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AP 5000 Report

Report title:	**AP5000 Report - Seismic Hazard and Risk assessments during three reference time periods (normal, stimulation and circulation)**
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EXECUTIVE SUMMARY

The region of Basel is an area with high population density that has suffered damages caused by tectonic earthquakes during the past centuries.

The objective of the work package AP5000 was to develop a probabilistic seismic risk assessment, intended to quantify the additional risk generated by the operation of the geothermal field.

The seismic risk is first quantified in a normal period, during which only the seismicity of tectonic origin is taken into account.

Next, the risk is estimated by considering two different phases of the geothermal field exploitation: a) the stimulation phase, which covers a short time period characterized by a high rate of hydraulic fracturation and induced seismicity, and b) the circulation phase, which corresponds to the lifespan of the field, during which induced and triggered seismicity are considered.

For each time period, a probabilistic seismic hazard assessment (PSHA) was conducted with the objective of defining the hazard curves, in a region covering a radius of 12 km around the site. The predicted parameter of the seismic motion is the macroseismic intensity, because the vulnerability curves are defined as a function of the intensity.

The PSHA method is consistent with the state-of-the-art: the uncertainties are propagated in the model by means of logical trees and Monte Carlo samplings.

The seismic hazard, in a normal period, is coherent with previous studies published in the literature. A macroseismic intensity of VII-VIII has a return period of 475 years (90% probability of non-exceedance in 50 years).

To consider the seismic activity during the stimulation period, two models stemming from the AP3000 workpackage are taken into account. The first one relies on empirical considerations to determine the maximum magnitude and the activity rate. It can be qualified as the more optimistic model, with the lowest activity rate. The second model is obtained from the AP3000 numerical simulations. It is considered as the more pessimistic model, with activity rate 10 times higher than the activity rate of the empirical model.

Two synthetic models are also included in a logic tree to model the induced seismic activity during the circulation period. They differ by the annual rate of activity. Using the outputs from AP4000 workpackage. the impact of the potential triggered seismicity on near regional faults is also considered.

The hazard comparison highlights several outcomes.

- At macroseismic intensities greater than VI-VII at the site itself, and at intensities greater than V-VI at a distance of 15 km to the site, the seismic activity caused by the geothermal field exploitation has no impact in terms of seismic hazard. Above those intensity thresholds, the seismic hazard is fully controlled by the natural seismic activity (of tectonic origin). Below, the seismic hazard is mainly controlled by the induced activity.

- The hazard increment is significantly higher during the stimulation period than during the circulation period. On the site, the probability of exceedance of an intensity V is increased by a factor 50 during the stimulation period. During the circulation period, it is only multiplied by a factor 3. The hazard increment decreases with increasing distance to the site, but remains significant even 15 km away. The multiplication factor becomes 7 during the stimulation and is close to 1,3 during the circulation.
- The seismic activity rate appears to be the main factor controlling the hazard. Because of very different activity rates associated to the empirical and synthetic models, the variability of the hazard curves is high during the stimulation period.
- Compared to the induced seismicity, the triggered seismicity has a negligible impact on the hazard.

In order to develop a probabilistic risk assessment at the scale of the urban area, the hazard curves are used in conjunction with vulnerability functions associated with the different building typologies,. The probabilistic risk assessment relies on an evaluation of the probabilities of losses during each time period and on risk scenarios, intended to provide F/N curves. The risk scenarios are obtained for intensities corresponding to various probabilities of exceedance. A deterministic scenario is also performed to appreciate the consequences due to an occurrence of the estimated maximum magnitude.

In order to obtain consistent comparison between prediction and observation, the predictive risk model was first calibrated by reproducing the impact of the earthquake of December 8th, 2006.

Several conclusions can be obtained from the risk assessment results.

- The seismic activity due to the geothermal field exploitation, is not responsible for a human risk increment, but only generates additional financial losses. This is because only damages D1 of the EMS 98 scale are expected. Heavy damages or partial collapse are not expected.
- The risk increment during the stimulation is significant. We consider that the most likely loss could be 45 M CHF within the few weeks of the stimulation period. It represents approximately 6 times the loss observed during the earthquake of December 8th, 2006. This amount is approximately 10 times higher than the predicted loss only associated to the seismic risk of natural origin.
- Considering the stimulation hazard curves associated to the percentiles 15 % and 85 %, that explain a large uncertainty, the financial losses could vary between 35 Millions CHF to 300 Millions CHF. The loss due to the stimulation could represent between 0,017% and 0,02% of the total insured value.
- Other uncertainties, such as the uncertainties associated with the vulnerability functions or to the cost function, contribute to enlarge the abovementioned variability between 10 Millions CHF and 640 Millions CHF.
- Compared to the stimulation, the risk increment between the circulation and the normal periods is low (multiplication factor of 1.06). However, because the lifespan of the field is 30 years, the absolute losses would be higher during the circulation period

than during the stimulation period. The corresponding loss increment represents 170 Millions of CHF over 30 years of operation.

- In terms of insurance, the additional risk associated to the stimulation period could be covered by an insurance prime of 430 CHF/building. The annual insurance prime to cover the tectonic risk is estimated to be close to 840 CHF/building/year. 50 CHF/building/year would be necessary to cover the risk increment during the circulation period.
- Considering the different models of induced seismicity developed within the AP3000 workpackage, the estimated maximum magnitude (3.7±0.4) has a great chance to be bserved during the reservoir operation. In that case, the losses would be superior to the losses observed in 2006. We consider that they could vary between 50 Millions CHF (Mw=3.7) to 160 Millions CHF (Mw=4.1). These values must be balanced using multiplication factor of 0.5 and 2 to account for uncertainties.
- The F/N curves resulting from the risk scenarios represent the annual frequency of exceedance of financial losses. They indicate that the highest risk increment would be observed during the first year of operation. During the first year of operation, the potential losses due to the stimulation and the circulation are cumulative. In this case, for an annual rate of exceedance of 1, the risk is approximately 17 times higher than the tectonic risk. The risk increment decreases with the annual rate of exceedance. For annual rates lower than 0,01, the risk increment becomes negligible, because the hazard remains controlled by the natural seismicity.

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1 INTRODUCTION – SCOPE OF THE STUDY

1.1 Objectives and scope of works

On December 8th 2006 a shallow earthquake of moment magnitude[1] Mw=3.2 was generated, during the stimulation phase of the geothermal reservoir, located in a dense urban area (*Figure 1*). This earthquake was assumed to be responsible for numerous damages on current buildings. The affected buildings were located in a rather large radius around the reservoir: 280 current buildings were damaged with a damage level D1 on the EMS98 macroseismic scale, corresponding to approximately 6-7 CHF millions of repair cost.

In the late 2008, the Basel-City Canton commissioned a risk assessment study to the SERIANEX group. The objective of the risk assessment study was to obtain decision criteria to assess the possibility of re-opening and continuing exploitation of the geothermal field.

Within the SERIANEX project, Geoter SAS and Resonance Ingenieurs-Conseils SA. are performing the seismic risk assessment (AP5000). Geoter SAS is responsible for the hazard and risk assessment. Resonance SA is responsible for the vulnerability assessment.

The Basel region is located in an area historically prone to earthquake. The seismic risk is a preoccupation of local authorities in normal period. The specificities of the seismic activity generated by a geothermal field exploitation, which is based on the principle of water injection at high pressure in the upper crust, require considering two different time periods during the geothermal field lifespan (Figure 3):

- A stimulation period in which, the induced seismic activity rate is high and does not follow a stationary process with time. The duration period is generally a few weeks long (a period of 12 days will be considered here) ;
- A circulation period in which, an induced seismicity can be observed within the reservoir. This longer time period can also be responsible for triggered earthquakes on pre-existing near regional faults (a period a 30 years will be adopted here).

[1] In the context of seismic hazard, the moment magnitude M_w is used instead of the local magnitude M_L. In this study, the strength of seismic events will therefore by quantified by M_w whenever possible. Note that for the magnitude range considered here, M_w is slightly smaller than M_L.

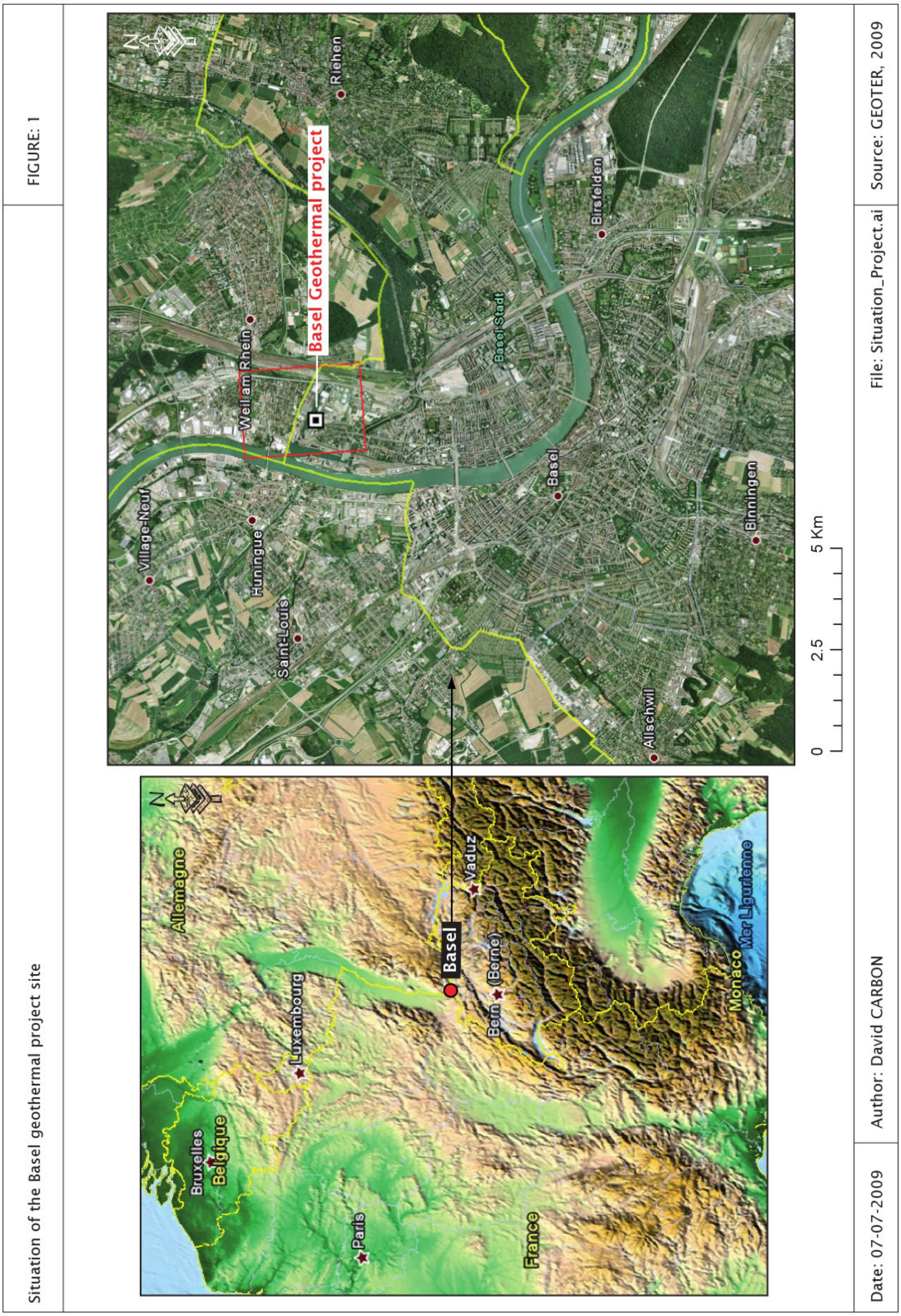

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Figure 1: Situation of the Basel geothermal project site

Figure 2: Investigated area and repartition of the districts and municipalities.

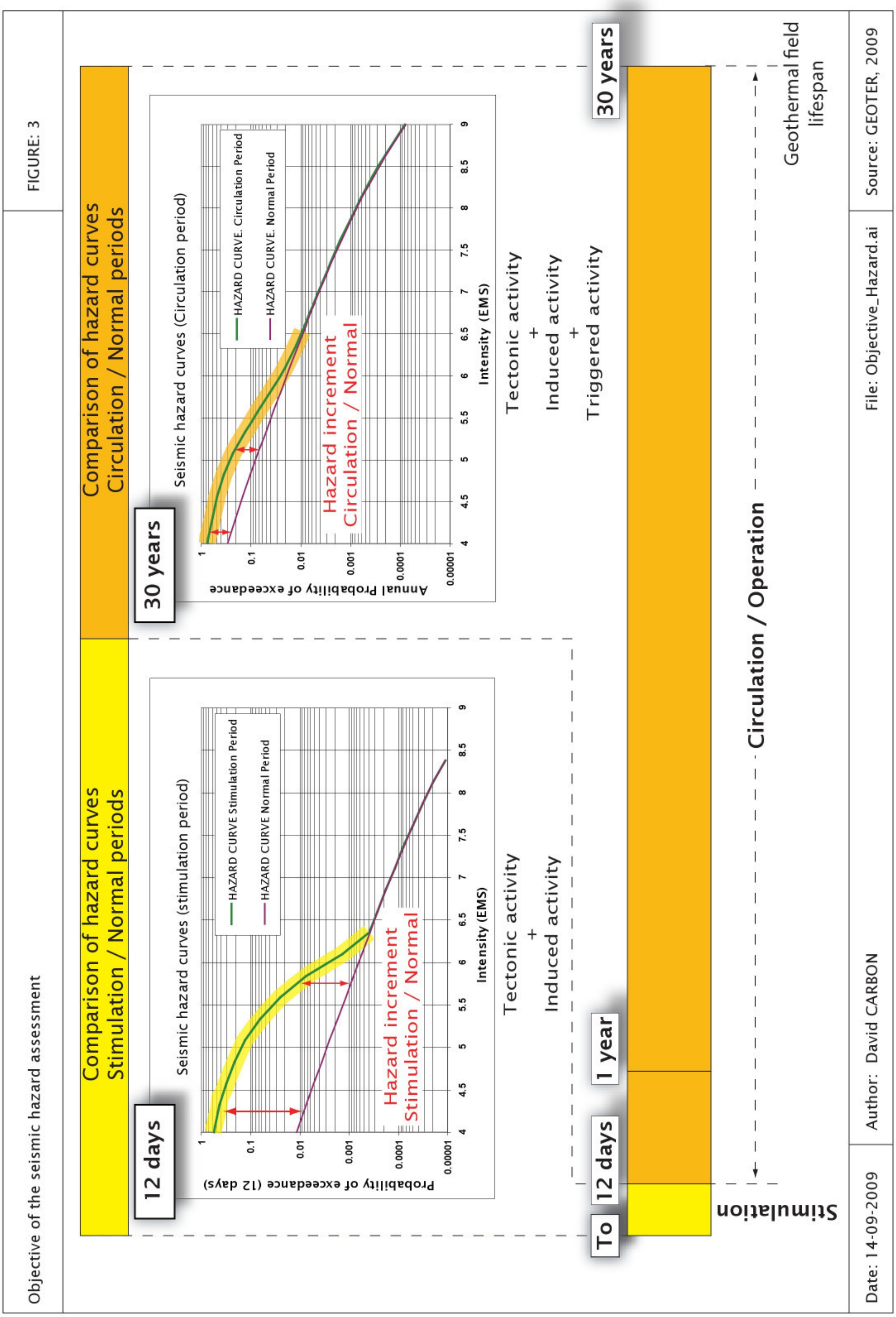

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Figure 3: Objective of the seismic hazard assessment.

During the stimulation and circulation periods, the additional induced/triggered seismicity is responsible for a hazard increment. If the vulnerability of the built-environment is constant, the hazard increment obviously leads to a potential risk increment.

The objective of the AP5000 work package was to provide an estimate of the observed hazard increment (Figure 3) and the subsequent risk increment between the stimulation and circulation periods and the normal period. To this end, a probabilistic risk analysis is adopted to estimate the probable losses that could be experienced during each of the three reference periods. The durations of the two periods were defined in the AP3000 work package. The durations for the stimulation and the circulation are 12 days and 30 years respectively.

The objective of the seismic hazard assessment was to calculate the seismic hazard curves in the area of interest. These curves provide, during each period of reference, the probabilities of exceedance of a ground motion parameter at a given site. In order to quantify the hazard increment, the obtained hazard curves will be compared to the hazard curves representative of the tectonic hazard (Figure 3). They will also be used in conjunction with the vulnerability functions associated with the elements at risk to: a) calculate the seismic risk, and b) compare the risk within each period of reference to the risk in a normal period.

1.2 Report organization

- Chapter 2 introduces the methodology.
- Chapter 3 presents the input data used to develop the probabilistic seismic hazard assessment (PSHA).
- Chapters 4, 5 and 6 introduce the PSHA models and the results obtained for the three reference time periods. A comparison of these results is shown in Chapter 7.
- The methodology used to perform the probabilistic risk assessment is developed in Chapter 8 and the results and their uncertainties are described and commented in Chapter 9.
- The Appendix 2 presents the Resonance technical report: Seismic vulnerability of the building stock in Basel – Lörrach – Saint-Louis area.
- The detailed results of the Probabilistic Seismic Risk Assessment for each district/municipality are synthesized in Appendix 1 and are provided in an excel file.

2 METHODOLOGY

In this report, the seismic risk represents the expected losses in a given area, over a specified time period. The “area” is characterized by the elements at risk that it contains. For the project, this area is composed by the city districts and municipalities, that are located within a 12 km radius around the geothermal field (*Figure 1*).

The seismic hazard assessment is undertaken following a probabilistic approach to define the seismic hazard curves in each of the areas. To consider its spatial variability, the hazard curves are calculated at the centers of a regularly spaced mesh of 0.03° (~3km, Figure 4).

2.1 Key considerations to develop the methodology

Risk is schematically expressed as the product of hazard curves and vulnerability functions. Considering that the vulnerability is almost constant during the different periods of interest, it is save to assume that the potential risk increment that we try to quantify will be mainly controlled by the seismic hazard increment.

Several input data and considerations have influenced the development of the model.

2.1.1 Ground motion parameter

When a PSHA is implemented for a seismic design purpose, the objective is to calculate uniform response spectra, which provide the spectral acceleration determined for the same return period, as a function of the frequency. However, in a risk analysis, the estimated ground motion parameter must be defined in such a way that it can be used as an input parameter to exploit the vulnerability functions.

The vulnerability functions are mainly derived from the level-I method of the Risk_UE project (See Resonance report). They provide a damage probability distribution as a function of the macroseismic intensity and of a vulnerability index associated to each building typology.

In order to avoid transformation from PGA to intensity, and taking into account that the vulnerability curves are calibrated in intensity instead of in acceleration, **the choice has been made to perform the PSHA in intensity**.

Performing the PSHA in intensity also allows using attenuation laws defined from macroseismic data from Switzerland (Fäh et al., 2003). Attenuation laws in acceleration are generally defined using data from other tectonic contexts and can be responsible for higher epistemic uncertainty.

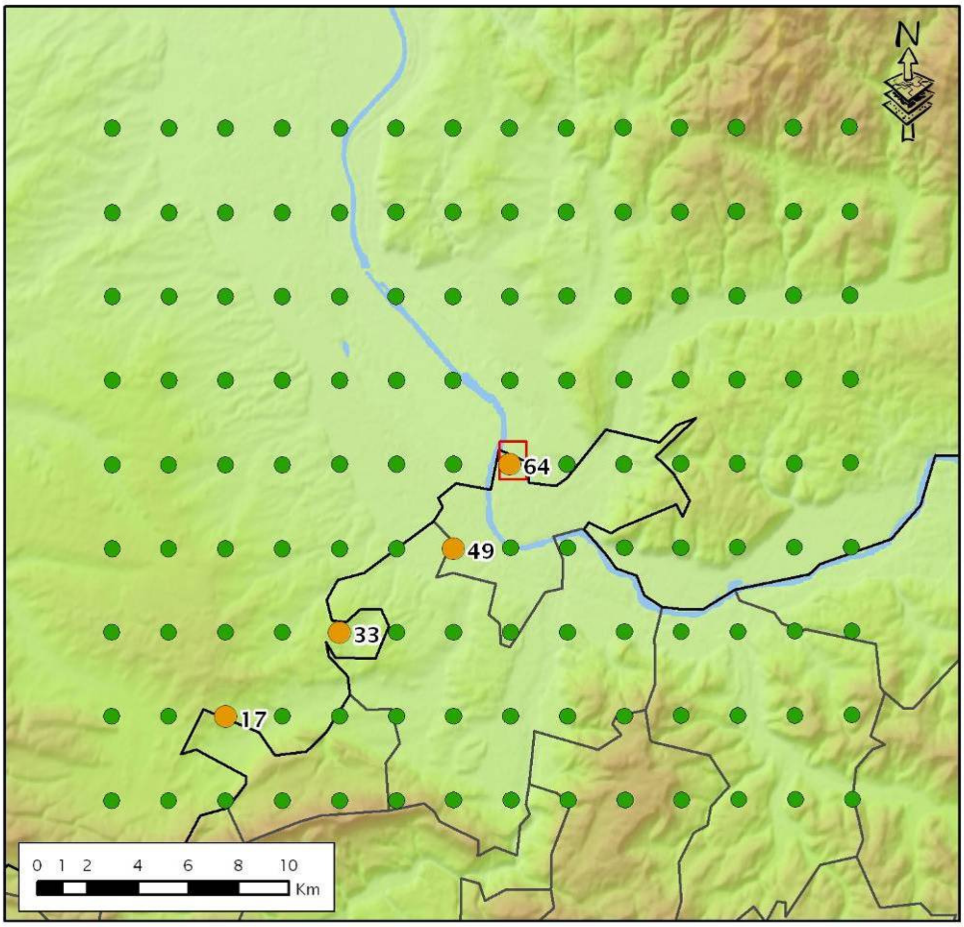


Figure 4: Calculation grid used in the PSHA and selected reference points

2.1.2 Minimum magnitude

A PSHA is generally implemented either to seismic design a critical plant at a given site, or with the more general objective to define the seismic motions enforced in a national or municipal seismic code. In those cases, the use is to consider earthquakes with magnitudes above 4.0 to 5.0 depending on the seismic area and the objective of the PSHA, because earthquakes that have significant effects on structures basically interest us.

Regarding the level of the seismic activity associated to the geothermal field activities, it is evidenced from past experiences that the activity rate of small magnitudes is very high during the stimulation period and that earthquake magnitudes remain low. From AP3000, the maximum estimated magnitude (Mw), varies from Mw=3.25±0.5 in the case of the empirical model to Mw=3.7±0.4 in the case of the synthetic model (see chapter 5). Those magnitude levels are lower than the minimum magnitude threshold usually considered to develop a PSHA study on a critical facility site.

Because damages were observed during the December 8th 2006 small earthquake, consideration must be paid to smaller magnitudes than usually considered for a classical PSHA study. Considering that damages of level D1 have been reimbursed in areas where the intensity was probably not higher than III or III-IV, and that magnitudes around 2.5 (Mw) at shallow depth, can be responsible for such a level of intensity, the choice has been made to consider a minimum magnitude of 2.5 (Mw).

As one of the objectives is to compare the probabilities of exceedance of the same levels of intensities between the different reference periods, it imposes to consider the same minimum magnitude threshold, whatever can be the origin of the seismicity. **For that reason, a minimum magnitude of 2.5 is adopted in all the models.** This also means that some of the empirical functions necessary to implement the process, must be used outside the data validity domain of the empirical sample.

2.1.3 Introduction of a near-regional fault model

The triggered seismicity model developed within the AP4000 workpackage is based on the structural model of (potentially) seismogenic faults in the Basel region provided by the AP2000 workpackage. For these faults, it was investigated how the perturbation forces introduced by the geothermal reservoir might trigger earthquakes on these faults, and how might be perturbed the seismic cycle of characteristic magnitudes on these faults.

As the hazard assessment accounting for the triggered seismicity was obviously requesting a fault model, such a model is also introduced in the basic model developed to assess the seismic hazard during the normal period (*i.e.* without considering the impact of the seismicity originated by the geothermal activities).

2.2 Specificities of the hazard calculation models for each reference period

The assessment must account for four types of seismicity: the tectonic seismicity, the induced seismicity during the stimulation period, the induced seismicity during the circulation period and the potential triggered seismicity on near-regional faults.

One PSHA is conducted for each of the following reference time-periods.

2.2.1 Normal Period

During the normal period, the urban area of Basel is only prone to tectonic earthquakes.

The PSHA during this period is performed according to the present state of the art methodology.

We exploit:

1) The Swiss ECOS catalog updated up to 2008. This catalog is homogenized in terms of moment magnitude, Mw.

2) A seismotectonic model including the following description of the seismic sources:

   a) A regional model based on area sources of diffuse seismicity. The Poisson model is used to model the distribution of the seismicity.
   b) A near-regional fault model taking into account the seismotectonic sources identified around the site. This fault model is based on the AP2000 and AP4000 results. The distribution of the seismicity activity associated to the faults is modeled using as input

data the return periods associated to different magnitudes according to the interface between AP2000 and AP4000.

3) A stationary Poisson model to fit the seismic distribution of the seismic sources. The temporal distribution of the seismicity is supposed to be stationary and the distribution of the magnitudes is supposed to follow a doubly truncated exponential distribution. It leads to the definition of the classical Gütenberg-Richter law characterized by λ and β parameters (here truncated to Mmin and Mmax).

4) The ECOS macroseismic attenuation relations developed during the revision of the Earthquake catalog of Switzerland ECOS finalized in 2002 (SED, 2002; Fäh et al. 2003).

5) A logic tree and Monte Carlo sampling technique to propagate the uncertainties associated to the seismic distribution parameters (λ and β of the Gutenberg-Richter relations, and the maximum magnitude of the seismic sources). The objective being to develop a seismic hazard of reference, and not to develop a detailed seismic hazard assessment, the logic tree neglects the propagation of epistemic uncertainties like those associated to the seismotectonic models.

The software used for the probabilistic calculations is CRISIS 2007. It basically uses the methodology developed by Cornell (1968). It allows to model the seismic sources (3-D faults or zones of diffuse seismicity) using the Poisson model for the temporal and spatial occurrence of earthquakes combined with the doubly truncated exponential distribution of magnitudes.

2.2.2 Stimulation Period

Referring to the AP3000 results, this period is a short time period (here we considered 12 days) during which the geothermal field is stimulated and generates a significant induced seismicity responsible of a hazard increment.

The assessment of the seismic hazard is carried out considering the following seismotectonic sources:

a) The same aforementioned sources considered for the normal period to account for the current tectonic hazard;

b) A new seismic source associated to the geothermal field, delineated and characterized using the AP3000 results.

The discussions on the interface between AP3000 and AP5000 lead to adopt two seismic distribution and characterization models, to describe the induced seismicity.

a) The first model is called “empirical” model because the calibration of some of the parameters results from an analysis of empirical case studies including the 2006 sequence (AP3000 report) and due to the use of the 2006 seismic sequence catalog to calculate the seismic distribution parameters. In this model, the seismic activity can be fitted using the stationary Poisson model or a non-stationary model of occurrence like the Omori model.

b) The second one consists in a synthetic model developed in AP3000 based on the modeling of the seismic ruptures during the stimulation period using finite elements methodologies. This model is called synthetic model. In this case, the output data provided by AP3000 only allow to consider a stationary model.

The Poisson model supposes a stationary activity. As we are interested by the probability of exceedance of the ground motion during the whole stimulation period (and not by the daily probability of exceedance), such a model can be used to fit the seismicity, and to calculate an averaged rate over the time period, even if the observed seismicity follows a non-stationary behavior.

The Omori model is a non-stationary seismic model well adapted for the description of the aftershocks sequences. It predicts a high seismic rate of earthquakes after the main earthquake and the seismic activity decreases quickly with the elapsed time from the main earthquake. The seismic sequence after the Mw=3.2 earthquake of 8th December 2006 looks like an aftershock sequence. Therefore, the Omori model was deemed to be well adapted to describe the recorded data after the main event and to consider the time dependence of the seismic hazard (at a given time after the main event). Nevertheless, this model is not adapted to model the seismicity from the beginning of the water injection: The 2006-recorded distribution presents an increasing activity rate during the first days up to reaching the main event and a decreasing activity after (Figure 17).

Considering the test we made with both models, we decided to use only the stationary Poisson process due to the following reasons:

1) The input data issued from the AP3000 work package consist in an activity rate of earthquake exceeding a given magnitude, a maximum magnitude and a b-value corresponding to the slope of a Gutenberg-Richter law ;
2) As presented in the following sections, the induced seismic activity will be modeled using two synthetic models for the circulation period and using one synthetic model and one empirical model for the stimulation period. The non-stationary model could only be used in the case of the empirical model, because it is the only model for which a consistent catalog is available. To keep homogeneity and facilitate the comparison between the models, the choice is done to use the same model to characterize the seismicity distribution.
3) The Poisson model is commonly used to describe the induced seismicity of geothermal fields (Majer et al., 2007)
4) An Omori law does not properly adjust the recorded seismicity distribution when we consider the beginning of the seismic distribution. This law can only be adjusted from the occurrence time of the maximum event

Some tests were performed using the whole seismic sequence recorded 200 days after the main 8th December 2006 earthquake. With this set of data, we defined an Omori law, used to calculate the seismic activity rate during two weeks after the main shock. We calculated also a Poisson model, only using the seismic data recorded the two weeks after the main shock, and then the seismic activity rate for a two-week period. We observed consistent activity rates (Figure 5), justifying that both models are suitable to be used in the seismic hazard analysis.

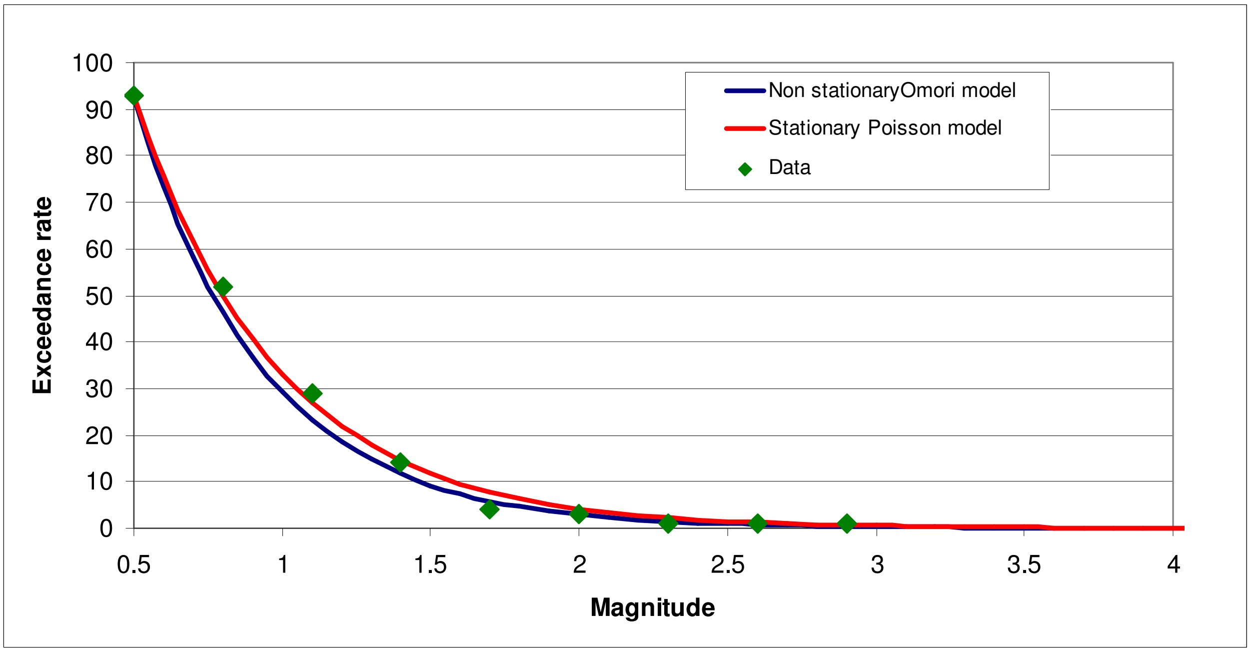


Figure 5: Comparison of seismic occurrence models: Poisson and Omori.

2.2.3 Circulation Period

It is the operating period of the geothermal field. From AP3000, it corresponds to 30 years. During this period, the seismic activity that we consider is the tectonic activity, the induced activity and the potential triggered seismicity on near-regional faults.

The seismic hazard assessment is performed using the same process as for the stimulation period. The main differences come from:

a) The modifications introduced in the near-regional fault to account for the effects of stress changes and related acceleration/deceleration of the seismic cycle. These modifications are analyzed in AP4000 and quantified in terms of increment or decrement of the return periods associated to different levels of magnitude on each fault. Therefore, the original Gutenberg-Richter laws used in the normal period model are modified accordingly. As these increments are negligible compared to the characteristic magnitudes return period, the impact in terms of seismic hazard is very low.

b) The use of two models of induced seismicity which correspond to the following AP3000 inputs:

a. Synthetic model 1: A Mmax magnitude of 3.7±0.4, a Poisson model considering a seismic activity of one annual earthquake of Mw≥3.3 and a b slope of the Gutenberg-Richter b=0.96±0.1.

b. The second model, Synthetic model 2, refers to the empirical model described in the AP3000 report, except that we considered a larger Mmax. The figure 29 of AP3000 report shows that the observed Mmax in 2006 was closed to the 2σ confidence interval of the relationship between Mmax and the logarithm of the reservoir dimension. For this reason, we decided to adopt the upper limit of Mw=3.7 for a 2 km² reservoir size, with the same confidence limit as in the synthetic model 1, instead of considering the central value of the data fit. A Poisson model is adopted, considering a seismic activity of a single earthquake of magnitude Mw=3.7 during the 30 years of operation and the same b value.

2.3 Hazard comparison criteria

Considering the geothermal field activities, two time periods are considered:

- The 12 days stimulation period ;
- The 30 years circulation period.

The objective is to compare the hazard within these two reference periods with the current tectonic hazard.

The first criterion corresponds, for different intensity thresholds, to the ratio of the probability of exceedance during the period of interest over the probability of exceedance during normal period.

The ratios between stimulation and normal periods are explained considering 12 days of stimulation.

The ratios between circulation and normal periods are explained considering 1 year of circulation.

The Table 1 gives an example of such a comparison.

To appreciate the ratios spatial variability, they are calculated at 4 reference points of the grid, located at different distances to the geothermal field: 0, 5, 10 and 15 km. The reference points are n° 64, n°49, n°33 and n°17 on Figure 4.

T=12 days	P(I>V)	P(I>VI)	P(I>VII)	P(I>VIII)
Normal period	2.80E-03	6.35E-04	1.40E-04	2.46E-05
Stimulation period	1.53E-01	7.41E-04	1.41E-04	2.47E-05
Multiplicative ratio	**54.6**	**1.2**	**1.0**	**1.0**

Table 1: Comparison of the probabilities of exceedance of intensity V, VI, VII and VIII during 12 days at point n°64.

A second criterion consists in a comparative plot of the seismic hazard curves corresponding to each reference period. The Figure 6 compares the normal and stimulation hazard curves during 12 days of the stimulation period. The Figure 7 compares the normal and circulation hazard curves during one year of the circulation period.

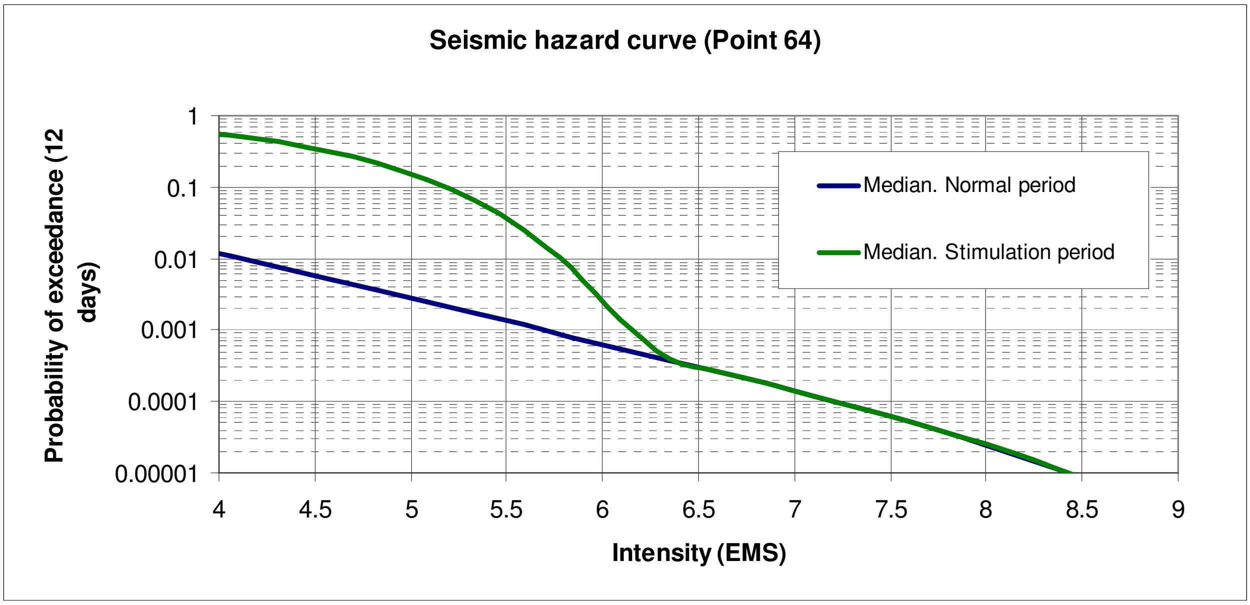


Figure 6: Example of comparison of seismic hazard curves corresponding to normal and stimulation period. Period of time considered: 12 days

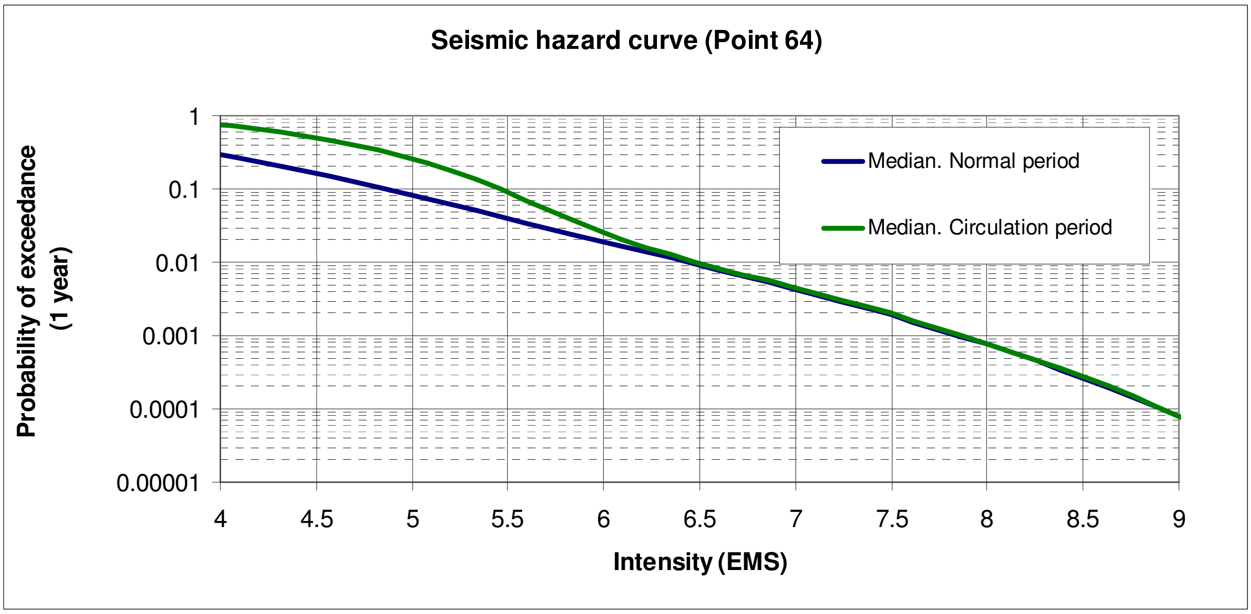


Figure 7: Example of comparison of seismic hazard curves corresponding to normal and circulation period. Period of time considered: 1 year.

Finally, a last comparison is done plotting the seismic hazard maps corresponding to the 3 periods (normal, stimulation and circulation) at 3 different return periods: 1, 10 and 30 years.

A seismic hazard map at 475 years of return period will also be presented. This is the return period adopted in seismic codes to design current buildings.

2.4 Risk assessment

The term *seismic risk* here refers to the expected losses to a given *element at risk* due to the *seismic hazard* and considering the *vulnerability* of the *element*, over a specified future *time period*. The element at risk may be a building, a group of building, a district, the total urban area, the human population, or the economic properties. According to the way the elements at risk are defined, the risk may be measured in terms of expected affected buildings number, in terms of expected victims (fatalities) number, or in terms of expected economic losses (insured values losses). Using the probabilistic approach the risk is expressed in terms of most probable expected losses, and quantifies:

- The most probable number of fatalities during a given period and due to the seismic hazard during one of the three reference time-periods (Normal, stimulation, circulation) ;
- The most probable number of buildings affected by damages, during the same periods of time and due to the same hazard ;
- The most probable repair costs or insured values losses.

Two types of risk assessment models are applied:

- **Probabilistic risk assessment**. The objective is to calculate the most probable losses within a given time-period, considering :
    - the probabilities of exceedance of all the ground motions, from the weaker to the higher, during the time period, that is provided by the seismic hazard assessment ;
    - the probabilities to observe each damage level (from null damage to destruction), under all the ground motions loading, that is provided by the vulnerability assessment.
    - In that case, a full exploitation of the hazard curves is done to quantify the most probable impact during the three reference time-periods.
- **Scenario assessment**. In that case, the objective is to calculate the effects of a given earthquake located at a given place or the effects due to ground motions that have a given probability to be exceeded during a fixed time period. This type of evaluation is based using as seismic input data the intensity maps in the studied area, which results from each specific scenario such as:
    - A specific earthquake like the 8th December 2006 earthquake (Magnitude Mw=3.2) located under the geothermic field. This scenario will be used here to calibrate the model
    - The maximum induced earthquake magnitude that could be generated by the geothermal field. These scenarios will be developed to provide a loss evaluation associated to these assumed largest magnitudes due to the field activities ;

  - The ground motion that have x% probability to be exceeded during a y years period. These scenarios will be developed to provide AP6000 with Frequency/Cost functions that can be compared with functions available for other risks.

Both risk assessment models are developed under GIS oriented approach. It allows:

- To use the hazard curves calculated for each reference period at each point of a mesh. These hazard curves represent the probabilities to exceed all the ground motions (from very weak to very high) within the specified time-period ;
- To use the ground motion (intensity) maps calculated for the entire urban area, for a given earthquake, or considering a specific probability of exceedance ;
- To take into account the geographical repartition of the different building typologies and their associated vulnerability;
- To evaluate the damage grade distribution of the building stock of each area at risk. For a given period of time, it is then possible to estimate the buildings number in each damage grade, the corresponding insured value loss and human losses;
- To aggregate the physical damages and human and financial losses to get the global consequences associated to each period of reference, at the scale of the whole urban area or at the scale of districts.

3 INPUT DATA FOR PSHA

3.1 Earthquake catalogs

Two types of seismic data prepared in previous work-packages are used:

a) The first one is the regional seismicity catalog based on the ECOS2002 catalog provided by the SERIANEX group updated up to 2008. The data are homogenized in terms of Mw moment magnitude. This catalog is used to calculate the distribution law parameters (i.e. Gütenberg-Richter) of the seismotectonic sources. The aftershocks of the regional catalog were removed using temporal and spatial windows adapted to each magnitude range.

b) The second one corresponds to the induced seismicity recorded from the beginning of the water injection (beginning of December 2006) to the end of July 2008, during the partial stimulation of the reservoir, and after it was stopped. The moment magnitudes are homogenized to Swiss Seismological Survey (SED) moment magnitude using the relation (SED report, 2007): Mw(SED) =Mw(D)*1.3-0.95. They are consistent with the magnitudes of the tectonic earthquakes. The induced catalog is used to fit the seismic distribution parameters of the geothermal field source.

The periods of completeness are calculated using distribution histograms and the Stepp-plot methodology.

3.2 Seismotectonic model

3.2.1 Origin of the seismotectonic model

In order to assess the seismic hazard, a seismotectonic model is developed based on all available tectonic, geophysical, seismological and seismic hazard information published for the region (Northwestern Alps and its foreland). The bridge between the geological and seismological databases and any calculation model for deriving hazard levels is a regional seismotectonic model, which is based on a coherent merging of the total regional database. In its construction, all existing interpretations of the seismotectonic characteristics of the region that found in the available literature are usually considered.

A comprehensive seismotectonic modeling with thorough understanding of uncertainties therein requires the detailed analysis of geological, geophysical and seismological information. The standard procedure is to integrate all relevant and available data and information, in a coherent seismotectonic model consisting of a discrete set of seismogenic structures (faults) or sources (zones).

In area of moderate seismic activity, geological evidence of faults at the surface with recognized recent seismic or paleoseismic activity is generally lacking. As tectonic deformations occur along structures at depth without surface expression, their knowledge need to be inferred from indirect observations. The return period of large earthquakes along individual faults is also usually long and exceeding the seismological observation periods. As a result, the number of seismogenic structures and their knowledge is generally limited and most of the time the consideration of seismogenic faults is limited to some parts of the whole model, where the state of knowledge allows formulating hypothesis on the association between earthquakes and faults.

The objective being to determine a seismic hazard of reference in normal period (i.e. a background tectonic hazard) and not to develop a full seismic hazard assessment like it would be done for the seismic design of a critical facility, and due to the limited size of the project, we adapted a seismotectonic model issued from previous works, without accounting and propagating all of the uncertainties, as it would be done to reach an other objective.

The seismotectonic model differentiates two types of seismic sources:

- Those localized seismogenic structures which can be identified and whose seismic activity can be characterized from published specific studies. This near-regional fault model is specifically considered to address the potential triggered seismic activity during the field operation ;
- Diffuse seismicity zones not correlated to specific tectonic structures but which rather define crustal volumes with homogeneous tectonic, seismicity and deformation patterns.

The main features and data used to define the regional seismotectonic zonation and seismogenic structures of the northwestern Alps and its foreland domain are:

- The available bibliography on the area;
- The geological setting and the major tectonic features;
- The regional stress field derived from the analysis of earthquake focal mechanisms and the kinematics of the major active faults (type and rate of relative motions);
- The historical and instrumental seismic activity (3D spatial distribution, frequency, size, focal mechanisms);
- The analysis of neotectonic ruptures and paleoearthquake evidences;
- The review of available previous Seismic Hazard Assessments [new probabilistic seismic zonation of France (Martin *et al.*, 2002); ESC-SESAME unified hazard model for European-Mediterranean region (Jimenez *et al.*, 2001, 2003); Swiss Seismotectonic zonings for PSHA (Giardini *et al.*, 2004)].

Within the framework of this study, the seismotectonic model used for the seismic hazard assessment combines:

- A regional zonation in which the seismic sources are defined by diffuse seismicity zones. This regional model has been developed by GEOTER for previous studies;
- A near regional fault model based on the structural model of potential seismogenic faults proposed by Delacou *et al.* (2009) in the AP2000 workpackage.

