6	21	370	90
7	6.0	47.42	7.56	12	15	21	370	60

Table 1: Source parameters for the earthquakes assumed in different scenarios and the number of Swiss settlements affected (intensity V and larger), as well as the number of settlements in the region where casualties are expected (intensity VII and larger). The distance from the city of Basel and the assume hour of day are also listed.

The dataset for settlements in Switzerland was augmented above the level of detail that exists in the worldwide database of QUAKELOSS. The population numbers for Swiss settlements are those published by the Swiss Amt fuer Statistik for the 2002 census. For Germany and France the default data in QUAKELOSS's database were used. This means that the losses for Germany and France are likely to be underestimated. Considering that our focus is on the Swiss losses, this shortcoming is acceptable.

The building stock properties are those routinely used in QUAKELOSS for central Europe. To introduce new fragility curves for the region of northwestern Switzerland would go beyond the scope of this approximate study.

Local amplification of strong motion due to soil and topographical conditions, as well as the attenuation function of seismic waves are important factors influencing the degree of damage. For the city of Basel, local amplification factors have been evaluated based on microzonation studies [*Kind*, 2002; *Noack, et al.*, 1997]. However, this information is not available for any of the other cities and towns in the region. The current version of QUAKELOSS does not provide opportunity for input of microzonation data with sub-settlement resolution. For this reason, and because amplification for the majority of the settlements is not known, we made no specific input for local amplification of strong ground motion. By this decision we follow the principle of averaging that is all-important for success in our approximate method estimating losses worldwide: In the applications QUAKELOSS has been designed for, the unknown amplification factors average out because the number of settlements shaken range from 100 to 4,000, and the population numbers range from 0.5 to 10 million.

For attenuation, there exists a model valid for Switzerland (ECOS) for distances shorter than about 200 km [*Fäh, et al.*, 2003]. The database of QUAKELOSS contains a number of attenuation functions, including one for central Europe. The attenuation used for a calculation can be changed by the operator of the program. For this study, we selected a function based on [*Shebalin*, 1968] with the following parameters.

$$I(r) = bM - v \lg \sqrt{(r^2 + h^2)} + c$$

where the constants used are *c*=1.5, *v*=4.5 and *c*=3.6. *M* signifies magnitude, r is the epicentral distance and *h* stands for hypocentral depth. This parameterization reflects well the intensity levels and attenuation behavior known from the 1356 event. In this way, we matched correctly the intensities of shaking observed in Basel in 1356, near the epicenter and in Bern at the periphery of the region sustaining slight damage. Thus, we can be confident that the overall pattern of the strong motions in this hypothetical calculation is approximately correct.

Method

Estimating losses in likely future earthquakes is based on experience with historic earthquakes. As a first step, we assume an earthquake with the parameters of a historic earthquake will occur again. The source parameters of the 1356 Basel earthquake are those in scenario 2 (Table 1). In a second step, the computer program QUAKELOSS calculates the intensity of the ground motion at the locations of all settlements in the database.

The characteristics of the building stock are defined in the database. For each settlement, a distribution of percentages of buildings into the classic building classes is assumed. For each of the building classes, a fragility curve is given. These data contain the probability of a certain level of damage (for example collapse) as a function of the ground motion intensity. Thus, in the second step the damage to buildings is calculated, by estimating the percentage of buildings that fall into five damage classes, as a consequence of the strong ground motion. From this distribution, an average damage state is calculated for each settlement and displayed by a color code on a map (e.g. Figure 1).

In a third step, the human losses (number of fatalities and injured) is estimated by equations that govern the probability that a person in a building with a given damage state(for example collapse) is killed, injured or walks out unscathed, respectively. Finally, the results are modified, taking into account the percentage of people indoors versus outdoors, as a function of the hour of day. The steps in this method are explained in detail by [*Shakhramanian, et al.*, 2000].

The success of this approximate approach practiced for loss estimates in developing countries, where little information on all necessary input parameters exist, depends on two elements: averaging and calibration. When thousands of settlements are affected by a large earthquake, differences in ground motions due to local soil and building stock conditions tend to average out, and calibrating the results of QUAKELOSS for countries where damaging earthquakes are frequent insures that the results are approximately correct, for these countries.