3.2.2 Regional area sources model

The regional model in area sources corresponds to our own interpretation of the collected data allowing to characterize the mechanisms of regional seismotectonic deformations. It is based on the updating or review of the previous seismic zonation (new probabilistic seismic zonation of France for Eurocode 8 application (Martin *et al.*, 2002) in order to take into account the knowledge evolution regarding the geodynamic of Western Alps and the mechanism of crustal deformation (seismic data, focal mechanisms, recent geodesic data, paleoseismic studies…). It takes also benefit from different regional seismic zonations that were developed to assess the probabilistic seismic hazard of several special risk installations in France (nuclear and chemical installations, dams) and in Switzerland (dams), and that have been agreed by different public authorities in France and in Switzerland:

- Probabilistic seismic hazard assessment for the Saint-Alban nuclear site (Rhône valley) (GEOTER report n°GTR/EDF/1106-329, November 2006);
- Probabilistic seismic hazard assessment for the chlorine plant in Pont-de-Claix (Isère) (GEOTER report n°GTR/RHO/1207-431, December 2007);
- Probabilistic seismic hazard assessment for 240 sites of dams in France (GEOTER report n°GTR/EDF/0909-601, September 2009);
- Probabilistic seismic hazard assessment for the Fah and Serra dams in Valais (Switzerland) (GEOTER report n°GTR/EOS/1108 Rev1, November 2008);
- Probabilistic seismic hazard assessment for the Salanfe, Fully, Cleuson, l'Hongrin, Gebidem dams (Switzerland) (reports GEOTER n°GTR/EOS/0109-555, GTR/EOS/0209-565, GTR/EOS/0209-565, GTR/EOS/0209-566, GTR/EOS/0209-567, GTR/EOS/0209-568, January and February 2009).

3.2.2.1 Input data

The knowledge of the geodynamic and seismotectonic context of Northwestern Alps took advantage, these last years, from many university or institutional works. They allowed in particular to better understanding the current mechanisms of deformation of the alpine region and its foreland domain.

The results published in the framework of European scientific research programs on the seismotectonic and geodynamic thematic brought new informations and knowledge which allow an actualization of the most recent seismotectonic models. It concerns in particular:

- The project of the European Commission **PALEOSIS** [1998-2000] "Ev*aluation of the potential for large earthquakes in regions of present-day low seismic activity* in Europe" which concerns paleoseismic research applied to various geological domains (Alps, Pyrenees, Upper and Lower Rhine graben);
- The project of the European Commission **SAFE** [2001-2003] "Slow Active Faults in Europe". SAFE objectives are to develop innovative research methodologies supplying data for seismic hazard assessment in key regions of Western Europe;
- The project **GEOFRANCE 3D** "Characterization of the recent and current deformations". It concerns a scientific program controlled by the BRGM, based on a in three dimension modeling of various geological structures induced by recent tectonics;

- The **ENTEC** Program [2001-2004] "Environmental tectonics in the northern Alpine foreland natural laboratory". The EU funded interdisciplinary ENvironmental TECtonics research network (ENTEC) addresses relationships between deeper lithospheric processes, neotectonics and surface processes in the Northern Alpine foreland. Its objectives are to quantify the effects of ongoing Alpine collision on NW European Foreland intraplate deformation and its impact on surface geomorphology and natural hazards. Three natural laboratories were selected: the Lower Rhine Graben, the Upper Rhine Graben and the Vienna Basin (*e.g.* Cloetingh & Cornu, 2005; Cloetingh *et al.,* 2005, 2006; Tesauro *et al*., 2006).
- The project **EUCOR-URGENT** [1999-2003] "*Upper Rhine Graben Evolution & Neotectonics",* is a collaborative network of 25 Universities and governmental agencies from Germany, France, the Netherlands and Switzerland, whose focus is on the seismic hazards and neotectonics in the Upper Rhine Graben and surrounding areas, as well as on the management of the water resources of the Quaternary graben fill. (e.g. Dèzes *et al*., 2004 ; Cloetingh *et al*., 2005, 2006 ; Kissling *et al*., 2006 ; Bourgeois *et al*., 2007).
- The inventory of **neotectonic rupture evidences** which affect quaternary formations in France and neighbouring areas in relation with major active faults (Baize *et al*., 2002);
- The National database of **neotectonic deformation evidences** and paleoearthquakes NEOPAL (http://www.neopal.net/, BRGM *et al*., 2009), last update July 2009.
- The follow-up of the Research and Development works undertaken by the CEA (LDG) and IRSN in the framework of nuclear safety (*e.g.* : Marin *et al.* 2004 ; Beauval, 2003 ; Scotti et Beauval, 2003; Scotti *et al*., 2003; Clément *et al*., 2003, 2004);
- The new **probabilistic seismic zonation of France** realized by GEOTER (Martin *et al*., 2002). This zonation (EPAS 2002) is based on the geological and tectonic parameters listed and validated in France by a group of experts of the French Association for Earthquake Engineering (AFPS) in the framework of the EPAS working group (Autran *et al*., 1998);
- The new **Seismic Hazard Assessment of Switzerland** realized by the Swiss Seismological Service of the Federal Institute of Technology in Zurich (SED) (Giardini *et al*., 2004);
- The studies in **paleoseismicity** in Switzerland of the interdisciplinary research group "PALEOSEIS" of the Swiss Seismological Service of ETH Zurich (Becker *et al*., 2005).

In addition, many recent scientific thesis were carried out at regional scale on the Western Alps and its foreland domain. They concern in particular:

- Bastien Delacou "Current tectonic and geodynamic setting of the alpine arc - Insights from seismotectonics and numerical modelling" (Thesis, Universities of Neuchatel and Nice-Sophia Antipolis 2004; Delacou *et al.*, 2004, 2005);
- Jean-Daniel Champagnac "Brittle tectonics of the inner parts of the W-Alpine belt; geodynamic implications" (Thesis, University of Neuchatel and Grenoble 1, 2004; Champagnac *et al.*, 2006);
- Pierre-Jean Alasset "Seismotectonic and identification of seismic sources in slow deformation context: the case of western Pyrenees and Northern Alps (France)" (Thesis, University of Strasbourg 1, 2005).
- Gwendolyn Peters "Active Tectonics in the Upper Rhine Graben: Integration of paleoseismology, geomorphology and geomechanical modelling" (Thesis, University of Amsterdam, 2007).
- Mathieu Alexis Ferry "Adaptation of the paleoseismological approach to local tectonic regime: comparative study on the intraplate Basel-Reinach fault, Switzerland and the interplate North Anatolian fault, Turkey" (Thesis, Swiss Federal Institute of Technology of Zurich, 2004).

The main results of these recent studies were taken into account and exploited to develop the seismotectonic model in source area for the Northwestern Alps and its foreland domain.

3.2.2.2 Delimitation of the seismic zones

The final seismic zonation proposed by GEOTER consists in 29 regional seismotectonic zones. The regional area source model presented in Figure 8 and Figure 9 is mainly constrained by:

- the kinematics of the present-day deformations deduced from the stress inversion of focal mechanisms. The regionalization map of strain and stress field proposed by Delacou *et al.* (2004, 2005) was used to define the dominant mechanism of deformation in each seismic zone;
- the expression of recent deformations deduced from morphostructural analysis and neotectonic deformations;
- the geometry and orientation of the principal regional crustal structures responsible of the seismic activity (*e.g.* Presence of permo-carboniferous basins limited by NE-trending faults overlying by the Meso-Cenozoic folded sedimentary cover of Jura, NE-trending faults of the crystalline external massifs, NNE-trending border faults of the upper Rhine graben…);

These geological units are generally delimited by important tectonic contact often corresponding to the most mobile zones (*e.g.* Belledonne border fault, Prealps border thrusts, Rhône-Simplon fault, Insubric line, frontal thrust of Jura…).

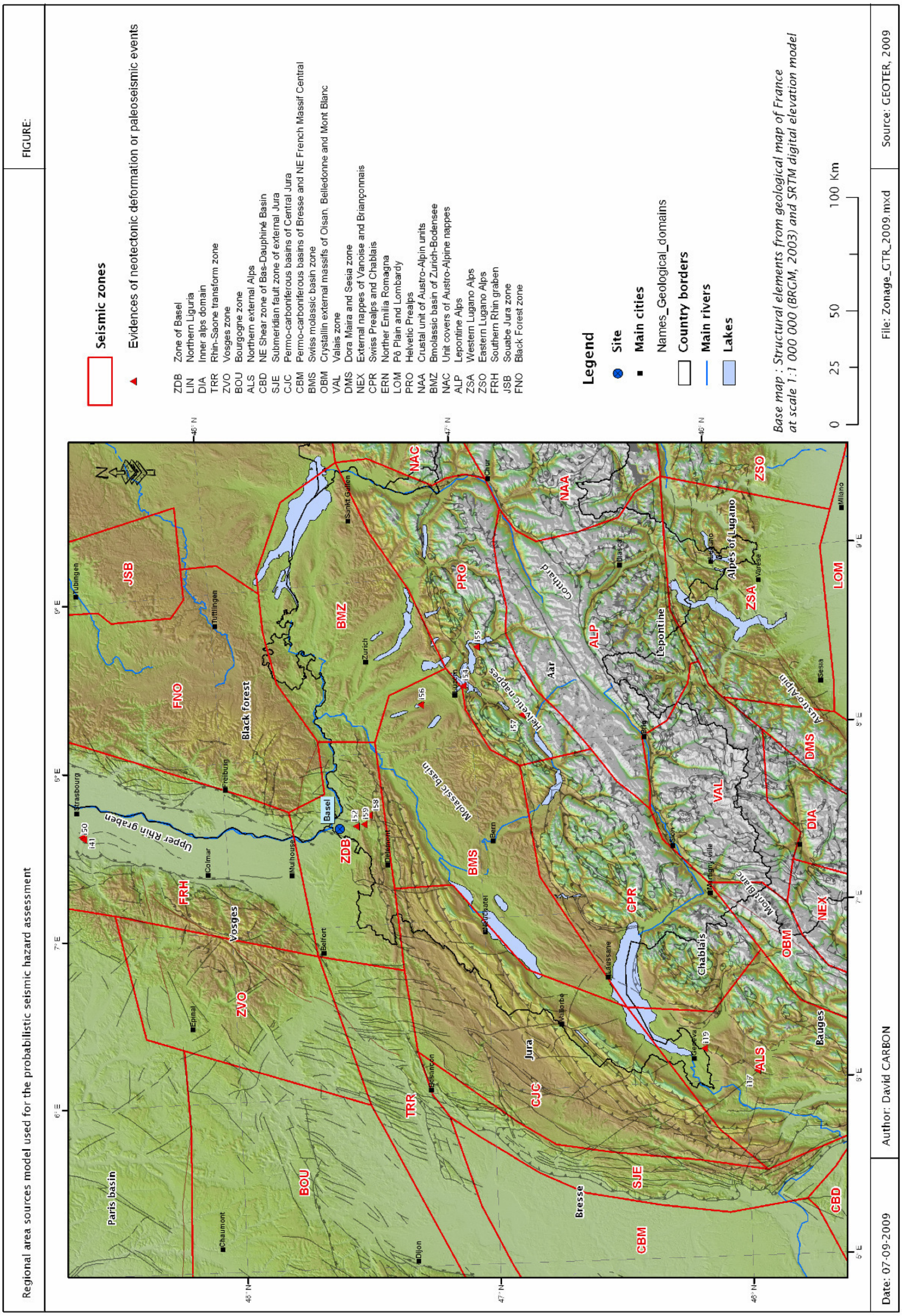
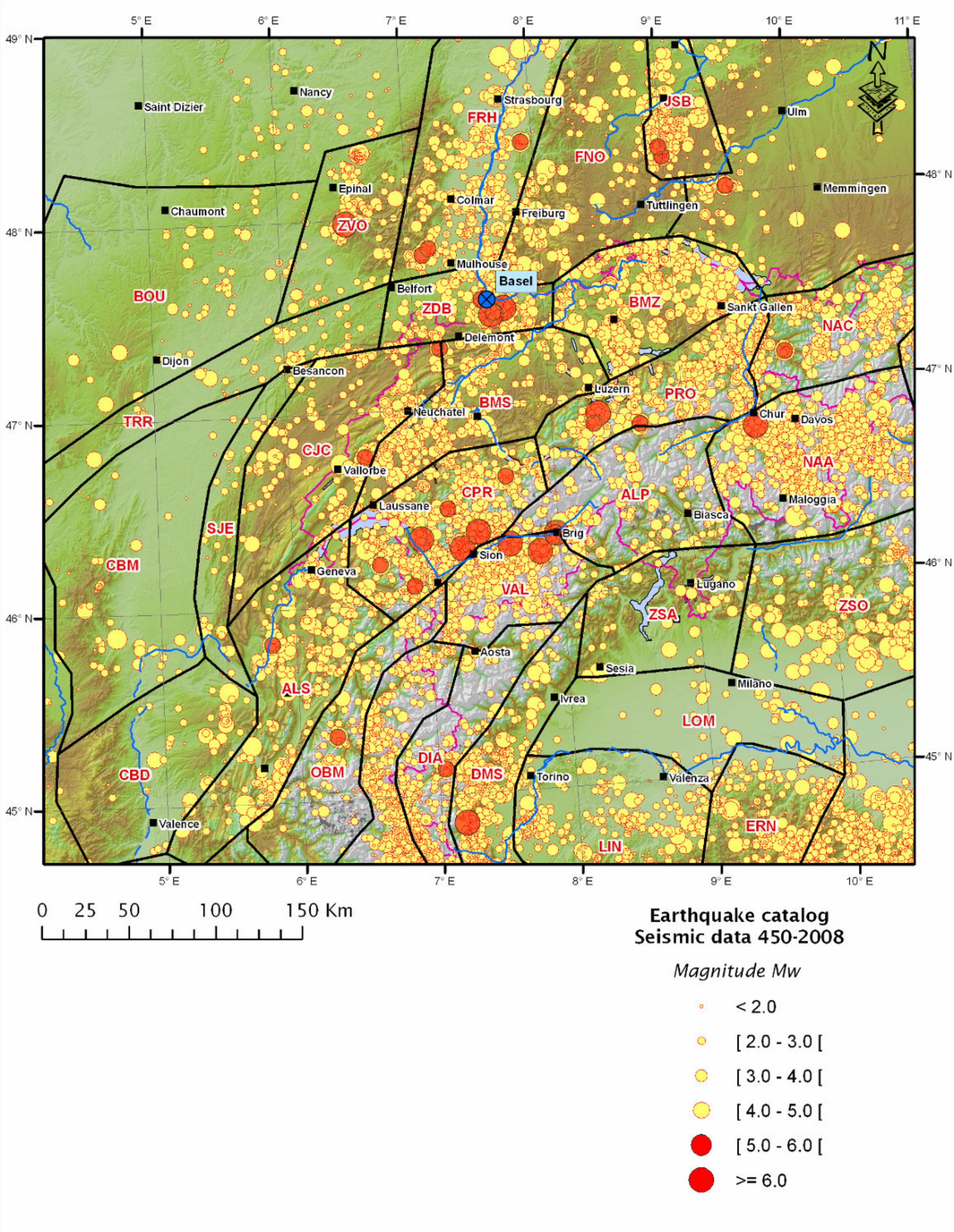


Figure 8: Regional area sources model used for the probabilistic seismic hazard assessment.

Seismicity superposed to the regional area sources model	FIGURE:



Date: 07-09-2009	Author: David CARBON	File: Zonage_Seismicity.mxd	Source: GEOTER, 2009

Figure 9: Seismicity superposed to the regional area sources model

3.2.2.3 Synthesis of the seismic zone parameters

Focal depth ranges

The focal depth of earthquakes is an important input to PSHA not only to define source zones, but also for ground motion prediction. In particular, the depth of source areas has an influence on the seismic hazard calculation when the used attenuation laws are parameterized according to a measurement of the distance which integrates this parameter, such as the hypocentral distance or distance to the rupture.

The depth of the source areas is expressed between two bounds of value to express random uncertainty relating to the evaluation of this parameter. These two bounds allow to propagate uncertainty in the calculation process using Monte Carlo random sampling. The depths of the source areas are generally those validated by working groups and teams of experts at the origin of zonation.

The focal depths ranges attributed to the seismic zones for the regional seismotectonic model are issued from the existing models. These values are adapted or supplemented for the eastern part of the model according to:

- The in-depth geometry of the major tectonic structures deduced from crustal scale geological cross-sections interpreted from the deep seismic profiles ECORS-CROP, NFP 20 West and NFP 20 East (*e.g.* Marchant, 1993 ; Schmid et Kissling, 2000 ; Schmid *et al*., 2004);
- The analysis along several cross-sections of the in-depth distribution of instrumental earthquakes. These seismic profiles were built through the western Alpine arch in order to evaluate the earthquake depth distribution relative to the seismic zone boundaries.

The values of focal depth ranges proposed for each seismic zone are listed in the Table 2, p. 41.

Evaluation of the maximum possible earthquake size (Mmax)

The maximum possible earthquake, Mmax, is recognized as a critical parameter with important influence on the final hazard at least for long return periods. The historical and instrumental seismicity as well as neotectonic and paleoseismic evidences are analyzed to determine the regional distribution of the strongest earthquakes and to constrain the maximum magnitude. Table 2 indicates the date and magnitude Mw of the maximum historical earthquake observed in the catalogue for each zone, as well as the presence of neotectonic ruptures or paleoearthquake evidences and the published paleoseismic magnitudes.

The analysis of seismic activity by zone emphasizes strong contrasts in the maximum magnitudes observed between certain close zones. This is in particular the case in the internal Alps. In order to ensure a better coherence in the definition of maximum magnitudes, GEOTER developed a global solution which consists in gathering the seismotectonic zones by regional geodynamic context of deformation.

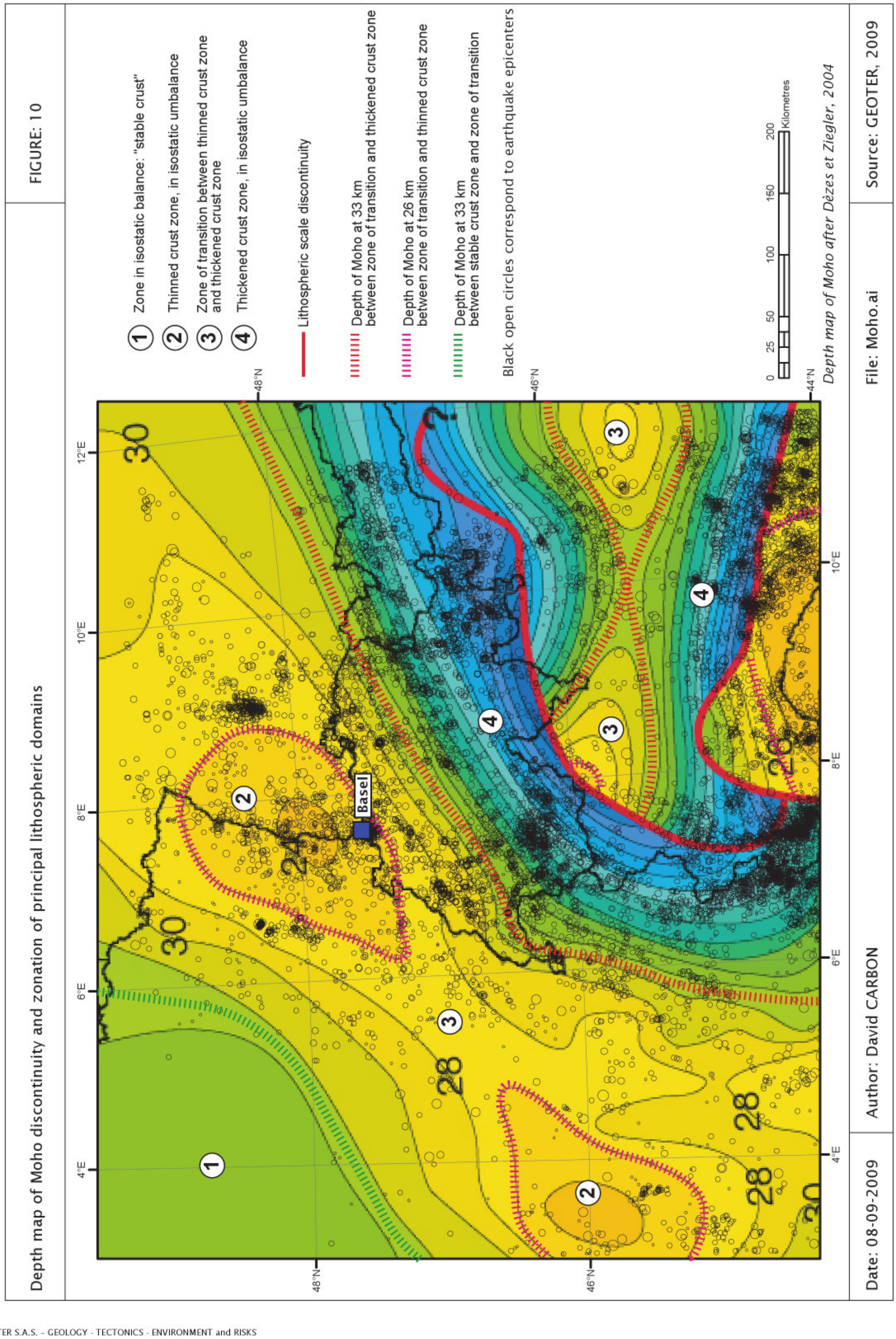


Figure 10: Depth map of Moho discontinuity and zonation of principal lithospheric domains

The confrontation of geological, geophysical and topographical data which characterize the crustal deformations on a large scale shows that it is possible to distinguish geodynamical contexts which are represented by stable crust domain in isostatic balance (fossil Moho) and unstable crust domain in isostatic unbalance (recent and mobile Moho) (Ziegler and Dèzes, 2006) (Figure 10).

These geodynamic contexts at differentiated rates of deformation are as follows:

1. The context with passive deformation where the fossil MOHO is in isostatic balance at an average depth of 30 ± 3 km, currently represents the most stable zones of the Western European platform and thus the least seismic ones (for example the Paris basin and most of Northern Europe).
2. The context of active deformation with strong seismic activity where the recent and mobile Moho is isostatically unbalanced. This unbalance is related either to the crustal extension of the rifting zones or above hot points of the Massif Central, Rhine Graben and Gulf of Lion (depth of Moho at 15-26 km), or to the crustal thickening of the alpine and Pyrenean orogenic zones (depth of Moho at 33-55 km).
3. Between these domains of active deformation, transition domains correspond to depth of Moho ranging between 27 and 33 km which underline a major reduction of deformation rate and seismic activity.

In the area covered by the seismic zonation, the seismic zones belong either to the second or the third context.

The maximum possible earthquake per seismic zones is expressed between two bounds of values in order to consider random uncertainties related to the evaluation of this parameter. The Mmax parameter is defined taking into account the magnitude of the maximum credible earthquake of each zone and the magnitude of potential paleoearthquakes published in the literature:

- **6.7≤ Mmax ≤ 7.3 for the zones in context of active deformation and unbalanced continental crust;**
- **6.1≤ Mmax ≤ 6.7 for the zones belonging to the transition domain with lesser seismic activity and weaker rate of deformation.**

In the context of active deformation, the maximum observed magnitude reached 6.9 (assumed magnitude of the 1356 Basel earthquake). Nevertheless, a strong uncertainty persists on the evaluation of this magnitude deduced from macroseismic data. Its value published in the IRSN catalog (Levret *et al.* 1996) and more recently by Lambert *et al.* (2005) is thus revalued to 6.2.

According to the paleoseismological studies (Ferry, 2004), at least three paleoearthquakes with magnitude ranging between 6.3 and 6.7 affected the Basel area in the last 8000 years. The most recent rupture would correspond to the 1356 Basel earthquake.

The most important historical earthquake observed within the transition domain corresponds to the 1682 Remiremont earthquake with an epicentral intensity of VIII. Its macroseismic magnitude is estimated at 6.0. In addition, an indirect evidence of paleoearthquake is listed in relation to sedimentary paleolandslides in the Baldegg Lake located in the molassic Swiss basin. Its magnitude is estimated at 6.2 (Becker *et al.,* 2005).

The maximum magnitudes of **7.0 ± 0.3** considered for the active deformation zones and of **6.4 ± 0.3** for the transition zones, covers the uncertainties of the maximum magnitude historically observed or measured by paleoearthquake ruptures. They at least raise the maximum observed magnitude of 0.5 units and their upper bound adopts an additional margin of at least 0.3 units.

Dominant mechanisms of deformation

In the framework of this study the regionalization map of strain and stress of western Alps and its foreland domain realized by Delacou (2004) is used in order to define the dominant mechanisms of deformation of each seismic zone within the seismotectonic model. Figure 11 presents the superposition of the seismic zones with this current stress field map which shows the localization of domains in extension (in blue) in the internal Alps in particular compared to the domains under compression (in red). The green domains correspond to a dominant strike-slip mechanism of deformation.

Table 2 provides the dominant mechanism of deformation considered for each seismic zone.

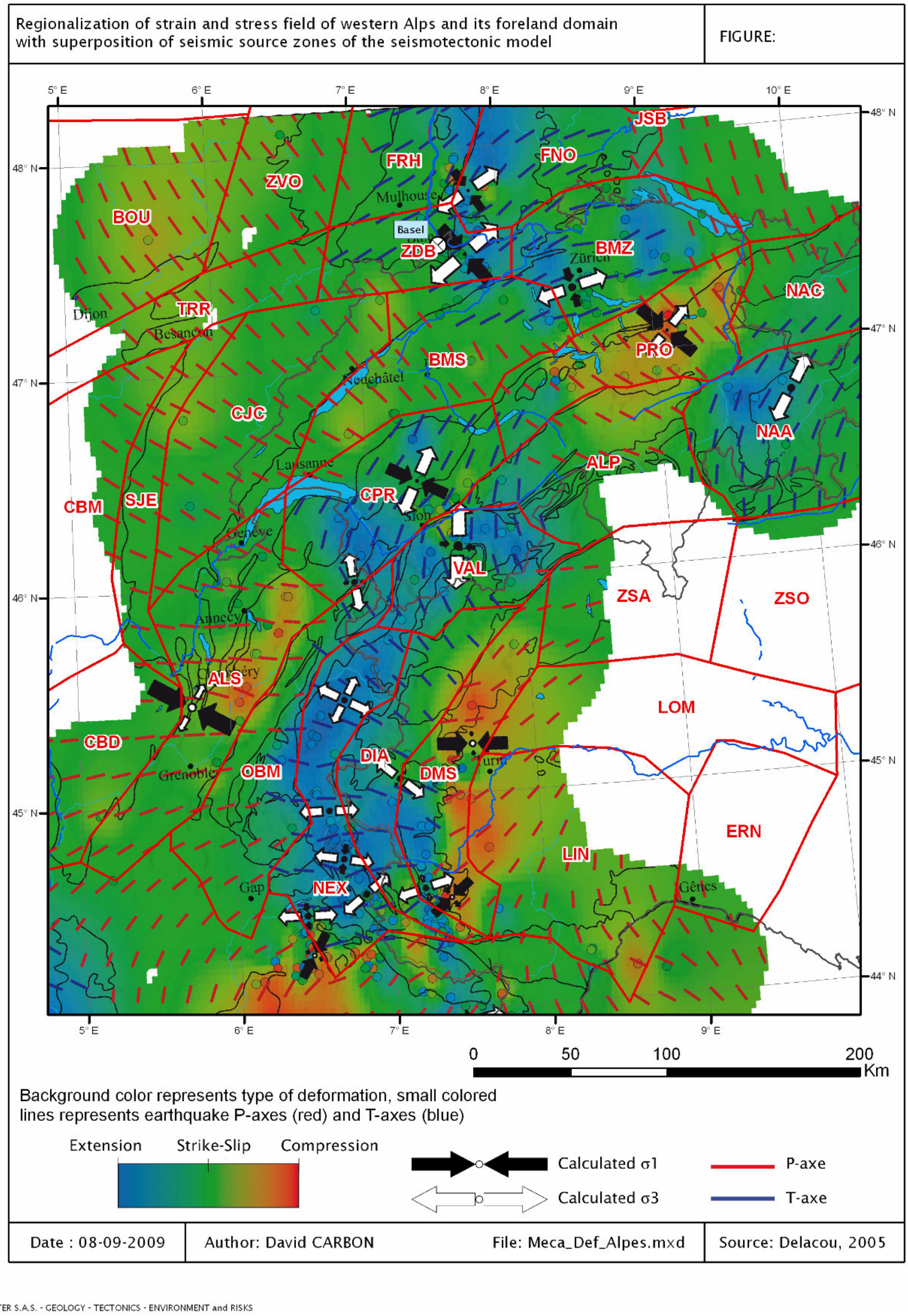


Figure 11: Regionalization of strain and stress field of western Alps and its foreland domain with superposition of seismic source zones of the seismotectonic model

3.2.2.4 Synthesis of the seismic zone parameters of the GEOTER zonation

The following table synthesizes the seismic source parameters of the seismotectonic model.

Seismic zone					Major historical earthquakes		Source parameters			
Name zone	ID zone	Dominant mechanisms of deformation	Neotectonic rupture or paleoseismic evidence	$M_{paleo-seismic}$	Date	Mw	Mmax min	Mmax max	H min	H max
ZONE OF BASEL	ZDB	Transtensif	i52, i58, i59	6.3 to 6.7 Ferry, 2005	18-10-1356	6.9	6.7	7.3	5	15
NORTHERN LIGURIA	LIN	Transpressif			22-10-1541	5.3	6.1	6.7	5	15
INNER ALPS DOMAIN	DIA	Extensif (S) to Transtensif (N)	i53		12-9-1785	5.8	6.7	7.3	5	15
RHINE SAONE TRANSFORM ZONE	TRR	Strike-slip			30-10-1828	5.4	6.1	6.7	5	15
VOSGES ZONE	ZVO	Strike-slip			12-5-1682	6.0	6.1	6.7	5	15
BOURGOGNE ZONE	BOU	Transpressif			6-7-1783	4.7	6.1	6.7	5	15
NORTHERN EXTERNAL ALPS	ALS	Transpressif to strike-slip	i16, i17, i19	6.1 to 6.4 Baize et al., 2002	19-2-1822	5.6	6.7	7.3	3	15
NE SHEAR ZONE OF BAS-DAUPHINE BASIN	CBD	Strike-slip			18-2-1889	5.1	6.1	6.7	5	15
SUBMERIDIAN FAULT ZONE OF EXTERNAL JURA	SJE	Strike-slip			9-9-1879	4.7	6.1	6.7	3	15
PERMO-CARBONIFEROUS BASINS OF CENTRAL JURA	CJC	Transpressif			17-8-1846	5.5	6.1	6.7	3	15
PERMO-CARBONIFEROUS BASINS OF BRESSE AND NE FRENCH MASSIF CENTRAL	CBM	Transtensif			24-6-1878	5.4	6.1	6.7	5	15
SWISS MOLASSIC BASIN	BMS	Transpressif (SW) to transtensif (NE)	i56	~6.2 Becker *et al.*, 2005	1-3-1929	5.3	6.1	6.7	3	10
CRYSTALLIN EXTERNAL MASSIFS OF OISAN, BELLEDONNE AND MONT BLANC	OBM	Transpressif (S) to Transtensif (N)	i18		22-7-1881	5.8	6.7	7.3	5	15
VALAIS ZONE	VAL	Extensif to transtensif			25-7-1855	6.4	6.7	7.3	5	15
DORA MAIRA ET SESIA ZONE	DMS	Transpressif (N) to Transtensif (S)			2-4-1808	6.2	6.7	7.3	5	20
EXTERNAL NAPPES OF VANOISE AND BRIANCONNAIS	NEX	Extensif to transtensif			12-7-1904	5.4	6.7	7.3	5	15
SWISS PREALPS AND CHABLAIS	CPR	Transtensif			11-3-1584	6.4	6.7	7.3	3	15
NORTHERN EMILIA ROMAGNA	ERN	Transtensif			9-10-1828	5	6.7	7.3	5	15

Seismic zone					Major historical earthquakes		Source parameters			
Name zone	ID zone	Dominant mechanisms of deformation	Neotectonic rupture or paleoseismic evidence	$M_{paleo\text{-}seismic}$	Date	Mw	Mmax min	Mmax max	H min	H max
LPO PLAIN AND LOMBARDY	LOM	Strike-slip			15-5-1951	4.7	6.1	6.7	5	20
HELVETIC PREALPS	PRO	Transpressif to compressif	i54, i55, i57	~6.2 Becker *et al.*, 2005	18-9-1601	6.2	6.7	7.3	3	15
CRUSTAL UNIT OF AUSTRO-ALPINE UNITS	NAA	Extensif to transtensif			4-9-1295	6.5	6.7	7.3	3	15
MOLASSIC BASIN OF ZURICH-BODENSEE	BMZ	Extensif to Transtensif			11-8-1771	5.4	6.1	6.7	5	25
UNIT COVERS OF AUTRO-ALPINE NAPPES	NAC	Strike-slip			27-8-1787	5.5	6.7	7.3	3	15
LEPONTINE ALPS	ALP	Transpressif			23-3-1960	5.3	6.7	7.3	3	15
WESTERN LUGANO ALPS	ZSA	Transpressif			1-2-1369	5.1	6.1	6.7	5	20
EASTERN LUGANO ALPS	ZSO	Transpressif			25-12-1222	5.7	6.7	7.3	5	20
SOUTHERN RHINE GRABEN	FRH	Transtensif	i40, i41, i42, i50	6.0 to 6.5 Baize *et al.*, 2002	3-8-1728	5.5	6.7	7.3	5	15
BLACK FOREST	FNO	Trantensif to extensif			30-12-1935	5.3	6.1	6.7	5	15
SOUABE JURA ZONE	JSB	Strike-slip			16-11-1911	5.8	6.1	6.7	5	15

Table 2: Synthesis of the seismic zone parameters of the GEOTER zonation

3.2.3 Near regional fault model

As a result of AP2000 and AP4000, the analysis of the potential triggered seismicity has been analyzed considering a near-regional fault model. The objective being to assess an hazard increment between the normal period and the operating period, it was necessary to introduce the near-regional fault model as part of the whole seismotectonic model.

The AP4000 workpackage was developed to investigate how the perturbation forces introduced by the geothermal reservoir might trigger earthquakes on the faults, and how might be perturbed the normal seismic cycle of characteristic magnitudes on these faults. As main results, it provides acceleration or deceleration values of the return periods associated to different characteristic magnitudes.

The identification and 3D geometry of the faults considered for this fault model are based on the AP 2000 workpackage « Structural model of potential seismogenic faults » (Delacou *et al.,* 2009) and are presented in Figure 12.

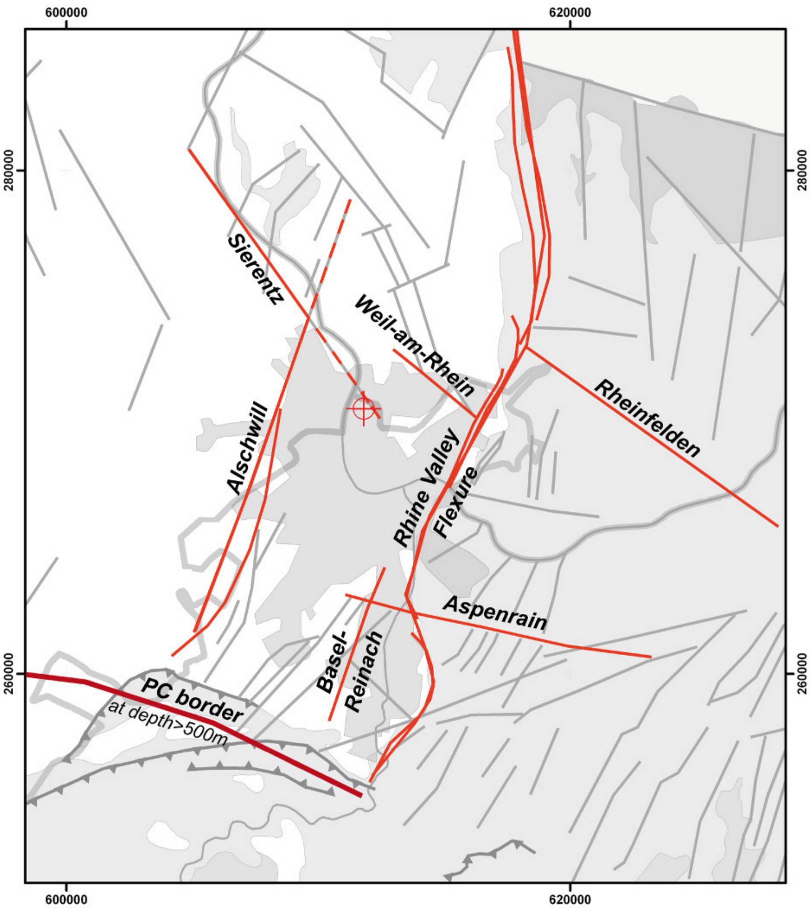


Figure 12: Selected faults for the risk analysis provided by AP2000 work package.

This structural model counts 8 faults or fault systems (several segments) with variable lengths located in a radius of approximately 15 km around the geothermic field site. Their geometric characteristics are synthesized Table 3.

Fault name	Segment	Mean orientation	Mean dip and dip direction	Depth for the model	Length (min)	Length (max)
Alschwill Fault	East	025°	70°W	4 km		11 km
	West	**020°**	**70°W**	**13 km**	**13.2 km**	18.3 km
Rhine Valley Flexure fault	**2-1**	**020°**	**70°W**	**17 km**		**13.2 km**
	2-2	020°	70°W	17 km	7.6 km	43.1 km
Sierentz fault		**145**	**84°SW**	**15 km**	**8.2 km**	13.2 km
Basel-Reinach fault		**20°**	**70°E**	**6 km**		**6.5 km**
Weil-am-Rhein fault		**130°**	**75°SW**	**5 km**		**4.3 km**
Aspenrain fault		**101°**	**70°S**	**10 km**		**12.4 km**
PC border fault		**103°**	**70°N**	**10 km**		**26 km**
Rheinfelden fault		**125°**	**70°NE**	**12 km**		**12.3 km**

Table 3: Fault geometric characteristics of the near regional fault model as determined in AP2000. In bold characters: considered segments for the near regional fault model for the hazard evaluation

The dimensions (length, surface area of fault planes) make these faults prone to large magnitudes (M>5), and the impact of a possible modification of their seismic cycle by geothermal exploitation, as defined in AP4000, will be analyzed, considering their proximity to the geothermal field. No other more distant fault was included in the structural model.

A simplification is introduced for the two fault systems (RVF and Alschwill fault systems) characterized by two parallel segments. The final set of faults exploited for the PSHA model is presented Figure 13.

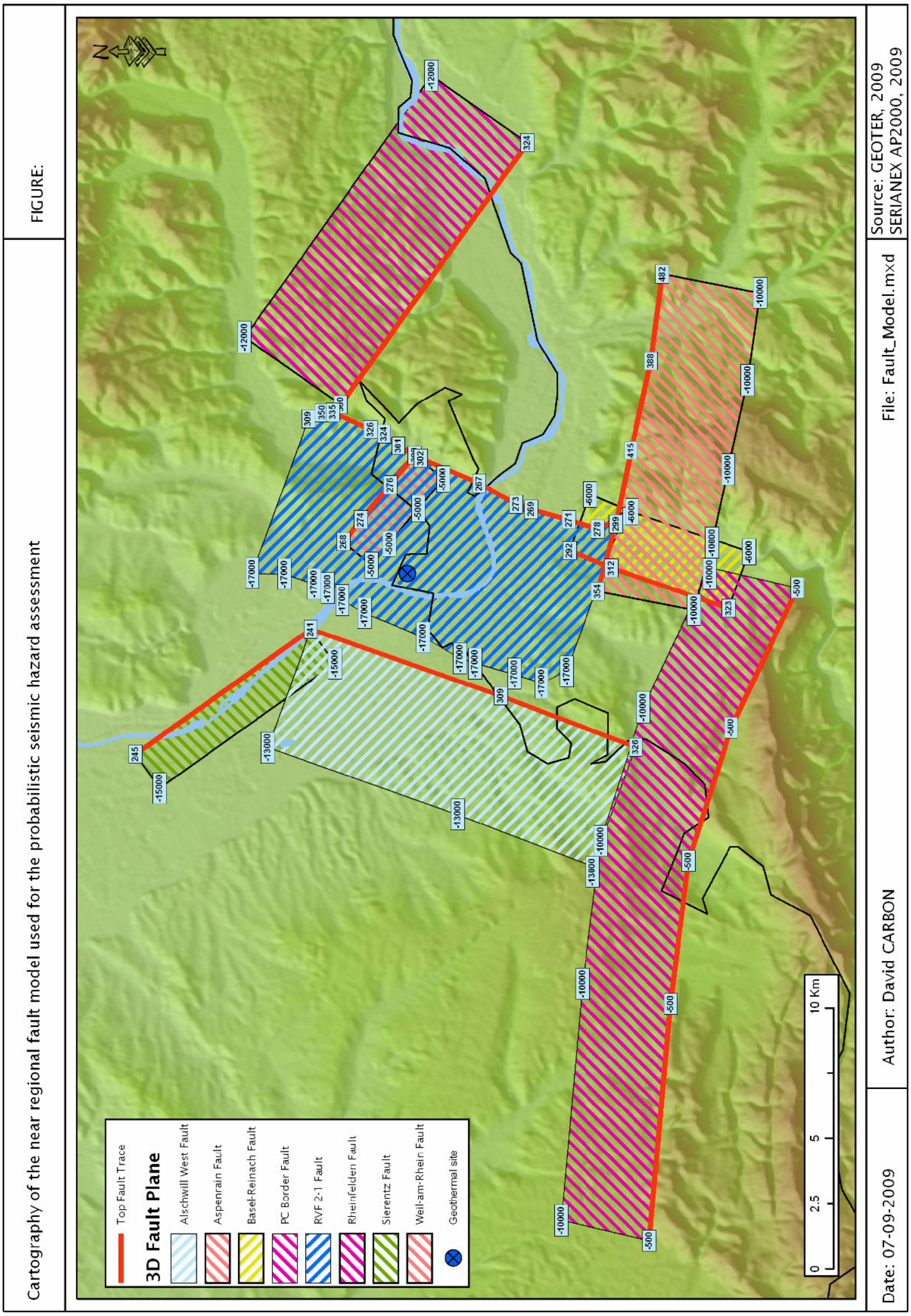


Figure 13: Cartography of the near regional fault model used for the probabilistic seismic hazard assessment

3.2.4 Seismic source associated to the Geothermal reservoir

This zone is considered as a square area of 1 km wide. The depth of the induced earthquakes ranges from 3 to 5 km following the data of the SERIANEX catalog and the indications of AP3000.

3.3 Attenuation laws

The choice of attenuation law is one of the most influent parameter of a PSHA assessment, and the consideration of epistemic and aleatory uncertainties has a key influence on the predicted ground motions. This is particularly true when the PSHA is developed to predict peak ground accelerations and spectral acceleration, because in area of moderate activity the attenuation models are not calculated from regional empirical database but from database available in more active areas.

However, as the objective of the project was not the seismic design of an installation, and because the calculation is performed in intensity, it was possible to use attenuation models developped in intensity from the statistical exploitation of the Swiss national database on macroseismic data. As a consequence and due to the limited budget available to develop the PSHA, the choice is done not to propagate the epistemeic uncertainty. A specific attenuation law can however be associated to each seismotectonic area of the model.

The attenuation laws used correspond to the ECOS macroseismic attenuation relations calculated by SED as a part of the revision of the earthquake catalog of Switzerland finalized in 2002 (SED, 2002; Fäh *et al.*, 2003). The equations of these attenuation laws are a function of the epicentral distance (with a distinction between far distances and short distances < 55 km), on the type of deformation (Alpine belt or Foreland) and on the depth of seismic events (shallow or deep events; we assumed shallow for 10 or less km and deep otherwise depending on the depth associated to the seismotectonic areas).

We used the appropriate attenuation law according to the consistency of the seismotectonic zone definition with afore mentioned parameters (see Table 5). The equations of different attenuation laws are the following:

For sites in the 0-55 km distance range:

- Iexp=1.27*M-0.043*R+0.096 (shallow)
- Iexp=1.44*M-0.030*R+1.73 (deep)

For sites in the 55-200 km distance range:

- Iexp=1.27*M-0.0115*R+1.65 (shallow-Foreland)
- Iexp=1.27*M-0.0064*R+1.93 (shallow-Alpine)
- Iexp=1.44*M-0.0115*R+2.76 (Deep-Foreland)
- Iexp=1.44*M-0.0064*R+3.04 (Deep-Alpine)

For the near-regional fault model and for the geothermal reservoir source we used the attenuation law corresponding to shallow earthquakes at close distance.

The standard deviation of the attenuation law remains an influent parameter. As the SED report doesn't provide any value of the standard deviation, we adopted a standard deviation of 1 degree of EMS intensity in agreement with a discussion we had with Dr Donat Fäh (personal communication). This value is also consistent with the standard deviations obtained by GEOTER using only French macroseismic data (Martin *et al.* 2008).

Regarding the propagation of the aleatory uncertainty associated to the attenuation law, the choice was done to consider 3 standard deviations on the integration process, when considering the seismic activity of the tectonic sources. Nevertheless, we integrated only until 2 standard deviations when considering the zone associated to the geothermal field, and accounting for the attenuation of induced earthquakes. This choice is mainly based on the macroseismic empirical data of the seismic sequence of December 2006 that show that the observed intensities never exceed the epicentral intensity by an increment of more than 2. We think that this parameter could be even taken with a lower value. This should be nevertheless be based on the analysis of real macroseismic data based on real earthquakes.

3.4 Common input parameters

Minimum magnitude:

The same minimum magnitude must be considered to allow a consistent comparison between induced hazard and tectonic hazard. The maximum magnitude associated to the induced seismicity varies between 3.2 and 3.7 depending on the model. The threshold of perception of shallow earthquake is around 2.5 and the minimum magnitude of all the seismic sources is set to 2.5. This is probably a conservative approach. A different choice would decrease the probabilities of exceedance of low intensities.

Integration of the standard deviation of the attenuation law:

Comparing predictive PSHA models in intensity and observed felt intensities in France, Martin et al. (2008) defined that model integrating up to 3 standard deviations leaded to better consistency with observations than model integrating at lower values or at infinity. It was decided to adopt the same number of standard deviation here.

However for the geothermal field seismic source, there is no evident reason to consider such a value. Due to the shallow depth of the induced event, it is probable that a more rapid attenuation is observed compared to tectonic events. Considering the attenuation law and the macroseismic intensity that is associated to a magnitude Mw=3.2, the observed damages doesn't exceed the epicentral intensity by more than 1.5. Even if a precise definition would require the analysis of a great number of small earthquakes, we decided to limit the integration to 2 standard deviations.

Maximum magnitudes of the area seismic sources:

They are described in the chapter on the seismotectonic model.

Maximum magnitude of the geothermal field source zone:

The maximum magnitude has been defined in AP 3000 work-package. Depending on the AP3000 model considered, the maximum magnitude is set to:

- 3.2±0.5 for the “empirical” model (only used when considering the stimulation period)
- 3.7±0.4 for the synthetic models (used when considering the stimulation and circulation periods)

4 BACKGROUND SEISMIC HAZARD (NORMAL PERIOD)

4.1 Seismic source parameters

For the near-regional fault model, the seismic parameters are synthesized in Table 4. The activity rates of each fault are calculated using the a and b parameters provided by AP2000 for the Basel zone. The activity rates are distributed as a function of the faults number and considering that all earthquakes greater than a magnitude Mw=4.5 are originated by the faults.

Fault Name	a	b	λ (Mwmin=4.5)	β	Mmax
Alschwill	2.31	0.9	0.00227±0.0004	2.07233±0.4	7.0±0.3
BaselReinach	2.31	0.9	0.00227±0.0004	2.07233±0.4	7.0±0.3
RVF	2.31	0.9	0.00227±0.0004	2.07233±0.4	7.0±0.3
Sierentz	2.31	0.9	0.00227±0.0004	2.07233±0.4	6.0±0.5
Weil-Am-Rhein	2.31	0.9	0.00227±0.0004	2.07233±0.4	6.0±0.5
Aspenrain	2.31	0.9	0.00227±0.0004	2.07233±0.4	7.0±0.3
PC border Fault	2.31	0.9	0.00227(0.0004	2.07233±0.4	7.0±0.3
Rheinfelden	2.31	0.9	0.00227(0.0004	2.07233±0.4	7.0±0.3

Table 4: Seismic parameters associated to near-regional fault model.

For the area source model, the seismic parameters are detailed in chapter 3 and presented in Table 5. The Gutenberg-Richter parameters (a, b, λ and β) of the area sources are calculated using the maximum likelihood methodology developed by Weichert (1980). This methodology allows to take into account different completeness periods for each magnitude range and to determine the uncertainties.

4.2 Logic tree used and treatment of the uncertainties

For simplification, and due to budget limitation, the choice was done to limit the consideration of the epistemic uncertainties. A simplified logic tree is used to perform the PSHA (Figure 14).

A single seismotectonic model combining area sources and near-regional sources is adopted. This limits the consideration of epistemic uncertainty on the seismic source delineation and characterization, which is not a constraint for the project, the objective being to obtain a reference representative of the tectonic hazard. It is only recalled here that such a model would require refinements if the objective were the design of a critical facility.

As all the calculations are performed in intensity, no epistemic uncertainty is introduced on the attenuation laws model. This choice is justified by the fact that the available ETH attenuation laws have been calculated with Swiss data and are consequently representative of the different seismotectonic domains and distances. Each seismic source is characterized by one of the attenuation laws described in chapter 3.3, depending on the general seismotectonic context (Alps/Foreland), on the depth of the seismogenic crust and on the distance.

Only the random uncertainties associated to the maximum magnitude, Mmax, the seismic activity rate parameters, λ, and the slope of the Gutenberg-Richter law, β, are propagated. The influence of the depth is negligible because the attenuation law is parametred as a function of the epicentral intensity.

The random samples on λ and their correlated β parameter are obtained adopting a normal distribution truncated to 1 standard deviation. The random samples of Mmax are calculated using a uniform distribution between the maximum and minimum value of Mmax.

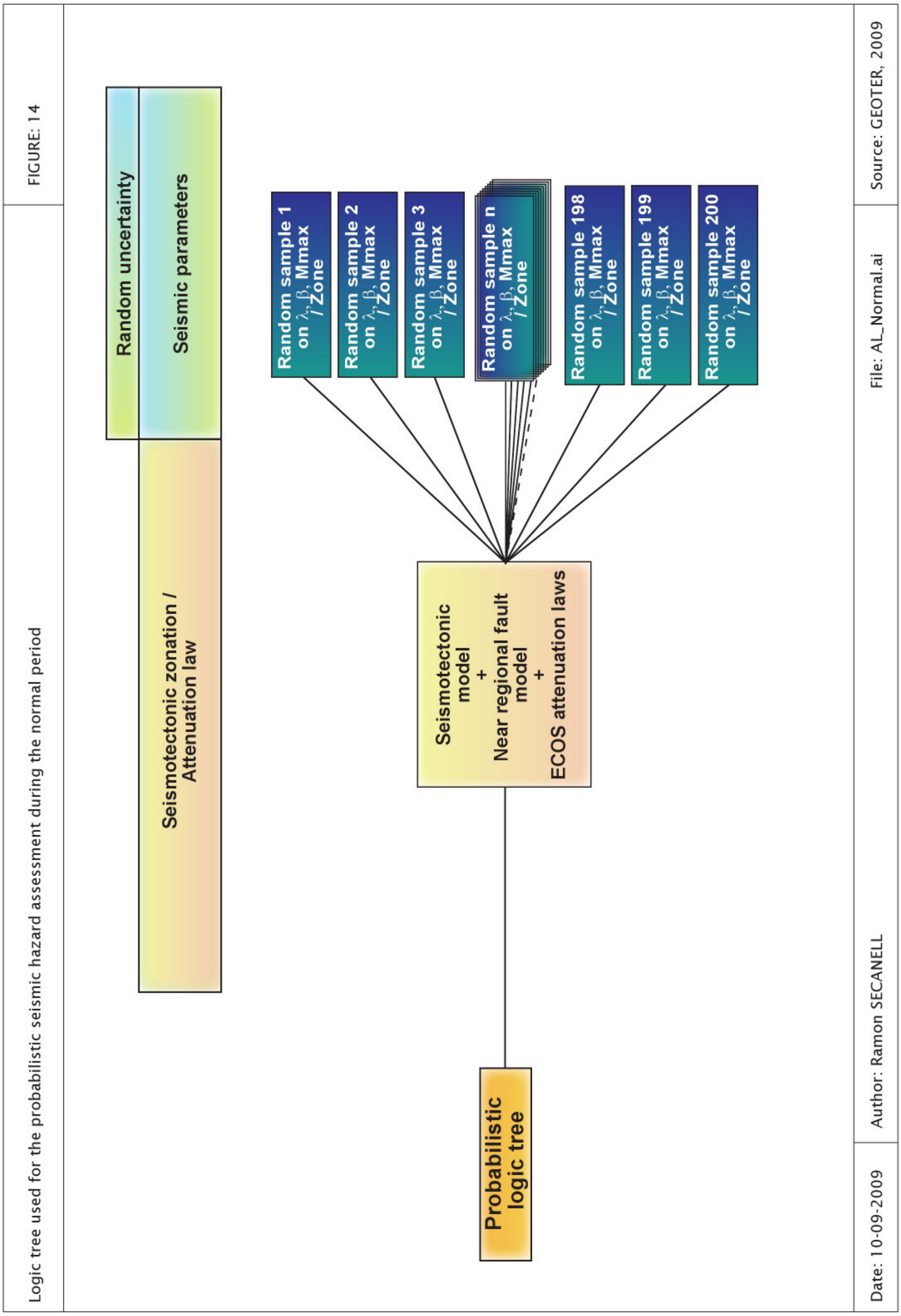


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Figure 14: Logic tree used for the probabilistic seismic hazard assessment during the normal period.

AREA SOURCES MODEL SEISMIC PARAMETERS																					
	Calculated parameters											Adjustement to the same Mmin									
ZONE	a	b	σa	σb	λ	β	σλ Mmin adjust	σβ	Mmin adjust	Mmax Obs.	Step mag	λ Mmin=2.5	λ / κm² *10^6	β	σλ Mmin	Mmin calcul	σβ	H	Mmax	Attenuation. law	surface (km)
ZDB	2.27	-0.90	0.20	0.08	1.033	2.079	0.12	0.19	2.5	6.7	0.5	1.0324	297	2.079	0.1206	2.5	0.19	5 à 15	4.5	Clo_Sha_For	3,471
LIN	3.37	-1.13	0.08	0.04	17.057	2.596	0.20	0.10	1.9	5.3	0.3	3.5929	338	2.596	0.0424	2.5	0.10	5 à 15	6.1 à 6.7	Lar_Sha_Alp	10,617
DIA	1.85	-0.78	0.30	0.11	0.391	1.792	0.11	0.25	2.9	5.8	0.3	0.8000	155	1.792	0.2195	2.5	0.25	5 à 15	6.7 à 7.3	Lar_Sha_Alp	5,150
TRR	1.46	-0.83	0.44	0.20	0.160	1.922	0.12	0.47	2.7	5.4	0.3	0.2342	28	1.922	0.1768	2.5	0.47	5 à 15	6.1 à 6.7	Lar_Sha_For	8,351
ZVO	1.78	-0.82	0.40	0.15	0.205	1.898	0.10	0.35	3.0	6.0	0.3	0.5294	102	1.898	0.2682	2.5	0.35	5 à 15	6.1 à 6.7	Lar_Sha_For	5,193
BOU	2.15	-1.02	0.23	0.12	1.265	2.354	0.18	0.28	2.0	4.7	0.3	0.3899	20	2.354	0.0548	2.5	0.28	5 à 15	6.1 à 6.7	Lar_Sha_For	19,854
ALS	2.37	-0.87	0.09	0.05	4.339	1.994	0.16	0.11	2.0	5.6	0.3	1.6008	178	1.994	0.0588	2.5	0.11	3 à 15	6.7 à 7.3	Lar_Sha_Alp	8,992
CBD	1.74	-0.84	0.17	0.09	1.130	1.937	0.16	0.21	2.0	5.1	0.3	0.4289	52	1.937	0.0608	2.5	0.21	5 à 15	6.1 à 6.7	Lar_Sha_For	8,246
SJE	2.05	-1.06	0.36	0.18	0.533	2.436	0.16	0.40	2.2	4.7	0.3	0.2567	76	2.436	0.0786	2.5	0.40	3 à 15	6.1 à 6.7	Lar_Sha_For	3,390
CJC	2.32	-0.92	0.12	0.06	3.044	2.113	0.16	0.14	2.0	5.5	0.3	1.0588	118	2.112	0.0563	2.5	0.14	3 à 15	6.1 à 6.7	Clo_Sha_For	8,939
CBM	1.29	-0.78	0.27	0.14	0.319	1.789	0.14	0.33	2.3	5.4	0.2	0.2232	17	1.789	0.0958	2.5	0.33	5 à 15	6.1 à 6.7	Lar_Sha_For	13,032
BMS	2.27	-0.87	0.10	0.05	3.374	2.011	0.15	0.12	2.0	5.3	0.3	1.2341	189	2.011	0.0566	2.5	0.12	3 à 10	6.1 à 6.7	Clo_Sha_For	6,545
OBM	2.52	-1.06	0.16	0.08	2.489	2.445	0.17	0.18	2.0	5.8	0.3	0.7331	113	2.445	0.0510	2.5	0.18	5 à 15	6.7 à 7.3	Lar_Sha_Alp	6,500
VAL	2.37	-0.85	0.08	0.04	4.741	1.955	0.15	0.09	2.0	6.4	0.3	1.7838	429	1.955	0.0568	2.5	0.09	5 à 15	6.7 à 7.3	Lar_Sha_Alp	4,159
DMS	2.36	-0.80	0.28	0.10	0.922	1.835	0.14	0.22	3.0	6.2	0.3	2.3070	422	1.835	0.3542	2.5	0.22	5 à 20	6.7 à 7.3	Lar_Dee_Alp	5,463
NEX	2.22	-0.81	0.29	0.10	0.614	1.863	0.10	0.23	3.0	5.4	0.3	1.5596	255	1.863	0.2635	2.5	0.23	5 à 15	6.7 à 7.3	Lar_Sha_Alp	6,117
CPR	2.70	-0.89	0.06	0.03	8.355	2.049	0.15	0.07	2.0	6.4	0.3	3.0009	454	2.049	0.0550	2.5	0.07	3 à 15	6.7 à 7.3	Lar_Sha_Alp	6,608
ERN	3.81	-1.26	0.21	0.08	4.573	2.902	0.20	0.20	2.5	5.0	0.3	4.5725	866	2.902	0.1952	2.5	0.20	5 à 15	6.7 à 7.3	Lar_Sha_Alp	5,279
LOM	2.30	-1.01	0.24	0.12	1.921	2.321	0.20	0.28	2.0	4.7	0.3	0.6019	78	2.321	0.0640	2.5	0.28	5 à 20	6.1 à 6.7	Lar_Dee_Alp	7,700
PRO	2.20	-0.77	0.07	0.03	4.609	1.770	0.15	0.08	2.0	6.2	0.3	1.9017	341	1.770	0.0604	2.5	0.08	3 à 15	6.7 à 7.3	Lar_Sha_Alp	5,584
NAA	2.86	-0.94	0.06	0.03	9.558	2.164	0.16	0.07	2.0	6.5	0.3	3.2393	337	2.164	0.0526	2.5	0.07	3 à 15	6.7 à 7.3	Lar_Sha_Alp	9,624
BMZ	3.67	-1.16	0.51	0.15	0.414	2.664	0.09	0.34	3.5	5.4	0.3	5.9402	967	2.664	1.2454	2.5	0.34	5 à 25	6.1 à 6.7	Clo_Dee_For	6,145
NAC	2.57	-0.91	0.08	0.04	5.580	2.105	0.15	0.10	2.0	5.5	0.3	1.9480	329	2.105	0.0539	2.5	0.10	3 à 15	6.7 à 7.3	Lar_Sha_Alp	5,926
ALP	2.36	-1.01	0.15	0.08	2.200	2.321	0.16	0.18	2.0	5.3	0.3	0.6891	98	2.321	0.0495	2.5	0.18	3 à 15	6.7 à 7.3	Lar_Sha_Alp	7,036
ZSA	1.56	-0.85	0.27	0.15	0.718	1.960	0.20	0.34	2.0	5.1	0.3	0.2694	45	1.960	0.0750	2.5	0.34	5 à 20	6.1 à 6.7	Lar_Dee_Alp	6,047
ZSO	2.38	-0.78	0.08	0.04	6.554	1.799	0.19	0.09	2.0	5.7	0.3	2.6659	230	1.799	0.0783	2.5	0.09	5 à 20	6.7 à 7.3	Lar_Dee_Alp	11,570
FRH	2.13	-0.78	0.14	0.06	1.528	1.796	0.13	0.13	2.5	5.5	0.3	1.5286	126	1.796	0.1268	2.5	0.13	5 à 15	6.7 à 7.3	Clo_Sha_For	12,096
JSB	2.57	-0.84	0.36	0.11	0.415	1.940	0.09	0.24	3.5	5.8	0.3	2.8890	852	1.940	0.6050	2.5	0.24	5 à 15	6.1 à 6.7	Lar_Sha_For	3,393
FNO	2.35	-0.94	0.13	0.06	2.910	2.174	0.17	0.15	2.0	5.3	0.3	0.9812	98	2.174	0.0559	2.5	0.15	5 à 15	6.1 à 6.7	Clo_Sha_For	9,989

Table 5: Seismic parameters associated to the area sources of the seismotectonic model

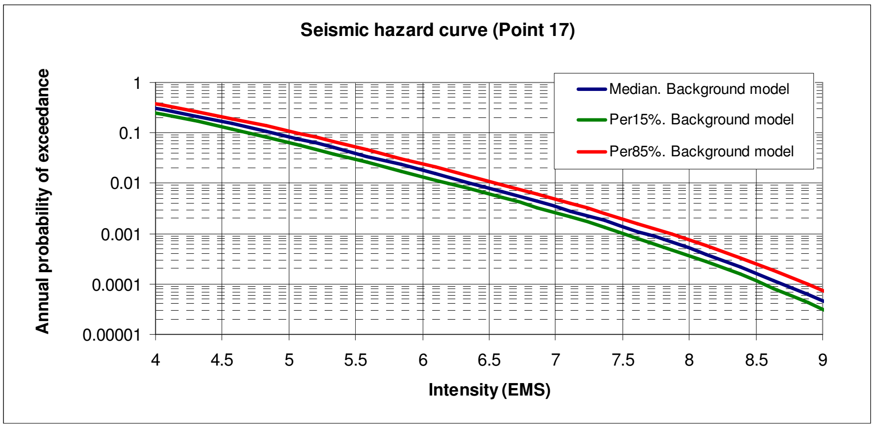
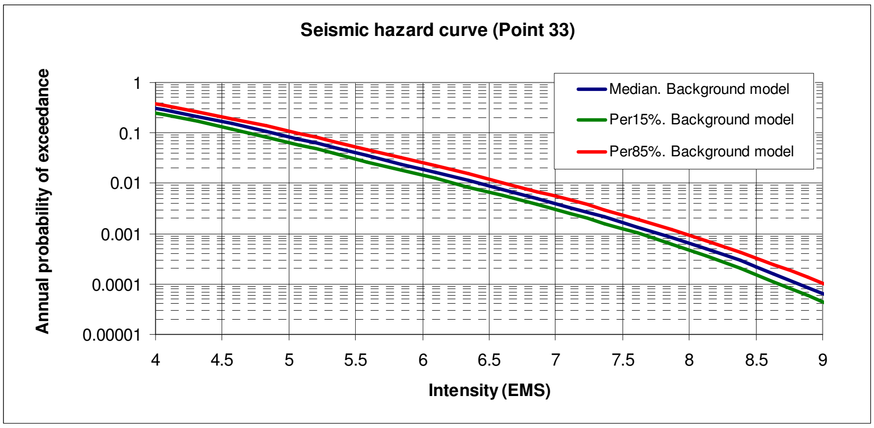
4.3 PSHA results during the normal period

4.3.1 Hazard curves at the calculation reference points

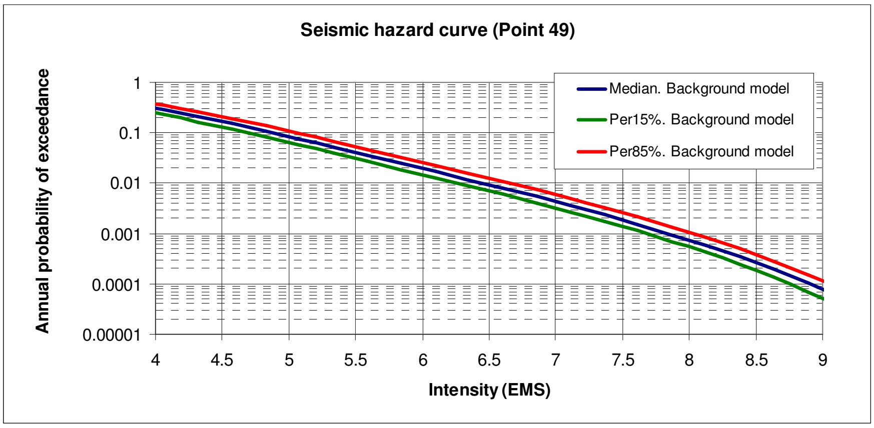
One hazard curve is calculated at each point of the calculation grid (Figure 4). To address the hazard variability, the hazard curves are presented on the Figure 15 at different points, the epicentral distance to the field varying between 0 km (geothermal field, point 64), 5 km (point 49), 10km (point 33) and 15 km (point 17).

If we consider the return period of 475 years, which is the return period considered in the recent seismic codes for current buildings seismic design, it appears that the corresponding intensity slightly varies between 7.3 and 7.5. This return period is associated to a probability of exceedance of 10% in 50 years or to an annual probability of exceedance of $2*10^{-3}$. At a return period of 10.000 years (see Figure 15), which is the return period considered to determine the input motions for the design of high critical facilities, the intensity is 8.8. The annual probability of exceedance of this intensity is 10^{-04}. The probability of exceedance is 0,5% in 50 years.

Figure 15 presents the median and percentiles 15% and 85% seismic hazard curves at the 4 reference points. They provide the annual probability of exceedance of the different intensities.

Point 17	
Point 33	

Point 49



Point 64

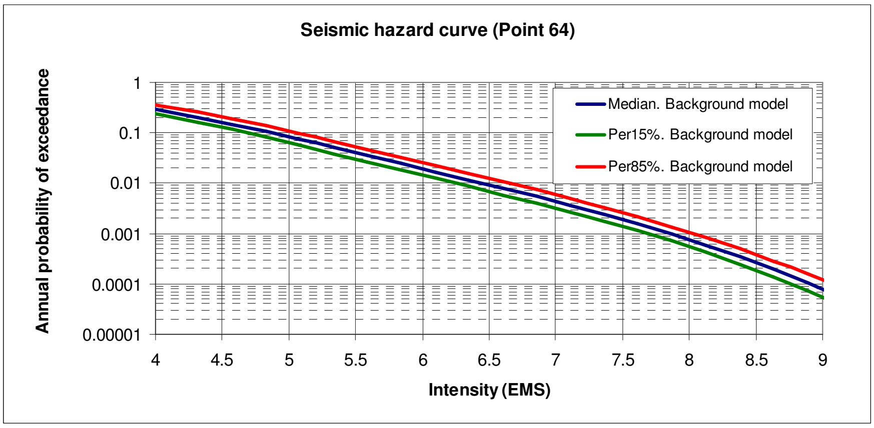


Figure 15: Normal period. Seismic hazard curves at the 4 reference points.

The results show a rather low variability (0.4 degree of intensity between percentile 15% and percentile 85%). This is due to the weak epistemic uncertainty propagation on the seismotectonic model and on the attenuation propagation model. As the attenuation laws are parametrized in epicentral distance, the variability of the depth plays a minor role. Only the aleatory uncertainties on Mmax, on the GR seismic parameters (λ and β), and on the attenuation model are considered. Such a weak variability was observed in France by Martin *et al.* 2008, and in Italy by Gomez et al. (2006), even using intensity models including the uncertainties propagation on the seismotectonic and attenuation models. The differences between percentile 15% and percentile 85% were not exceeding 1 intensity degree for the French model or the Italian. Even when epistemic uncertainties are propagated the variability is lower in an intensity model than in an model in acceleration.

The inclusion of the epistemic uncertainty on the seismotectonic model and attenuation laws would increase the seismic hazard uncertainty.

4.3.2 Comparison with other seismic hazard models

They are few recent publications on PSHA developed in intensity. For the Basel area our results are consistent with the published works of Grünthal et al. (1998), at least at 475 years of return period, the corresponding macroseismic intensity being similar (VII-VIII). In their approach Grünthal et al. (1998) used completely different source zones model, seismicity data set and attenuation model.

In order to determine the consistency of the background model with other existing PSHA models, we performed a simple test to compare the seismic hazard obtained in this study with a PSHA in intensity recently developed in France (Martin *et al.*, 2008). In this last PSHA, the probabilistic predictions were compared to real observed data (using the SISFRANCE historical database). A good agreement was found between predictions and observations for the city of Mulhouse, for intensities VI or higher and a weak over-estimation of the predictions was found for intensities IV and V.

The French assessment was carried out using completely different sets of data and hypothesis than in the present project:

- French catalogue of historical earthquakes where the events are defined in terms of epicentral intensity and not in magnitude (SISFRANCE catalogue, www.sisfrance.net);
- Two seismotectonic models (one close to the model adopted here);
- 14 regional attenuation laws depending on the French region (two models for each one of 7 regions) calibrated on French macroseismic observations;
- A minimum intensity set to Imin = V ;
- Integration of the standard deviation up to 3 standard deviations. The standard deviation of each attenuation law was close to 1 degree of intensity.

We used this model to develop a calculation on the site and to compare with the results obtained with the SERIANEX model, and with a simplified version of the SERIANEX project. The simplified version consists in closer hypothesis to the French model, eliminating the near-regional faults model, and adopting a minimum magnitude of 4.0 instead of 2.5.

Table 6 presents a comparison of the intensities obtained at the site with the three models and at 5 different return periods.

Model of PSHA	T = 475 years	T = 975 years	T = 1975 years	T = 5000 years	T = 10000 years
SERIANEX model	**7.5**	**7.6**	**8**	**8.5**	**8.8**
Simplified SERIANEX model	**7.0**	**7.4**	**7.8**	**8.2**	**8.6**
FRENCH model and data	**7.0**	**7.4**	**7.8**	**8.2**	**8.5**

Table 6: Intensities at 475, 975, 1975, 5000 and 10000 years of return period obtained from two different PSHA models using independent sets of input data.

The two independent assessments lead to similar results, when considering close hypothesis (French and Simplified SERIANEX model). The introduction of the fault model and the reduction of the minimum-magnitude tend to increase the hazard. For large return periods, the hazard increment is mainly caused by the fault model, while for small return periods the reduction of the minimum magnitude contributes to a significant hazard increment.

The background hazard model appears consistent with the independent French model.

4.3.3 Seismic hazard maps

Figure 16 presents the median seismic hazard maps at four different return periods: 1, 10, 30 and 475 years.

At one year of return period, the macroseismic intensity is close to the human perception threshold (III). This means that each year one earthquake should be felt in Basel. This probably exceeds reality and could be due to the low minimum magnitude that we adopted (Mw=2.5) together with the use of the attenuation model outside its magnitude validity domain.

The intensity associated to a return period of 10 years is ranging from 4.8 to 5.0.

The intensity associated to a return period of 30 years is between 5.5 and 5.7.

The seismic hazard map at 475 years of return period shows intensities between 7.2 and 7.5. At this larger return period the near-regional fault system becomes influent on the hazard distribution, while this effect is negligible at short return periods.

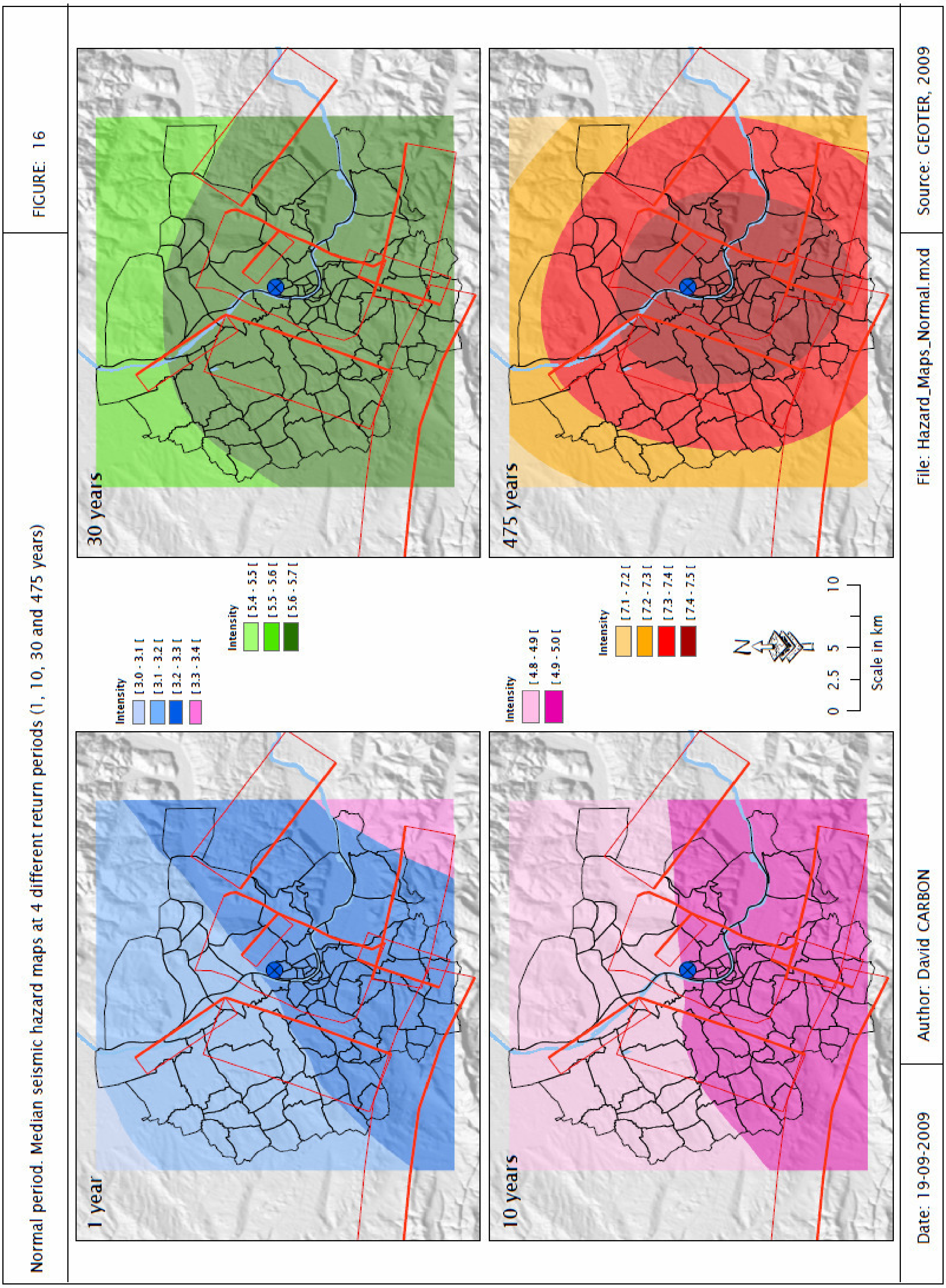


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Figure 16: Normal period. Median seismic hazard maps at 4 different return periods (1, 10, 30 and 475 years)

5 SEISMIC HAZARD DURING THE STIMULATION PERIOD

5.1 Specificities of the seismic activity distribution and controlling parameters

Within the field lifespan, the stimulation is a full non stationary process. The stimulation period only occurs one time the first twelve days (Figure 3). As a consequence, the hazard assessment including the induced activity associated to the stimulation period is only valid during these 12 days.

The seismotectonic model considers:

- The same seismotectonic model used for the normal period to account for the tectonic activity;
- The seismic source associated to the geothermal reservoir that accounts for the induced seismicity during the stimulation.

This induced seismicity is modelized using two seismic distributions based on the Poisson distribution. The first one (here called “empirical model”) uses the first set of hypotheses provided by AP3000 and the 2006 induced seismicity empirical catalog which is assumed to be more representative than the synthetic catalogs obtained from theoretical simulation. The second one (here called synthetic model) uses the second set of hypothesis provided by AP 3000.

During the stimulation, the seismic hazard appears controlled by the induced seismicity due to the high seismic activity rates of small earthquakes.

Among the hypothesis formulated in AP3000 on the Mmax value, the maximum magnitude during the stimulation is 3.7±0.4. Applying the SED attenuation law at the epicenter, no intensity higher than 6.8 could be observed, even considering 2 standard deviations. Therefore, we expect a great increase of the exceedance rates of low intensities (from III to VI mainly) and consequently a hazard increment at low intensities with a negligible effect for intensities above 6.8.

5.2 Empirical model

5.2.1 Seismic distribution analysis

After discussion with the partners, we decided to use the empirical recorded data instead of the synthetic catalog, paying more confidence in a real sequence than to the theoretical model. The reason was the overestimation of the activity rates compared to observations, when simulating the 2006 sequence.

The induced seismicity file contains 3158 earthquakes, 408 of them with Mw(SED) ≥0.5, during the first 12 days after the beginning of the fluid injection. The statistical analysis of SED (ETH report, 2007), shows that the completeness magnitude is Mw=0.3.

Considering the 12 days of seismicity after T0, the Figure 17 displays the temporal distribution of the seismicity (number of earthquakes/day). It shows a non-stationary behavior, as expected. The number of earthquakes (activity rate) increases with time until the occurrence of the December 8 2006 earthquake and it decreases after. The consideration of a stationary model (GR law) to model this seismicity implicitly implies the consideration of an averaged stationary rate of seismicity, $\lambda(M \geq 0.3)=263$, that would correspond to the red horizontal line on Figure 17. Assuming this hypothesis, the activity rate during the stimulation period is the same considering a stationary model or a non stationary model. The differences in daily activity rates predicted by both models have no interest here, because we are only interested in the exceedance rates during the whole stimulation period.

We tested that the cumulated exceedance rates of the 12 days after the main earthquake of the 8th December 2006 earthquake, using the Omori model, was almost equivalent to the averaged or cumulated exceedance rate using the Poisson model on the same period of time.

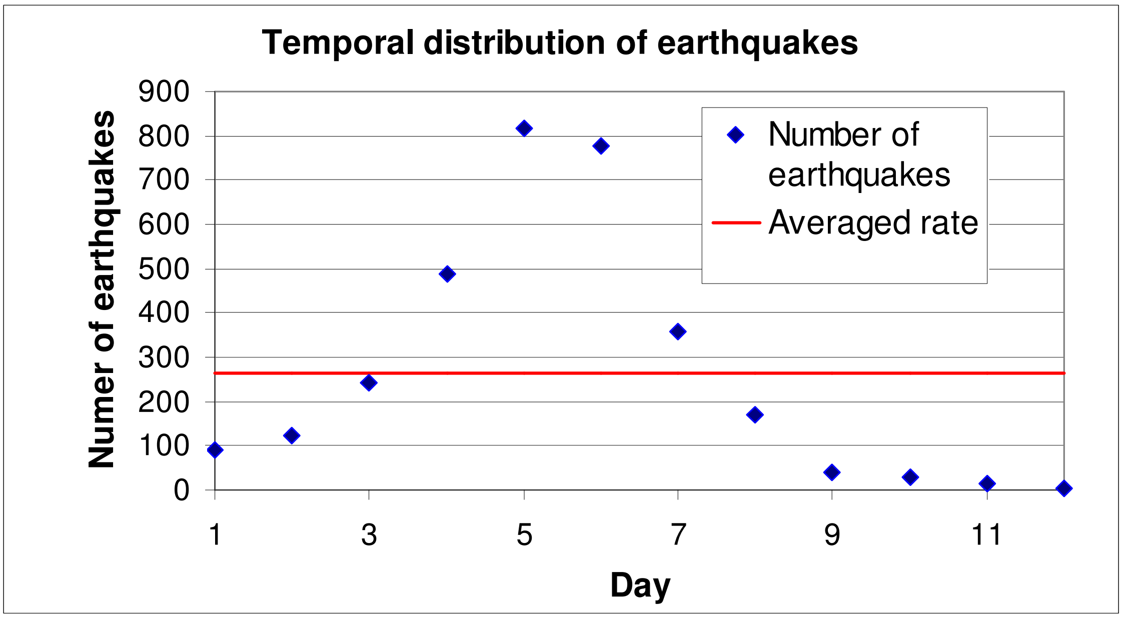


Figure 17: Temporal distribution of the seismicity 12 days after the beginning of the water injection

Figure 18 presents the distribution of magnitudes of the same seismic sample. The blue points represent the real data and the line the doubly truncated distribution of magnitudes.

We note that the seismic activity rate during the 2006 stimulation is time-dependent and the observed activity rate increases with time (Figure 17). For determining a mean activity rate for the 2006 seismic sequence, we averaged over a period of 12 days (Figure 17). This time window covers the injection period as well as approximately 6 days of the post-injection period, during which the largest magnitude event occurred. By choosing this rather large time window, we obtain an optimistic estimate of the seismic activity rate for the 2006 stimulation. This (optimistic) activity rate enters into the PSHA calculations. We note, however, that the seismic activity rate during future re-stimulation operations may exhibit a more complicate behaviour, with extremely low rates at the beginning of re-stimulation (e.g. Figure 18 of AP3000). Without detailed knowledge of future stimulation strategies, the accompanying (mean) seismic activity rate can only be roughly estimated. Although the seismic activity rate determined here may underestimate future activity rates, we note that the synthetic models developed in AP3000 tend to overestimate the seismic activity rate which counterbalances the optimistic figure determined here.

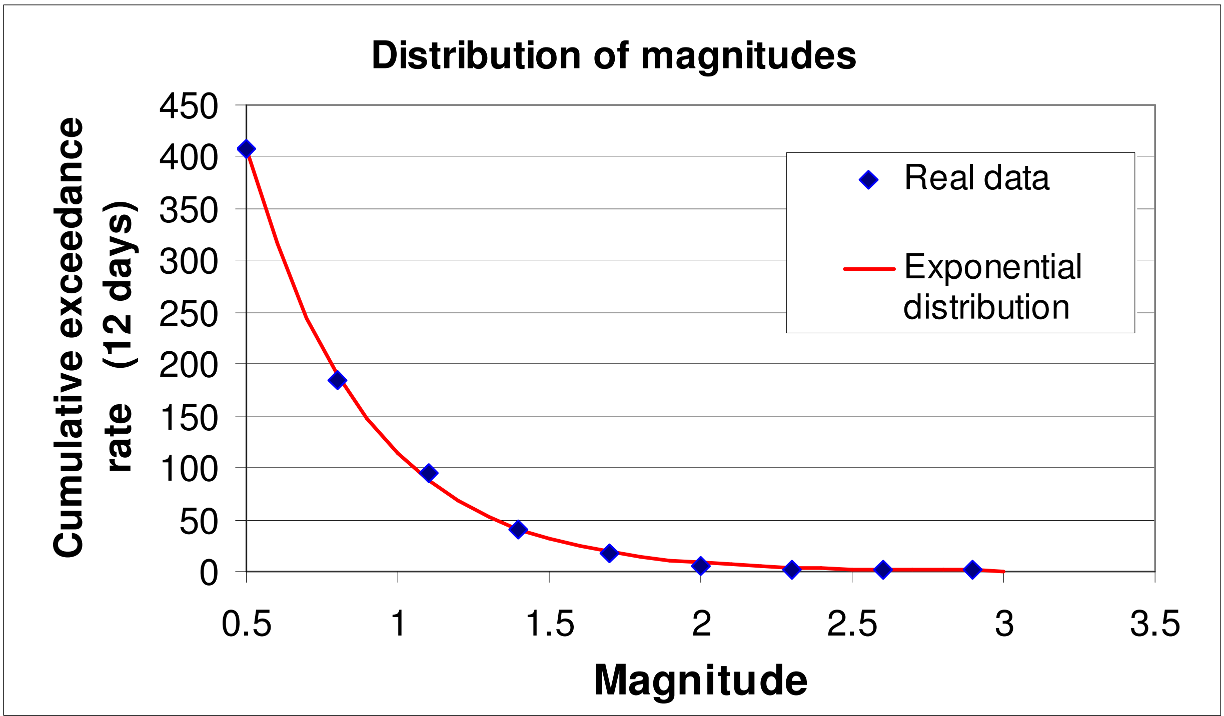


Figure 18: Distribution of magnitudes during the 12 days after the beginning of water injection.

5.2.2 Gütenberg-Richter law

The analysis of Figure 17 and Figure 18 shows that the GR law (which assumes a spatial and temporal Poisson occurrence model of earthquakes and an exponential distribution of magnitudes) properly fit the data. The maximum likelihood method of Weichert (1980) is applied to compute the λ and β parameters and associate uncertainties (Table 7, Figure 19), considering Mmin=0.5 and magnitude steps of 0.3.

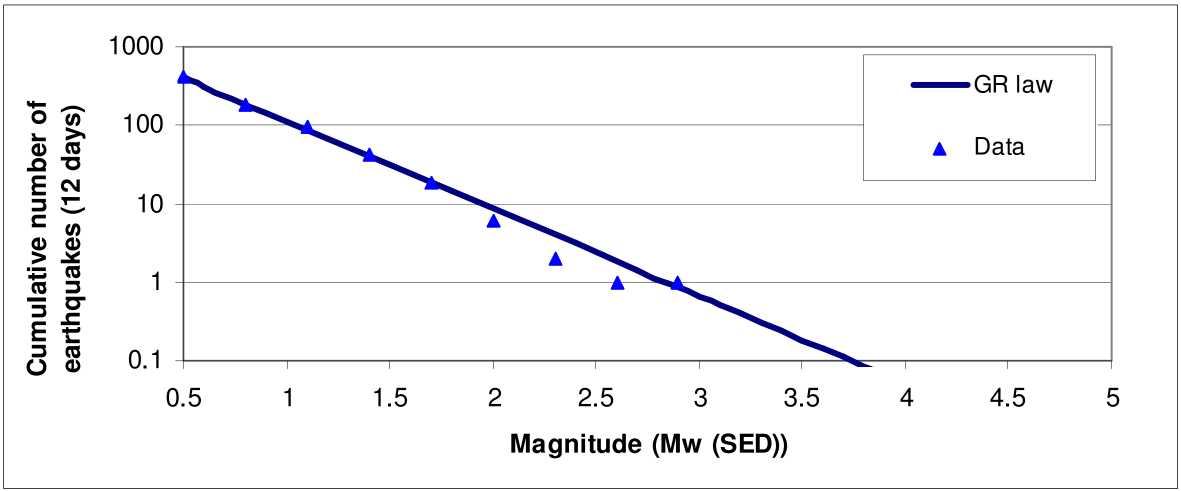


Figure 19: Gutenberg-Richter law of the geothermal field of Basel 12 days after the beginning of the water injection

Table 7 synthesizes the seismic parameters scaled to a Mmin=2.5 and used in the PSHA.

In this first model, the maximum magnitude is controlled by the geothermal reservoir size (AP3000) and corresponds to an event of Mw= 3.25 +/- 0.5.

	λ (annual, Mw_{min}=2.5)	$\sigma(\lambda)$	β	$\sigma(\beta)$	Mw_{max}	H(km)
Empirical model	73.003	1.0	2.568	0.12	3.25 +/- 0.5	3 to 5

Table 7: Seismic parameters and uncertainties. Empirical model - Stimulation period.

5.3 Synthetic model

The second model is issued from the interpretation of numerical simulations performed in AP3000, which assumes an activity rate of 86 earthquakes of moment magnitude greater or equal than 2.0 during the 12 days of the stimulation period, a b-value equal to 0.96, and a maximum magnitude Mmax= 3.7±0.4 resulting from the AP3000 simulations. The occurrence rate of Mw≥2.5 is 10 times higher than in the empirical model. Two earthquakes of magnitude Mw≥3.7 are assumed to occur during the stimulation while only 0.1 earthquake was considered in the previous model.

Table 8 displays the seismic parameters (seismic activity rate scaled to a Mmin=2.5) used in the PSHA.

	λ (annual, Mw_{min}=2.5)	$\sigma(\lambda)$	β	$\sigma(\beta)$	Mw_{max}	H(km)
Synthetic model	866.18	86.6	2.21	0.22	3.7 +/- 0.4	3 to 5

Table 8: Seismic parameters and uncertainties. Synthetic model- Stimulation period.

5.4 Logic tree and treatment of the uncertainties

The logic tree (Figure 20) uses the same seismotectonic model and the same attenuation laws as for the normal period. In addition, the geothermal field source is included in the model introducing two distinct branches refering to the empirical and synthetic models issued from AP3000.

As a result of the discussions on the interface between AP3000 and AP5000, a weight of 0.8 is assigned to the empirical model while a weight of 0.2 is assigned to the model issued from numerical simulations. As the adopted weight strongly influence the median hazard curve, a sensitivity analysis is planed in the risk analysis, using as input data the hazard curves associated to the percentiles 15% and 85%.

The random uncertainties are propagated on the maximum magnitude Mmax and on the seismic activity parameters λ and β. As in the case of the normal period, we use a normal distribution truncated to 1 standard deviation to sample the λ and their correlated β parameters, and a uniform distribution between the maximum and minimum value of Mmax to sample Mmax.

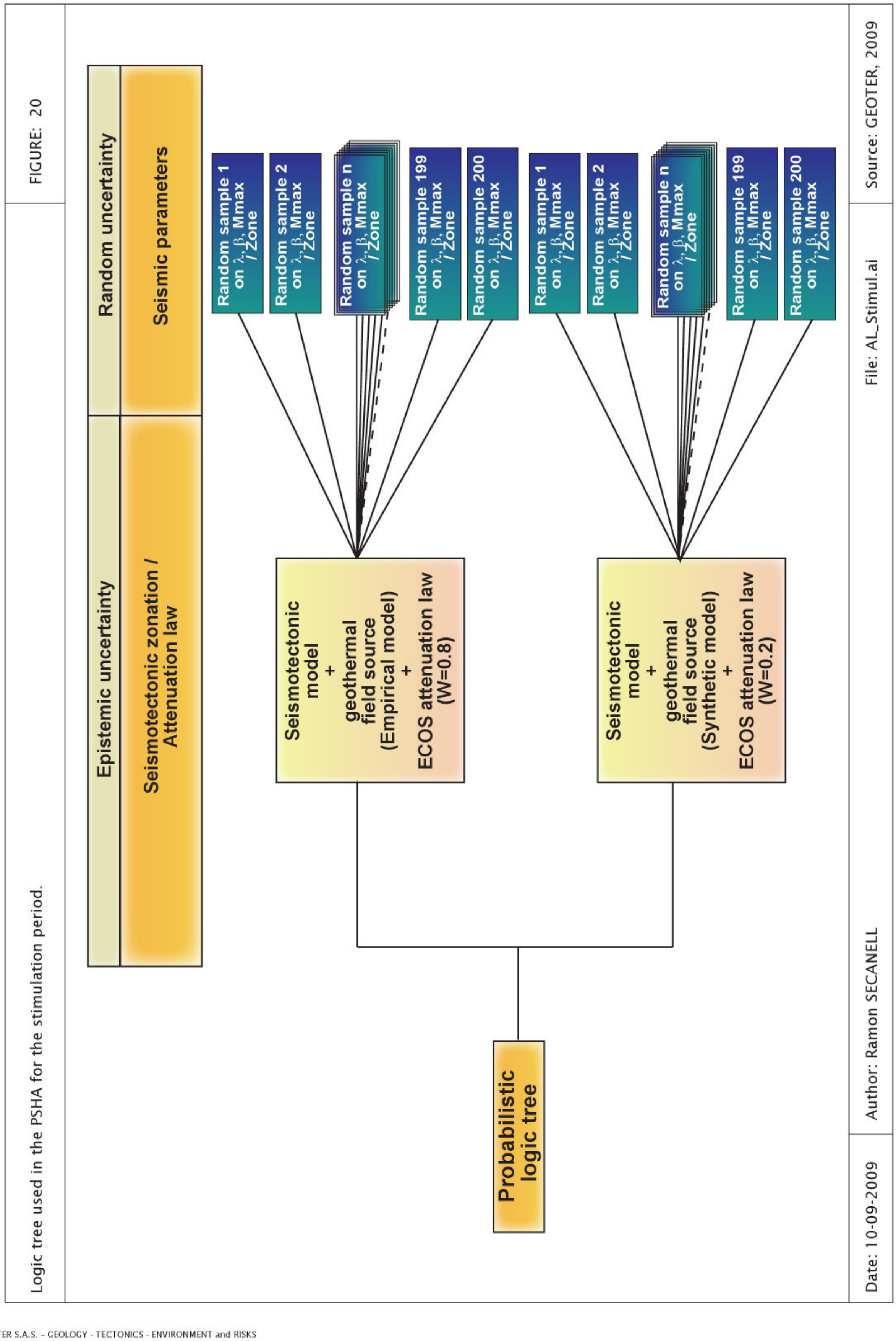


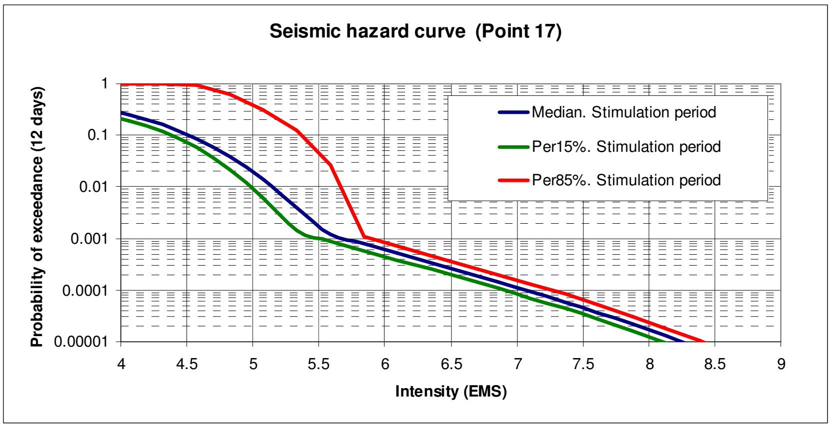
Figure 20: Logic tree used in the PSHA for the stimulation period.

5.5 PSHA results during the stimulation period

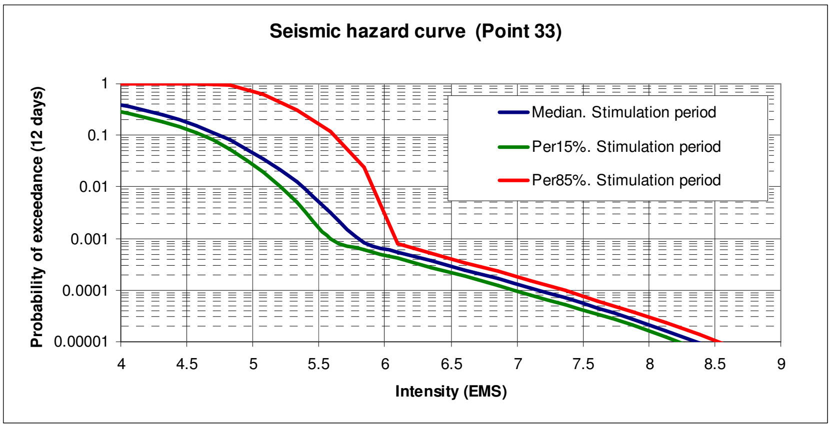
5.5.1 Hazard curves at the calculation reference points

Figure 21 presents the median and percentile 15% and 85% seismic hazard curves during the stimulation period at the four reference points.