Results

An overall impression of the effect that an M6.9 earthquake near Basel is likely to have is demonstrated by the map of average damage in settlements in the region (Figure 1). In this scenario calculation (scenario 2, Table 1), we find that the number of affected Swiss settlements is 1,150. The expression “affected” means a minimum of slight damage (intensity

V) is expected. Approximately 3.3 million people live in these Swiss settlements. The people in the three affected countries living in the area defined as “affected” are estimated to number about 5.5 million.

The zone in which fatalities and injuries are likely are those of intensities VII and larger. The number of Swiss settlements in these zones is about 380, and their population is roughly 0.5 million. 99% of the fatalities are expected to occur in this zone.

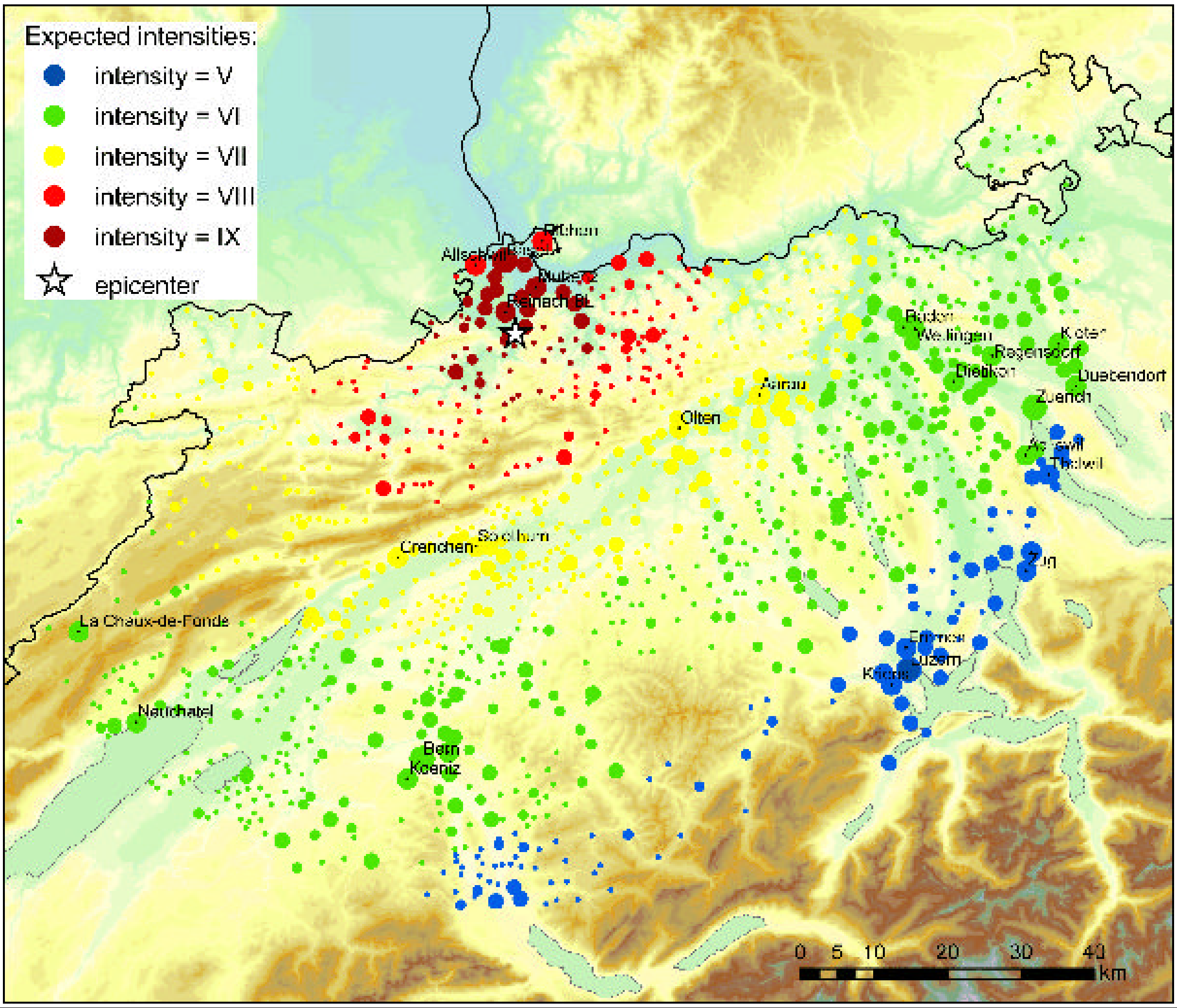

Figure 1: Map of estimated intensity on the modified Mercalli scale in case of a repeat of the 1356 M6.9 earthquake near Basel. The size of dots is proportional to the population. Most fatalities and injuries are expected in the areas where settlements are shown in brown and red, where heavy damage would be expected. Some fatalities would occur in the area of yellow settlements, none in the green and blue ones. The settlements marked by green dots would experience moderate damage, those with blue dots only slight damage. The settlements in France and Germany are not shown because for these countries, the worldwide database in QUAKELOSS has not been augmented as it has been for Switzerland. The parameters of the attenuation function are selected such that the intensities observed in 1356 are modeled approximately correctly.

The epicenter assumed for the calculation yielding Figure 1 is located at 10 km distance form the center of the city of Basel (Table 1). Neither the historic nor the possible future epicenters are accurately known. Therefore, scenarios using a magnitude of 6.9 with the three epicenters at distances of 6, 10 and 15 km (Table 1) were calculated. The attenuation function was adjusted such that the intensity in Basel city reached 8.8 for scenario 2, modeling the known soil amplification and adapting the result to the observed macroseismic intensities of the 1356 event in a way that is consistent with the findings of [*Gisler*, *et al.*, 2007] stating an intensity of (VIII-) IX for the city of Basel. All scenarios are calculated with the same model of combining attenuation and amplification effects.

Scenario	Location	Mag.	Fat(min)	Fat(max)	Inj(min)	Inj(max)	Percent	Factor
1	Europe	6.9	12,000	23,000	25,000	42,000		
	Swiss		10,800	22,000	23,000	36,000	100	
	Basel		4,000	8,000	8,000	12,000	36	
	Swiss no Basel		6,800	14,000	15,000	24,000	64	1.8
2	Europe	6.9	9000	18000	18000	32000		
	Swiss		8500	17000	13000	23000	100	
	Basel		2300	4800	5000	9000	28	
	Swiss no Basel		6100	12300	8000	14000	72	2.6
3	Europe	6.9	6000	12300	13000	27000		
	Swiss		5800	12100	13200	22600	100	
	Basel		1100	2400	2300	5400	20	
	Swiss no Basel		4700	9700	10000	20000	80	4.0
4	Europe	6.5	4050	8700	8720	19740		
	Swiss		3960	8403	8470	18530	100	
	Basel		1450	3080	3080	6710	37	
	Swiss no Basel		2508	5323	5390	11820	63	1.7
5	Europe	6.5	1700	3900	3650	10440		
	Swiss		1690	3864	3620	10280	100	
	Basel		250	600	500	1890	16	
	Swiss no Basel		1440	3264	3120	8390	84	5.4
6	Swiss	6.0	560	1382	1160	4410	100	
	Basel		190	460	370	1510	33	
	Swiss no Basel		370	922	790	2900	67	2.0
7	Swiss	6.0	160	450	430	1650	100	
	Basel		10	30	30	160	6	
	Swiss no Basel		160	420	390	1490	94	16.3

Table 2: Human losses in hypothetical earthquakes near Basel, similar to and smaller than the 1356 event. For fatalities and number of injured people minima and maxima are given. The percentages of fatalities in Basel city and outside Basel are compared.