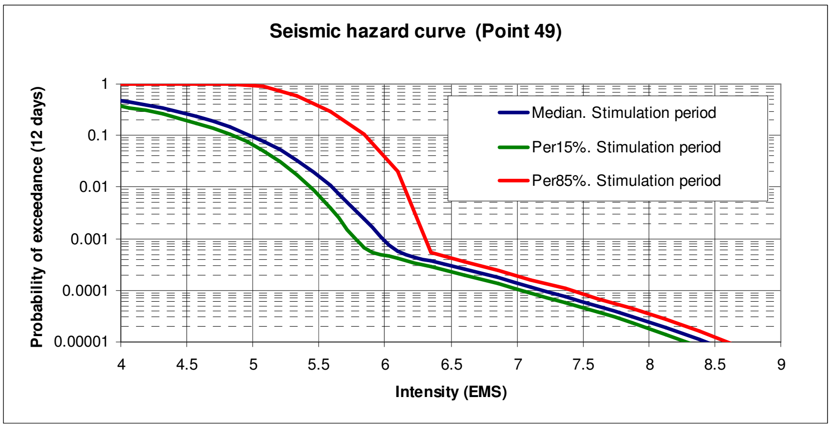
Point 17



Point 33



Point 49



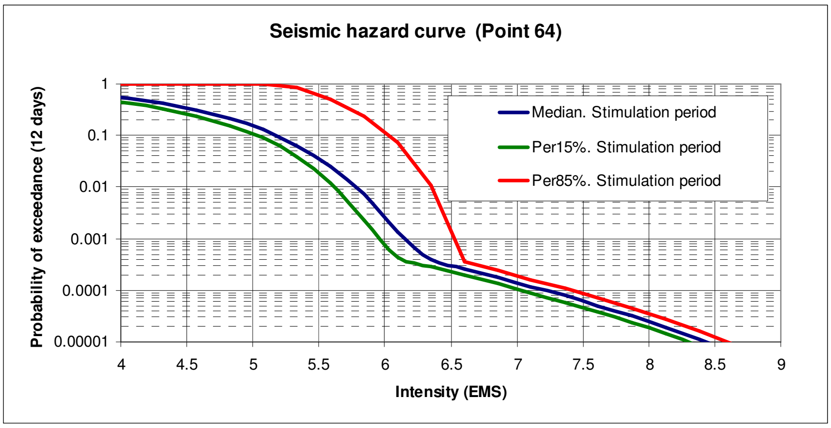
Point 64	

Figure 21: Seismic hazard curves for the stimulation period at 4 reference points in terms of probability of exceedance within 12 days.

The seismic activity rate appears as the main factor controlling the hazard. Because of very different activity rates associated to the empirical and synthetic models, the variability of the hazard curves is high during the stimulation period. For a 0.1 probability of exceedance, the intensity is 5.0 for the percentile 15% and 6.0 for the percentile 85%, i.e. close to one degree of intensity. Considering the intensity 6.0, the probability of exceedance during 12 days varies between 0.0008 for the percentile 15% and 0.1 for the percentile 85%, i.e. the scaling factor is of the order of 140.

Such a result reflects the huge differences between the activity rates respectively issued from the empirical and synthetic models. The percentile 85% seismic hazard curve mainly reflects the synthetic model, while the percentile 15% reflects the empirical model. As a weight of only 0.2 was assigned to the synthetic model, the median hazard curve remains close to the 15% fractile hazard curve (Figure 20*)*.

Regarding the spatial variability of the seismic hazard curves, the highest seismic hazard curve corresponds to the reference point 64 (geothermal reservoir site). Farther is the distance to the site, lower is the impact of the induced seismicity. On the site, the probability of exceedance of an intensity V is multiplied by a factor 50 and remains significant even 15 km away, where the multiplication factor is close to 7.

The induced activity has no impact in terms of seismic hazard, at macroseismic intensities greater than VI-VII at the site itself, and at intensities greater than V-VI at a distance of 15 km to the site (Figure 21). Those values constitute a threshold above which the seismic hazard is fully controlled by the natural seismic activity, of tectonic origin, and bellow which the seismic hazard is mainly controlled by the induced activity.

This threshold is strongly dependent on the maximum magnitude adopted. Higher would be the Mmax, higher would be the intensity threshold.

5.5.2 Seismic hazard maps

The hazard curves are exploited to represent hazard maps at different probabilities of exceedance within the stimulation period. The correspondence between the probabilities and the return periods is explained in Table 9. For instance, considering a probability of exceedance within 12 days of 0.032 means that the corresponding ground motion has a return period of 1 year. For a probability of exceedance of $6.9*10^{-5}$ within 12 days, the return period is 476 years.

Probability of exceedance in 12 days	t =12 days	Return period T in days	Return period T in years
0.032	12	369.0	1.0
0.0032	12	3744.0	10.3
0.001	12	11994.0	32.9
0.000069	12	173907.0	476.5

Table 9: Relation between the return periods and the probabilities of exceedance

Figure 22 presents the median seismic hazard maps for different probabilities of exceedance within 12 days: $3.2*10^{-2}$, $3.2*10^{-3}$, 10^{-3} and $6.9*10^{-5}$. This representation allows to appreciate the hazard variability around the geothermal field.

The intensity associated to a probability of exceedance of $3.2*10^{-2}$ or a return period of 1 year is ranging between 5.0 and 5.6.

The intensity associated to a probability of exceedance of $3.2*10^{-3}$ varies from 5.3 to 6.0. For a probability of exceedance of 10^{-3} the intensity varies between 5.6 and 6.2, and for a probability of exceedance of $6.9*10^{-5}$ between 7.3 and 7.5.

At high probabilities of exceedence, the seismic hazard maps are completely controlled by the reservoir source. The attenuation of intensities is centered on the geothermal field. At low probability of exceedance, the seismic hazard map is comparable to the map obtained for the normal period, and the impact of the induced seismicity is negligible, the hazard being mainly controlled by the tectonic activity.

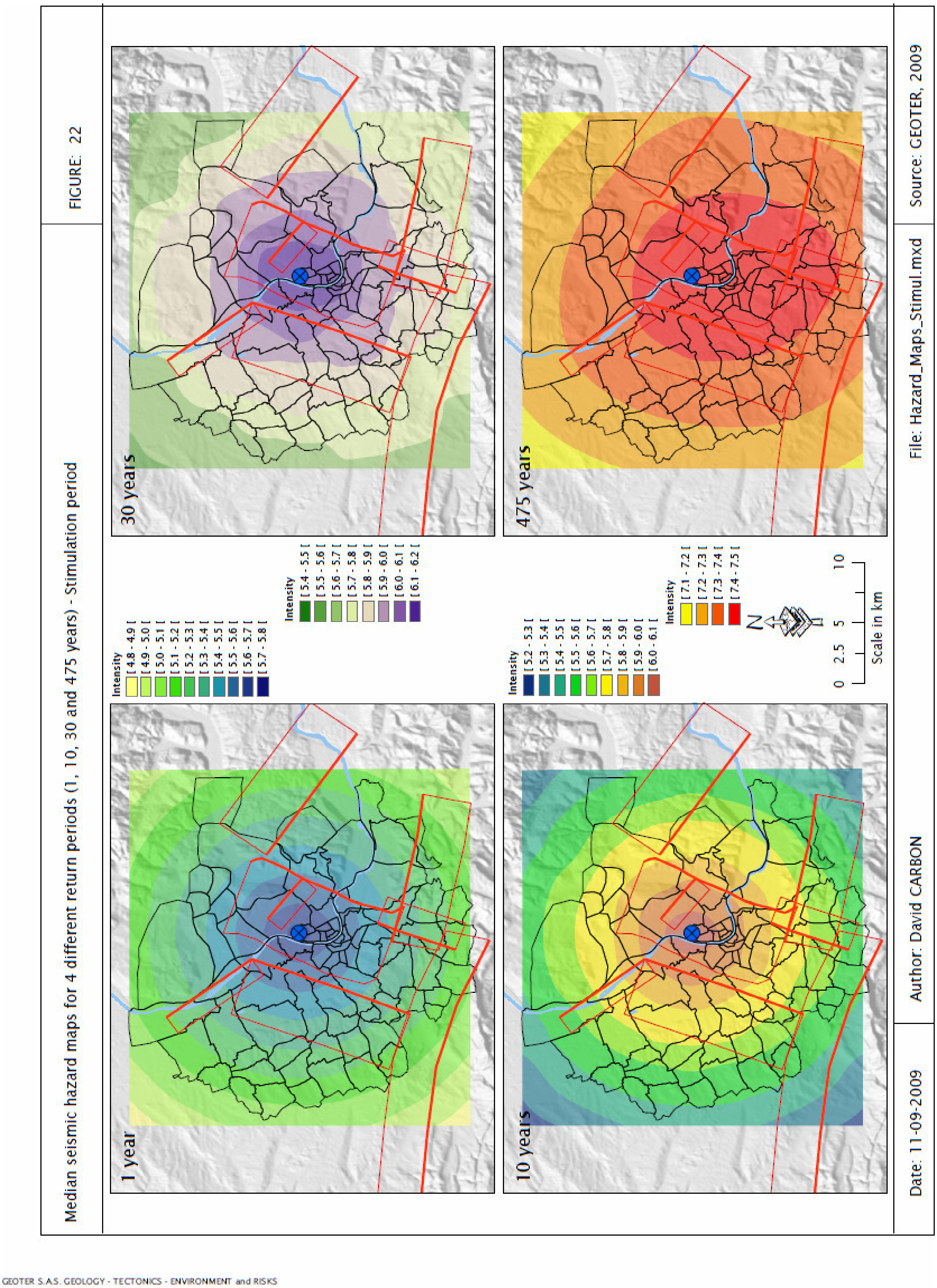


Figure 22: Median seismic hazard maps for 4 different return periods (1, 10, 30 and 475 years) - Stimulation period.

5.6 Hazard comparison between normal and stimulation periods

The comparison of the seismic hazard curves between stimulation and normal periods, indicates that there is no difference for intensities above 6.5 or for probabilities of exceedance within 12 days bellow $4*10^{-4}$ (i.e. for return periods greater than 80 years, Figure 23).

Table 10 to Table 13 synthesize the probabilities of exceedance within the stimulation period to exceed intensities from V to VIII as well as the probabilities ratio (multiplicative factor of the hazard for a given intensity).

P17. T=12 days	P(I>V)	P(I>VI)	P(I>VII)	P(I>VIII)
Normal period	2.83E-03	5.92E-04	1.13E-04	1.67E-05
Stimulation period	1.93E-02	6.00E-04	1.13E-04	1.67E-05
Multiplicative factor	**6.8**	**1.0**	**1.0**	**1.0**

Table 10: Comparison of the probabilities of exceedance during 12 days during the stimulation and normal periods - Point 17

P33. T=12 days	P(I>V)	P(I>VI)	P(I>VII)	P(I>VIII)
Normal period	2.87E-03	6.27E-04	1.30E-04	2.13E-05
Stimulation period	4.69E-02	6.39E-04	1.30E-04	2.13E-05
Multiplicative factor	**16.3**	**1.0**	**1.0**	**1.0**

Table 11: Comparison of the probabilities of exceedance during 12 during the stimulation and normal periods - Point 33

P49.T=12 days	P(I>V)	P(I>VI)	P(I>VII)	P(I>VIII)
Normal period	2.84E-03	6.42E-04	1.40E-04	2.44E-05
Stimulation period	9.65E-02	9.81E-04	1.40E-04	2.44E-05
Multiplicative factor	**34.0**	**1.5**	**1.0**	**1.0**

Table 12: Comparison of the probabilities of exceedance during 12 days during the stimulation and normal periods - Point 49

P64. T=12 days	P(I>V)	P(I>VI)	P(I>VII)	P(I>VIII)
Normal period	2.80E-03	6.35E-04	1.40E-04	2.46E-05
Stimulation period	1.53E-01	7.41E-04	1.41E-04	2.47E-05
Multiplicative factor	**54.6**	**1.2**	**1.0**	**1.0**

Table 13: Comparison of the probabilities of exceedance during 12 days during the stimulation and normal periods - Point 64

For both periods, Table 14 to Table 17 indicate the intensities predicted for a fixed probability of exceedance.

P17. T=12 days	P=0.01	P=0.001	P=0.0001
Normal period	4.1	5.6	7.0
Stimulation period	5.2	5.6	7.0
Differences in intensity	**1.1**	**0.0**	**0.0**

Table 14: Comparison of the predicted intensities at three probabilities of exceedance – Point 17

P33. T=12 days	P=0.01	P=0.001	P=0.0001
Normal period	4.1	5.6	7.1
Stimulation period	5.4	5.7	7.1
Differences in intensity	**1.3**	**0.1**	**0.0**

Table 15: Comparison of the intensities at three probabilities of exceedance - Point 33

P49. T=12 days	P=0.01	P=0.001	P=0.0001
Normal period	4.1	5.6	7.2
Stimulation period	5.6	6.0	7.2
Differences in intensity	**1.5**	**0.4**	**0.0**

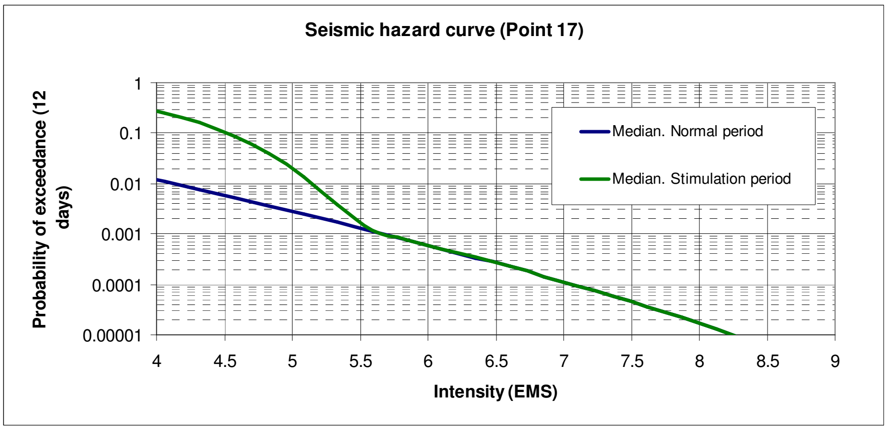
Table 16: Comparison of the intensities at three probabilities of exceedance - Point 49

P64. T=12 days	P=0.01	P=0.001	P=0.0001
Normal period	4.1	5.7	7.3
Stimulation period	5.7	6.1	7.3
Differences in intensity	**1.6**	**0.4**	**0.0**

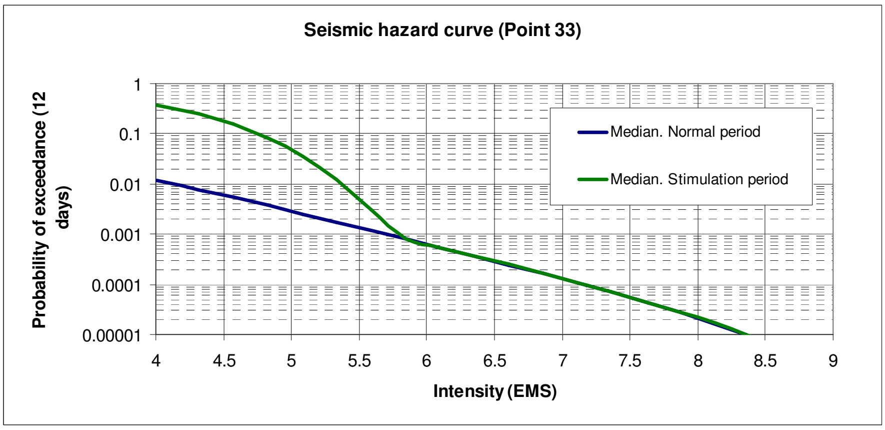
Table 17: Comparison of the intensities at three probabilities of exceedance - Point 64

Figure 23 provides the comparative hazard curves during the stimulation and normal periods at the four reference points.

Point 17



Point 33



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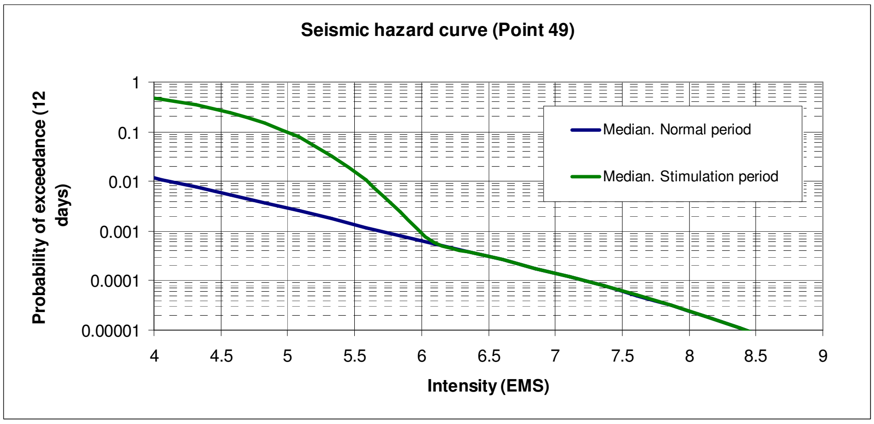
<tr><td>Point 49</td><td>
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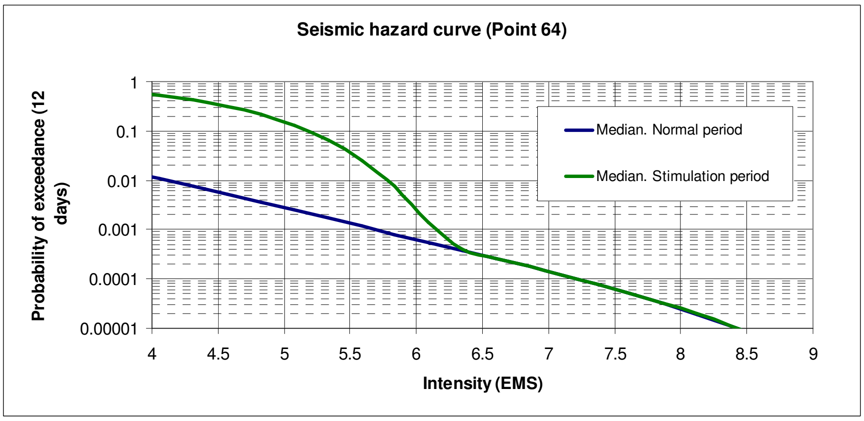
(Geothermal
Field)</td><td>
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Figure 23: Comparison of the seismic hazard curves for the normal period and stimulation period at 4 reference points in terms of probability of exceedance within 12 days.

The results point out that:

- The geothermal field is not responsible of an hazard increment when considering intensities greater than 6.5 ;
- Compared to the normal period, the probability of exceedance of intensity 5 is multiplied by 50 on the geothermal field and by 7 for the sites located 15 kilometers away ;
- As most of the damages reported during the 2006 sequence were slight damages associated to low intensities, the significant hazard increment could be responsible of a significant risk increment.

6 SEISMIC HAZARD DURING THE CIRCULATION PERIOD

6.1 Specificities of the seismic activity distribution and controlling parameters

For the circulation period, the hazard is calculated assuming a 30 years geothermal field lifespan. The extrapolation of the results out from this temporal window has no sense. From the AP3000, two synthetic models are considered, mainly differing from the viewpoint of the activity rates (one earthquake of Mw=3.3 per year, or only one earthquake of Mw=3.7 during the 30 years of operation).

The PSHA model takes consideration of:

- The same seismotectonic model as for the normal period. Nevertheless, the near-regional fault model is modified to take into account the effects of the potential triggered seismicity. This latest contributes to modifications of the return periods associated to characteristics magnitudes. The chapter 6.2 is dedicated to the triggered seismicity and associated triggered hazard
- The seismic source associated to the geothermal reservoir and of the induced seismicity during the field operation
- A maximum magnitude of 3.7±0.4, for both of the synthetic models.

6.2 Triggered seismicity

The AP4000 working-package focused on the potential impact of the field operations on the seismicity associated to near-regional faults. The objective was to appreciate how the stress changes could modify the seismic cycle of the faults. The AP4000 analysis resulted in potential perturbations (acceleration or deceleration) of the return periods of different characteristic magnitudes ranging from 4.5 to 6.5.

The return periods associated to these characteristic magnitudes have been firstly determined from AP2000 results. Eight faults are considered and the return periods are calculated using the seismic parameters of Giardini *et al.* (2004), assuming an equivalent repartition of the seismicity on the 8 faults. The Table 18, issued from AP4000, synthesizes the return periods in normal period and the modifications induced by the perturbation forces. For each magnitude, t0 indicates the increment/decrement that must be applied to the return period of a given characteristic magnitude (a positive value indicates a reduction of the return period) and ***sd*** indicates the standard deviation on ***t0***.

To calculate the seismic parameters during the circulation period the increments/decrements of the return periods of each fault, ***t0***, are applied and new GR laws are generated (Table 19).

Compared to the normal period, the variations are only significant for three faults: Alschwill, RVF and Weil-Am-Rhein faults. Figure 24 illustrates the impact of the triggered seismicity on the GR law associated to the Weil-Am-Rhein fault.

A new PSHA is undertaken considering these modifications.

	Mw 4.5			Mw 5.5			Mw 6.5		
Fault name	**t0 (yrs)**	**sd (yrs)**	**T (yrs)**	**t0 (yrs)**	**sd (yrs)**	**T (yrs)**	**t0 (yrs)**	**sd (yrs)**	**T (yrs)**
Alschwill	7.6	5.7	448	35.7	22.2	3574	20.5	10.6	20100
BaselReinach	-0.0133	0.0087	448	-0.14	0.01	3574	-4.9	5.3	20100
RVF	35.0	32.6	448	89.3	51.3	3574	44.6	18.2	20100
Sierentz	0.052	0.011	448	-0.18	0.24	3574	-	-	20100
WeilAmRhein	76.2	68.0	448	32.8	16.1	3574	-	-	20100
Aspenrain	0.169	0.092	448	0.091	0.055	3574	-0.9	0.4	20100
PCborderFault	0.156	0.095	448	0.90	0.53	3574	0.5	9.5	20100
Rheinfelden	-0.038	0.025	448	-0.51	0.35	3574	-5.2	2.3	20100

Table 18: Seismic parameters associated to the 8 faults retained for seismic risk calculation.

	Normal period		Circulation period	
Fault name	**λ (Mwmin=4.5)**	**β**	**λ (Mwmin=4.5)**	**β**
Alschwill	0.00227	2.07233	0.00232	2.08370
BaselReinach	0.00227	2.07233	0.00227	2.07233
RVF	0.00227	2.07233	0.00246	2.11300
Sierentz	0.00227	2.07233	0.00227	2.07233
WeilAmRhein	0.00227	2.07233	0.00267	2.17000
Aspenrain	0.00227	2.07233	0.00227	2.07233
PCborderFault	0.00227	2.07233	0.00227	2.07233
Rheinfelden	0.00227	2.07233	0.00227	2.07233

Table 19: Seismic activity parameters adopted for each fault during the normal circulation periods.

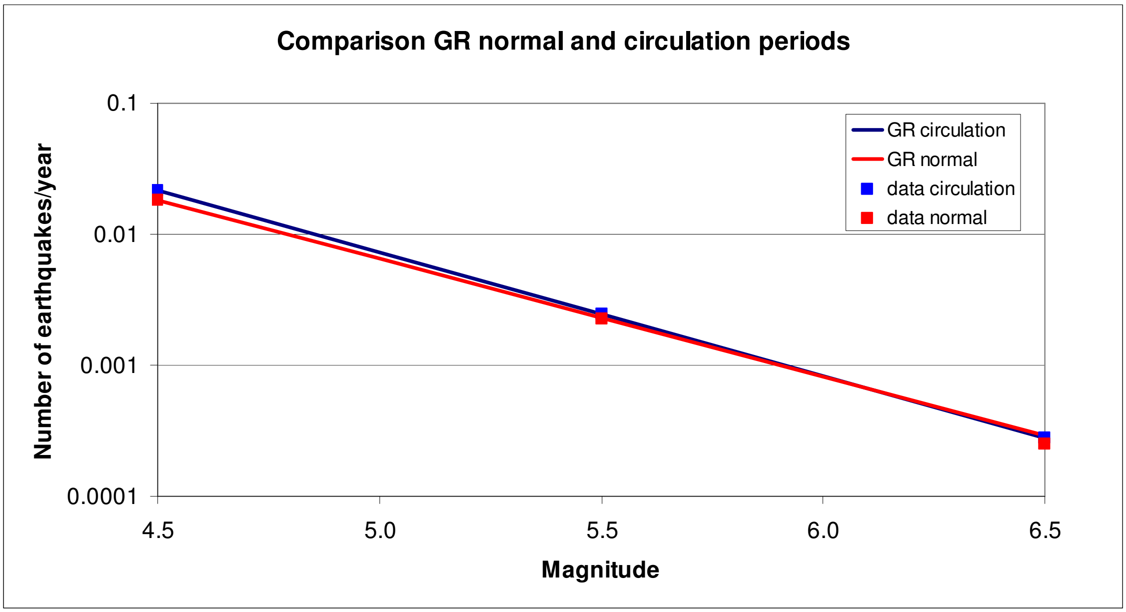

Figure 24: Comparison of GR laws during the normal and circulation periods. Weil-Am-Rhein fault.

Figure 25 displays the comparison between the seismic hazard curves during the normal period and during the circulation period considering only the triggered seismicity. The triggered seismicity impact is negligible.

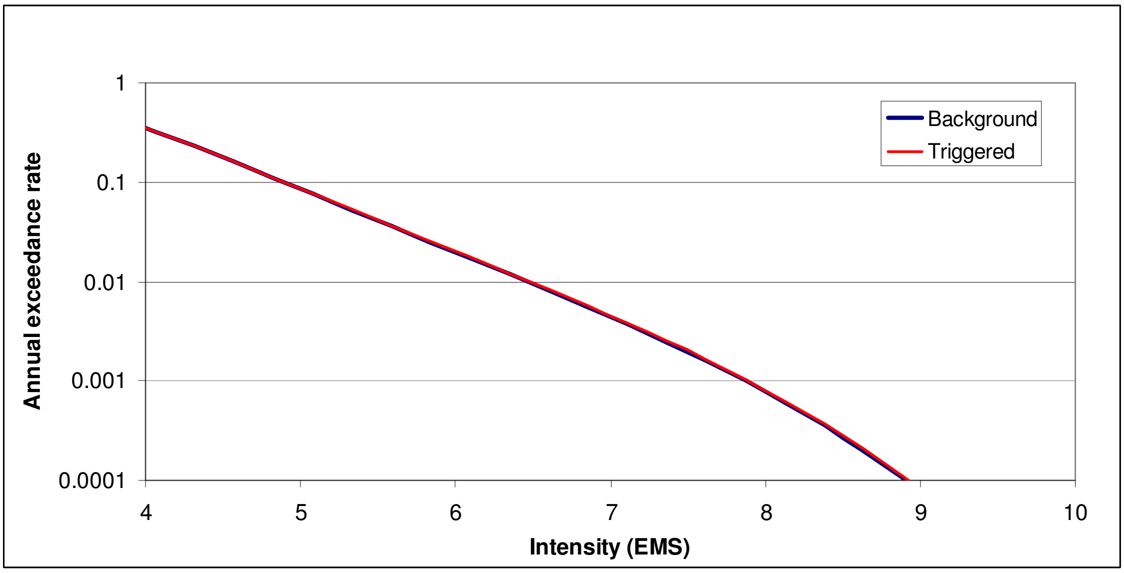

Figure 25: Comparison of seismic hazard curves obtained during the normal period, and considering the impact of the triggered seismicity on the return periods of characteristic magnitudes.

6.3 Synthetic model 1: annual occurrence of Mw=3.3

The first model provided by AP3000 is described by the following parameters:

- The activity rate corresponds to one earthquake of magnitude Mw=3.3 per year. Within 30 years of operation the maximum magnitude could be observed 12 times ;
- A b-value of 0.96 is adopted ;
- The maximum magnitude is 3.7±0.4.

Table 20 synthesizes the seismic parameters and the associated uncertainties.

	λ (annual, $M_w$min=2.5)	$\sigma(\lambda)$	β	$\sigma(\beta)$	Mwmax	H(km)
Synthetic model 1	5.86	0.58	2.21	0.22	3.7 +/- 0.4	3 to 5

Table 20: Seismic parameters and their uncertainties - Circulation period. Synthetic model 1.

6.4 Synthetic model 2: one occurrence of M=3.7 in 30 years

The second model provided by AP3000 is decribed by the following parameters:

- The activity rate corresponds to one earthquake of magnitude Mw=3.7 during 30 years of the plant operation ;
- A b-value of 0.96 is adopted ;
- The maximum magnitude is 3.7±0.4.

Table 21 synthesizes the seismic parameters and the associated uncertainties.

	λ (annual, $M_w$min=2.5)	$\sigma(\lambda)$	β	$\sigma(\beta)$	Mwmax	H(km)
Synthetic model 2	0.473	0.05	2.21	0.22	3.7 +/- 0.4	3 to 5

Table 21: Seismic parameters and their uncertainties - Circulation period. Synthetic model 2.

6.5 Logic tree and treatment of the uncertainties

The logic tree (Figure 26) uses the same seismotectonic model and the same attenuation laws as for the normal period. The near-regional fault model is modified to account for the triggered seismicity impact even if this latest is negligible.

The geothermal field source is again included in the model introducing two distinct branches referring to each synthetic models issued from AP3000. It was though that there was no objective reason to favor one numerical model than another, and an equivalent weight of 0.5 is assigned to each model.

The random uncertainties are propagated on the maximum magnitude Mmax and on the seismic activity parameters λ and β. As in the case of the normal period, we use a normal distribution truncated to 1 standard deviation to sample the λ and their correlated β parameters, and a uniform distribution between the maximum and minimum value of Mmax to sample Mmax.

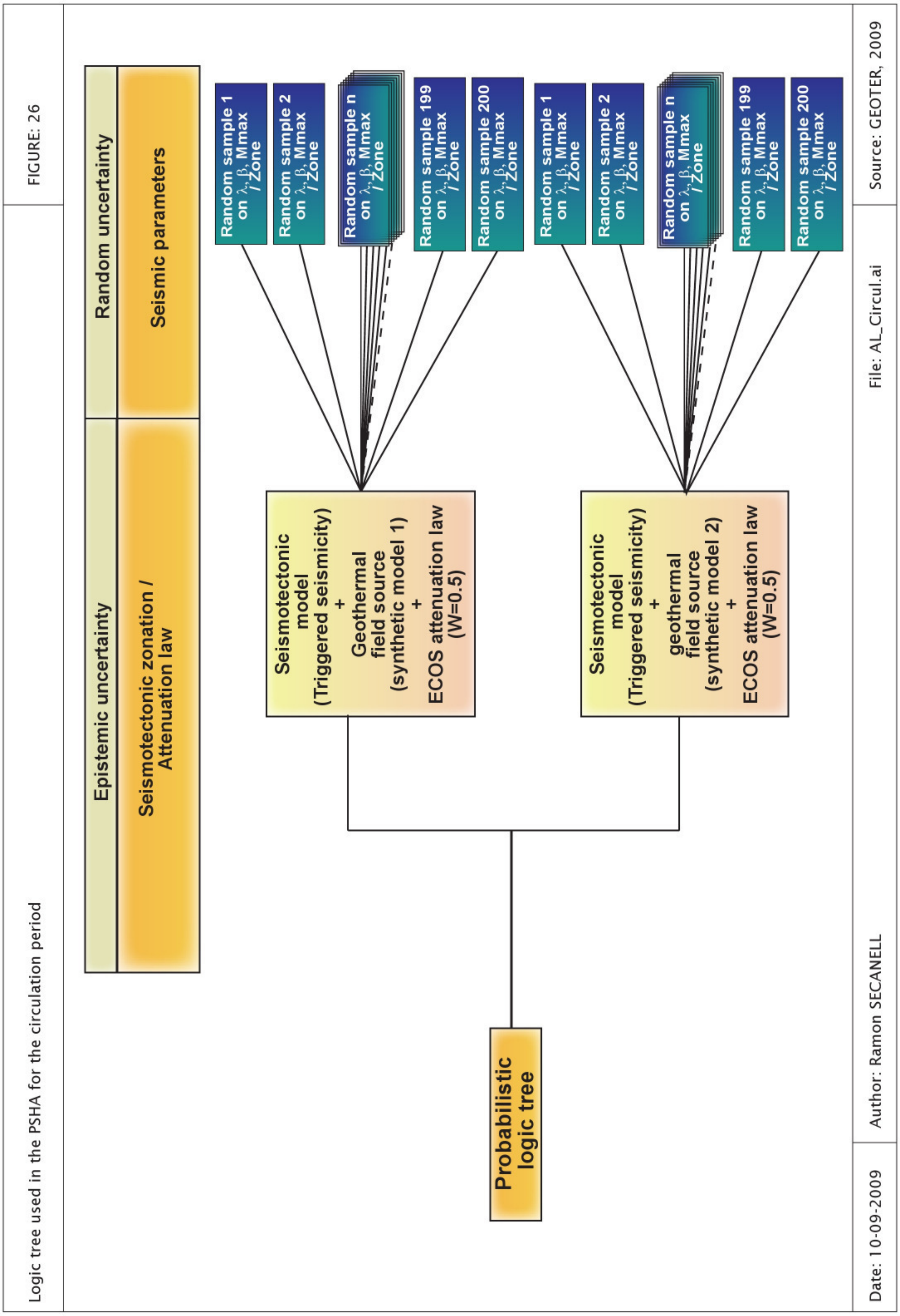

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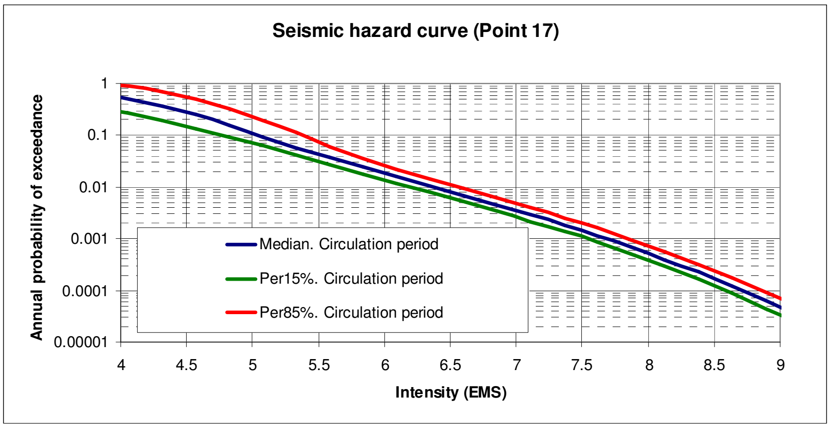
Figure 26: Logic tree used for the seismic hazard assessment during the circulation period.

6.6 PSHA results during the circulation period

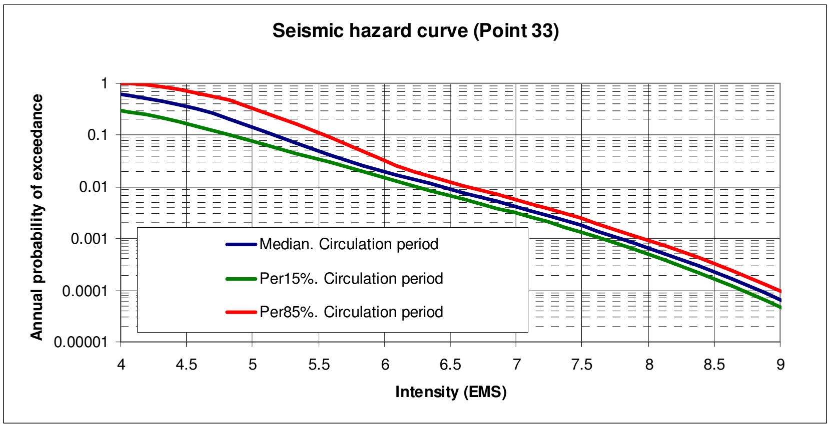
6.6.1 Hazard curves at the calculation reference points

Figure 27 presents the median and percentiles 15% and 85% seismic hazard curves during the circulation period at the four reference points.

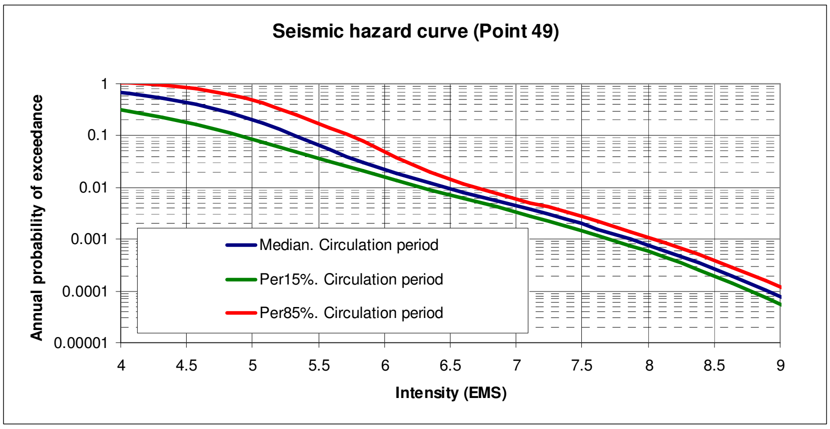
Point 17



Point 33



Point 49



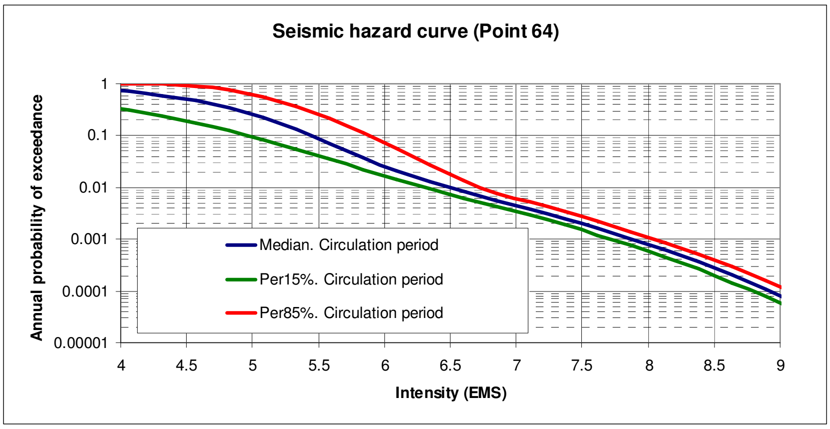
Point 64	

Figure 27: Circulation period. Seismic hazard curves at 4 reference points (annual probability of exceedance).

The variability of the results (differences between percentiles and median) is higher than for the normal period but lower than for the stimulation period.

For a probability of 0.1 exceedance at point 64, the intensity is 5.0 for the percentile 15% and 5.8 for the percentile 85%, i.e. close to one degree of intensity. Considering the intensity VI, the annual probability of exceedance varies between 0.02 for the percentile 15% and 0.07 for the percentile 85%, i.e. the scaling factor is of the order of 4.

As observed during the stimulation period, the induced activity has no impact in terms of seismic hazard, at macroseismic intensities greater than VI-VII at the site itself, and at intensities greater than V-VI, 15 km away.

Regarding the seismic hazard curves spatial variability, the highest seismic hazard curves correspond to the reference point 64 (geothermal reservoir site). Farther is the distance to the site, lower is the impact of the induced seismicity. The probability of exceedance of intensity V is multiplied by 3 at the site and by 1.3, 15 km away.

6.6.2 Seismic hazard maps

The hazard curves are exploited to represent hazard maps at different probabilities of exceedance within the stimulation period. Figure 28 presents the median seismic hazard maps for different annual probabilities of exceedance: $3.2*10^{-2}$, $3.2*10^{-3}$, 10^{-3} and $6.9*10^{-5}$. This representation allows to appreciate the hazard variability around the geothermal field.

The intensity associated to an annual probability of exceedance of $3.2*10^{-2}$ is ranging between 3.7 and 4.3.

The intensity associated to a probability of exceedance of $3.2*10^{-3}$ varies from 5.0 to 5.5. For a probability of exceedance of 10^{-3} the intensity varies between 5.6 and 6.0, and for an annual probability of exceedance of $6.9*10^{-5}$ between 7.3 and 7.5.

At high probabilities of exceedence, the seismic hazard maps are again completely controlled by the reservoir source, as during the stimulation period. The attenuation of intensities is centered on the geothermal field. At low probability of exceedance, the seismic hazard map is almost comparable to the map obtained for the normal period, and the impact of the induced seismicity is negligible, the hazard being mainly controlled by the tectonic activity. However, the values are slightly increased due to the consideration of the triggered seismicity.

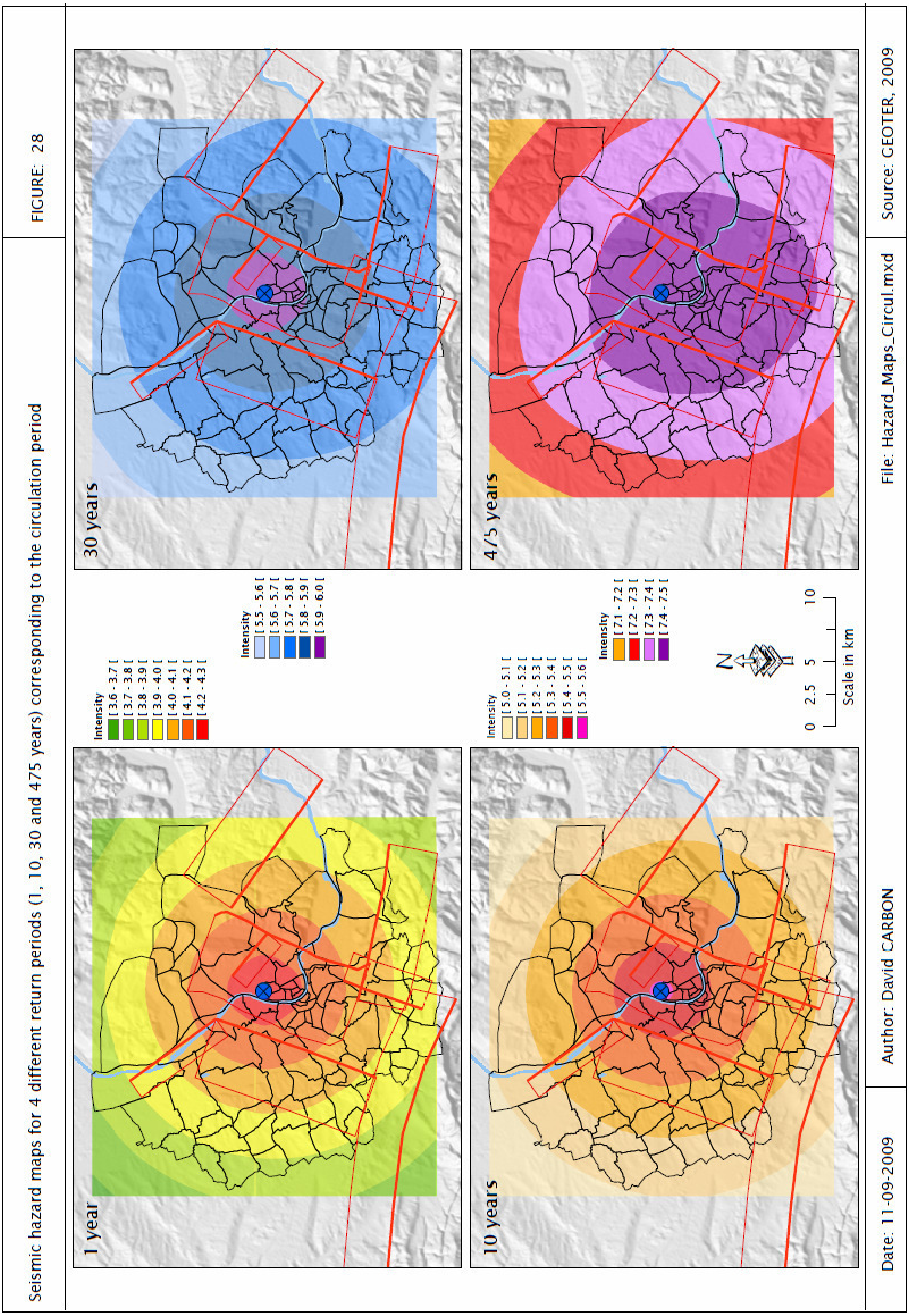


Figure 28: Seismic hazard maps for 4 different return periods (1, 1, 30 and 475 years) corresponding to the circulation period.

6.7 Hazard comparison between normal and circulation periods

The comparison of the seismic hazard curves between circulation and normal periods, indicates again that there is no hazard increment for intensities above 6.5 and for annual probabilities of exceedance lower than 10^{-2} (

Figure 29).

Table 22 to Table 25 synthesize the annual probabilities of exceedance to exceed intensities from V to VIII as well as the probabilities ratio (multiplicative factor of the hazard for a given intensity). The hazard increment is significantly lower than during the stimulation period. For an intensity V, it varies between 1.3 at 15 km from the field to 3.2 at the field.

P17 - T=1 year	P(I>V)	P(I>VI)	P(I>VII)	P(I>VIII)
Normal period	8.27E-02	1.79E-02	3.42E-03	5.08E-04
Circulation period	1.11E-01	1.85E-02	3.50E-03	5.19E-04
Multiplicative factor	**1.3**	**1.0**	**1.0**	**1.0**

Table 22: Comparison of the annual probabilities of exceedance during the normal and circulation periods - Point 17

P33 - T=1 year	P(I>V)	P(I>VI)	P(I>VII)	P(I>VIII)
Normal period	8.38E-02	1.89E-02	3.94E-03	6.48E-04
Circulation period	1.45E-01	2.01E-02	4.06E-03	6.68E-04
Multiplicative factor	**1.7**	**1.1**	**1.0**	**1.0**

Table 23: Comparison of the annual probabilities of exceedance during the normal and circulation periods - Point 33

P49 - T=1 year	P(I>V)	P(I>VI)	P(I>VII)	P(I>VIII)
Normal period	8.29E-02	1.93E-02	4.24E-03	7.41E-04
Circulation period	2.01E-01	2.23E-02	4.41E-03	7.71E-04
Multiplicative factor	**2.4**	**1.2**	**1.0**	**1.0**

Table 24: Comparison of the annual probabilities of exceedance during the normal and circulation periods - Point 49

P64 - T=1 year	P(I>V)	P(I>VI)	P(I>VII)	P(I>VIII)
Normal period	8.18E-02	1.91E-02	4.26E-03	7.49E-04
Circulation period	2.62E-01	2.60E-02	4.46E-03	7.85E-04
Multiplicative factor	**3.2**	**1.4**	**1.0**	**1.0**

Table 25: Comparison of the annual probabilities of exceedance during the normal and circulation periods - Point 64

For both periods, Table 26 to Table 29 indicate the intensities predicted for a fixed probability of exceedance.

P17. T=1 year	P=0.1	P=0.01	P=0.001
Normal period	4.9	6.3	7.6
Circulation period	5.0	6.3	7.6
Differences in intensity	**0.1**	**0.0**	**0.0**

Table 26: Comparison of the predicted intensities at three annual probabilities of exceedance - Point 17

P33. T=1 year	P=0.1	P=0.01	P=0.001
Normal period	4.9	6.4	7.7
Circulation period	5.2	6.4	7.7
Differences in intensity	**0.3**	**0.0**	**0.0**

Table 27: Comparison of the intensities at three annual probabilities of exceedance – Point 33

P49. T=1 year	P=0.1	P=0.01	P=0.001
Normal period	4.9	6.5	7.8
Circulation period	5.3	6.5	7.8
Differences in intensity	**0.4**	**0.0**	**0.0**

Table 28: Comparison of the intensities at three annual probabilities of exceedance – Point 49

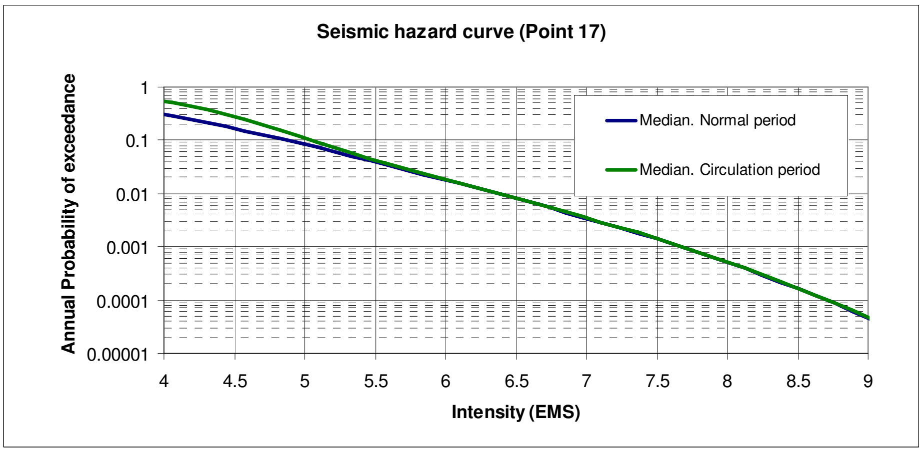
P64. T=1 year	P=0.1	P=0.01	P=0.001
Normal period	4.9	6.5	7.8
Circulation period	5.5	6.5	7.8
Differences in intensity	**0.6**	**0.0**	**0.0**

Table 29: Comparison of the intensities at three annual probabilities of exceedance – Point 64

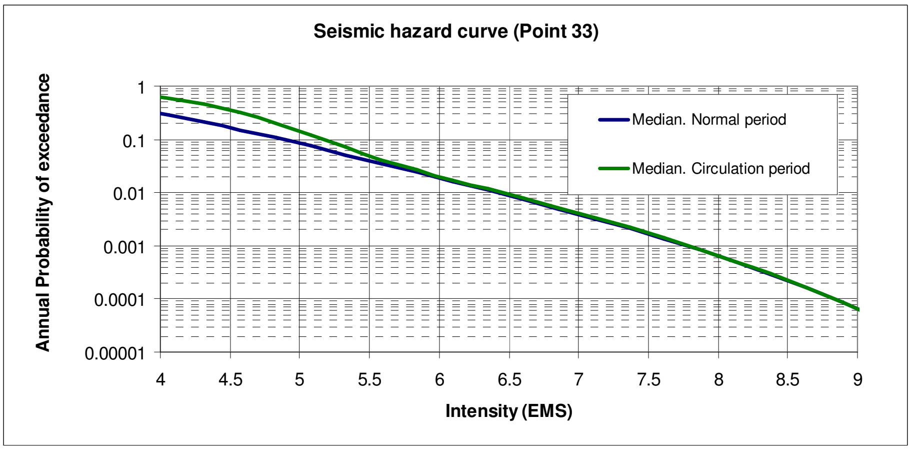
Figure 29 provides the comparative hazard curves during the circulation and normal periods at the four reference points. The results point out that:

- During the circulation period, the geothermal field is not responsible for an hazard increment at intensities greater than 6.5, or annual probabilities lower than 0.01 ;
- At high intensities small differences may exist but they are not significant and due to the consideration of the triggered seismicity ;
- Compared to the normal period, the probability of exceedance of intensity 5 is multiplied by 3 on the geothermal field and by a factor 1,2 for the sites located 15 kilometers away ;

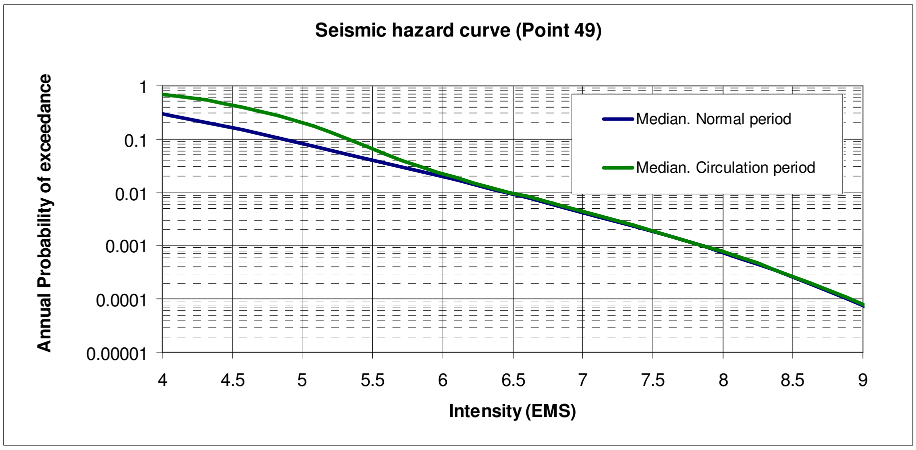
Point 17



Point 33



Point 49



Point 64

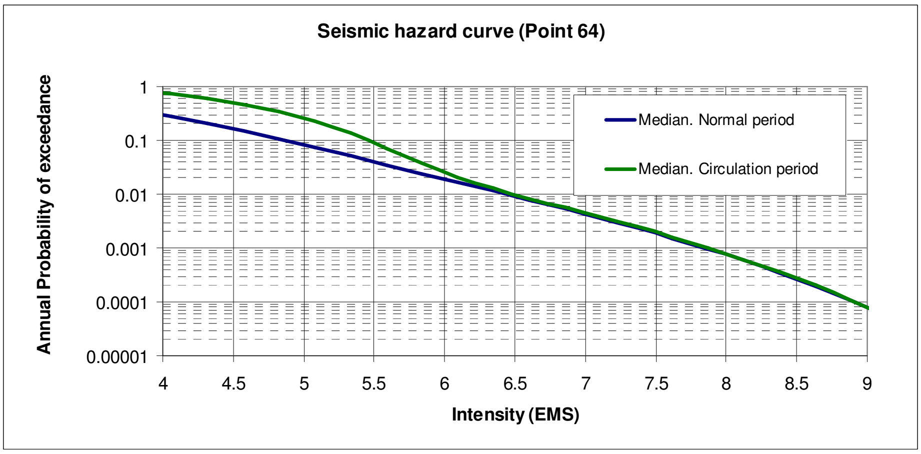
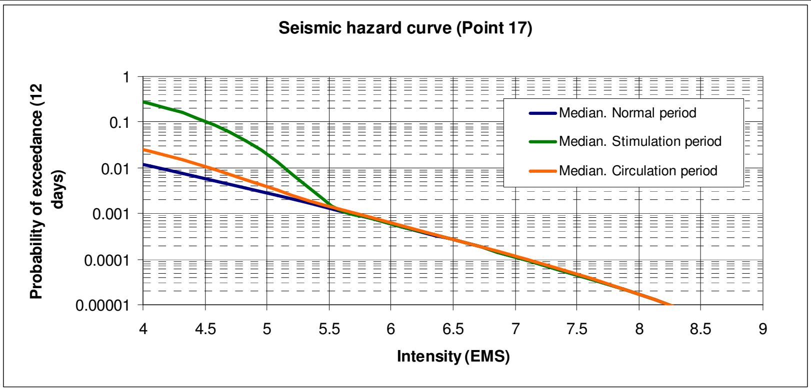


Figure 29: Comparison of the median seismic hazard curves between normal and circulation periods at the 4 reference points.

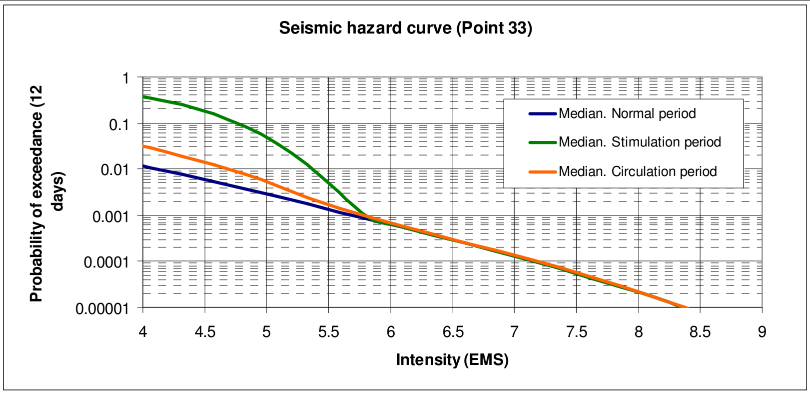
7 HAZARD COMPARISON BETWEEN NORMAL, STIMULATION AND CIRCULATION PERIODS

In order to appreciate the hazard exposure during the three characteristic periods, a comparison of the hazard curves is proposed in Figure 30, representing the probabilities of exceedance during a common period of 12 days at the four reference points.

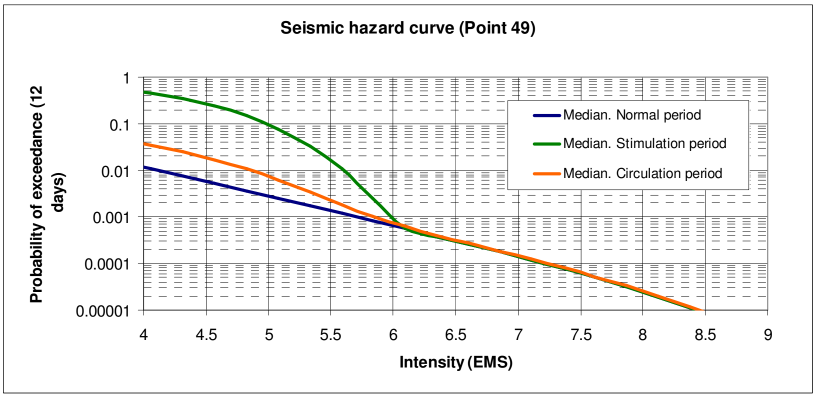
Point 17



Point 33



Point 49



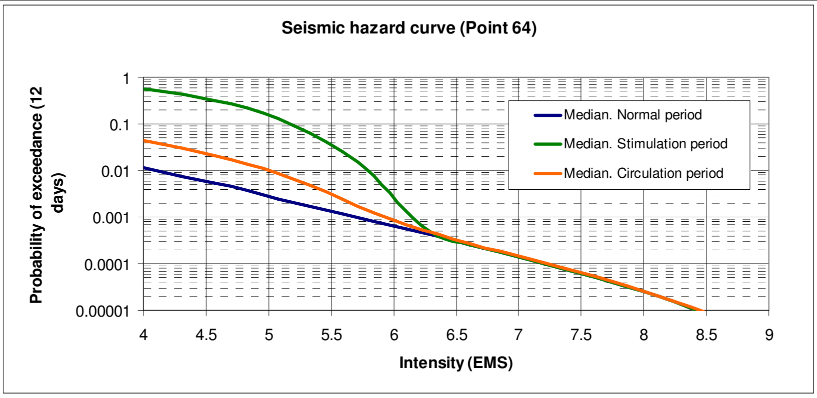
Point 64 (geothermal Field)	

Figure 30: Comparison of the median seismic hazard curves for the normal, stimulation and circulation period at 4 reference points in terms of probability of exceedance within 12 days

The seismic hazard curves during the stimulation are equal or exceed all of the curves associated to the other periods. The three curves intersect each other at a value of intensity or of probability that varies as a function of the distance to the geothermal field.

At the geothermal field (point 64) the probability of exceedance of an intensity 5 is 54 times higher during the stimulation than during the normal period. 15 km away, the ratio is only 7 times higher.

The circulation period is also responsible for an hazard increment. At the geothermal field (point 64) the probability of exceedance of an intensity 5 is 3.4 times higher than during the normal period and 1.3 times higher 15 km away.

It is worth noting that **the influence of the geothermal activities does not affect the seismic hazard curve above 6.5 on the geothermal field site, above 6 5km away from the site, above 5.8 10 km away and above 5.5 at 15 km from the field.**

It is emphasized that, although the stimulation is responsible for the highest hazard increment it only represents a short period of the geothermal field total lifespan.

The hazard increment respectively due to the stimulation period and to the circulation period will be considered in the risk analysis.

8 PROBABILISTIC RISK ASSESSMENT MODEL

8.1 Seismic hazard

The seismic hazard was presented in previous sections. The total hazard curves are exploited to perform the risk analysis, from the lower intensities levels (highest annual probabilities of exceedance) to the higher (lowest annual probabilities of exceedance).

The hazard curves defined in term of probability of exceedence ($Pb_{exc}(I)$) are converted in term of probability of occurrence ($Pb_{occ}(I)$) calculated with an intensity interval of 0.25 (Figure 31):

$$Pb_{occ}(I) = Pb_{exc}(I+0.125) - Pb_{exc}(I-0.125)$$

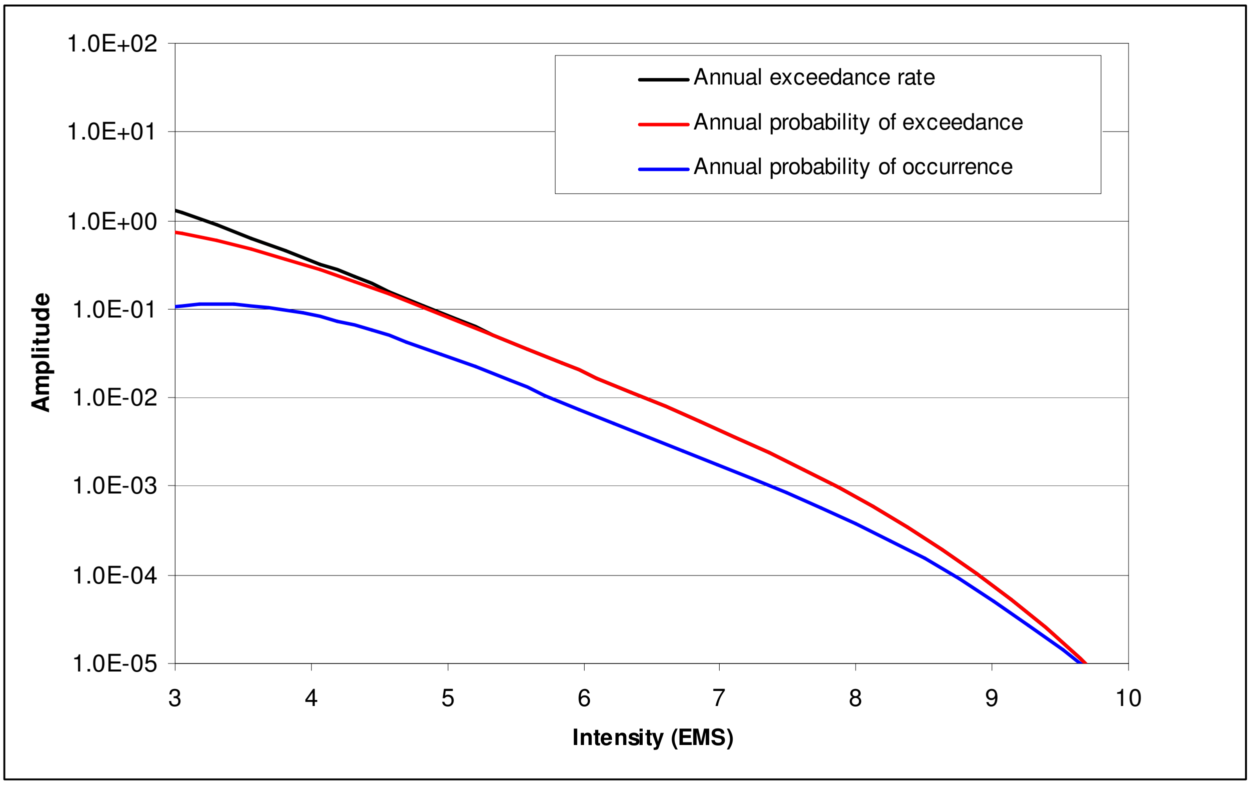


Figure 31: Comparison of the annual exceedance rate, the annual probability of exceedance and the annual probability of occurrence (calculated using an intensity interval equal to 0.25).

8.2 Vulnerability assessment

The vulnerability input data are described in the annexed report. The vulnerability is defined for each of the 79 studied areas (Figure 2). A vulnerability index (Vi) is associated to each building considering:

- A structural type (construction typology) ;
- A construction period;
- A housing units number;

Each area is described by a total buildings number, an inhabitants number and a total insured value (Table 31).

Country	Area name	Construction typology	Construction period	Housing unit number	Building number	Vulnerability index (Vi)
Suisse	Aesch	M1	<- 1919	1U	50	0.75
Suisse	Aesch	M1	<- 1919	2U+	33	0.75
Suisse	Aesch	M3	1946-1960	1U	199	0.606
Suisse	Aesch	M3	1946-1960	2U+	28	0.606
Suisse	Aesch	M3	1961-1980	1U	427.7	0.606
Suisse	Aesch	M3	1961-1980	2U+	89.55	0.606
Suisse	Aesch	M3	1981-2000	1U	169.4	0.606
Suisse	Aesch	M3	1981-2000	2U+	77.2	0.606
Suisse	Aesch	M5	1919-1945	1U	60	0.64
Suisse	Aesch	M5	1919-1945	2U+	19.5	0.64
Suisse	Aesch	M7	1919-1945	1U	60	0.67
Suisse	Aesch	M7	1919-1945	2U+	19.5	0
Suisse	Aesch	RC2	1946-1960	2U+	19.6	0.376
Suisse	Aesch	RC2	1961-1980	2U+	69.65	0.376
Suisse	Aesch	RC2	1981-2000	1U	30.8	0.376
Suisse	Aesch	RC2	1981-2000	2U+	57.9	0.376
Suisse	Aesch	RC3	1946-1960	2U+	8.4	0.39
Suisse	Aesch	RC3	1961-1980	1U	183.3	0.39
Suisse	Aesch	RC3	1961-1980	2U+	39.8	0.39
Suisse	Aesch	RC3	1981-2000	1U	92.4	0.39
Suisse	Aesch	RC3	1981-2000	2U+	57.9	0.39
Suisse	Aesch	W1	1981-2000	1U	15.4	0.437

Table 30: Vulnerability description example for the Aesh district.

Area name	Building number	Population	Insured value	Cost unit
Aesch	1891	9392	2482556000	CHF
Allschwil	3131	17311	4642731000	CHF
Arlesheim	1756	8115	2672989000	CHF
Bättwil	268	930	469857332	CHF
Bettingen	276	986	483883000	CHF
Biel-Benken	841	2565	862700000	CHF
…	…	…	…	…

Table 31: Area description example.

8.2.1 Vulnerability index

The vulnerability Index (V_I) which has been defined in Appendix 2, is a continuous parameter that quantifies the disposition of a building (or of a set of buildings) to be damaged under the effect of a given ground motion, expressed in terms of macroseismic intensity. The vulnerability index is a score that is assigned to a building by means of available information on the typology and other structural and constructive characteristics. Issued from the European Risk_ue approach, the original V_I values are calibrated using European database on earthquake damages, and are adjusted to account for the regional or local specificities.

The vulnerability index approximately ranges between 0 and 1: the most vulnerable buildings present V_I values close to 1, while low values are associated to recent code designed structures.

8.2.2 Vulnerability curves

Vulnerability curves correlate:

- The hazard, in terms of **macroseismic intensity** (I) ;
- with the damage, in terms of **mean damage grade μ_D**.

The Risk_ue method proposed an analytic expression, which offers the mean damage grade μ_D as a function of the macroseismic intensity *I*, only depending from the parameter V_I (**vulnerability index**). The vulnerability curves, are so expressed (Equation 1):

Equation 1: $$\mu_D = \frac{5}{2} \cdot \left[1 + \tanh\left(\frac{I + 6.25 \cdot V_I - 13.1}{2.3} \right) \right]$$

This equation allows defining an analytic vulnerability curve for each building type characterized by a vulnerability index (Figure 32).

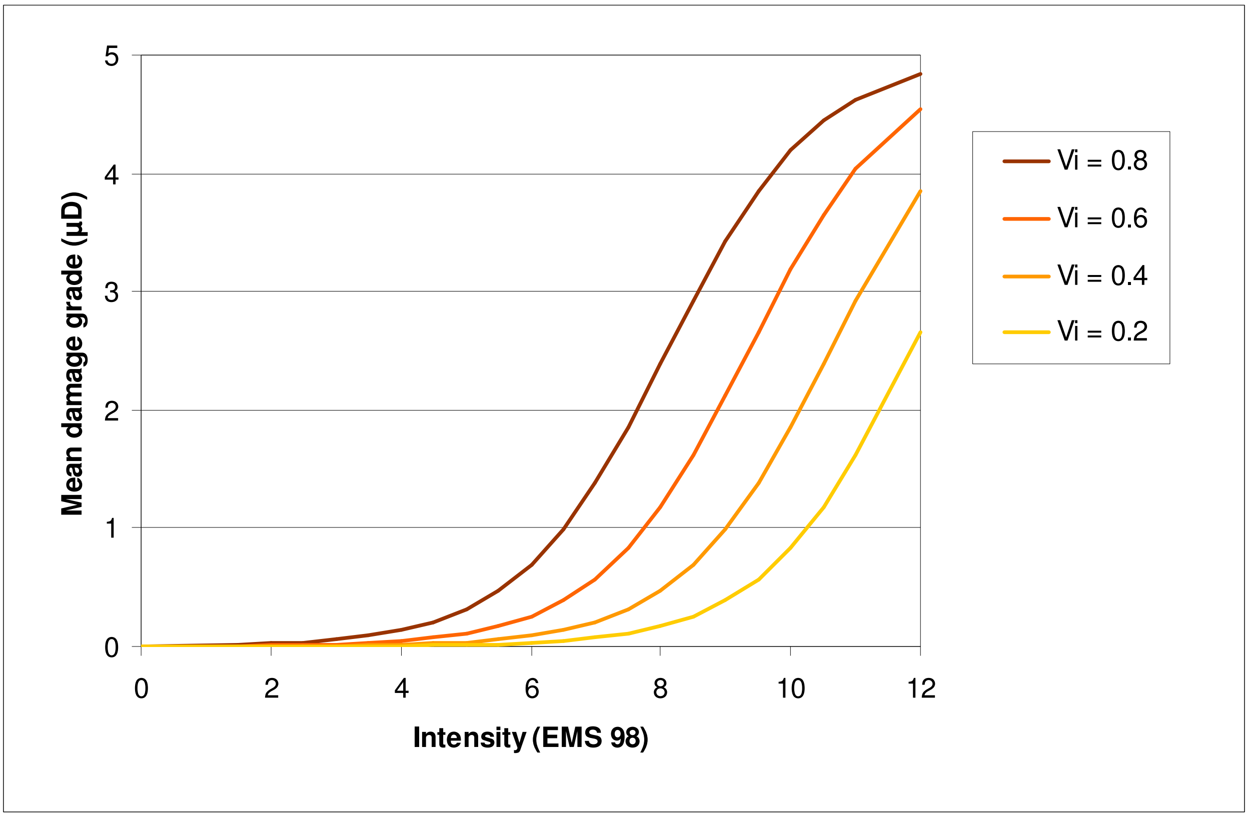


Figure 32: Vulnerability curves for different vulnerability index.

8.2.3 Damage description

The damage grades qualify the post-earthquake states of the structure. They are a linguistic expression of the state of the buildings structural system, after an earthquake action. In modern macroseismic scales such as the European Macroseismic Scale (EMS-98), the damage is represented in a discrete form through **damage grades** D_k (D_k; k=0,1,2,3,4,5; Table 32), which represent an apparent damage that could be ascertained in case of an earthquake.

The methodology uses five damage grades (Table 32), as defined by the European Macroseismic Scale (EMS 98).

Damage Grades	Damage Description	Damage states		Damage index (D_I)
5 (D5)	Very heavy structural, partial or total collapse	Destruction	Extensive	1.00 (0.95 – 1.00)
4 (D4)	Heavy structural Very heavy non structural	Very heavy		0.75 (0.50 – 0.95)
3 (D3)	Moderate structural Heavy non structural	Severe		0.35 (0.20 – 0.5)
2 (D2)	Slight structural Moderate non structural	Moderate		0.1 (0.05 – 0.20)
1 (D1)	Negligible to slight damage	Minor		0.01(0.002 – 0.05)
0 (D0)	No damage	None		0.0 (0.0 – 0.002)

Table 32: Damage grades and loss index (according to Risk-UE project).

8.2.4 Damage grade distribution

For buildings with the same vulnerability index affected by the same seismic action (a given intensity), the analysis of damage data from past earthquakes shows that a non unique damage can be attributed to the building class, which is characterized by a distribution of damages. Some authors have shown that such a distribution can be approximated by a binomial distribution (Braga *et al.*, 1982) that well represents the distribution of damage grades for a set of almost homogeneous buildings or the probability to have each level of damage for a single building (Equation 2).

This distribution of damage grade probabilities for a given intensity, is called the **Damage Grade Distribution** (DGD).

Equation 2: $$p_k = \frac{5!}{k!\cdot(5-k)!}\cdot\left(\frac{\mu_D}{5}\right)^k\cdot\left(1-\frac{\mu_D}{5}\right)^{5-k}$$ $0 \le \mu_D \le 5$ and $k = 1, 2, 3, 4, 5$.

Moreover for each damage grade (D_k) it depends upon a single parameter: the mean damage grade (μ_D).

For example, a mean damage grade (μ_D) of 2.5 leads to 31% probability of damage grade D2, 31% probability of damage D3 and 38% probability of other damage grades (Figure 33).

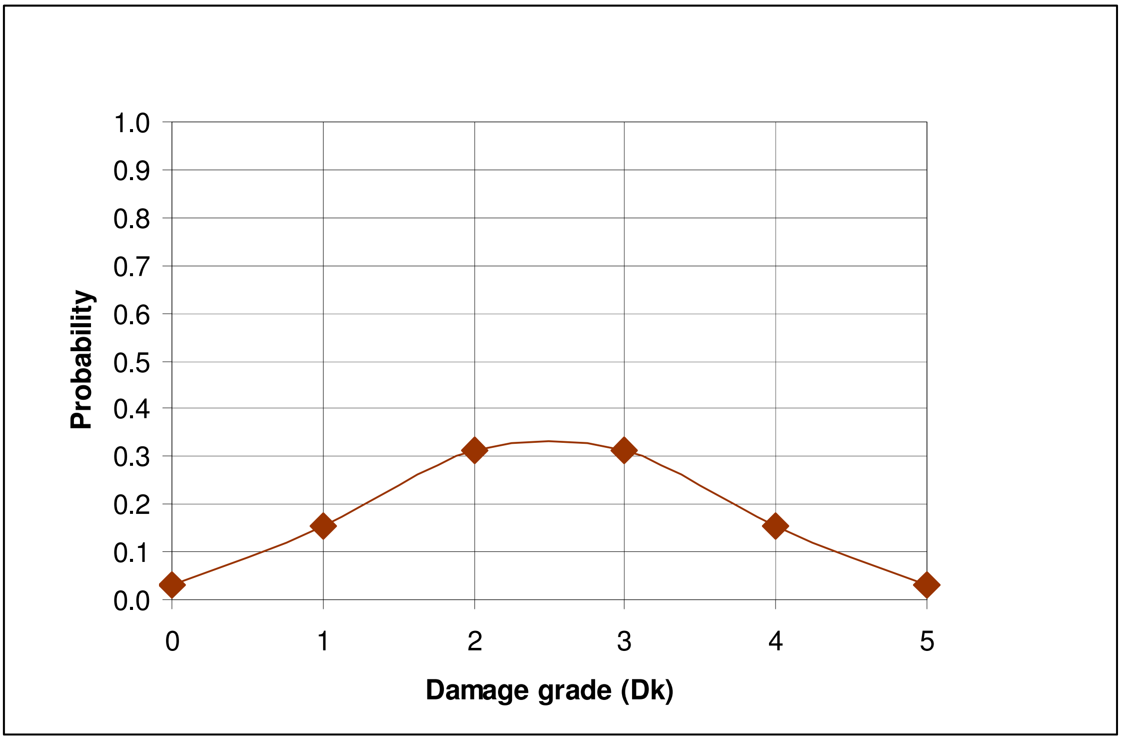


Figure 33: Damage grade distribution for a mean damage grade (µD) of 2.5.

8.2.5 Damage grade curves

Vulnerability curves and damage grade distributions are combined to provide damage grade curves. For a given vulnerability index they provide the probability of occurrence of the damage grades as a function of the macroseismic intensity (Figure 34, Figure 35).

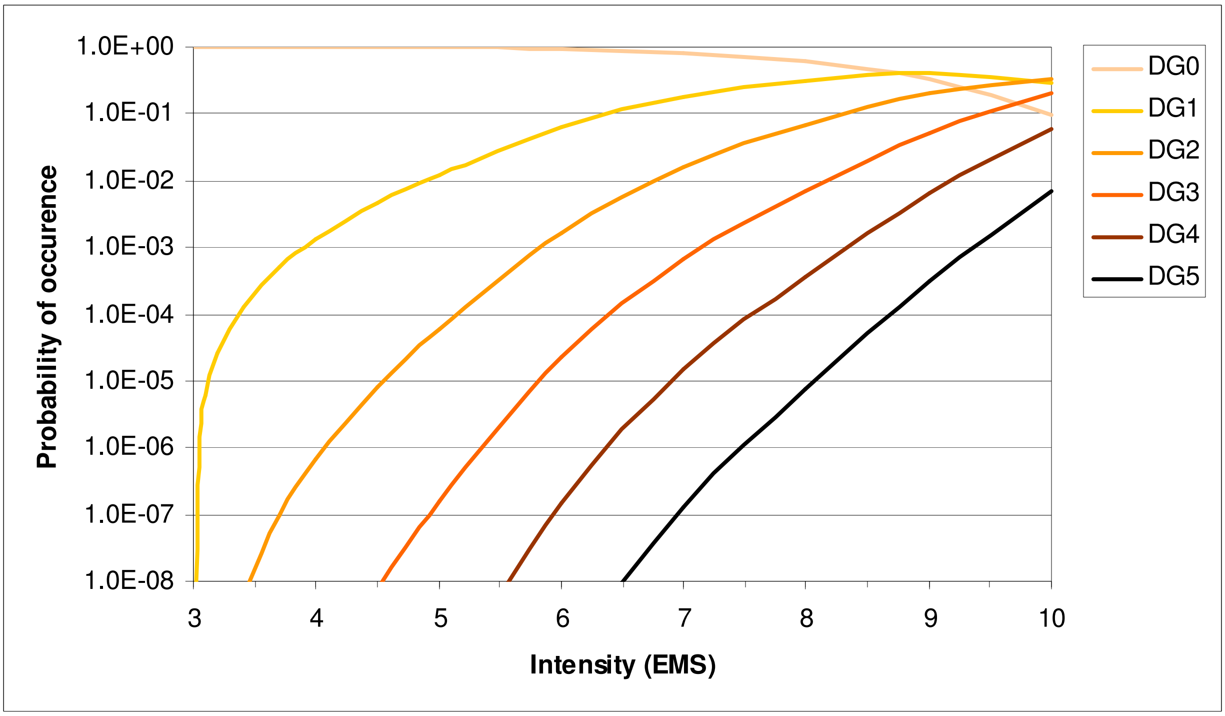


Figure 34: Damage curves: Probability of occurrence of the damage grade as a function of the intensity (building with Iv = 0.4).

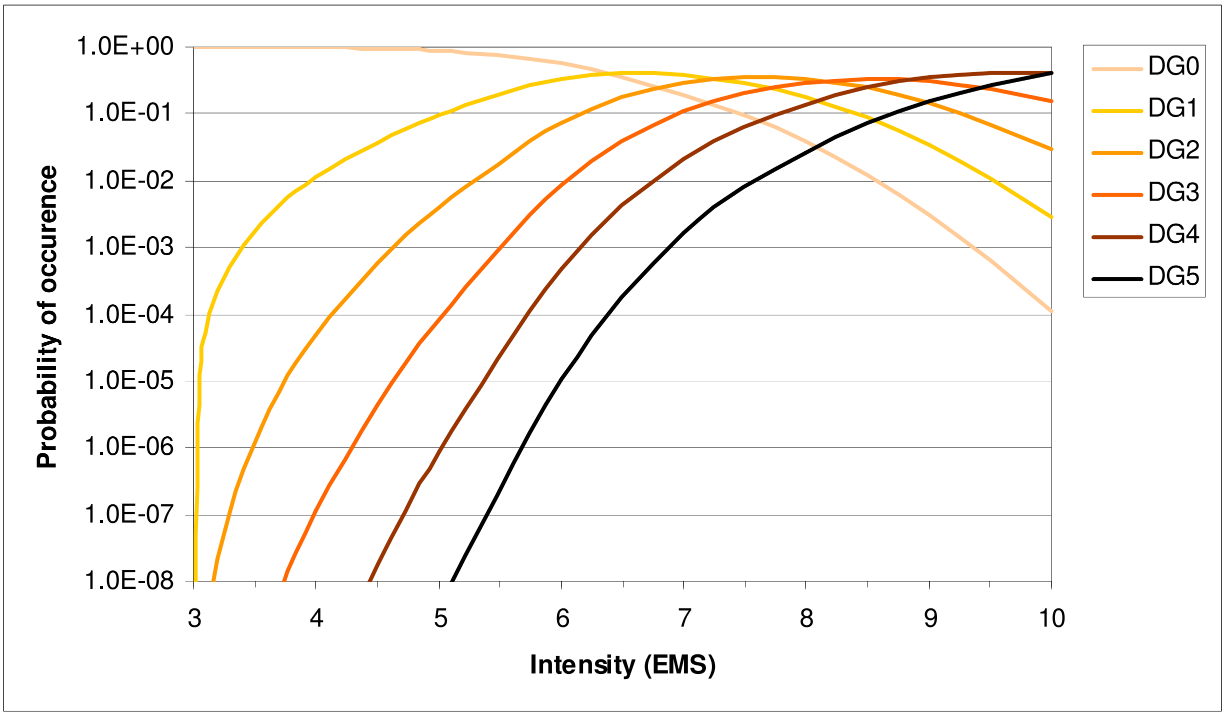


Figure 35: Damage curves: Probability of occurrence of the damage grade as a function of the intensity (building with Iv = 0.8).

8.3 Probabilistic risk calculation process

The risk calculation is based on the convolution of a hazard curve with a damage grade curve. In a probabilistic approach, the process considers all possible combinations of hazard probabilities and damage grade probabilities leading to a damage grade. A discrete process is introduced to integrate the hazard all along the hazard curve, so that all probabilities of exceedance of all the macroseismic intensities are considered:

Probability to observe damage DGx =

$$\sum_{Intensity=3}^{10} \text{(Probability of occurrence of intensity I) x (probability to observe damage grade DGx under intensity I)}$$

- The probability of occurrence of intensity I is derived from the hazard curve.
- The probability to observe damage grade DGx under intensity I is provided by the damage grade curve.

On the Figure 36, a damage grade 2 could appear due to intensity VIII with a high probability (0.32), but could also appear due to an intensity V with a lower probability ($3.4\ 10^{-03}$). If we consider the hazard curve, the probability to observe an intensity VIII is lower ($3.8\ 10^{-04}$) than the probability to observe an intensity V ($3.1\ 10^{-02}$). Finally, the probability to observe a damage grade D2 is similar for an intensity VIII ($0.32 \times 3.8\ 10^{-04}=1.2\ 10^{-04}$) than for an intensity IV ($3.4\ 10^{-03} \times 3.1\ 10^{-02}=1.1\ 10^{-04}$). Regarding the periods of interest for the project, and because hazard is dominated by low intensities (that present the highest probabilities of occurrence), the low damage grades will have the highest chances to be observed, while high damage grades will be affected by very low probabilities.

Considering a given hazard curve and vulnerability curve, the probability to observe a damage grade is the sum, for all the intensities, of the products of the probability of intensities occurrence by the probability of damage grade occurrence under each intensity.

The computation is done for all the damage grades (0 to 5) and leads to a **Global Damage Grade Distribution** (GDGD) (Figure 37).

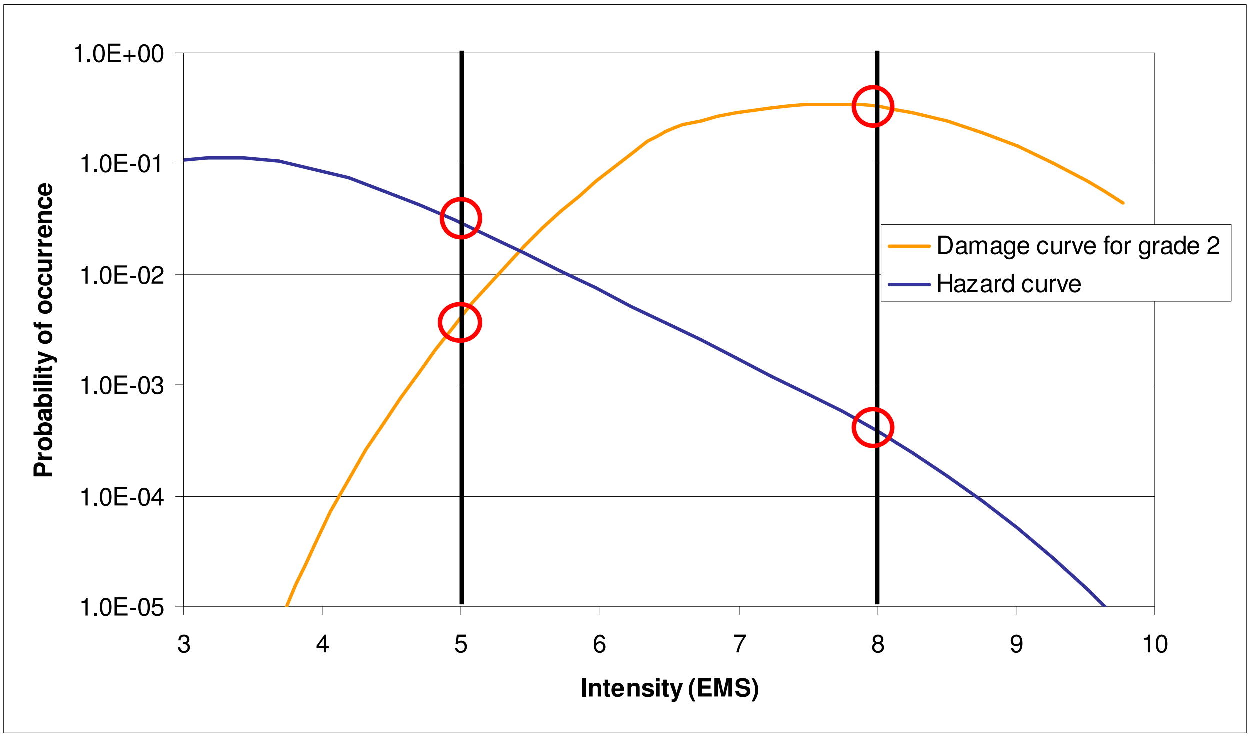


Figure 36: Probability of D2 damage grade occurrence (for a building with Iv = 0.8) and probability of intensity occurrence.

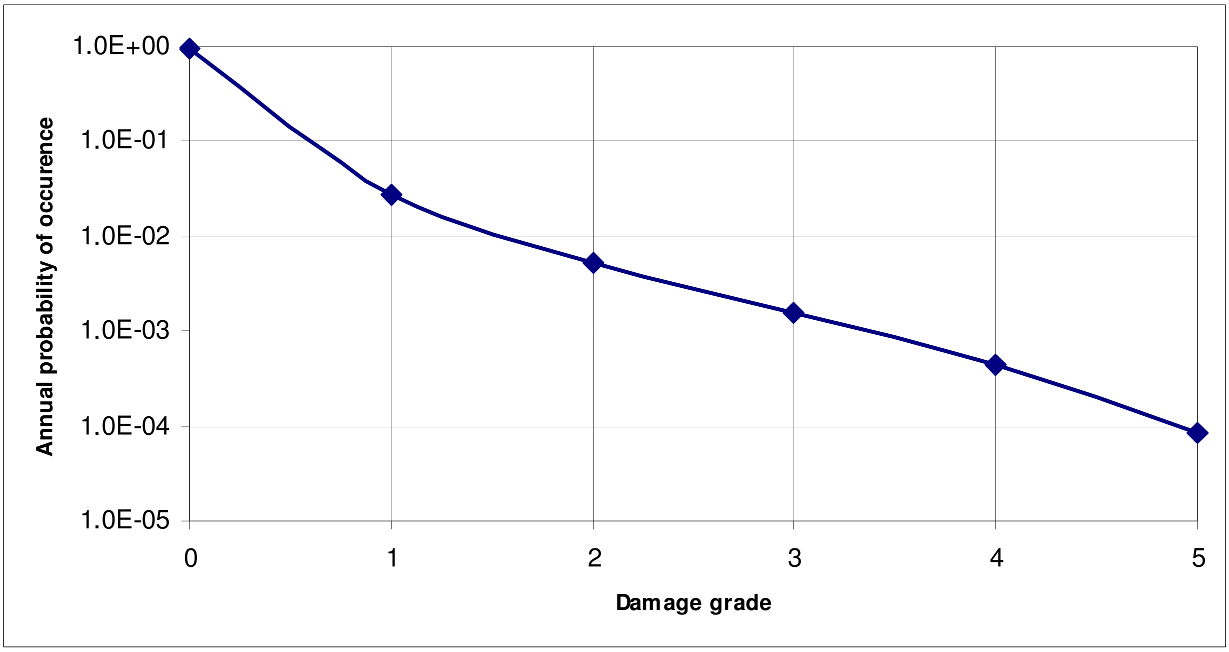


Figure 37: Global damage grade probability distribution, for a high vulnerability building, during the normal period, considering the probabilities of occurrence of all the intensities.

8.4 Cost estimation

The damage can be measured in economic terms through the **Mean Damage Ratio** (MDR) parameter, defined as the ratio between the repair cost and any reference cost (which is taken here as the insured value).

The AP5000 Resonance report describes some correlations proposed between the Mean Damage Grade (MDR) and the Damage Grade (Dk) (Figure 38), which have been obtained by processing the data of repair and rebuilding costs of damaged structures, after significant earthquakes. The cost estimation is unfortunately very imprecise.

In the project, we use a cost function that represents an average curve, irrespectively the building typology or the building size.

In its report, Resonance proposes two cost curves. The basis average curve relies on the interpretation of the works of Cochrane and Shaad (1992). A second curve based on expert judgment, is calibrated to better fit the refund payments, after the 2006 earthquake (Figure 38, Table 33).

The calculations are done using the expert-judgment curve. In order to introduce some variability and uncertainty, an other function will be considered to perform a sensitivity analysis. This curve was established during the Risk_ue project, but was never published.

	Damage grade (D_k)					
Cost function	0	1	2	3	4	5
Resonance expert judgement curve	0%	2%	15%	55%	91%	100%
Resonance average curve from Cochrane and Shaad (1992) works	0%	5%	20%	58%	94%	100%
Risk_ue	0%	1%	10%	35%	75%	100%

Table 33: Values of the different cost functions considered in the project.

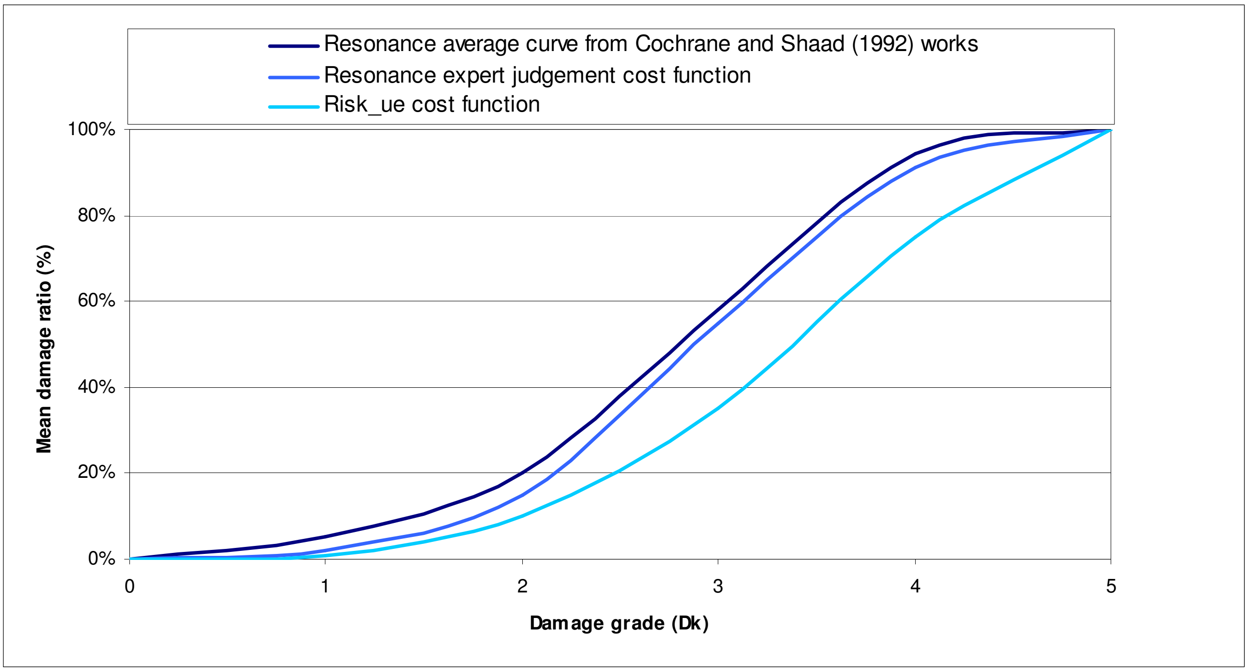


Figure 38: The different cost functions considered in the project

If we consider the variability of the cost function, the repair cost associated to a D_1 grade can vary between 16 000 CHF and 80 000 CHF assuming a 1 600 000 CHF insured value, which means a ratio of 5.

As loss estimates are highly approximate data, we would suggest to preferably use the loss assessment in a relative sense rather than in an absolute sense.

As the input data are based on Insured Value (IV), the loss costs will be expressed in terms of Insured Value Loss (IVL).

8.5 Calibration of the model with 2006 empirical data

The first estimations that we obtained with our models leaded to surprisingly high amounts of repair costs. Several constraints or assumptions done to develop the model could result in an overestimation:

- Necessity to consider magnitudes as low as 2.5 and to use the attenuation law outside its validity domain ;
- Above mentioned uncertainty to define a precise repair cost, especially at low intensities;
- Poor empirical calibration of the existing vulnerability curves in the low intensities domain.

It was not possible within the project nor the objective, to calibrate all the models and curves introduced in the risk calculation process, with observed data, which would require significant scientific efforts. However, we considered important that our model is able to reproduce somehow the effects of the December 8 2006 earthquake. We then used our model to develop a deterministic scenario, in order to calibrate some key parameters, using the 2006 data.

The effects of the 2006 event were responsible, in the studied area, of around 280 buildings affected by slight damages D1 and 6-7 Millions CHF refunded by the insurance companies (AP5000 Resonace repport). Even if it is not proven (and as far as we know, no attempt was done in that sense), that damages were for sure caused by the earthquake, we consider these values as the direct consequences of the 2006 earthquake.

We applied the 2006 earthquake epicenter at the geothermal field, and calculated the resulting intensity map using the SED attenuation law for shallow earthquakes and short distances, which is used in our model. The predicted number of buildings affected by damage state D1 being significantly higher than the observed number, the following principles were adopted to implement a calibration.

One of the reasons of the overestimation could be due to the intensity attenuation law or to the contribution of low magnitudes in our hazard model. However to make possible the comparison of the risk between the different time periods, it was necessary to consider, in the background model, a minimum magnitude as low as the minimum magnitudes considered for the induced seismicity. Even if the intensity attenuation law is empirically poorly constrained by low intensities data, it was not possible during the project to scale another law or to arbitrarily modify the attenuation law coefficients. The same is true for the cost function; its calibration would require a specific economical approach. Even if we could have modified the cost ratio associated to D1 damage grade, it was not done, since this value was scaled considering the estimated repair costs during the 2006 event and the insured value (AP5000 Resonance report).

It was decided not to modify the vulnerability index values because they result from empirical data analysis. On the contrary, because the damages database from which the shape of the damage grade function has been calibrated, contains very few damages associated to intensities lower than VII, it is recognized that the shape of the μ_D function (Equation 1) is poorly constrained at low intensities. For that reason, we decided to modify the μ_D function, only in the low intensities domain (Figure 39).