The average number of Swiss fatalities is estimated as approximately 13,000 in scenario 2 with a distance of 10 km. Closer and farther from the city (scenarios 1 and 3, Table 1), the results suggest 16,000 and 9,000 Swiss fatalities, respectively (Table 2). For the three M6.9 scenarios, the average percentage of fatalities in Basel compared to the overall number in Switzerland is 28%, whereas the average portion of fatalities outside Basel is 72%. Thus, the number of fatalities outside Basel is larger in all scenarios than those inside the city. In case of an M6.9 earthquake, the ratio of outside to inside the city ranges from 1.8 in scenario 1 to 4 in scenario 3 (Table 2).

The ranges of error in fatalities and injured given in Table 2 derive from the uncertainties in building damage and the uncertainties in the impact on people, given an estimated degree of damage to a building. Uncertainties in earthquake source parameters and transmission properties of seismic waves in the Earth are not included in this error estimate.

The number of fatalities and injured in an earthquake is generally a function of the hour of day. It is assumed that the fatalities are minimal in those hours when a maximum of people is outdoors. Here we calculated the model using 21h, the time of the 1356 earthquake, getting a maximum of casualties. The number of casualties would be assumed less by about 5%, if we set the time of the earthquakes as 7h.

We also calculated losses for earthquakes with assumed magnitudes of 6.5 and 6.0 (Table 1) because such events are more likely than an event of magnitude 6.9. The likelihood of an M6.0 earthquake is roughly 10 times larger that that for an M6.9 event, based on the frequency-magnitude distribution of earthquakes in general. For each of these additional magnitude choices (Table 1), we selected a position close to and one farther from Basel, corresponding to the locations of scenarios 1 and 3 (Table 1).

For a magnitude 6.5 event, the position 6 km from Basel yields closely the same ratio of fatalities inside to outside the city as for the M6.9 case (Table 2). However, at the farther distance of 15 km, 5.4 times more fatalities are expected outside Basel city (Table 2). The number of settlements affected by this size event is estimated to be about 700, and the number of fatalities is still expected to be substantial (Table 2).

The smaller the magnitude, the smaller the area within which losses are sustained. Thus, a magnitude 6 earthquake at 15 km causes few human losses (scenario 7, Tables 1 and 2, Figure 2). In this case, the ratio of losses inside to outside is 15. For an M6 event at 6 km from Basel, the ratio of losses inside to outside remains roughly the same as for the larger magnitudes at the same location (Table 2). The number of settlements affected by an M6 event in NW Switzerland is 370 and the number of fatalities is strongly reduced, compared to the scenarios with larger magnitudes.

Discussion

The most reliable result is that the losses in the city of Basel are less than the sum of those in the settlements around the city. Most input errors that can affect the values of the absolute loss estimates cancel, when the ratio is taken. The regional analysis we present here does not negate the fact that the city of Basel is in all scenarios with epicenter close to Basel the community with the largest losses. Nevertheless, our results suggest that the focus of preparedness should be shifted to include the communities surrounding Basel.

Also, it is clear that moving the hypothetical epicenter away from Basel to the SW, where faults have been mapped [*Meghraoui, et al.*, 2001], reduces the human losses not only in Basel city, but also in the medium sized communities located to the SE of Basel. The resulting increase of losses in the Jura is minor, because the settlements there are small (e.g. Figure 2).

The case of scenario 7 illustrates an example of the effects of a major earthquake almost anywhere in Switzerland. Part of the area affected is populated by medium sized cities (by Swiss standards) and part is populated by small villages only.

We have not prepared a list of communities most at risk, as in the study concerning the Himalayas [*Wyss*, 2005]. We believe that the faults that may generate a future earthquake near Basel are not well enough known for defining risks of individual settlements. In the Himalayas, a list of cities at major risk could be compiled because there the tectonic information available for the Himalayan megathrust is fairly precise.