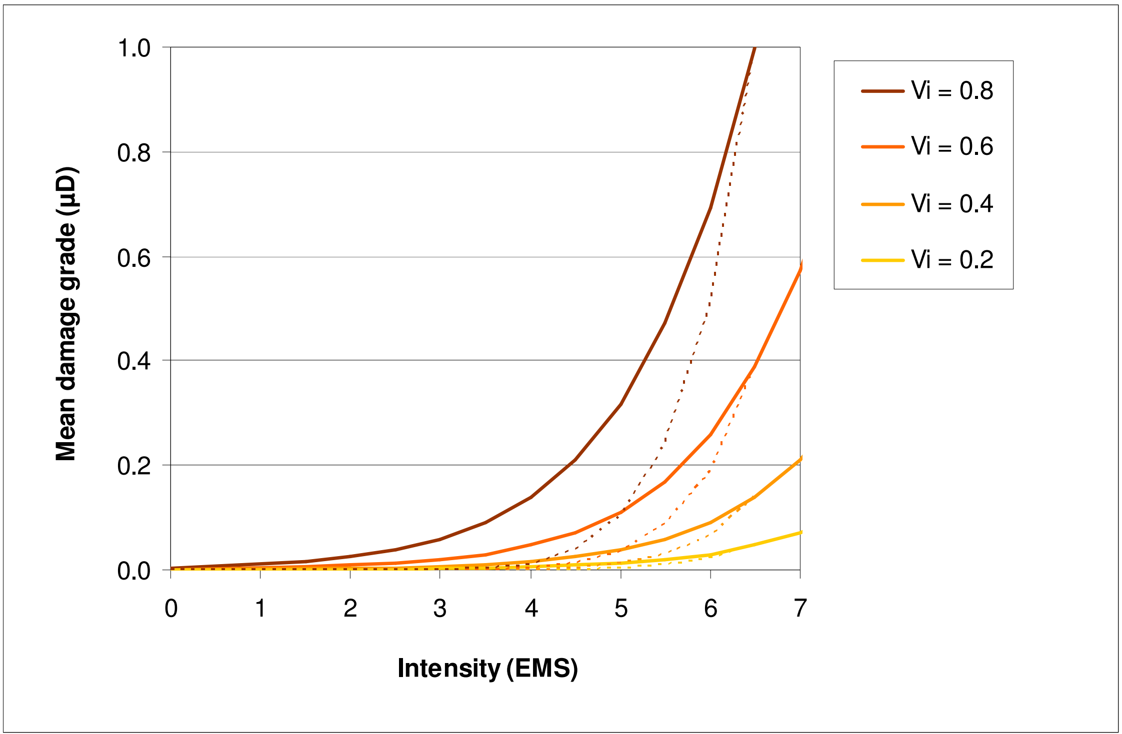


Figure 39: Vulnerability curves zoom for low intensities. In dotted lines, the modified vulnerability curves compared to the original curves.

The calibration of the vulnerability curve was performed according the following principles:

- No damage is associated to intensities lower than III, because this level corresponds to the human perception level. The μ_D function is set equal to 0 for intensities lower than III ;
- The Equation 1 is consistent with the empirical data set for intensity above VI-VII, reflecting the validity domains of the empirical database. For intensities greater or equal to VI-VII we adopted the published μ_D function;
- To calibrate the function with the available data of the 2006 event a reduction factor is introduced for intensities between III and VI-VII. This factor corresponds to the square of the linear equation between the two points corresponding to intensity III (with μ_D =0) and VI-VII (with μ_D set to its original value) (Figure 40).

The impact of the reduction factor on vulnerability curves is represented Figure 40.

Using this calibration, the simulated scenario leads to 296 affected buildings instead of 280 observed, and to a repair cost of 10 millions of CHF instead of 6-7 millions of CHF, that we considered as a reasonable estimate.

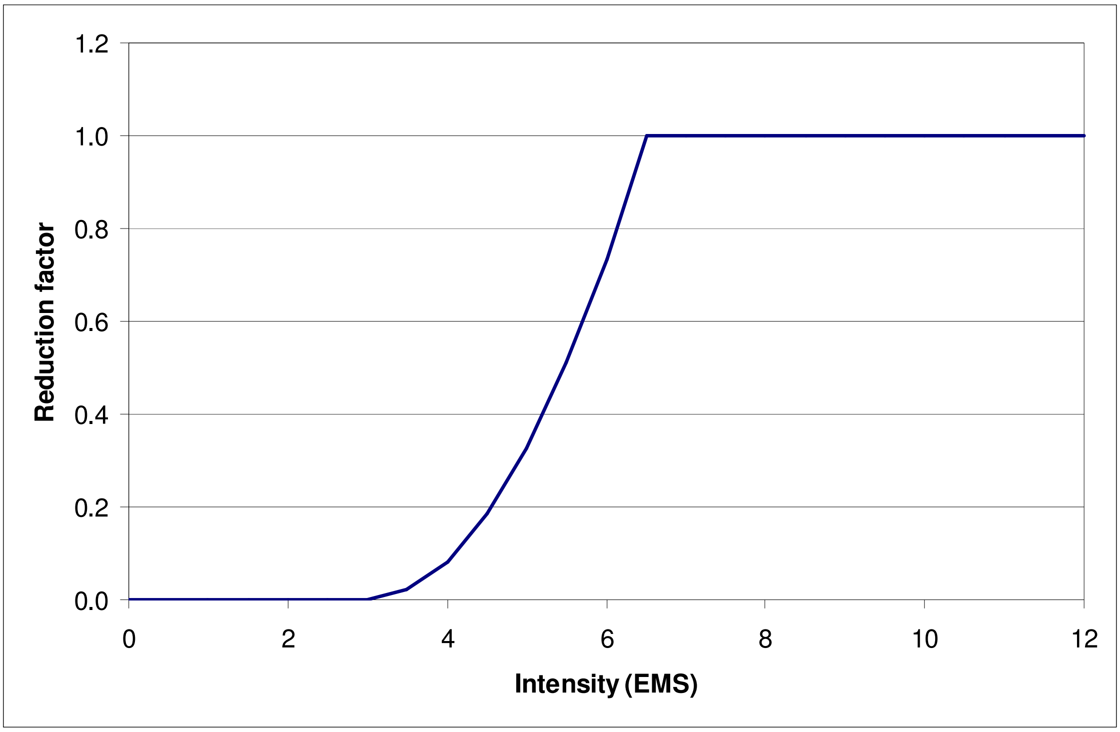


Figure 40: Reduction factor applied to the µD function, to calibrate the vulnerability model

8.6 Human losses

Due to the fact that the seismic risk, on the time periods we are interested in, is mainly controlled by low intensities distribution and low damage levels, the human losses are a less interesting parameter than the repair costs, because they do not allow a real discrimination between the three reference periods.

Casualty estimation is notoriously difficult. From the post-ertahquake feedback, it appears that casualty numbers are highly variable from one earthquake to another. Nevertheless, building collapse (D5, destruction) is the main cause of casualties (75 to 95% of deaths, according to COBURN and SPENCE, 2002).

Post-earthquake analysis and finding-outs gives some trends about consequences to people. The used method (Coburn and Spence, 2002) is based on the following equation and leads to a mortality rate (M_R) if the building collapses (i.e. Damage D_5).

Equation 3 : $M_R = M2 * M3 * (M4 + M5 * (1 - M4))$

Where:

- M_2 represents the rate of occupants in the building at the moment of the earthquake (0.5).
- M_3 represents the rate of occupants trapped by collapse (0.6).

- M_4 represents the mortality rate during the collapse (0.4).
- M_5 represents the mortality post-collapse rate (0.7).

The aforementioned rates are averaged values that we adopted to the project. The final mortality rate is 0.25 for buildings affected by a damage D5 and for occupants living or working in these buildings.

8.7 F/N curve for a single building

A F/N curve describes, for a given hazard, the probability to exceed (or the annual frequency to exceed) financial losses or human losses.

In the case of a single building described by its global damages grade distribution (GDGD), and using the damage cost curve, a F/N curve can be obtained.

It represents on the X-axis, the cost associated to each damages grade and on the Y-axis the probability to exceed the costs, during the reference period (Figure 41).

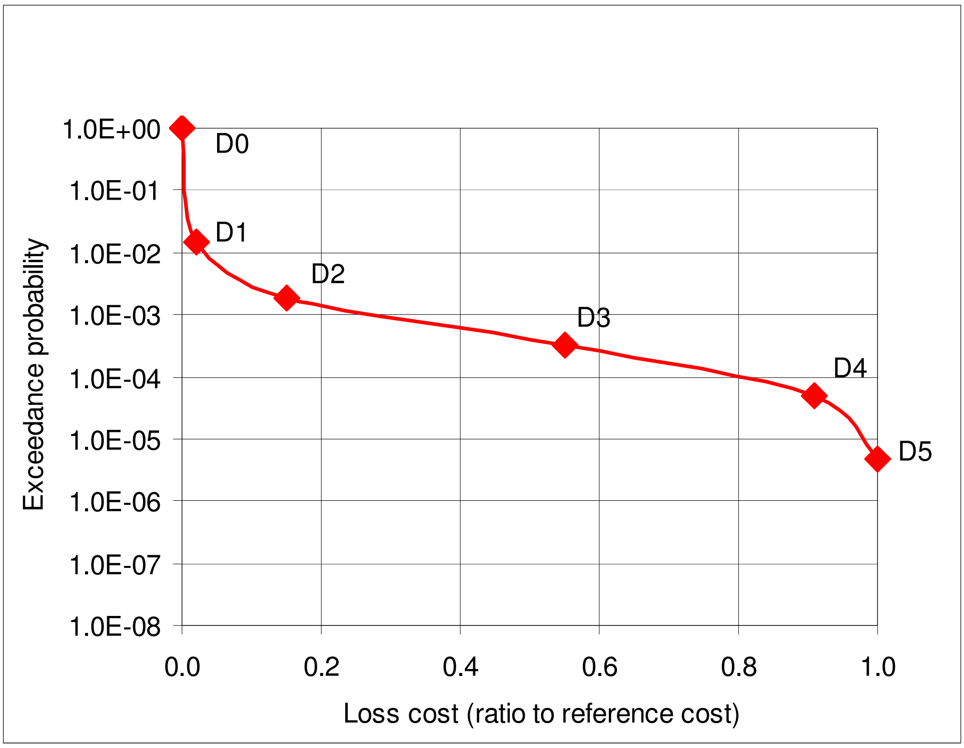


Figure 41: Example of F/N curve for a single building.

8.8 Application to the project

The aforementioned approach is applied to the project, considering the available information and characterization of the built environment in the different areas.

As the comparison of the seismic hazard curves does not show significant differences in probability exceedance above intensity VI-VII level, it was assumed that the risk increment mainly concerns **current buildings** and **not the critical facilities or lifeline systems.**

The post earthquake feedback indicates **that critical facilities** are able to sustain at least intensity VII without suffering slight damages or disruption. As the stimulation or circulation periods do not contribute to an hazard increment at intensities greater than VI-VII, it was assumed that these two periods could not be responsible for a significant risk increment on those facilities.

The situation is almost the same for **lifeline systems**. The node components (water treatment plant, power stations, substations, etc) are also assumed to be seismically designed, as elements with high important factor in all the seismic codes. The lines (water pipe, rails, etc.) are more sensitive to permanent ground deformation than to ground motion. Such permanent ground deformations are not expected for intensities bellow VI-VII.

According to these considerations, it was decided not to consider the facilities and lifeline systems in the risk analysis. Even if we cannot exclude that local and punctual damages could occur due to low intensities, it is thought that the risk increment associated to those elements, is not a key issue of the risk analysis.

8.8.1 Combination of hazard meshes and vulnerability areas

In order to consider the variability of the seismic motion, the geographical districts (areas of Figure 2) are intersected with the hazard meshes of Figure 4 to identify subareas characterized by (Figure 42):

- A surface (km²) ;
- Three hazard curves (one for each period of interest, i.e., normal stimulation and circulation) ;
- A building typology repartition (number of buildings belonging to each type of the building typology).

The buildings belonging to a given area (polygons of Figure 2) are assumed to have the same geographical density distribution. For a given area, the parameters (buildings number of each typology, insured value) of each subarea are equally distributed, proportionally to the subarea surface.

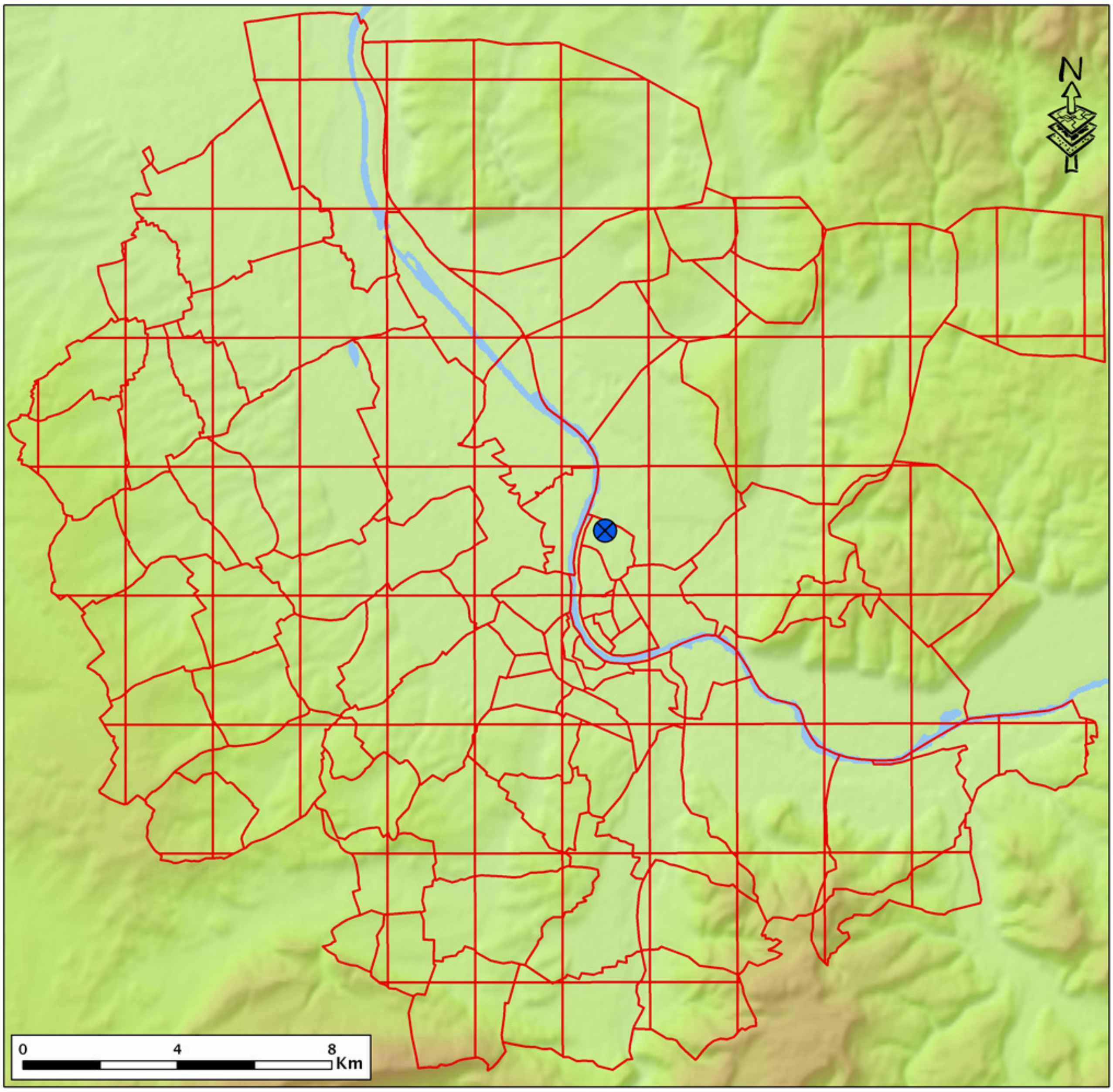


Figure 42 : Subareas: studied areas intersected by the hazard grid.

8.8.2 Risk calculation process

For each building belonging to a typology and a subarea, the risk calculation is based on the convolution of a hazard curve by a vulnerability curve defined by a vulnerability index. A discrete process is introduced to integrate the hazard all along the hazard curve, so that all probabilities of exceedance of all the macroseismic intensities are considered.

This computation leads to a Global Damage Grade Distribution (GDGD) probability to observe each damages grade (D0 to D5) for each building (Table 34, Figure 37).

				Global Damage Grade Distribution probability (annual)					
Area	Subarea	Building	Typology	P(D0)	P(D1)	P(D2)	P(D3)	P(D4)	P(D5)
A1	SA1	B1	T1	9.9E-01	1.3E-02	3.4E-04	2.4E-05	2.0E-06	9.7E-08
A1	SA1	B2	T1	9.5E-01	4.4E-02	2.9E-03	4.1E-04	7.3E-05	9.0E-06
A1	SA1	B1	T2	9.2E-01	7.2E-02	6.8E-03	1.2E-03	2.6E-04	4.3E-05
A1	SA2	B1	T1	9.9E-01	1.3E-02	3.4E-04	2.4E-05	2.0E-06	9.7E-08
…	…	…	…	…	…	…	…	…	…

Table 34: Result example of Global Damage Grade Distribution for different buildings.

8.8.3 Probabilistic considerations

A damage grade distributions is calculated for each building considering specific hazard and vulnerability curves. In order to obtain a result at the scale of an area (district or all the studied area), it implies to combine the probability distributions of all the buildings.

In the case of two buildings, each one has its own global damage grade distribution for each of the 6 damage grades (D0 to D5). It is necessary to take into account all the damage grade combinations and to estimate their associated probability (Table 35).

Then it exists 6^2=36 possible combinations between the damages grades of buildings and their associated probabilities and costs (Figure 43 and Figure 44).

In the case of n buildings, each one has also its own global damage grade distribution for each of 6 damages grade (D0 to D5). Then there are 6^n combinations between buildings damage grades. With about 100 000 buildings in the studied area, the combination number is so large that it is no conceivable to calculate it. Moreover, each combination would have a so small probability, that it is not computable.

A simplification is introduced by averaging the global damage grade distribution of all the buildings of a given area. This simplification leads to a **Mean Global Damage Grade Distribution** (MGDGD) which represents the **most probable** global damage grade distribution, but no probability can be associated to the distribution. The most probable value represents the average of the values weighted by their probability.

It implies, for the project results, that all values obtained at the scale of an area are computed with the previous simplification and have to be considered as **most probable evaluations**.

	Combinations	Combinations	Combinations	Combinations	Combinations
Building 1	D0	D0	D0	…	D5
Building 2	D0	D1	D2	…	D5
Probability	P(D0) x P(D0)	P(D0) x P(D1)	P(D0) x P(D2)	…	P(D5) x P(D5)
Loss cost	Cost (D0) + Cost (D0)	Cost (D0) + Cost (D1)	Cost (D0) + Cost (D2)	…	Cost (D5) + Cost (D5)

Table 35: Damage grade combinations for two buildings.

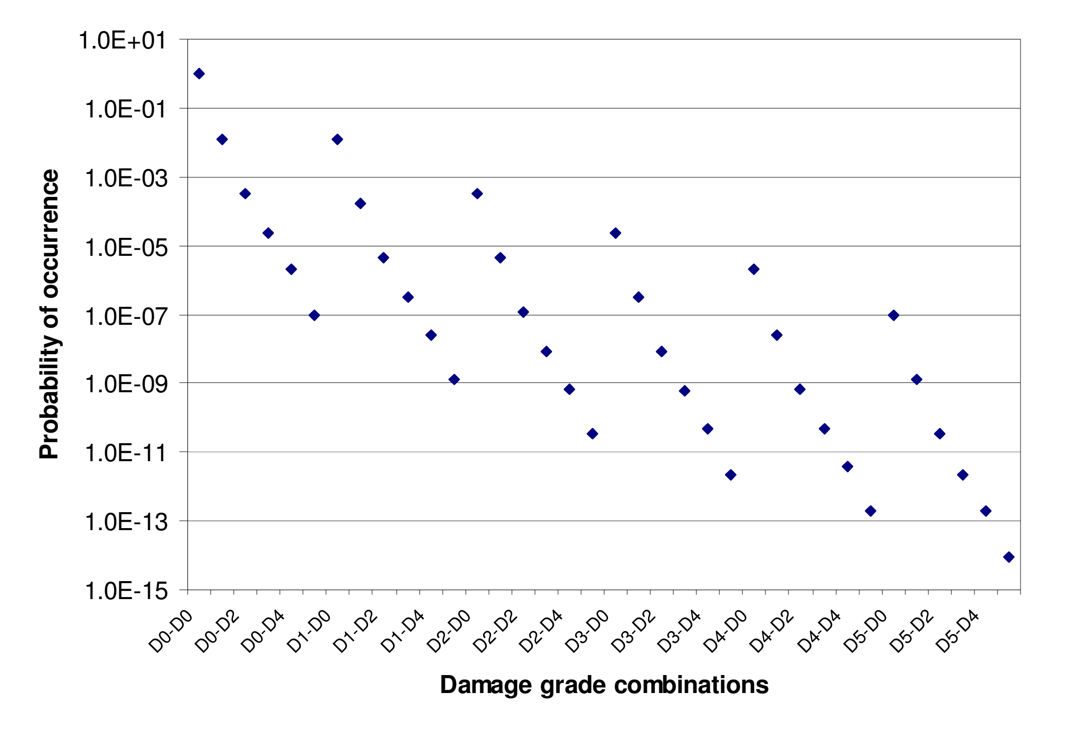


Figure 43: All damage grade combinations for two buildings and their associated probabilities.

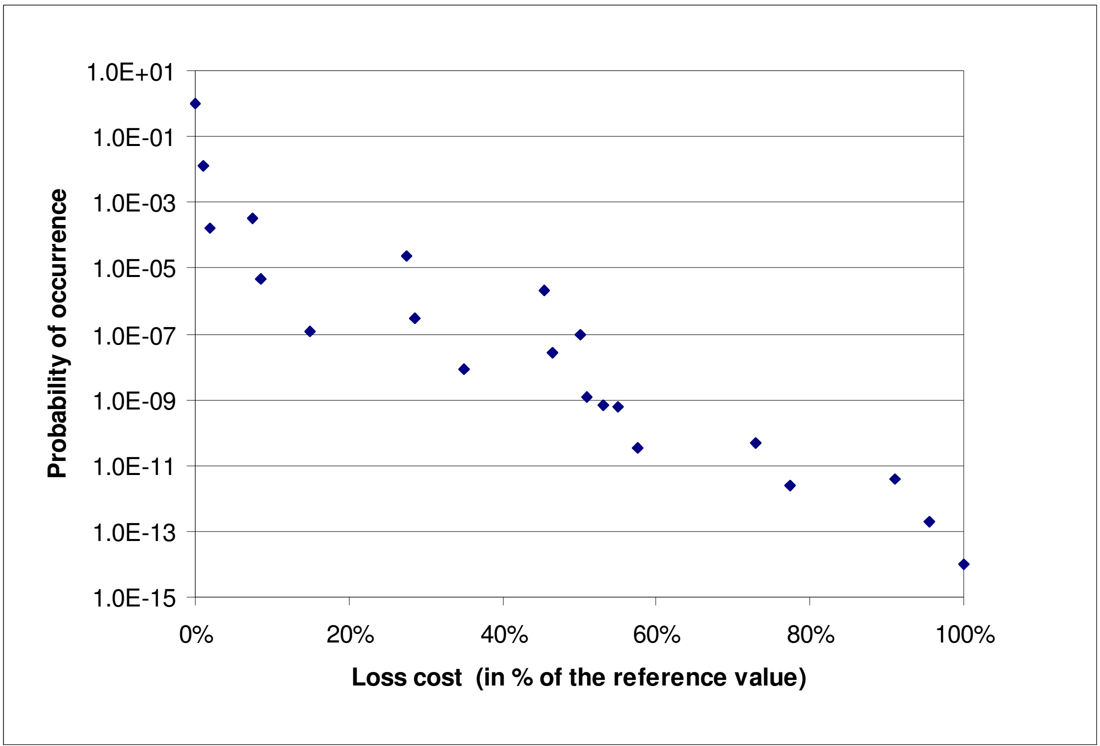


Figure 44: All possible loss costs for two buildings and the corresponding probability distribution.

8.8.4 Results aggregation in each area

Applying the above mentioned simplification, the Global Damage Grade Distributions (GDGD) are computed for each building and are averaged considering all the buildings belonging to the same area, to obtain the **Mean Global Damage Grade Distribution** (MGDGD) of the area.

8.9 Most probable affected buildings number

The losses are in this case quantified by the **Most Probable Buildings Number Affected** by each damage grade (MPABN(Dx)). It represents the product of the total buildings number of a given area by the probability to observe a damage grade in the area (MGDGD(Dx)) (outcome from the mean global damage grade distribution of the area).

MPABN(Dx) = Total building number * MGDGD(Dx)

The Most Probable Affected Building Number is the sum of the most probable buildings number affected by each damage grade from D1 to D5.

MPABN = MPABN(D1) + MPABN(D2) + MPABN(D3) + MPABN(D4) + MPABN(D5)

The values are computed for each area and for the whole studied area.

8.10 Most probable victims number

The losses are quantified by a **Most Probable Victims Number** (MPVN), that represents the product of the total buildings number of a given area affected by a damage grade D5 (MPABN(D5)) by the mortality rate (M_R), by the inhabitants number per building. The inhabitants number of a building is assumed to be the total inhabitants number of the area divided by the total building number of the area.

MPVN = MPABN(D5) * M_R * occupants number per building

The values are computed for each area and for the whole studied area.

8.11 Most probable insured value loss

The **Insured value** (IV) input data prepared by Resonance are used in the risk analysis. These values have been established for each of the 79 studied areas (district, commune …).

It is assumed that each building of an area has the same insured value (IVb) (i.e. the insured value of the whole area divided by the buildings number of the area).

The losses are quantified by the **Most Probable Insured Value Loss** (MPIVL) for each damage grade. It represents the product of the most probable buildings number affected by a damage grade (MPABN(Dx)) by the cost of the damage grade for these buildings (the product of the Mean Damage Ratio of the damage grade (MDR(Dx)) by the Insured Value of a building (IVb)).

MPIVL(Dx) = MPABN(Dx) * MDR(Dx) * IVb

The **Most Probable Insured Value Loss** is the sum of the most probable insured value loss of each damage grade from D1 to D5.

MPIVL = MPIVL (D1) + MPIVL (D2) + MPIVL (D3) + MPIVL (D4) + MPIVL (D5)

The values are computed for each area and for the whole studied areas.

8.12 Risk increment

The risk increment is measured as the loss ratio, respectively between the stimulation period and the normal period, and between the circulation period and the normal period. Three risk increments are quantified:

- **Affected buildings number increment:** the Most Probable Building Number Affected during the stimulation and the circulation period are divided by the Most Probable Building Number Affected during the normal period, this factor is called the **Affected Buildings Multiplication Factor**.
- **Human risk increment:** the Most Probable Victims Number during the stimulation and the circulation periods are divided by the Most Probable Victims Number during the normal period. This factor is called the **Human Risk Multiplication Factor.**
- **Financial risk increment:** the Most Probable Insured Value Loss during the stimulation and the circulation periods are divided by the Most Probable Insured Value Loss during the normal period, this factor is called the **Financial risk multiplication factor**.

8.13 Expression of the Results

For each area (79 zones of Figure 2), the results, for a given reference period, consist in (Table 36):

- Total buildings number of the area;
- Total Insured Value (IV) in CHF of the area;
- Most Probable Insured Value Loss (MPIVL) in CHF of the area;
- Ratio to the Insured Value of the Most Probable Insured Value Loss (MPIVL / IV);
- Insured Value Loss per building (MPIVL/NB Buildings) in CHF;
- Most Probable victims number of the area (MPVN);
- Most Probable affected buildings of the area (MPABN);
- Financial risk amplification factor (MPIVL during stimulation or circulation period / IVL during normal period);
- Most Probable Affected Buildings Number amplification factor (MPABN during stimulation or circulation period / MPABN during normal period).

The different values must be interpreted considering the duration of each reference period:

- 12 days for the **stimulation** period;
- 30 years for the **circulation** period.

In order to compare the stimulation and normal periods, the values are calculated considering an effective time-period of 12 days. To compare the circulation and normal periods, they are calculated on the 30 years of the field operation.

				Stimulation period (12 days)						
CODE	Area name	Total buildings number	Total Insured Value IV (CHF)	Most probable Insured Value loss IVL (CHF)	Ratio IVL / IV	IVL per building (CHF)	Most probable victims number	Most probable affected buildings number	Financial risk multiplication factor (stim/norm)	Affected buildings multiplication factor (stim/norm)
All area	**All area**	**106 478**	**174 952 012 000**	**45 447 835**	**2.60E-04**	**427**	**5.42E-02**	**1 051**	**10**	**20**
ch_aes_01_01	Switzerland Aesch	1892	2 482 560 000	291 595	1.2E-04	154	3.6E-04	9	**6**	**11**
ch_all_01_01	Switzerland Allschwil	3134	4 642 730 000	1 162 743	2.5E-04	371	1.4E-03	32	**10**	**20**
ch_am _01_01	Switzerland Am Ring	1175	2 627 340 000	1 510 868	5.8E-04	1 286	2.9E-03	24	**11**	**26**
ch_arl_01_01	Switzerland Arlesheim	1758	2 672 990 000	429 550	1.6E-04	244	4.6E-04	12	**7**	**14**
ch_aug_01_01	Switzerland Kaiseraugst	471	820 497 000	100 802	1.2E-04	214	1.3E-04	2	**7**	**12**
ch_bac_01_01	Switzerland Bachletten	2469	5 520 990 000	2 050 010	3.7E-04	830	1.8E-03	36	**12**	**24**
ch_bat_01_01	Switzerland Bättwil	270	469 857 000	55 147	1.2E-04	204	3.0E-05	1	**7**	**12**
ch_bet_01_01	Switzerland Bettingen	278	483 883 000	101 887	2.1E-04	366	4.2E-05	2	**11**	**20**

Table 36: Results example.

9 PROBABILISTIC RISK ASSESSMENT RESULTS

The probabilistic risk assessment is conducted in two ways:

- **At a building scale**: The risk is computed for a single building, the vulnerability of which and the distance to the geothermic field varying in order to appreciate the risk increment for individual buildings ;
- **At the scale of the urban area**: The risk is computed for the whole buildings stock of the studied area, in order to appreciate the global impact of the geothermal field activity. The results are also available for each district or municipality.

9.1 Results for individual buildings

We considered:

- 4 different distances to the geothermal field: 0, 5, 10 and 15 km
- One building (with an insured value of 1,6 Million of CHF) with high vulnerability and one with low vulnerability represented by two vulnerability index Vi (0.8 and 0.4)

We compare, Figure 45, the F/N curves obtained for 12 days of stimulation period and for 12 days of normal period.

The stimulation period is responsible for a significant risk increment, the effect of which decreases with the distance to the geothermal field. The risk increment is higher for a highly vulnerable building than for a less vulnerable building. It is also higher in the low cost domain than in the high costs losses.

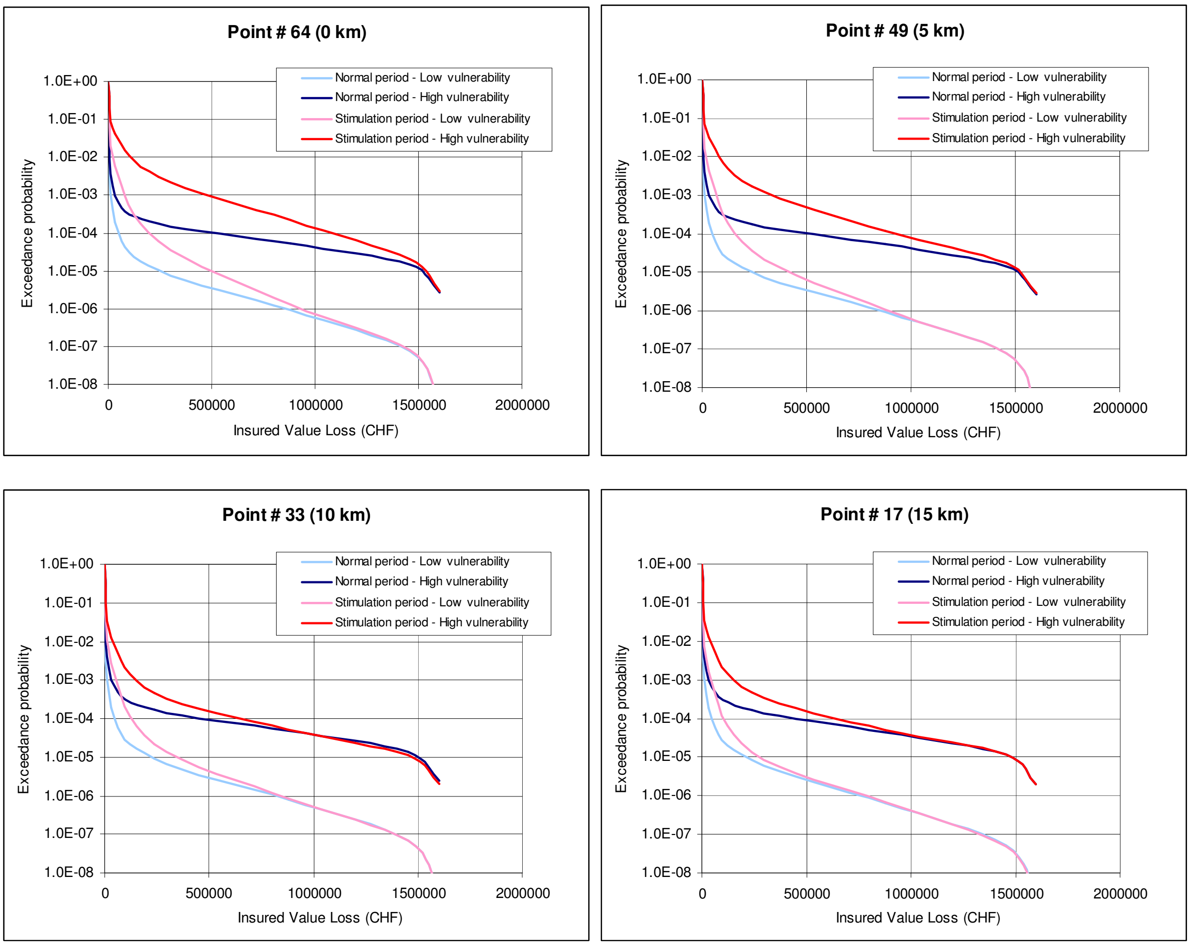


Figure 45 : Comparison of F/N (Frequency / Insured value loss) curves between 12 days normal period and stimulation period for a low vulnerable and a high vulnerable individual building of a value of 1,6 million CHF, located at 0, 5, 10 and 15 km from the geothermic field.

We compare, Figure 46, the F/N curves obtained for 30 years of circulation period and for 30 years of normal period. In that case, the risk increment is not significant except in the field site vicinity.

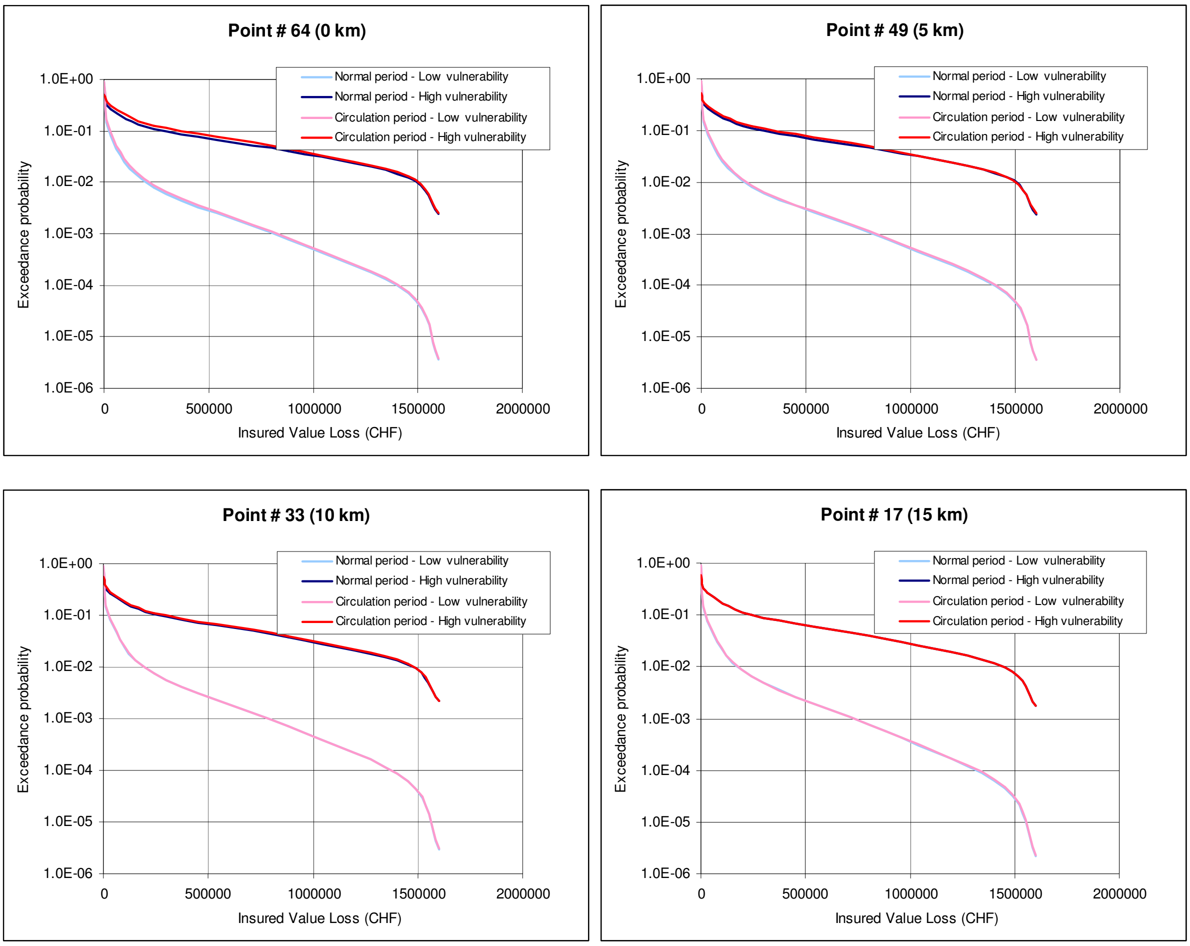


Figure 46 : Comparison of FN (Frequency / Insured value loss) curves between 30 years normal period and circulation period for a low vulnerable and a high vulnerable individual building of a value of 1,6 million CHF, located at 0, 5, 10 and 15 km from the geothermic field.

9.2 Results for the whole urban area

9.2.1 Risk increment between stimulation period and normal period

The risk comparison between stimulation and normal period is synthesized in Table 37, in terms of financial losses and human losses over a time period of 12 days. Results for each area are listed in the Appendix 2.

The MPIVL parameter represents the most probable insured value loss resulting from the SERIANEX model, during a period of 12 days of re-stimulation of the field. From these values a MPIVL loss cost is estimated per building. It represents the insurance prime that would be necessary to cover the risk.

The most probable victims number and the affected buildings number are also provided. However the victims number is not a significant nor discriminant parameter during the stimulation period. This is because during the short period of time of 12 days, the risk is mainly caused by low intensities occurrence, and because high intensities that could be responsible for high damage grade have only very low probabilities of exceedance.

It is worth noting that the financial risk multiplication factor is incomparably higher during the stimulation period.

During a re-stimulation period of 12 days and considering the model that was developed within AP3000 and the AP5000 risk model, the insured value loss would correspond to approximately 6 times the repair costs associated to the 2006 event.

Considering the total buildings number, this risk could be covered with an insurance prime of 430 CHF/building. This number must be compared to 41 CHF, which correspond to the insurance prime that would be necessary to be covered against the tectonic risk, during the same duration as the stimulation (i.e. 12 days). As the stimulation is assumed to occur only one time per year the cost calculated for the stimulation period can be considered as an annual cost.

The geographical distribution of the risk increment (Figure 47) shows a rapid decay with the distance to the field. There is a factor 3 between the multiplication factor on the field site and 12 km away. By comparing the area “Kleinhüningen” located on the field and the area “Ettingen” located at a 13 km from the field:

- The financial risk multiplication factor varies from 17 at Kleinhüningen to 6 at Ettingen;
- The most probable affected buildings number multiplication factor varies from 34 at Kleinhüningen to 11 at Ettingen.

Comparison between stimulation and normal periods during 12 days of stimulation.							
Period	Total buildings number	Total Insured Value IV (CHF)	Most probable Insured Value loss MPIVL (CHF)	Ratio MPIVL / IV	MPIVL per building (CHF)	Most probable victims number MPVN	Most probable affected buildings number MPABN
Normal	106 478	174 952 012 000	4 350 887	2.5E-05	41	5.4E-02	52
Stimulation	106 478	174 952 012 000	45 447 835	2.6E-04	427	5.4E-02	1 051

Financial risk multiplication factor	Human risk multiplication factor	Most probabale affected buildings multiplication factor
10.4	1.0	20.1

Table 37: Comparison between stimulation and normal periods during 12 days of stimulation.

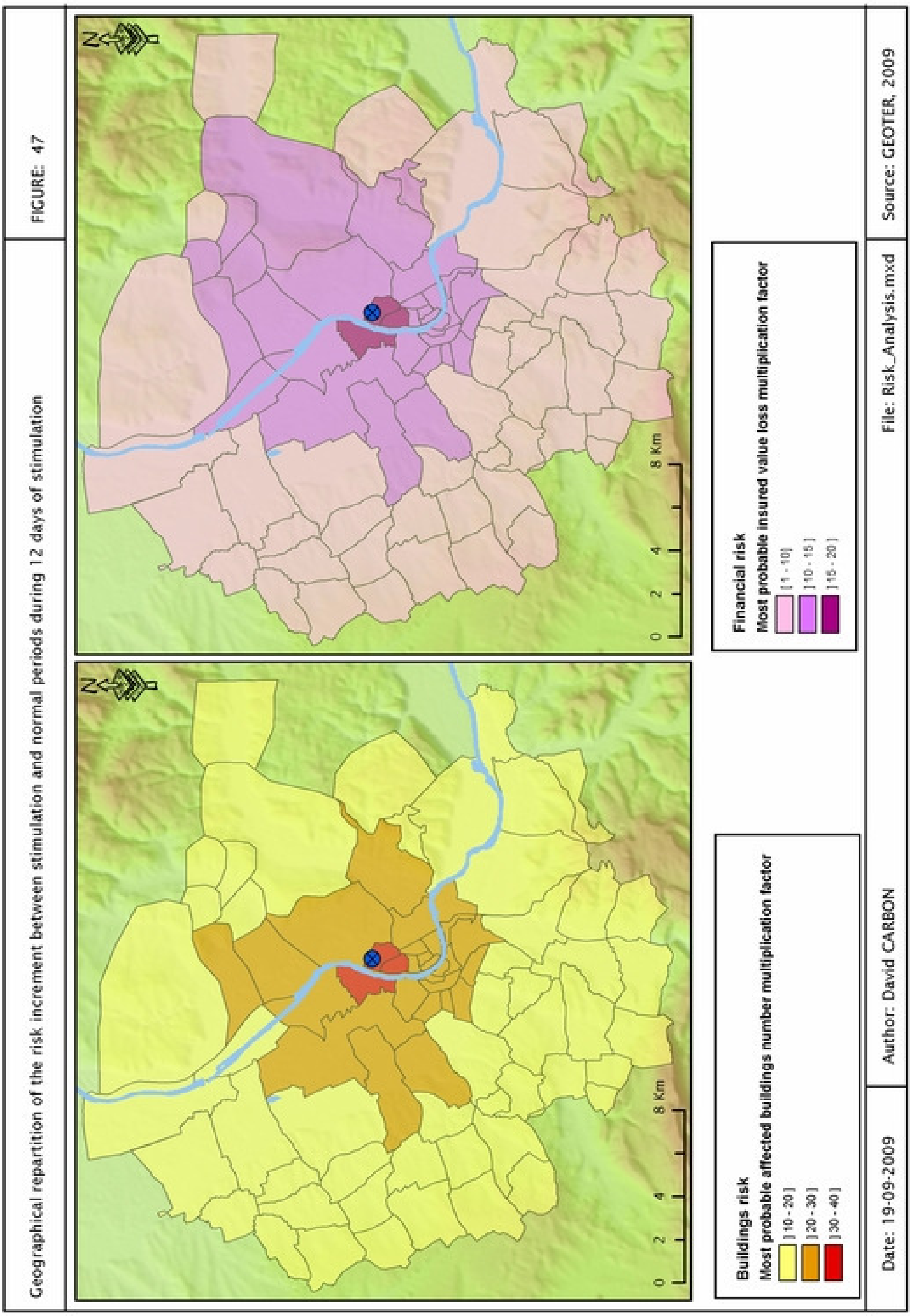


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Figure 47: Geographical repartition of the risk increment between stimulation and normal periods during 12 days of stimulation.

9.2.2 Risk increment between circulation and normal periods

The risk comparison between circulation and normal period is synthesized in Table 38, in terms of financial loss and human loss over a time period of 30 years. Results for each area are listed in Appendix 2.

The risk increment is much less significant when comparing the circulation period and the normal period: the insurance optimal cost of 840 CHF that would annually be necessary to be covered against tectonic risk, should be increased by 50 CHF (factor 1.06) to cover the additional risk associated to the field activities.

The human risk multiplication factor is not significant because as for the stimulation period, the circulation period do not generate intensities that could induce high damage grade and victims.

The impact on the most probable affected buildings number is less than 20% for areas next to the field and not significant for the most distant areas.

The geographical distribution of the risk increment shows that there is also an attenuation with the distance to the field. By comparing the area “Kleinhüningen” located on the field and the area “Ettingen” located at a 13 km from the field:

- The financial risk multiplication factor varies from 1.12 at Kleinhüningen to 1.03 at Ettingen ;
- The most probable affected buildings number multiplication factor varies from 1.2 at Kleinhüningen to 1.0 at Ettingen.

Compared to the stimulation, the risk increment between the circulation and the normal periods is low. However as the lifespan of the field is 30 years, the absolute losses are higher during the circulation period than during the stimulation period.

Comparison between circulation and normal periods during 30 years of operation.								
Period	Total buildings number	Total Insured Value IV (CHF)	Most probable Insured Value loss MPIVL (CHF)	Ratio MPIVL / IV	MPIVL per building (CHF)	MPIVL per building per year (CHF)	Most probable victims number MPVN	Most probable affected buildings number MPABN
Normal	106 478	174 952 012 000	2 677 502 919	1.5E-02	25 146	838	48	20 813
Circulation	106 478	174 952 012 000	2 845 532 496	1.6E-02	26 724	891	50	22 494

Financial risk multiplication factor	Human risk multiplication factor	Most probabale affected buildings multiplication factor
1.06	1.0	1.1

Table 38: Comparison between circulation and normal periods during 30 years of operation.

9.3 Uncertainties quantification

The uncertainties quantification relies on sensitivity tests.

Uncertainties due to hazard variability

The above results were obtained using the median hazard curves. Other calculations are done using as input hazard data, the hazard curves of the percentiles 15% and 85%.

The median results have to be multiplied with a respective factor of:

- 0.85 and 6.8 for the stimulation period;
- 0.75 and 1.5 for 1 year of circulation period;
- 0.95 and 1.08 for 1 year of normal period.

Uncertainties associated to the vulnerability assessment

There are many sources of uncertainties that remain difficult to quantify:

- Uncertainties on :
  - Number of building
  - Distribution of typologies within the areas
- Uncertainties on the vulnerability functions associated to the different typologies.

Without any precise identification of the uncertainty we tried to appreciate their potential impact by applying a modifying factor, respectively of -0.1 and + 0.1 to all of the vulnerability indexes. The results of the median model have to be respectively multiplied by factors of:

- 0.5 and 2 on the most probable insured value loss;
- 0.2 and 3.6 on the most probable victims number;
- 0.6 and 1.5 on the most probable affected buildings number.

Costs functions

When applying the unpublished Risk_UE cost function, the losses are multiplied by a factor of:

- 0.55 for the stimulation period;
- 0.60 for the circulation and normal periods.

In a first approximation, and keeping in mind that the uncertainty on the vulnerability and cost functions remain difficult to quantify, it appears that the main source of uncertainty in the loss assessment is due to the variability of the hazard curves. The most likely loss of 45 M CHF estimated during the stimulation period could vary between 35 Millions CHF and 300 Millions CHF, if we consider the hazard curves associated to the percentiles 15 % and 85 %. This potential loss represents between 0,017% and 0,02% of the total insured value considered in our study.

10 RISK SCENARIOS

Risk scenarii are developed to provide AP6000 with values that can be compared with other risks, with F/N curves for the entire urban area and to assess what could be the losses due to the occurrence of a specific induced earthquake.

10.1 Principle

The risk model remains the calculation model adopted for the full probabilistic approach, the difference being only introduced by the hazard input, that either consists in an intensity map associated to a given earthquake occurring in the geothermal field (deterministic scenario) or in an intensity map associated to a specific probability of exceedance (semi-probabilistic scenario).

In this last case, the scenario is deterministic by the calculation of the consequences due to imposed intensity values, but remains probabilistic by the possible association of probability of exceedance to the estimated costs.

10.2 Adopted scenario

To comply with the AP6000 requirements the scenario are done :

- To simulate the December 8, 2006 earthquake (Mw=3.2) ;
- To simulate deterministic scenarios associated to the maximum magnitudes of Mw=3.7 and Mw=4.1;
- To simulate the consequences due to ground motions that have different rates of exceedance during a fixed period. These last scenarios are developed in order to obtain Frequency/Cost curves.

10.3 Risk scenarios results

10.3.1 2006 earthquake scenario

The input hazard map is generated adopting the attenuation law for shallow earthquakes at short distances and considering a magnitude Mw=3.2.

A most probable insured loss value of 10 Millions CHF is calculated. They are 296 affected buildings and a number of fatalities remains negligible (Table 39). These values are consistent with the observations that indicate a refunded cost of 8 Millions CHF for 260 affected buildings and no victim.

Scenario	Total buildings number	Total Insured Value IV (CHF)	Most probable Insured Value loss MPIVL (CHF)	Ratio MPIVL / IV	MPIVL per building (CHF)	Most probable victims number	Most probable affected buildings number
8th sept. 2006 earthquake	106 478	174 952 012 000	10 521 479	6.0E-05	99	0.0E+00	296

Table 39: Scenario simulating the 2006 8 December earthquake (Mw=3.2).

10.3.2 Maximum magnitude scenarios

Among the different models developed within the AP3000 workpackage, the maximum magnitude has a value Mw=3.7±0.4. We developed two scenarii assuming a value of 3.7 and a value of 4.1.

These two scenarii indicate respectively an insured loss value of 54 and 160 Million CHF (Table 40).

In both cases the most probable victims number is negligible.

Scenario	Total buildings number	Total Insured Value IV (CHF)	Most probable Insured Value loss MPIVL (CHF)	Ratio MPIVL / IV	MPIVL per building (CHF)	Most probable victims number	Most probable affected buildings number
Mw=3.7 earthquake	106 478	174 952 012 000	53 946 072	3.1E-04	507	1.7E-06	1 458
Mw=4.1 earthquake	106 478	174 952 012 000	158 832 248	9.1E-04	1 492	1.9E-04	3 905

Table 40: Results of scenarii simulating Mw=3.7 and Mw=4.1 induced earthquakes.

10.3.3 Semi-Probabilistic risk scenarios

In order to compare the risk during stimulation and circulation periods with other risks and available F/N plots, the AP 6000 needs, as input data, the costs associated to different annual exceedance rates.

To provide this information we adopted the following approach:

1- Four different annual exceedance rates are selected (i.e. 1, 0.1, 0.01 and 0.001);

2- The intensity maps are defined from the hazard curves by extracting the intensity values corresponding to each exceedance rate and at each point of the hazard mesh;

3- The risk model is applied using as input these intensity maps;

4- The F/N curves are plotted.

The comparison is firstly done considering a common time-period of 12 days.

From Figure 48, Figure 49 and Table 41, the following observations are outlined:

- Compared to the normal period, the probable losses induced by the stimulation are multiplied by a factor close to 150 at high exceedance rates and close to 3 at low exceedance rates ;
- Compared to the circulation, the losses induced by the stimulation are multiplied by a factor close to 10 at high exceedance rates and close to 3 at low exceedance rates.

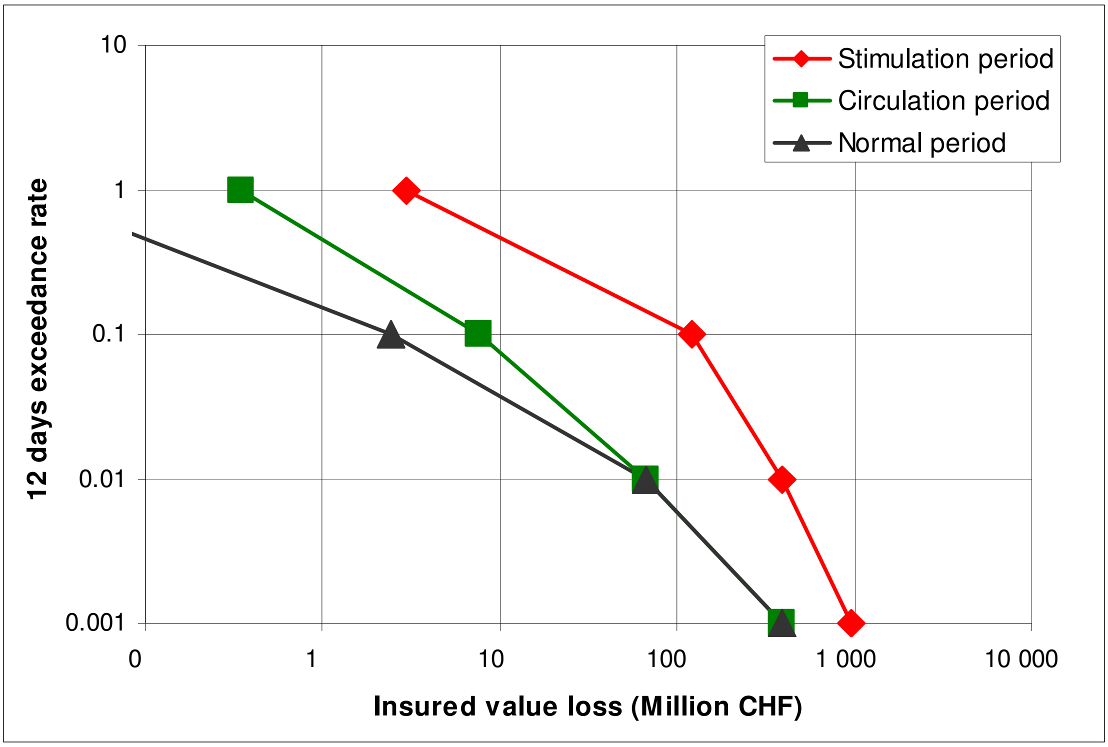

Figure 48: F/N plot: Loss estimation comparison considering a period of 12 days.

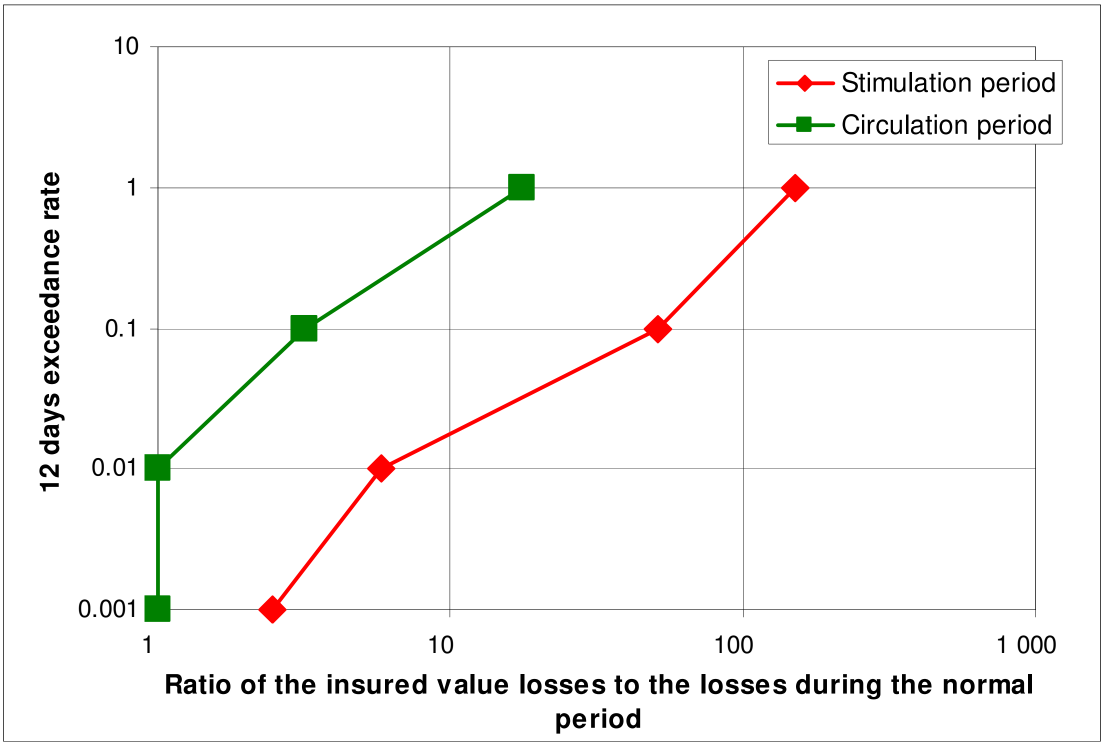

Figure 49: Losses ratio between stimulation or circulation period and the normal period during a 12days time-period.

As the F/N plots available for other risks are defined as a function of the annual exceedance rate, a tentative exercise is undertaken to convert the risk defined over 12 days of the stimulation period to an annual risk. Considering the first year of the field operation, it is assumed that the stimulation does occur only one time during the first 12 days, and that the circulation becomes effective the rest of the year (Figure 3). Then, during the first year of operation, the insured value loss includes the loss during the 12 days stimulation period and the loss during 353 days of circulation period.

Annual first year operation loss =

*12 days stimulation period loss + (365-12)/365 * Annual circulation period loss*

It is then possible to compare the annual F/N curves associated to: the first year of operation, one year of normal period and one year of circulation.

From Figure 50, Figure 51 and Table 41, the following observations are outlined:

- For low annual exceedance rate (≤0.01) and high insured value losses, the three curves are equivalent. This is because for low annual exceedance rate (<0.01) or high intensities (>6.5), the hazard curves of the three periods are similar (i.e. the stimulation and the circulation can't generate high intensity);
- During the first year of operation, where stimulation takes place, the annual cost is multiplied by a factor of 1.2 compared to one year of circulation ;
- For an annual exceedance rate of 1 (annual frequency of 1), one year of field operation (the first year or one year of circulation) would increase the seismic risk by a factor close to 17;
- For an annual exceedance rate of 0.1, one year of field operation (the first year or one year of circulation) would increase the seismic risk by a factor close to 3;

The potential insured value loss is significantly increased by one year of field operation for high annual exceedance rate values (between 0.1 and 1). The first year of the field operation, where the stimulation occurs, does not increase significantly the insured value loss compared to one year of circulation.

Period	Period duration	Exceedance rate	Intensity at the geothermal field	Most probable insured value loss (Millions CHF)
Stimulation	12 days	1	3.8	2.5
		0.1	5.2	122
		0.01	5.8	390
		0.001	6.2	968
First year of operation	1 year	1	-	14
		0.1	-	349
		0.01	-	2 364
		0.001	-	12 856
Circulation	1 year	1	4.2	11
		0.1	5.5	234
		0.01	6.5	2 035
		0.001	7.8	11 888
Normal	1 year	1	3.2	0.6
		0.1	4.8	73
		0.01	6.5	2 035
		0.001	7.8	11 888

Table 41: Semi-Probabilistic scenarios parameters and results.

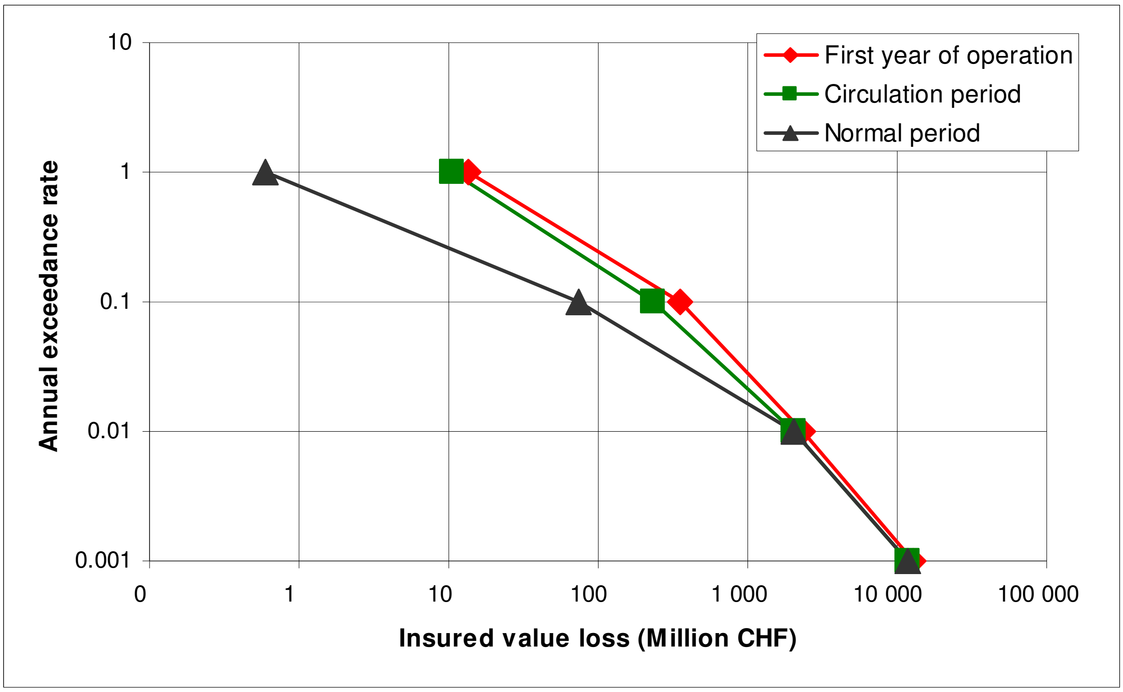

Figure 50: Frequency/Cost curves: Loss estimation comparison considering a period of 1 year.

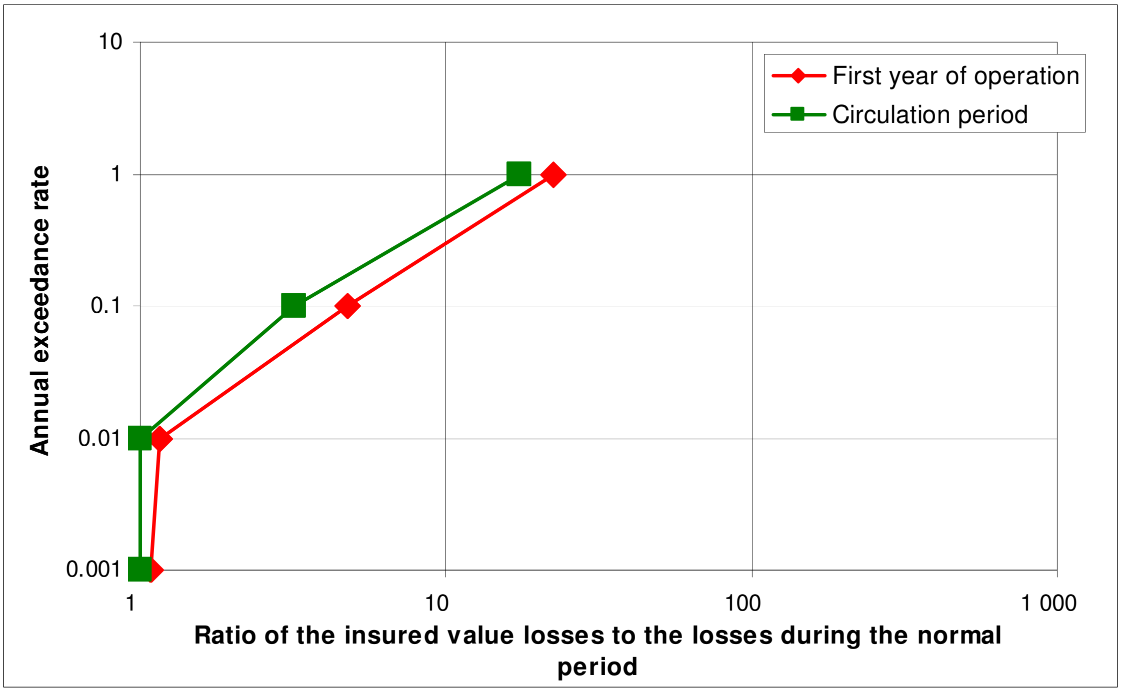

Figure 51: Losses ratio between stimulation or circulation period and the normal period during a 1 year time-period.

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APPENDIX

Appendix 1: Risk assessment results synthesis

Risk assessment results synthesis

				Normal period (12 days)					Stimulation period (12 days)							Normal period (30 years)					Circulation period (30 years)						
CODE	Area name	Total buildings number	Total Insured Value IV (CHF)	Most probable Insured Value loss MPIVL (CHF)	Ratio MPIVL / IV	MPIVL per building (CHF)	Most probable victims number	Most probable affected buildings number	Most probable Insured Value loss MPIVL (CHF)	Ratio MPIVL / IV	MPIVL per building (CHF)	Most probable victims number	Most probable affected buildings number	Financial risk multiplication factor (stim/norm)	Affected buildings multiplication factor (stim/norm)	Most probable Insured Value loss MPIVL (CHF)	Ratio MPIVL / IV	MPIVL per building (CHF)	Most probable victims number	Most probable affected buildings number	Most probable Insured Value loss MPIVL (CHF)	Ratio MPIVL / IV	MPIVL per building (CHF)	Most probable victims number	Most probable affected buildings number	Financial risk multiplication factor (Circu/norm)	Affected buildings multiplication factor (stim/norm)
All area	All area	106 478	174 952 012 000	4 350 887	2.49E-05	41	5.38E-02	52	45 447 835	2.60E-04	427	5.42E-02	1 051	10	20	2 677 582 919	1.53E-02	25 146	4.79E+01	20 813	2 845 532 496	1.63E-02	26 724	4.96E+01	22 494	1.06	1.1
ch_aes_01_01	Switzerland Aesch	1892	2 482 560 000	48 004	1.9E-05	25	3.6E-04	1	291 595	1.2E-04	154	3.6E-04	9	6	11	28 649 346	1.2E-02	15 142	3.2E-01	342	29 497 692	1.2E-02	15 591	3.3E-01	355	1.03	1.0
ch_all_01_01	Switzerland Allschwil	3134	4 642 730 000	116 861	2.5E-05	37	1.4E-03	2	1 162 743	2.5E-04	371	1.4E-03	32	10	20	71 958 700	1.5E-02	22 961	1.2E+00	645	76 022 336	1.6E-02	24 257	1.3E+00	695	1.06	1.1
ch_am_01_01	Switzerland Am Ring	1175	2 627 340 000	133 312	5.1E-05	113	2.8E-03	1	1 510 868	5.8E-04	1 286	2.9E-03	24	11	26	83 652 362	3.2E-02	71 193	2.5E+00	341	89 894 235	3.4E-02	76 506	2.6E+00	377	1.07	1.1
ch_arl_01_01	Switzerland Arlesheim	1758	2 672 990 000	60 089	2.2E-05	34	4.6E-04	1	429 550	1.6E-04	244	4.6E-04	12	7	14	36 350 913	1.4E-02	20 677	4.1E-01	344	37 689 061	1.4E-02	21 444	4.2E-01	360	1.04	1.0
ch_aug_01_01	Switzerland Kaiseraugst	471	820 497 000	15 245	1.9E-05	32	1.3E-04	0	100 802	1.2E-04	214	1.3E-04	2	7	12	8 953 768	1.1E-02	19 010	1.2E-01	82	9 257 913	1.1E-02	19 656	1.2E-01	85	1.03	1.0
ch_bac_01_01	Switzerland Bachletten	2469	5 530 990 000	176 474	3.2E-05	71	1.8E-03	1	2 050 010	3.7E-04	830	1.8E-03	36	12	24	109 754 854	2.0E-02	44 453	1.6E+00	573	117 510 865	2.1E-02	47 595	1.6E+00	630	1.07	1.1
ch_bat_01_01	Switzerland Bättwil	270	469 857 000	8 226	1.8E-05	30	3.1E-05	0	55 147	1.2E-04	204	3.0E-05	1	7	12	4 905 859	1.0E-02	18 170	2.7E-02	46	5 069 849	1.1E-02	18 777	2.8E-02	48	1.03	1.0
ch_bet_01_01	Switzerland Bettingen	278	483 883 000	9 703	2.0E-05	35	4.2E-05	0	101 887	2.1E-04	366	4.2E-05	2	11	20	5 895 281	1.2E-02	21 206	3.8E-02	51	6 246 617	1.3E-02	22 470	3.9E-02	56	1.06	1.1
ch_bie_01_01	Switzerland Biel-Benken	844	862 700 000	15 928	1.8E-05	19	9.3E-05	0	118 153	1.4E-04	140	9.3E-05	0	7	14	9 562 487	1.1E-02	11 330	8.3E-02	148	9 922 911	1.2E-02	11 757	8.5E-02	155	1.04	1.0
ch_bin_01_01	Switzerland Binningen	2651	3 879 930 000	105 476	2.7E-05	40	1.2E-03	1	1 023 174	2.6E-04	386	1.2E-03	28	10	20	65 063 276	1.7E-02	24 543	1.1E+00	570	68 680 112	1.8E-02	25 907	1.1E+00	614	1.06	1.1
ch_bir_01_01	Switzerland Birsfelden	1075	2 444 030 000	58 462	2.4E-05	54	7.1E-04	1	695 704	2.8E-04	647	7.1E-04	13	12	23	36 043 861	1.5E-02	33 529	6.4E-01	215	38 585 002	1.6E-02	35 893	6.6E-01	236	1.07	1.1
ch_bot_01_01	Switzerland Bottmingen	1467	1 575 030 000	31 135	2.0E-05	21	2.2E-04	1	300 714	1.9E-04	205	2.2E-04	12	10	18	18 956 601	1.2E-02	12 921	2.0E-01	270	19 939 332	1.3E-02	13 592	2.0E-01	289	1.05	1.1
ch_bri_01_01	Switzerland Breite	654	1 461 370 000	44 763	3.1E-05	68	1.3E-03	0	521 712	3.6E-04	798	1.3E-03	9	12	25	27 759 423	1.9E-02	42 446	1.1E+00	139	29 801 688	2.0E-02	45 568	1.2E+00	153	1.07	1.1
ch_bru_01_01	Switzerland Bruderholz	2032	4 545 250 000	133 452	2.9E-05	66	7.5E-04	1	1 251 346	2.8E-04	616	7.5E-04	23	9	19	82 472 799	1.8E-02	40 587	6.7E-01	476	86 874 156	1.9E-02	42 753	7.0E-01	511	1.05	1.1
ch_cla_01_01	Switzerland Clara	252	535 298 000	23 105	4.3E-05	92	8.7E-04	0	272 622	5.1E-04	1 082	8.8E-04	5	12	27	14 457 570	2.7E-02	57 371	7.7E-01	65	15 589 952	2.9E-02	61 865	8.0E-01	72	1.08	1.1
ch_dor_01_01	Switzerland Dornach	1423	2 230 880 000	47 192	2.1E-05	33	2.5E-04	1	287 209	1.3E-04	202	2.5E-04	8	6	11	28 199 338	1.3E-02	19 817	2.3E-01	270	29 050 028	1.3E-02	20 415	2.3E-01	280	1.03	1.0
ch_eft_01_01	Switzerland Ettingen	1129	1 038 280 000	19 160	1.8E-05	17	1.6E-04	0	116 271	1.1E-04	103	1.6E-04	5	6	11	11 412 253	1.1E-02	10 108	1.5E-01	198	11 750 314	1.1E-02	10 408	1.5E-01	205	1.03	1.0
ch_fre_01_01	Switzerland Frenkendorf	1062	1 375 510 000	27 530	2.0E-05	26	2.2E-04	0	172 070	1.3E-04	162	2.2E-04	6	6	11	16 258 399	1.2E-02	15 309	2.0E-01	195	16 772 027	1.2E-02	15 793	2.0E-01	203	1.03	1.0
ch_got_01_01	Switzerland Gotthelf	971	2 166 320 000	86 804	4.0E-05	89	1.4E-03	1	981 464	4.5E-04	1 011	1.4E-03	16	11	25	54 215 519	2.5E-02	55 835	1.2E+00	250	58 070 456	2.7E-02	59 805	1.3E+00	275	1.07	1.1
ch_gro_01_01	Switzerland Grossbasel	490	1 098 830 000	69 993	6.4E-05	143	8.1E-04	0	806 850	7.3E-04	1 647	8.2E-04	13	12	28	43 991 781	4.0E-02	89 779	7.2E-01	163	47 469 058	4.3E-02	96 876	7.5E-01	181	1.08	1.1
ch_gun_01_01	Switzerland Gundeldingen	1415	3 157 730 000	142 744	4.5E-05	101	4.9E-03	1	1 607 002	5.1E-04	1 136	4.9E-03	26	11	26	89 146 036	2.8E-02	63 001	4.3E+00	379	95 765 803	3.0E-02	67 679	4.5E+00	418	1.07	1.1
ch_hir_01_01	Switzerland Hirzbrunnen	1526	3 250 180 000	77 584	2.4E-05	51	6.0E-04	1	1 054 419	3.2E-04	691	6.0E-04	20	14	26	47 933 438	1.5E-02	31 411	5.3E-01	311	51 929 652	1.6E-02	34 030	5.6E-01	347	1.08	1.1
ch_ise_01_01	Switzerland Iselin	1449	3 231 580 000	105 784	3.3E-05	73	2.5E-03	1	1 213 800	3.8E-04	838	2.6E-03	21	11	25	65 815 565	2.0E-02	45 421	2.3E+00	324	70 491 249	2.2E-02	48 648	2.3E+00	357	1.07	1.1
ch_klb_01_01	Switzerland Kleinbasel	286	601 411 000	32 212	5.4E-05	113	7.2E-04	0	375 330	6.2E-04	1 312	7.3E-04	6	12	27	20 204 181	3.4E-02	70 644	6.4E-01	85	21 794 882	3.6E-02	76 206	6.6E-01	95	1.08	1.1
ch_klh_01_01	Switzerland Kleinhüningen	163	349 757 000	8 405	2.4E-05	52	2.5E-04	0	146 264	4.2E-04	897	2.6E-04	3	17	34	5 217 803	1.5E-02	32 011	2.2E-01	30	5 628 890	1.7E-02	35 760	2.4E-01	35	1.12	1.2
ch_kly_01_01	Switzerland Klybeck	438	931 973 000	32 034	3.4E-05	73	1.3E-03	0	539 101	5.8E-04	1 231	1.3E-03	9	17	36	20 064 194	2.2E-02	45 809	1.1E+00	100	22 417 084	2.4E-02	51 181	1.2E+00	116	1.12	1.2
ch_mat_01_01	Switzerland Matthaeüs	1115	2 380 050 000	121 094	5.1E-05	109	5.0E-03	1	1 440 090	6.1E-04	1 292	5.0E-03	24	12	27	75 830 227	3.2E-02	68 009	4.4E+00	316	81 962 840	3.4E-02	73 509	4.6E+00	351	1.08	1.1
ch_mun_01_01	Switzerland Münchenstein	2515	3 891 380 000	117 384	3.0E-05	47	1.2E-03	1	1 004 358	2.6E-04	399	1.2E-03	26	9	18	72 309 655	1.9E-02	28 751	1.1E+00	575	75 849 489	1.9E-02	30 159	1.1E+00	613	1.05	1.1
ch_mut_01_01	Switzerland Muttenz	3453	6 441 870 000	161 994	2.5E-05	47	1.1E-03	2	1 409 817	2.2E-04	408	1.1E-03	31	9	17	98 759 039	1.5E-02	28 601	1.0E+00	721	103 621 115	1.6E-02	30 009	1.1E+00	768	1.05	1.1
ch_obe_01_01	Switzerland Oberwil	2238	2 605 760 000	58 280	2.2E-05	26	5.2E-04	1	497 857	1.9E-04	222	5.2E-04	16	9	16	35 525 868	1.4E-02	15 874	4.7E-01	437	37 165 130	1.4E-02	16 606	4.8E-01	464	1.05	1.1
ch_pra_01_01	Switzerland Pratteln	2322	4 353 190 000	113 378	2.6E-05	49	1.1E-03	1	803 458	1.8E-04	346	1.1E-03	18	7	14	68 283 527	1.6E-02	29 407	9.9E-01	487	70 938 148	1.6E-02	30 550	1.0E+00	511	1.04	1.0
ch_rei_01_01	Switzerland Reinach	3853	4 791 270 000	96 241	2.0E-05	25	7.7E-04	2	749 227	1.6E-04	194	7.7E-04	26	8	15	58 317 280	1.2E-02	15 136	6.9E-01	711	60 661 606	1.3E-02	15 744	7.1E-01	748	1.04	1.1
ch_rie_01_01	Switzerland Riehen	3897	5 592 360 000	143 799	2.6E-05	37	1.5E-03	2	1 700 815	3.0E-04	436	1.5E-03	48	12	23	88 904 341	1.6E-02	22 814	1.4E+00	823	95 343 228	1.7E-02	24 466	1.4E+00	905	1.07	1.1
ch_ros_01_01	Switzerland Rosental	256	543 829 000	17 602	3.2E-05	69	6.9E-04	0	228 750	4.2E-04	894	7.0E-04	4	13	27	10 956 802	2.0E-02	42 800	6.2E-01	57	11 887 355	2.2E-02	46 435	6.4E-01	63	1.08	1.1
ch_sal_01_01	Switzerland St-Alban	1188	2 663 150 000	91 541	3.4E-05	77	1.5E-03	1	1 033 369	3.9E-04	870	1.5E-03	18	11	24	56 966 133	2.1E-02	47 951	1.3E+00	283	61 001 620	2.3E-02	51 348	1.4E+00	311	1.07	1.1
ch_sch_01_01	Switzerland Schönenbuch	400	696 020 000	11 787	1.7E-05	29	3.8E-05	0	97 769	1.4E-04	244	3.8E-05	2	8	15	7 080 276	1.0E-02	17 701	3.4E-02	66	7 381 437	1.1E-02	18 454	3.5E-02	70	1.04	1.1
ch_sjo_01_01	Switzerland St-Johann	1519	3 401 660 000	135 619	4.0E-05	89	3.9E-03	1	1 699 309	5.0E-04	1 119	3.9E-03	28	13	28	84 843 861	2.5E-02	55 855	3.4E+00	383	91 882 037	2.7E-02	60 489	3.6E+00	427	1.08	1.1
ch_the_01_01	Switzerland Therwil	2031	2 128 640 000	41 292	1.9E-05	20	3.3E-04	1	302 350	1.4E-04	149	3.3E-04	12	7	14	24 905 659	1.2E-02	12 263	3.0E-01	366	25 830 903	1.2E-02	12 718	3.0E-01	384	1.04	1.0
ch_vor_01_01	Switzerland Vorstädte	568	1 264 430 000	62 326	4.9E-05	110	1.2E-03	0	729 116	5.8E-04	1 284	1.3E-03	12	12	27	39 082 770	3.1E-02	68 808	1.1E+00	161	42 146 613	3.3E-02	74 202	1.1E+00	179	1.08	1.1
ch_wet_01_01	Switzerland Wettstein	673	1 435 280 000	54 948	3.8E-05	82	9.1E-04	0	657 014	4.6E-04	976	9.2E-04	12	12	26	34 320 773	2.4E-02	50 997	8.1E-01	173	36 952 577	2.6E-02	54 907	8.4E-01	192	1.08	1.1
ch_wit_01_01	Switzerland Witterswil	429	748 616 000	12 887	1.7E-05	30	4.0E-05	0	89 784	1.2E-04	209	4.0E-05	2	7	12	7 695 003	1.0E-02	17 937	3.6E-02	72	7 960 135	1.1E-02	18 555	3.7E-02	76	1.03	1.0
de_bin_01_01	Germany Binzen	778	1 234 000 000	20 946	1.7E-05	27	1.1E-04	0	223 981	1.8E-04	289	1.1E-04	8	11	20	12 838 940	1.0E-02	16 502	9.7E-02	127	13 631 531	1.1E-02	17 521	1.0E-01	137	1.06	1.1
de_efr_01_01	Germany Efringen-Kirchen	2233	5 309 620 000	92 077	1.7E-05	41	3.2E-04	1	773 323	1.5E-04	346	3.3E-04	14	8	16	56 570 119	1.1E-02	25 334	2.9E-01	367	59 156 163	1.1E-02	26 492	3.0E-01	388	1.05	1.1
de_elm_01_01	Germany Eimeldingen	510	802 363 000	14 055	1.8E-05	28	9.9E-05	0	178 499	2.2E-04	352	1.0E-04	5	13	24	8 651 167	1.1E-02	16 963	8.8E-02	84	9 301 837	1.2E-02	18 239	9.3E-02	93	1.08	1.1
de_fis_01_01	Germany Fischingen	200	316 225 000	5 769	1.8E-05	29	2.9E-05	0	61 344	1.9E-04	307	2.9E-05	2	11	20	3 556 247	1.1E-02	17 776	2.6E-02	34	3 770 672	1.2E-02	18 853	2.7E-02	37	1.06	1.1
de_gre_01_01	Germany Grenzach-Wyhlen	2930	4 019 560 000	75 885	1.9E-05	26	6.2E-04	1	711 715	1.8E-04	243	6.1E-04	22	9	17	45 775 849	1.1E-02	15 623	5.5E-01	502	48 172 387	1.2E-02	16 441	5.7E-01	537	1.05	1.1
de_inz_01_01	Germany Inzlingen	660	1 033 630 000	19 759	1.9E-05	30	1.1E-04	0	179 786	1.7E-04	272	1.1E-04	5	9	17	11 948 927	1.2E-02	18 104	1.0E-01	114	12 559 958	1.2E-02	19 030	1.1E-01	121	1.05	1.1
de_lor_01_01	Germany Lörrach	7731	11 627 000 000	199 970	1.7E-05	26	2.0E-03	3	2 075 864	1.8E-04	269	2.0E-03	58	10	19	121 893 847	1.0E-02	15 767	1.8E+00	1 240	129 152 985	1.1E-02	16 706	1.9E+00	1 337	1.06	1.1
de_rum_01_01	Germany Rümmingen	455	792 446 000	13 615	1.7E-05	30	6.1E-05	0	136 179	1.7E-04	299	6.2E-05	3	10	19	8 325 237	1.1E-02	18 297	5.5E-02	74	8 807 533	1.1E-02	19 357	5.7E-02	80	1.06	1.1
de_sch_01_01	Germany Schallbach	205	355 899 000	6 394	1.8E-05	31	3.0E-05	0	65 802	1.9E-04	321	3.0E-05	2	10	19	3 926 879	1.1E-02	19 156	2.6E-02	34	4 161 003	1.2E-02	20 298	2.8E-02	37	1.06	1.1
de_ste_01_01	Germany Steinen	2344	3 214 000 000	53 272	1.7E-05	23	3.4E-04	1	373 260	1.2E-04	159	3.4E-04	12	7	13	31 932 139	9.9E-03	13 623	3.0E-01	373	33 135 831	1.0E-02	14 136	3.1E-01	389	1.04	1.0
de_wei_01_01	Germany Weil am Rhein	5277	7 947 890 000	159 709	2.0E-05	30	1.8E-03	2	2 296 907	2.9E-04	435	1.8E-03	62	14	27	98 728 929	1.2E-02	18 709	1.6E+00	929	107 620 578	1.4E-02	20 394	1.6E+00	1 044	1.09	1.1
de_wit_01_01	Germany Wittlingen	265	457 585 000	7 676	1.7E-05	29	3.3E-05	0	74 198	1.6E-04	280	3.3E-05	2	10	18	4 686 013	1.0E-02	17 679	2.8E-02	43	4 946 254	1.1E-02	18 661	3.0E-02	46	1.06	1.1
fr_att_01_01	France Attenschwiller	345	594 334 000	12 857	2.2E-05	37	4.2E-05	0	102 692	1.7E-04	298	4.2E-05	3	8	15	7 808 567	1.3E-02	22 634	3.8E-02	67	8 138 021	1.4E-02	23 588	3.9E-02	71	1.04	1.1
fr_bat_01_01	France Bartenheim	1406	2 205 710 000	41 086	1.9E-05	29	1.3E-04	1	341 752	1.5E-04	243	1.3E-04	9	8	15	25 113 820	1.1E-02	17 862	1.2E-01	250	26 224 651	1.2E-02	18 652	1.2E-01	264	1.04	1.1
fr_blo_01_01	France Blotzheim	1571	2 465 300 000	49 689	2.0E-05	32	1.6E-04	1	469 055	1.9E-04	299	1.6E-04	13	9	18	30 417 688	1.2E-02	19 362	1.5E-01	293	31 987 675	1.3E-02	20 361	1.5E-01	313	1.05	1.1
fr_bri_01_01	France Brinckheim	134	226 163 000	4 718	2.1E-05	35	1.5E-05	0	36 132	1.6E-04	270	1.5E-05	1	8	14	2 871 997	1.3E-02	21 433	1.4E-02	26	2 989 158	1.3E-02	22 307	1.4E-02	27	1.04	1.1
fr_bus_01_01	France Buschwiller	369	645 177 000	14 163	2.2E-05	38	4.9E-05	0	128 080	2.0E-04	347	4.9E-05	3	8	17	8 643 516	1.3E-02	23 424	4.4E-02	72	9 070 387	1.4E-02	24 581	4.5E-02	77	1.05	1.1
fr_fol_01_01	France Folgensbourg	293	504 921 000	9 992	2.0E-05	34	2.8E-05	0	64 260	1.3E-04	219	2.9E-05	2	6	12	5 981 778	1.2E-02	20 416	2.6E-02	54	6 179 260	1.2E-02	21 090	2.6E-02	56	1.03	1.0
fr_hab_01_01	France Hagenthal-le-bas	400	699 526 000	14 680	2.1E-05	37	4.9E-05	0	107 105	1.5E-04	268	4.9E-05	3	7	14	8 859 713	1.3E-02	22 149	4.4E-02	76	9 196 064	1.3E-02	22 990	4.5E-02	80	1.04	1.0
fr_hah_01_01	France Hagenthal-le-haut	180	303 303 000	7 101	2.3E-05	39	3.1E-05	0	44 832	1.5E-04	249	3.1E-05	1	6	12	4 281 346	1.4E-02	23 785	2.8E-02	37	4 422 501	1.5E-02	24 569	2.9E-02	38	1.03	1.0
fr_heg_01_01	France Hégenheim	1088	2 031 080 000	47 750	2.4E-05	44	1.9E-04	1	491 720	2.4E-04	452	1.9E-04	11	10	20	29 353 599	1.4E-02	26 979	1.7E-01	220	31 047 242	1.5E-02	28 536	1.7E-01	237	1.06	1.1
fr_hel_01_01	France Helfrantzkirch	303	468 832 000	9 638	2.1E-05	32	3.3E-05	0	58 513	1.2E-04	193	3.4E-05	2	6	11	5 802 141	1.2E-02	19 149	3.0E-02	58	5 991 774	1.3E-02	19 775	3.1E-02	60	1.03	1.0
fr_hes_01_01	France Hésingue	789	1 519 770 000	34 175	2.2E-05	43	1.3E-04	0	365 336	2.4E-04	463	1.3E-04	8	11	21	21 029 039	1.4E-02	26 653	1.2E-01	156	22 299 641	1.5E-02	28 263	1.2E-01	169	1.06	1.1
fr_hun_01_01	France Huningue	2984	4 090 920 000	90 430	2.2E-05	30	4.1E-04	1	1 458 178	3.6E-04	489	4.1E-04	43	16	31	56 044 199	1.4E-02	18 782	3.6E-01	669	61 756 131	1.5E-02	20 695	3.8E-01	651	1.10	1.1
fr_kap_01_01	France Kappelen	196	338 367 000	6 652	2.0E-05	34	2.0E-05	0	47 937	1.4E-04	245	2.0E-05	1	7	13	4 027 462	1.2E-02	20 548	1.8E-02	36	4 180 160	1.2E-02	21 327	1.8E-02	38	1.04	1.0
fr_kem_01_01	France Kembs	1581	2 484 180 000	42 170	1.7E-05	27	1.2E-04	1	301 722	1.2E-04	191	1.2E-04	8	7	13	25 731 905	1.0E-02	16 276	1.1E-01	271	26 686 077	1.1E-02	16 879	1.1E-01	283	1.04	1.0
fr_mib_01_01	France Michelbach	116	201 618 000	4 317	2.1E-05	37	1.4E-05	0	35 304	1.8E-04	304	1.5E-05	1	8	15	2 628 137	1.3E-02	22 656	1.3E-02	23	2 742 973	1.4E-02	23 646	1.3E-02	24	1.04	1.1
fr_mih_01_01	France Michelbach-le-haut	116	201 618 000	4 223	2.1E-05	36	1.3E-05	0	28 537	1.4E-04	246	1.3E-05	1	7	13	2 541 290	1.3E-02	21 908	1.2E-02	22	2 631 124	1.3E-02	22 682	1.2E-02	23	1.04	1.0
fr_neu_01_01	France Neuwiller	223	385 704 000	8 781	2.3E-05	39	2.8E-05	0	71 623	1.9E-04	321	2.8E-05	2	8	16	5 338 836	1.4E-02	23 941	2.6E-02	45	5 570 644	1.4E-02	24 980	2.6E-02	47	1.04	1.1
fr_rab_01_01	France Ranspach	346	603 100 000	16 187	2.7E-05	47	6.5E-05	0	115 556	1.9E-04	334	6.5E-05	3	7	14	9 901 246	1.6E-02	28 616	5.8E-02	76	10 290 175	1.7E-02	29 740	5.9E-02	80	1.04	1.0
fr_rah_01_01	France Ranspach-le-haut	346	603 100 000	15 615	2.6E-05	45	5.8E-05	0	94 953	1.6E-04	274	5.8E-05	2	6	12	9 476 421	1.6E-02	27 386	5.2E-02	75	9 795 027	1.6E-02	28 309	5.3E-02	78	1.03	1.0
fr_ros_01_01	France Rosenau	794	1 392 040 000	25 059	1.8E-05	32	6.6E-05	0	262 671	1.9E-04	331	6.6E-05	6	10	19	15 388 952	1.1E-02	19 382	5.8E-02	140	16 274 235	1.2E-02	20 497	6.1E-02	151	1.06	1.1
fr_sie_01_01	France Sierentz	1033	1 623 610 000	29 760	1.8E-05	29	9.9E-05	0	203 730	1.3E-04	197	1.0E-04	6	7	13	18 133 873	1.1E-02	17 555	8.9E-02	181	18 794 353	1.2E-02	18 194	9.1E-02	189	1.04	1.0
fr_slo_01_01	France St-Louis	8889	13 370 300 000	248 923	1.9E-05	28	1.1E-03	4	3 017 603	2.3E-04	339	1.1E-03	83	12	23	153 124 603	1.1E-02	17 226	9.7E-01	1 489	163 911 413	1.2E-02	18 440	1.0E+00	1 633	1.07	1.1
fr_ste_01_01	France Stetten	115	194 605 000	4 234	2.2E-05	37	1.4E-05	0	26 027	1.3E-04	226	1.5E-05	1	6	12	2 564 688	1.3E-02	22 301	1.3E-02	22	2 650 452	1.4E-02	23 047	1.3E-02	23	1.03	1.0
fr_uff_01_01	France Uffheim	338	587 322 000	11 238	1.9E-05	33	3.2E-05	0	72 865	1.2E-04	216	3.2E-05	2	6	12	6 812 431	1.2E-02	20 155	2.9E-02	62	7 048 659	1.2E-02	20 854	2.9E-02	64	1.03	1.0
fr_vil_01_01	France Village-neuf	1475	2 330 560 000	49 415	2.1E-05	34	1.9E-04	1	650 074	2.8E-04	441	1.9E-04	17	13	25	30 601 063	1.3E-02	20 746	1.7E-01	281	32 980 173	1.4E-02	22 359	1.7E-01	312	1.08	1.1
fr_wen_01_01	France Wentzwiller	229	396 223 000	9 079	2.3E-05	40	3.7E-05	0	70 728	1.8E-04	309	3.7E-05	2	8	15	5 517 592	1.4E-02	24 094	3.3E-02	46	5 744 599	1.4E-02	25 086	3.4E-02	49	1.04	1.1

Appendix 2

AP 5000 report

Report title:	**AP5000 Report - Seismic vulnerability of the building stock in Basel – Lörrach - St-Louis area**
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Ref.:	**RT-292/MD/MK**
Report date:	**3rd November 2009**

SUMMARY

The area commissioned for the study of the seismic vulnerability of the building stock around the geothermal exploitation of the Geopower AG borehole was delimitated by a 12 km-radius boundary. Consequently, the defined zone includes an area in France, Germany and Switzerland.

A detailed building inventory of the study area around the geothermal site was possible due to a complete set of building statistics from the three considered countries and site visits. Based on this inventory, building typologies are defined and a vulnerability curve is associated to each typology; most curves are taken from the Risk-UE program. The determination of these curves was essentially based on data recorded for seismic events characterized by intensities from VII to IX (EMS-scale). Due to the shortage of data for small-intensity earthquakes, the damage grade for low intensities are less reliable as the portion of vulnerability curves for low intensities (III to VI) consists of an extrapolation.

In the framework of the SERIANEX project, it was evident that the original curves of the Risk-UE program do not fit with the recorded damage after the 2006 seismic event. They were therefore adjusted accordingly to allow for small-intensity earthquakes.

Besides the physical vulnerability curves, a representative curve for financial losses is defined on the basis of literature published by insurance companies and based on expert judgment.

It is worth mentioning that only buildings with at least one dwelling-unit have been taken into account. Although the financial losses for industrial and administrative buildings as well as cultural heritage sites may be different from residential buildings, nevertheless, the difference in financial costs is considered negligible with respect to the uncertainties of the loss estimate.

The issue of social losses is not addressed in this report.

Carouge, November 2009.

Mylène DEVAUX Martin KOLLER

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1 Introduction

1.1 Situation

In 2004, the project to build a geothermal power plant in the district of Kleinhüningen, Basel, was accepted by the authorities of the Canton of Basel-city. Two years later, the commissioned enterprise GEOPOWER AG drilled the first borehole. In December 2006, GEOPOWER AG began hydraulic stimulations by injecting water under high pressure into the host rock at 5000 m depth. On 8 December, these stimulation activities caused an M = 3.2 (Richter's scale) earthquake; the hydraulic stimulation was stopped and on 20 December, the executive committee of GEOPOWER AG decided to stop exploiting the borehole.

In order to investigate the risks associated with the exploitation of the existing borehole, the authorities of the Canton Basel-city commissioned the SERIANEX group to carry out an in-depth seismic vulnerability study. In this framework, the seismic vulnerability of buildings in the area of Basel and the potential damage costs resulting from earthquakes that could be generated by the geothermal borehole, have been assessed by GeoTer SA and Resonance Ingénieurs - Conseils SA.

The studied area is a compromise satisfying two requirements. On one hand, the area should be as wide as possible, include the Basel city and suburbs (CH) as well as the cities of Saint-Louis (F) and Lörrach (D). On the other hand, budget limitations have to be considered. On this basis, it was decided to define the area of investigation by a boundary with a 12 km radius around the city of Basel (Figure 1).