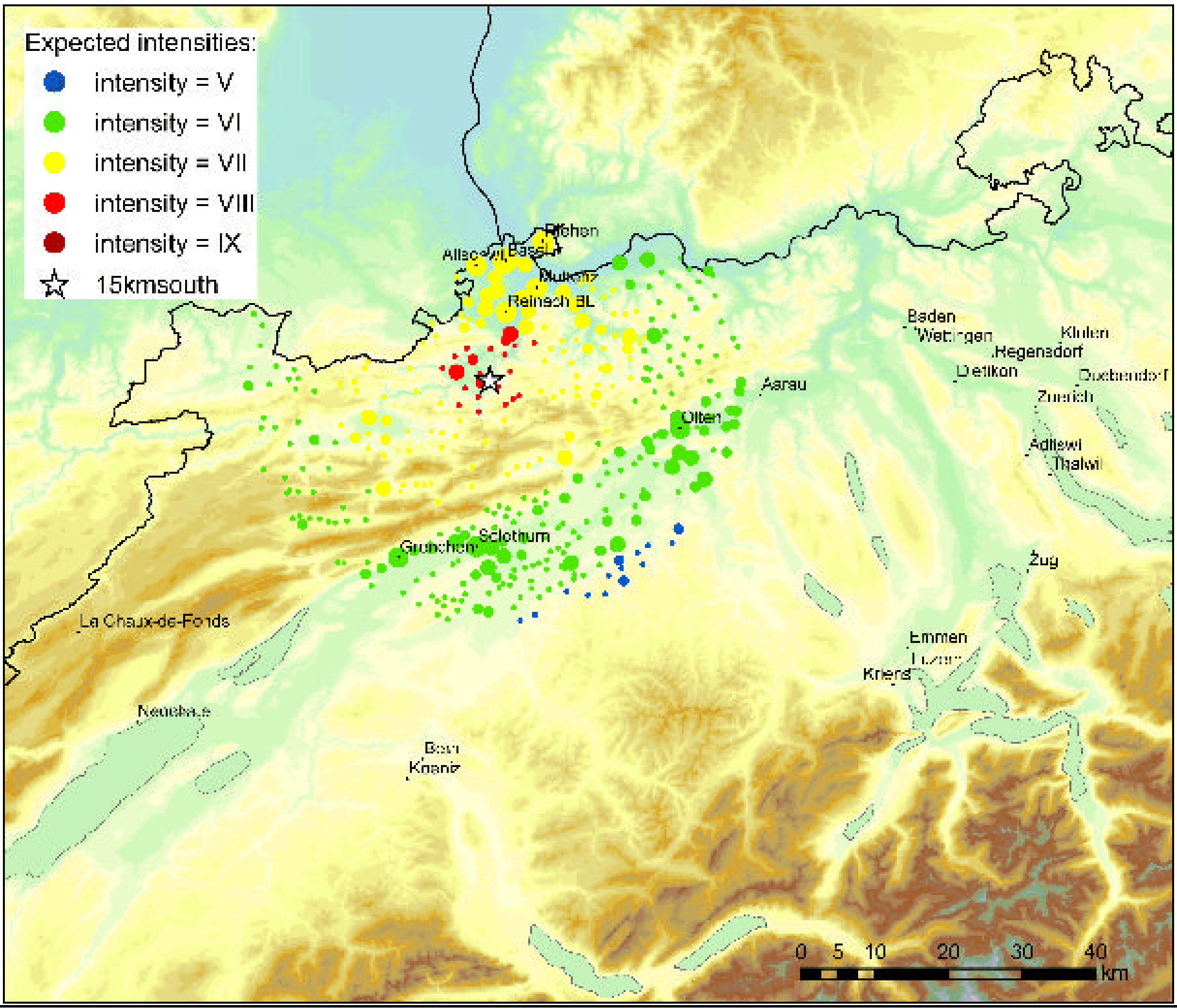

Figure 2: Map of estimated average damage to the building stock in case of an M6.0 earthquake at a distance of 15 km from Basel (scenario 7). In this case, the city of Basel plays a minor role; its human losses are about equal to that in four other settlements each. Symbols are the same as in Figure 1.

The values of fatalities generated by the scenarios with M6.9 range from 6,000 to 22,000 for all of Switzerland, with 1,000 to 8,000 expected in Basel city (Table 2). These numbers seem reasonable, considering losses in historic earthquakes in other parts of Europe. Nevertheless, they should not be relied on because recent information on building stock and site-specific amplification patterns were not included in the database. An update of our preliminary study should be carried out, with inclusion of as detailed information on buildings and geology as possible.

The number of settlements in which some buildings sustain at least slight damage, that is, with intensities equal to and larger than V, are large (Table 1). For the M6.9 scenarios, they lie above 1,000, and even for the smaller magnitudes they range from 370 to over 700. In the settlements experiencing intensity VII shaking, some casualties may occur and the repairs on buildings are expected to be major. The numbers of settlements in these high-risk areas are also substantial. In the scenarios with M6.9, the number of strongly damaged communities ranges from 320 to 400, with M6.5 they range from 170 to 230 and with M6.0 they range from 60 to 90. We conclude that it would take a major effort by governments at all levels in Switzerland, local to federal, to help these communities to get back on their feet.

The generic scenario for a major earthquake somewhere in Switzerland [*Anonymous*, 2004] could be adapted to the case of Basel for comparison with the results presented here. In the generic scenario it is assumed that 150,000 people live in what is called the "main damage zone" (intensity XI) and about 5,000,000 are assumed to be located in the "subsidiary damage zone" (intensities VII and VIII). In the case of our scenarios for Basel, the respective numbers of people are about 400,000 and 1,600,000, within Switzerland. Taking the numbers given in the generic report for fatalities and injured, and multiplying them with the ratio of the population numbers, one finds that the extrapolation from the generic report would expect about of 3,000 fatalities and 68,000 injured within Switzerland, for scenario 2 (Table 1). This means that the generic report would expect about twice as many injured as we calculated here, but the number of fatalities would be only about ¼ of those estimated with the assumptions made in QUAKELOSS. It is not known, at present, which factors lead to the different distribution of casualties into the fatalities and injured categories. It may be that the difference is diminished, when the newest information of fragility curves for buildings in Basel will be used. Also, there is evidence that the AC-13 method (used in *Anonymous*, 2004) overestimates casualties for some building types. We need to investigate what casualty rates result in Basel, if we use additional new methods to estimate them. Overall, the two estimates of the extent of the disaster are similar.

The total number of people in Swiss communities experiencing intensity VII and larger shaking is about 0.55 million in the scenarios with M6.9. Because damage in their communities is expected to be major, their lives would be significantly affected, and governments would have to shoulder the major burden to keep these communities functioning.

The hospitals and medical personnel would face the greatest challenge in case of a major earthquake in Switzerland. If we assume that 1/3 of the injured may need hospitalization, then we would expect an onslaught of 6,000 to 8,000 patients in the case of the M6.9 scenarios. For the M6.5 and the M6.0 cases the numbers of patients is estimated to range from 2,300 to 4,500, and 350 to 1,000, respectively.

Conclusions

Topics to which we have not contributed in this study include the following. (1) We have not proposed any new ideas on what the magnitude, the epicenter and the depth of future earthquakes near Basel may be. We have simply taking existing published source parameters for our scenarios. (2) We have not done any analysis of the possible time or probability of any of the hypothetical earthquakes for which we estimated losses. (3) Our loss estimates do not included secondary effects, such as fire, disease, damage to facilities that manage dangerous goods, as toxic chemicals. (4) We have not developed any evidence for or against the probability that future pumping of fluids into the Earth's crust in hydrothermal projects may trigger earthquakes with significant magnitudes.

The estimates of absolute numbers of fatalities, injured and patients that need hospitalization are preliminary. However, they may be taken as order of magnitude estimates, to get an idea what Switzerland would be faced with in case of a major earthquake. These estimates should be hardened in a follow-up study. The comparison with the generic scenario [*Anonymous*, 2004] shows that the question of the ratio of injured to fatalities may need to be investigated for the case of Switzerland.

The conclusion that the sum total of the human losses outside of the city of Basel is larger than that in the city is inescapable. Any preparation for a possible earthquake disaster near Basel should account for this fact.

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