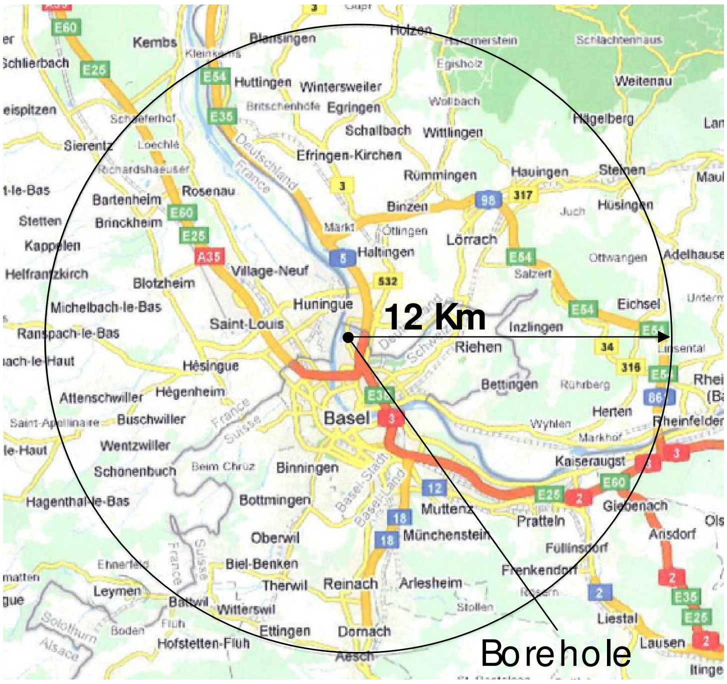


Figure 1: 12 km radius boundary around the geothermal site. Background picture: Google Maps.

1.2 Goals

In the aforementioned framework, the task of Résonance Ingénieurs-Conseils is to assess the seismic vulnerability of buildings that are situated within a 12 km boundary around the geothermal site. This means that an inventory of the buildings, i.e. number and types of structure, in the abovementioned area, a seismic vulnerability curve for each type of structure and the material costs generated by the damage to buildings due to earthquakes must be assessed. This data forms the basis for damage and loss calculations (financial and human) performed by Geoter SA.

1.3 Methodology

In order to reach the planned goals, the methodology shown in Figure 2 has been followed.

The most important data for the current study are: the insured value of buildings, the vulnerability curves for different building types, the inventory of existing buildings in the study area, the official damage caused by the 2006 earthquake and the number of inhabitants.

Information on the number of buildings, residential units and inhabitants was obtained from the Federal or Regional Offices for Statistics, as was the case for Germany and Switzerland, and at the INSEE (National Institutes for Statistics and Economic Studies) for France.

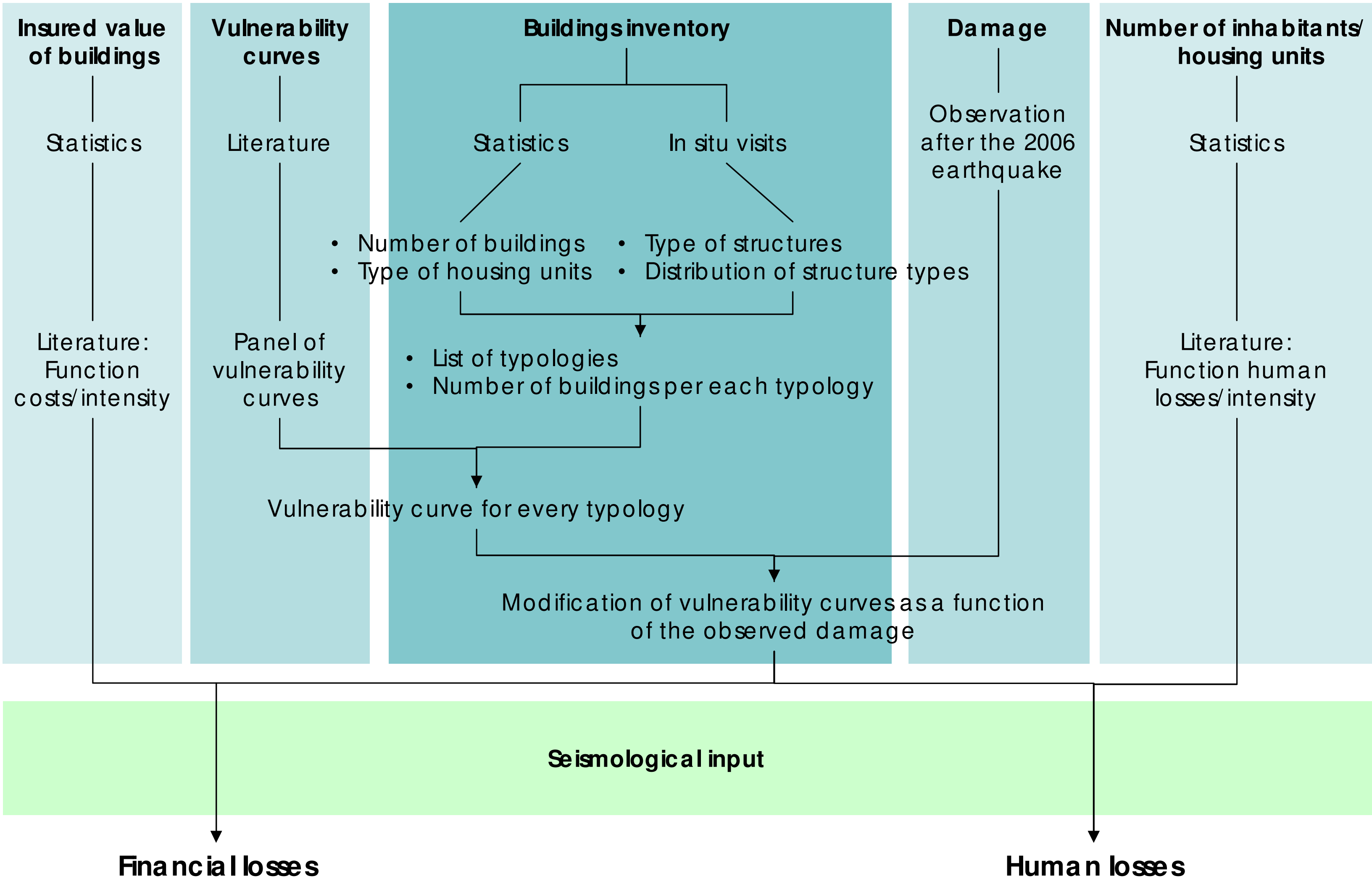
The choice of vulnerability curves is based on the EMS-98 scale [Gr 01], the Risk-UE report on the vulnerability of current buildings [MT 03] and the VulnérAlp method [GML 07], [Mc 07]. For most types of structures, it is assumed that the defined vulnerability curves in the aforementioned methods can be applied to the context of the Basel region. However, for a few buildings, such as half-timbered buildings, new vulnerability curves have to be defined.

The following step is to attribute a vulnerability curve to each building in the study area through a building inventory classification system that is defined according to in-situ surveys and literature. Moreover, this system of classification for the city of Basel were also discussed with Mr Markus Schmid from the office for preservation of monuments and historic buildings of the canton Basel-city,

The cost function is defined on the basis of papers published by insurance companies [CS 92], [PS 89].

Finally, the financial costs and human losses are estimated with the following parameters: the seismological input coupled with the defined vulnerability curves, the cost function, the number of buildings belonging to each vulnerability category and the human losses function.

Figure 2: Flowchart of the applied methodology.



2 Types of buildings

Basel city

Basel city is currently divided into 19 districts, which are: Grossbasel, Vorstädte, Am Ring, Breite, St-Alban, Gundeldingen, Bruderholz, Bachletten, Gotthelf, Iselin, St-Johann, Kleinbasel, Clara, Wettstein, Hirzbrunnen, Rosental, Matthäus, Klybeck and Kleinhüningen.

The oldest districts are Grossbasel and Kleinbasel. By 1870, the area between the old city of Grossbasel and the third city walls was occupied by new constructions that became the districts of Vorstädte and Am Ring. To the North, the Kleinbasel district extended northwards to the Badischer Bahnhof which is in the Clara and Rosental disctricts.

According to the 1859 "Basel Stadt Erweiterungsgesetz" (Guidelines for the city's extension), this aforementioned 1870 core extended southward. In 1920, St-Johann district was already partly occupied, as were the future districts of Iselin, Gotthelf and Bachletten too. The South area of the main station (Gundeldingen district) was, at that time, fully occupied by housing estates.

There was a boom in the construction of buildings around Basel city between 1910 and 1970. In the mid-20th century, the built-up areas of the city suburbs and the surrounding towns had got so close that the boundaries were no longer easily recognizable by 1980.

Basel country

Almost every town in Basel country started as a group of farms; since the Middle-Ages, due to their importance, patrician houses or castles were built in the centre of the towns. Population showed a significant increase at the beginning of the 20th century, which coincide with the start of industries in Basel [BR 86].

As mentioned previously, the closest villages have been simply merged in the Basel-city suburbs as are e.g. Allschwil, Binningen or Münchenstein.

France and Germany

Towns in France and Germany experienced a similar evolution as those in Switzerland. Most of them have still an old core of houses that began to be surrounded by new houses at the beginning of the 20th century. A large proportion of buildings therefore date between 1940-1990.

However, many old buildings in the city of Lörrach were destroyed during the Second World War.

The evolution of the building stock in the considered area is shown in the next figure.

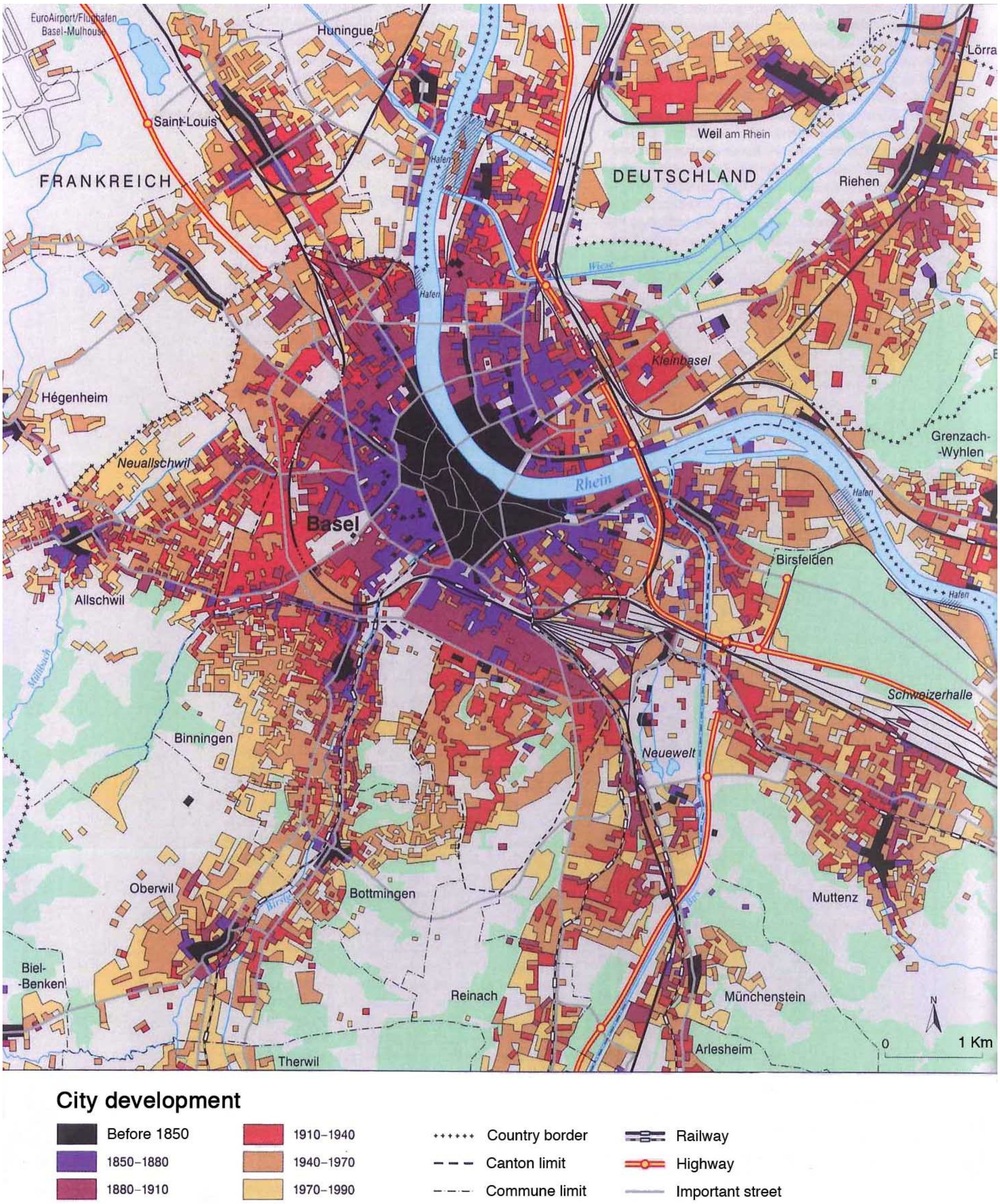


Figure 3: Development of Basel city and Basel region [Jm 03].

2.1 Basel city: districts

The figure below shows the division of the 19 districts of Basel city.

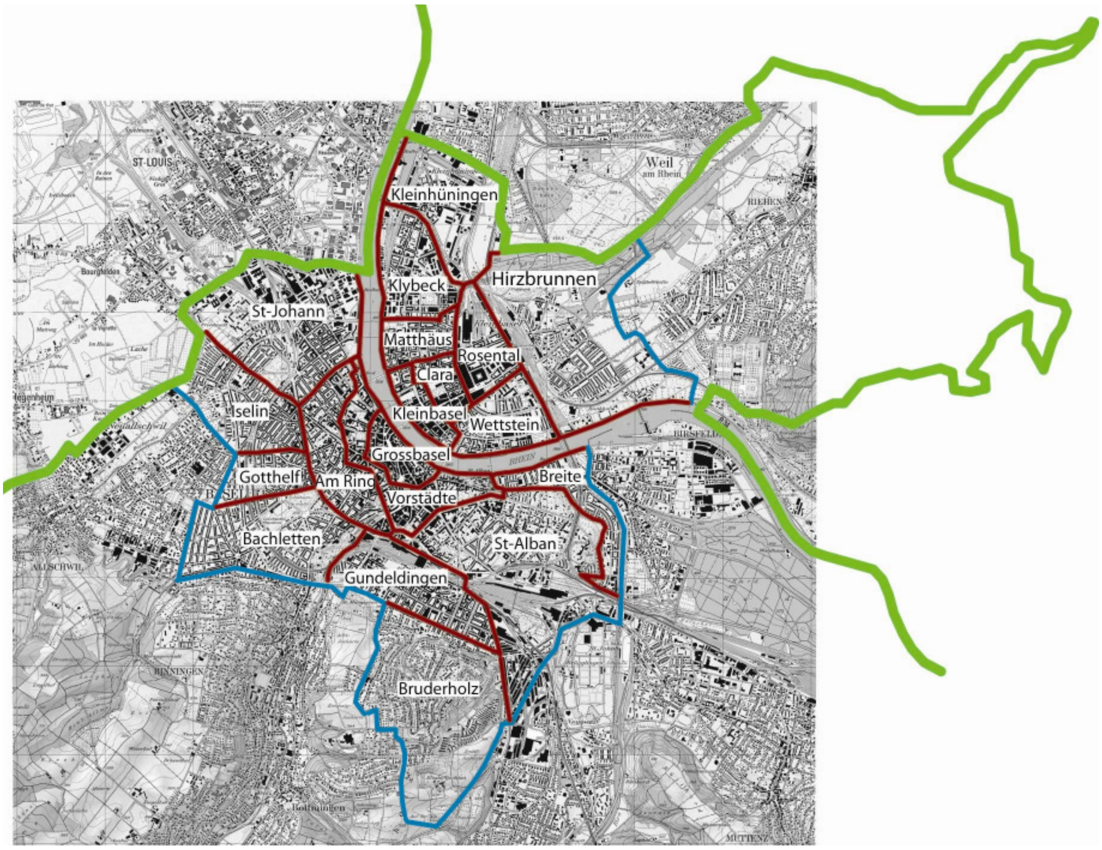


Figure 4: Districts of Basel city.

The following sections describe each of these districts in detail and are based on literature [BR 86], [Bo 75],[Fm 99], [NMM 06], [Jm 03] as well as on site visits.

2.1.1 Grossbasel and Kleinbasel

Grossbasel and Kleinbasel districts correspond to the area of Basel which was already occupied before the 10th century. Consequently, this part consists of most of the buildings that were erected before 1850. Walls of this kind of buildings were made of simple stone masonry while the floors were made of timber. Most of these buildings still exist in Basel city, though some of them, especially in the Grossbasel district, have been slightly transformed or replaced during the 19th and 20th centuries. In fact, this part of the city has become the shopping area and for this reason, the ground floor was transformed or, in case of replacement, the inner structure was sometimes made according to the **Hennebique's**[1] system.

[1] The definitions of these bold type words can be found in the appendices.

The retrofits and many reconstructions of buildings were carried out during the 19^{th} century; most of the buildings were erected before 1919 (73 % in Grossbasel and 59 % in Kleinbasel) and the majority of them were 4-5 storey buildings.

Apart from common forms of buildings, the Grossbasel district consists of many important public buildings such as the city hall, the city archives, museums and the main Post Office. Moreover, Basel cathedral as well as other old churches are also situated in the Grossbasel district. However, these special types of buildings are not considered in the present study.

2.1.2 Vorstädte, Am Ring, Clara

Buildings in these districts were mostly built after 1850, when the city grew larger. More than 50% of the buildings in the Vorstädte and Am Ring areas date back to 1919; around 20 % of buildings were built between 1961 and 1980. There are very few one-storey houses or buildings with more than height storeys. Around 50 % of the buildings in these districts have indeed 4-5 storeys.

Unlike the Vorstädte and Am Ring districts, Clara district is situated to the North of Kleinbasel. In 1855, new buildings due to the extension of the city from Kleinbasel district towards the ancient Badischen Bahnhof were erected in the current Clara district. Only 44 % of the buildings date from before 1919, while 29 % were erected during the period 1961-1980.

2.1.3 Gundeldingen, St-Johann, Matthäus

Gundeldingen and St-Johann districts are situated on the left bank of Rhine whereas Matthäus district is on the right bank.

The growth of industry influenced the type of construction within these districts. In the area of Gundeldingen, real estate companies built many four-storey family houses for Post and SBB officers during the period between 1872 and 1900 (40 % of the buildings were built before 1919 and 25 % between 1919 and 1945).

Because of industry, such as chemistry, gas and electricity factories, buildings in St-Johann are characterized by working class houses that were built around 1900 until 1945 (32 % and 35 % of the houses were erected at the beginning of the 20^{th} century and between 1919 and 1945, respectively).

On the right bank of the Rhine, between 1872-1893, the “Bläsitor” (Blaise’s gate) was demolished and new buildings were constructed to house factory workers (51 %). 21 % of all buildings in the Matthäus district were built between 1961 and 1980.

2.1.4 Bachletten, Hirzbrunnen, Iselin, Gotthelf, Breite, Rosental, Wettstein, St-Alban

Bachletten district is mostly residential; from 1871 to 1888, dwellings for workers were erected (Pfirtergasse). New housings were built close to the newly erected Paul’s church around 1900 (17 % of buildings are from before 1919). A social building complex was built in 1920 (56 %). In Hirzbrunnen, there are predominantly private houses (53.1 %) and mutual building cooperatives (34.4 %), mainly constructed between 1919 and 1945 (72 %).

The urbanisation of Gotthelf and Iselin districts was planned together. Though dating from different times, the majority of the buildings in these districts are residential. From 1869, a group of many two-storey houses was built along the Herrengrabenweg. New groups of family houses were built in 1904-1908 (Palmenstrasse), 1900-1920 (Strassburgerallee, Rixheimer- and Schlettstadterstrasse) 1920-1923 (Morgartenring, Pilatusstrasse). 28 % of the buildings were erected before 1919 and 41 % from 1919 to 1945. By 1920, these became the main residential districts of Basel, housing around 9000 inhabitants whilst only 2000 persons lived the city centre.

Breite is a district consisting mostly of working class houses. The first complex was built in 1854-57 (In der Breite); in 1877, new buildings were erected along the Birsfelderstrasse and in 1900, the area between St-Alban-Rheinweg and the Zürcherstrasse was occupied with rows of residential homes.

Rosental refers to the area between the ancient and new Badischen train station. This district contains many industrial buildings; around 1870, a spinning company and the chemical factory Geigy were constructed. In Wettstein, the chemical factory Hoffmann-La Roche was founded in 1889 (26% of buildings were erected before 1919 and 46 % between 1919 and 1945). Ciba AG also owned buildings in this area.

At the end of the 19th century, building types in St-Alban district were characterized by individual one- or two-storey dwelling houses (23%; before 1919). However, many plots of land were used later to build multiple-storey apartment buildings (a complex with 550 flats was constructed in 1955-1966). 33 % of buildings were built between 1919 and 1945 and 22 % between 1946 and 1960.

2.1.5 Bruderholz

According to the plans for the extension of Basel city, Bruderholz was planned to be a place with “Landhäuser” in contrast to St-Alban district. Houses must not have more than two floors (1904) and most were built according to the “**Heimatstil**” (1915). This district, which is on a small hill, is currently essentially residential with villas. Many private houses were constructed between 1915 and 1960 (1915-1945 (43%) ; 1946-1960 (36 %)).

2.1.6 Kleinhüningen, Klybeck

The Kleinhüningen district is situated to the north of Basel city; most of buildings are industrial buildings built between 1900 and 1980. Klybeck is also an industrial district; the Ciba headquarters buildings can be found in this district. Beside industry, there are areas with working-class residences too; the construction of the “workers’ city” started at the end of the 19th century.

2.1.7 Summary

Historical records show that most of the existing buildings in the districts Grossbasel, Kleinbasel, Vorstädte, Am Ring and Matthäus (in the centre of the city) were built before 1919 (73 %, 59 %, 53 %, 56 % and 51 % respectively). On the other hand, constructions dating from the period between the World Wars, i.e. 1919-1945, can be mostly found in the districts of Bachletten (21 %), Hirzbrunnen (16 %) and Bruderholz (13 %). The same districts, namely Bruderholz (23 %) and Bachletten (15 %), with Iselin district, consist of 48 % of the buildings dating from the industrial period of 1945 to1960 (23 %,15 % and 10 % respectively). Though quite well distributed among the whole city, the buildings erected from 1961 to 1980 are mostly found in the districts of Gundeldingen (13 %), Bruderholz (12 %), St-Johann (9 %) and Matthäus (9 %). The districts that contained most of the 1981-2000 buildings are Matthäus (11 %), Gundeldingen (10 %), St-Johann (10 %) and St-Alban (10 %).

More than half the city was erected before 1945 (64 %)[2].

2.2 Basel country

For this survey, it was decided to consider every town within a boundary of 12 km around the geothermal site. This circle includes the following towns in Switzerland: Aesch (part of), Allschwil, Arlesheim, Bättwil (part of) (SO), Bettingen, Biel-Benken, Binningen, Birsfelden, Bottmingen, Dornach (SO), Ettingen (part of), Frenkendorf (part of), Augst- Kaiseraugst (part of (BL and AG)), Münchenstein, Muttenz, Oberwil, Pratteln, Reinach, Riehen, Schönenbuch, Therwil, Witterswil (part of) (SO).

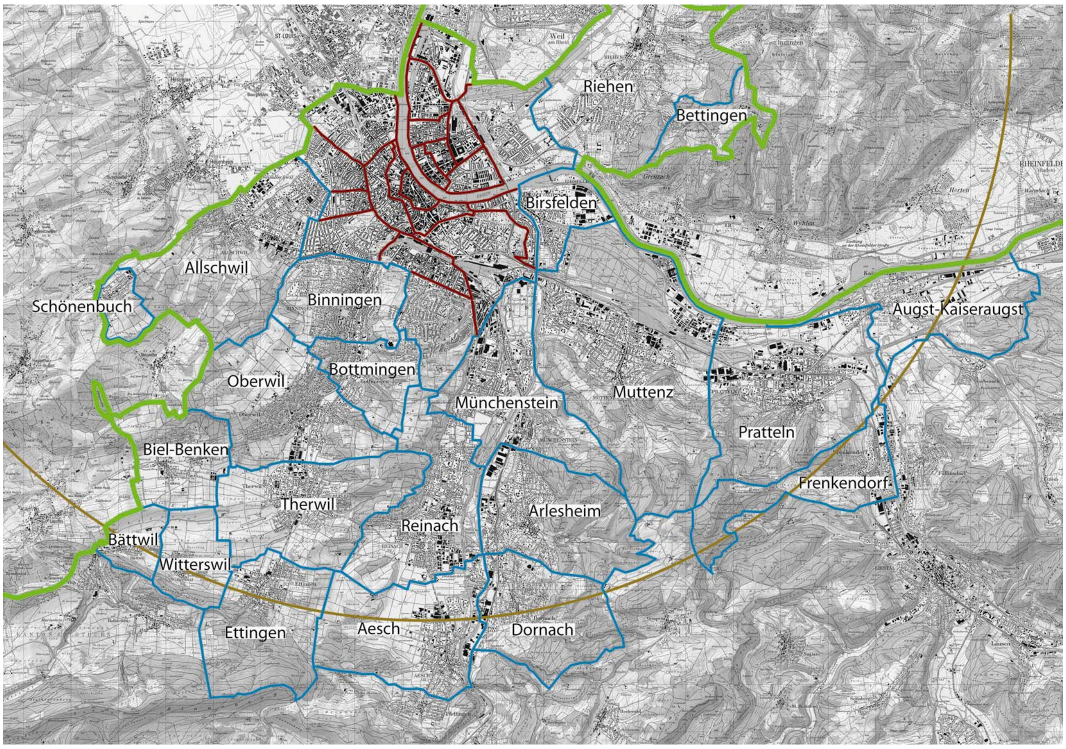


Figure 5: Basel considered rural towns (within the 12 km radius boundary). In blue: communes boundary; in green : country borders; in brown : study area boundary; in red: Basel-city districts.

[2] The number of buildings within every district of Basel city can be found in the appendices.

2.2.1 Short description of a few towns

The centre of most towns comprises a church, old typical Basler farms, old common houses and patrician houses. Except for the church, constructions usually are half-timbered structures. Centres sometimes also houses a castle.

Aesch

Though Aesch is quite far from Basel city, it is still part of Basel suburbs. However, there are more 1960-70 3-4-storey buildings than small family houses. From an architectural point of view, it looks more like a countryside town without an old city centre. A certain number of family houses (**Heimatstil**) are present.

Allschwil

Allschwil town is wholly included in the Basel city suburbs. Consequently, it also has the corresponding configuration, namely a few industrial buildings (generally brick masonry buildings from the beginning of the 20th century), many 1950 residential buildings, a few **Heimatsil** family houses, 3-4-storey 1980-2000 buildings (masonry and/or reinforced concrete) and a few buildings designed for commercial use.

There is also a small old centre with renovated farms (half-timbered structure) and patrician houses.

Bättwil

A few decades ago, Bättwil was still a farmers' town; nowadays, it is can be considered a residential town.

Binningen

This town with around 14'000 inhabitants is close to the area of Basel city. Since the mid-19th century, the medieval shape of the town changed due to industrialisation. A certain number of the residential houses built at that time still exist today. However, the biggest change to the town came around 1950 with the influx of workers to serve the Basler industry. From then on, Binningen became part of the city suburbs housing many tall (around 10-storey) 1950-70 buildings. Though there is still the old castle (rebuilt after a fire incident in 1414-15) with old typical Basler houses along the river.

Bottmingen

At the beginning of the 20th century, this town with around 6000 inhabitants featured a small old centre with farms, a church and houses. In addition, there is a castle dating back to the second part of the 13th century. This castle was transformed during the 17th century (German early Baroque) and the roof in the 18th century (French attic roof).

The rest of the buildings in the town are mostly residential: 1970-90 2- and/or 3-storey buildings in a city suburb.

Ettingen

In this town, there are no tall buildings; the tallest are 3 or 4 storeys high (1980-1990). Many 1920 village houses were built along the main street and close to the town centre, there are many 1990-2000 residential houses. The church in the centre is relatively new.

Frenkendorf

Frenkendorf is situated north of Liestal. There is a small town centre with a church and timber framed houses around it. However, most buildings were built in the 20th century: there are residential houses around the station, a few high-rises (more or less 20 floors) in addition to many 3-4-5 floor houses (around 1950). This town does have a number of industrial buildings.

Muttenz

Muttenz has a similar structure to Pratteln, in that it has a small centre with a church and a castle surrounded by farmer and bourgeois houses, mainly 3-4-5 buildings and a large industrial area (Schweizerhalle). There are around 17'000 inhabitants in this town.

Oberwil

The small centre of Oberwil, which is quite old, comprises old farm houses and the communal building still exists. Furthermore there are a few patrician mansions that might be built in the 18th century. From the town centre outward, a few old terraced houses and 2-3-4-storey buildings built between 1970 and 2000 can be found.

As in Muttenz and Pratteln, a large area is devoted to retail stores.

Pratteln

The town of Pratteln was nearly completely destroyed by the 1356 earthquake. Consequently, the oldest buildings date from the end of the 14th century. However, there are not many old buildings remaining in the centre of Pratteln, which now consists of a castle, a church and a few bourgeois and farmer houses.

Around the centre, many 3-storey and 4-storey buildings can be found. 2-storey houses (type **Heimatstil**) are also evident. A very large area is devoted to retail stores and industry (toward the Rhine river, Schweizerhalle).

There are around 15'000 inhabitants in Pratteln today.

Reinach

Though Reinach started as a village, today, it is part of Basel suburbs, housing 18'000 inhabitants. There are many residential houses (beginning of 20th century, **Heimatstil**), row houses (1970-80), 3-storey 1950 buildings, 5-storey 1990-2000 buildings, two or three 20-storey towers, a few half-timbered houses and industrial buildings (one-floor factory buildings). There are 18'000 inhabitants.

Riehen

Riehen has grown around an old city centre, which consists of a church and a few old houses. As one travels towards Basel city, there are more and more 3-4 level residential buildings. There are also terraced houses.

Therwil

Therwil is a very small old centre with a church (typical of the area). Around the church, a few old Basler farms (half-timbered buildings with a particular timber framework for the stall) can be found. Towards the Bruderholz hill, there are expensive dwellings whereas working-class terraced houses of the 1970s can be found on the opposite side. There are also many 1970-2000 buildings in this town and around 9500 inhabitants live in Therwil today.

2.2.2 Discussion/ Summary

The towns described above are divided into five groups according to the number of buildings in each location; these groups are:

Small town/ hamlet	< 500 buildings
Mid-size town	500 < < 2000 buildings
Large town	2001 < < 3000 buildings
City	> 3001 buildings

In the Basel rural area, hamlets and small towns were generally farmer towns; in such villages, the centre usually consists of a church surrounded by old farms (often half-timbered structures) and a few (more and more when getting close to Basel city) administrative buildings (wide masonry walls with timber slabs). These characteristics are similar for medium and large towns; the number of old buildings increased with the growing importance of the towns during the last four centuries. In the study context, the so-called city category actually corresponds to old towns that have merged over the years and hence becoming the city suburbs (Figure 3).

Furthermore buildings are categorised into five periods of construction, namely: before 1919, 1920-1945, 1946-1960, 1961-1980 and 1980-2000 since the last buildings inventory in Switzerland was carried out in 2000.

With regard to the structural attributes of buildings, most of those that were built before 1919 have no basements (bottom plate foundations for walls) and walls were usually constructed with stone masonry (massive or ashlar) and timber slabs. There are also many that were half-timbered structures. Around 1920, hollow-core bricks were also used for slabs and during this period, one began to build walls with brick masonry. At the end of the first half of the 20^{th} century, reinforced concrete became more and more popular in construction, especially with the introduction of multi-storied buildings.

2.3 French side

On the French side, there are around 23 towns within the study area, namely: Attenschwiller, Bartenheim, Blotzheim, Brinckheim, Buschwiller, Folgensourg, Hagenthal- le- Bas, Hagenthal- le- Haut, Hégenheim, Helfrantzkirch, Hésingue, Huningue, Kappelen, Kembs, Michelbach- le- Bas, Michelbach- le- Haut, Neuwiller, Ranspach, Rosenau, Sierentz, Stetten, St-Louis, Uffheim, Village-neuf and Wentzwiller.

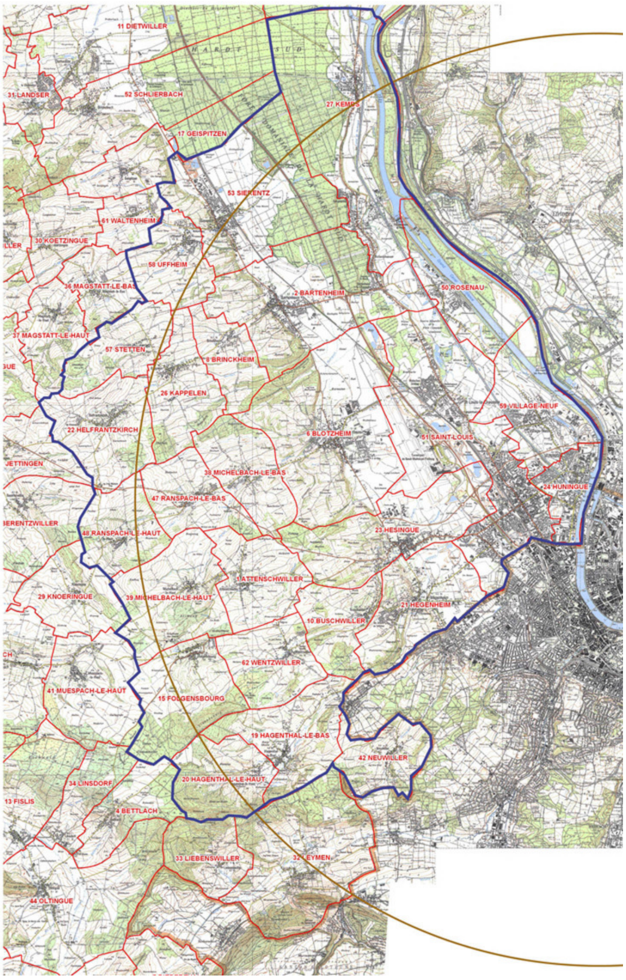


Figure 6: French towns included within the study area.

Only the city of Saint-Louis and the hamlets of Neuwiler and Wentzwiller, the towns of Hésingue, Huningue and Hégenheim as well as the city of Saint-Louis were surveyed. It is assumed that the building stock in the other towns or hamlets is similar to the surveyed ones.

2.3.1 Hégenheim

Hégenheim has about 3000 inhabitants[3]. It has a small town centre with a church and old timber-framed 1- or 2-storey houses. Around the centre, there are mostly family houses and a few 2-, 3-storey buildings.

2.3.2 Hésingue

Hésingue is slightly smaller than Hégenheim with its 2000 inhabitants. However the urban configuration is very similar, though more old half-timbered houses were observed during the on-site survey.

[3] The available French statistics date from 2006.

2.3.3 Huningue

Huningue is a small town with around 6000 inhabitants that is very close to the border with Germany and Switzerland. There are small houses (workers houses) and many 1970 2- and 3-storey buildings. There is no old centre.

2.3.4 Saint-Louis

Saint-Louis is a city with around 20’000 inhabitants. There are few old buildings constructed before the beginning of the 20th century. The buildings in the city centre exhibit many different architectural forms and are also of various heights. Many multi-storey apartment blocks can be found that were built between 1960-1990 (mostly reinforced concrete buildings).

2.3.5 Discussion/ summary

Statistics about the hamlets, towns or cities mentioned in this section were found on the INSEE website. Within the considered area, there are around 30’000 buildings[4], that can be classified either as houses, office buildings or blocks of flats. It was also possible to obtain the date of construction of the buildings and their type, namely houses with one residential-unit or multi-storey apartment blocks. However, the number of floors was not given[5] in the database.

On the basis of the number of buildings, the towns on the French side are divided into four groups:

Small town/ hamlet	< 500 buildings
Mid-size own	500 < <2000 buildings
Large town	2001 < <3000 buildings
City	> 3001 buildings

Structural features of buildings are similar to the Swiss side of the Basel region. However, the building stock built since the 1950s is constructed differently; more precisely, In this region, French solid masonry blocks are bigger than in Switzerland and apartment blocks are built with concrete frames with masonry infills and not concrete shear walls as common in Switzerland.

2.4 German side

On the German side, there are around 22 towns within the area of investigation, namely: Adelhausen, Binzen, Blansingen, Britschenhöfe, Efringen–kirchen, Egringen, Eichsel, Grenzbach, Hägelberg, Haltingen, Hauingen, Herten, Holzen, Hüsingen, Huttingen,

[4] The website was updated in June 2009; the statistics can date from 2003 to 2006.

[5] The main data regarding the date of construction and the type of buildings can be found in appendix.

Inzlingen, Istein, Kleinkems, Lörrach, Mappach, Maugenhard, Rümmingen, Steinen, Stetten, Weil am Rhein, Welmingen, Wintersweiler, Wittlingen and Wyhlen. However, the administrative distribution of communes is different in Germany compared to France and Switzerland. Some towns belong to larger communes. For example, Kleinkems, Blansingen, Welmingen Mappach, Huttingen, Istein, Winterweiler, Maugenhard, Egringen and Britschenhöfe are included within the commune of Efringen-Kirchen. Consequently, the considered areas in Germany actually consist of administrative communes. Furthermore, as some towns within the area of investigation are part of administrative communes that extend beyond the study area, not every town has been taken into account and a method of inclusion was devised. For instance, the towns of Herten and Degerfelden (to the East of the commune of Grenzach-Wyhlen) are comprised within the large commune of Rheinfelden. By considering the whole building stock in this commune, it would have biased the number of buildings for Germany since there are far more buildings in the commune of Rheinfelden than in Herten and Degerfelden. In order to account for this bias, the commune of Steinen is taken into account. This commune comprises towns outside the investigated area but serves the purpose of accounting for building stock of the towns that are inside the 12 km radius boundary but are not considered.

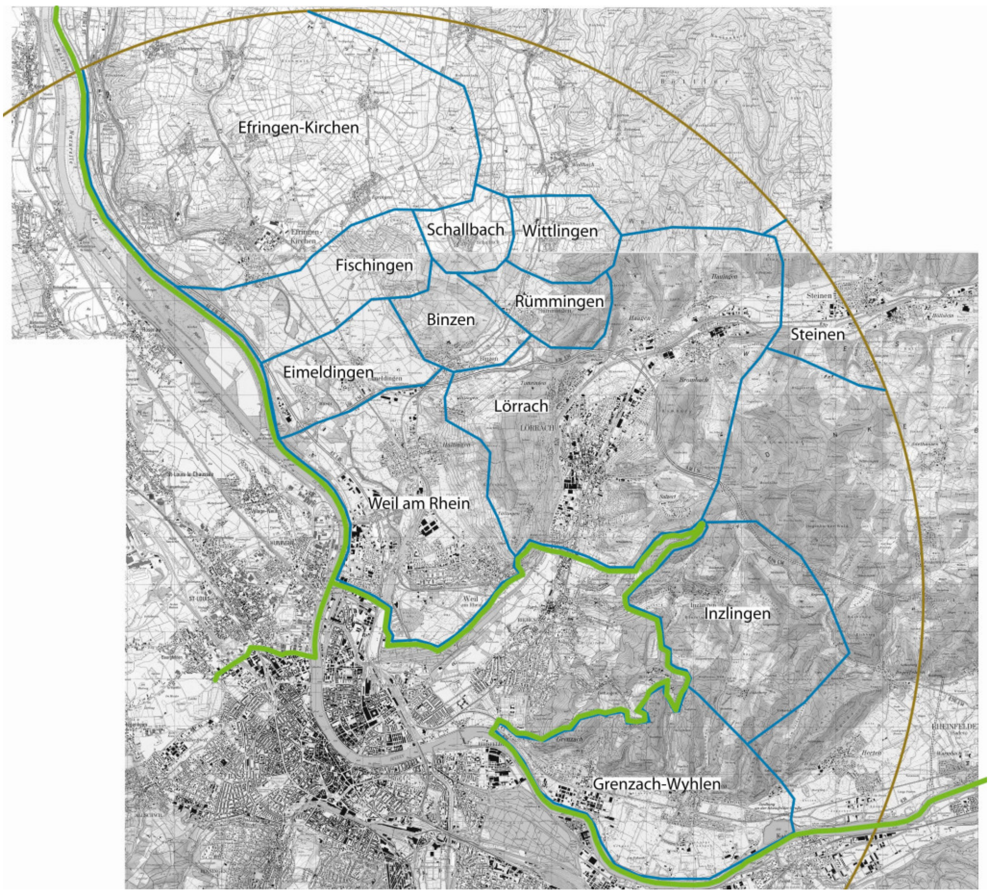


Figure 7: German towns included within the study area.

For the study, the cities of Weil am Rhein, Lörrach and the town of Stetten were surveyed.

2.4.1 Weil am Rhein

Weil am Rhein is the closest city to the geothermal site. It contains a small old city centre which is situated close to the German-Swiss border along the border of the town of Riehen. Old masonry as well as half-timbered residential buildings can be found in the city centre.

The rest of the city, which is located towards the French-German border, probably dates from the 20th century. This part of the city is crossed by the main commercial road and mainly consists of residential 3-4 storey buildings.

The commune of Weil am Rhein includes the towns of Öttlingen, Haltingen, Märkt and Weil am Rhein. The commune has 29'655 inhabitants (December 2007).

2.4.2 Lörrach

There are more inhabitants and buildings in Lörrach than Weil am Rhein. The centre, which is a commercial area, is composed of buildings of a similar age. Around this area, new buildings, probably built in the 20th century, are industrial and/or administrative; these structures are modern and can reach up to 20 storeys. Around this zone, there are residential buildings: terraced houses and 3-4 storey buildings. There are also a few high-rises of around 15 storeys.

The commune of Lörrach includes the following towns: Stetten, Tumringen, Tüllingen, Haagen, Brombach, Salzert and Hauingen.

2.4.3 Discussion/ summary

As for towns in France and Switzerland, the towns in the German study area are distributed into four categories according to the number of residential buildings. The categories are:

Small town/ hamlet	< 500 buildings
Mid- size town	500 < <2000 buildings
Large town	2001 < <3000 buildings
City	> 3001 buildings

It is assumed that structural attributes of buildings in Germany are very similar to the Swiss side of the Basel region.

3 Vulnerability curves

There are a few methods of calculating vulnerability that have been developed either in Europe or in the USA. Among them, the most widely applied are: European Macroseismic Scale 1998, Risk-UE and VulnérAlp. Hazus (FEMA) methodology has not been taken into account in this study because the European construction types notably differ from the USA.

3.1 Existing methods

3.1.1 European Macroseismic Intensity Scale 1998

The European Macroseismic Intensity scale 1998 (EMS-98) resulted from the updating of the European Macroseismic Intensity Scale 1992 that was carried out by the working group "Macroseismic scale" of the European Seismological Commission [Gr 01].

The EMS-98 scale (as the EMS-92 was) is based on the MSK (Medvedev-Sponheuer-Karnik) scale; it was designed by associating a damage degree to each seismic intensity level. The damage scale differs when considering reinforced concrete or masonry buildings; however, both scales are made up of five damage states, namely:

- D1 : negligible to slight damage
- D2 : moderate damage [slight structural damage, moderate non-structural damage
- D3 : substantial to heavy damage [moderate structural damage, heavy non-structural damage]
- D4 : very heavy damage [heavy structural damage, very heavy non-structural damage]
- D5 : destruction [very heavy structural damage]

Obviously, each damage state is translated to masonry or to reinforced concrete buildings differently.

Moreover, several types of structures are considered; seven types exist to describe masonry buildings, six for reinforced concrete, one for steel structures and one for timber structures. Each type of structure corresponds to a vulnerability category. There are six vulnerability categories (A, B, C, D, E and F) that allows for vulnerability to be defined for each of the structure types. Category A is the most vulnerable category and F is the least vulnerable category.

Although parameters that might influence the seismic vulnerability of a given building are mentioned in the EMS-98 [Gr 01], no quantification of their impact is proposed.

3.1.2 Risk-UE

Risk-UE was a European project aimed at creating advanced tools to assess earthquake risks. This project was divided into ten tasks each dealing with a topic linked to the earthquake risk. One of these topics was the seismic vulnerability of current buildings (WP4) [MT 03].

On the basis of the European Macroseismic Scale [Gr 01], the WP4 has developed vulnerability models that describe the relation between the probability of building damage and the seismic hazard. In [MT 03], this method is called LM1. This method is based on vulnerability categories and vulnerability indices; each category corresponds to a vulnerability index.

Included in this study is most of the European building stock; 23 building categories were distinguished. This list of typologies is similar to the EMS-98 though the Risk-UE study was more detailed (23 types against 15).

Based on expert opinions, a relation, which is a function of the vulnerability index, between the intensity and the damage was derived. This relation gives the Mean Damage Grade (μ_D) as a function of seismic intensity:

$$\mu_D = 2.5 * (1+\tanh((I+6.25\ V_I - 13.1)/2.3))$$

Where:

- I: seismic intensity
- V_I : vulnerability index

The index can be modified in order to account for parameters that can influence the seismic vulnerability. Among others, there are the state of maintenance, the number of floors, the presence of a soft-storey, the vertical and horizontal regularity, etc.

3.1.3 VulnérAlp

This method, which is also based on the EMS-98, was developed specifically for adaptation to the building stock in Grenoble [GML 07], [Mc 07]. Additional typologies and corresponding vulnerability curve were created; these curves were calibrated with experimental studies (ambient vibrations). Moreover, thanks to the application of their method, the authors were able to identify the most sensitive parameters for the seismic vulnerability of buildings.

3.2 Chosen method for SERIANEX project

The chosen method for the SERIANEX project is mainly based on the Risk-UE and VulnérAlp methods, which both use the EMS-98 methodology as a basis.

Risk-UE and VulnérAlp methods are more detailed than EMS-98 because they have more categories of different seismic vulnerabilities to characterize the considered buildings. Moreover, the average vulnerability index given by both methods can be modified through factors to take account of specific building parameters.

Vulnerability categories

The choice of vulnerability categories for the SERIANEX project takes into account the Risk-UE categories and the inventory of the building structures that have been identified in the Basel area (as was done for the city of Grenoble when applying the VulnérAlp method). Consequently, the adopted categories include Risk-UE's classes and height new ones. The additional building categories are shown in italics in table one; these have been derived from in situ surveys. The adopted vulnerability classes are listed in the table below:

Table 1: Vulnerability classes for the SERIANEX project.

Typology	Description	Most probable value of the vulnerability index
M1	Simple stone with timber slabs	0.74
M2	Massive stone with timber slabs	0.616
M3	Brick with concrete slabs	0.616
M4	*Simple stone with hollow-core slabs*	*0.7*
M5	*Brick with hollow-core slabs*	*0.65*
M6	*Massive stone with hollow-core slabs*	*0.65*
M7	Brick with timber slabs	0.74
RC1	Concrete moment frames	0.442
RC2	Concrete shear walls	0.386
RC3	*Concrete walls and brick masonry walls*	*0.4*
RC4	*Hennebique system*	*0.5*
RC5	Concrete moment frames with infills	0.402
S1	Steel structures (moment and brace F)	0.325
S2	*Old steel structures*	*0.4*
W1	Timber structures	0.447
W2	*Half-timbered structures*	*0.48*

Since most of the vulnerability classes are taken from Risk-UE, as are the majority of the most probable values of the vulnerability index, the vulnerability indices for typologies M4, M5, M6, RC3, RC4, S2 and W2, which are specific to the Basel area, have been defined by experts judgment on the basis of the most probable value of the vulnerability index for similar structural types.

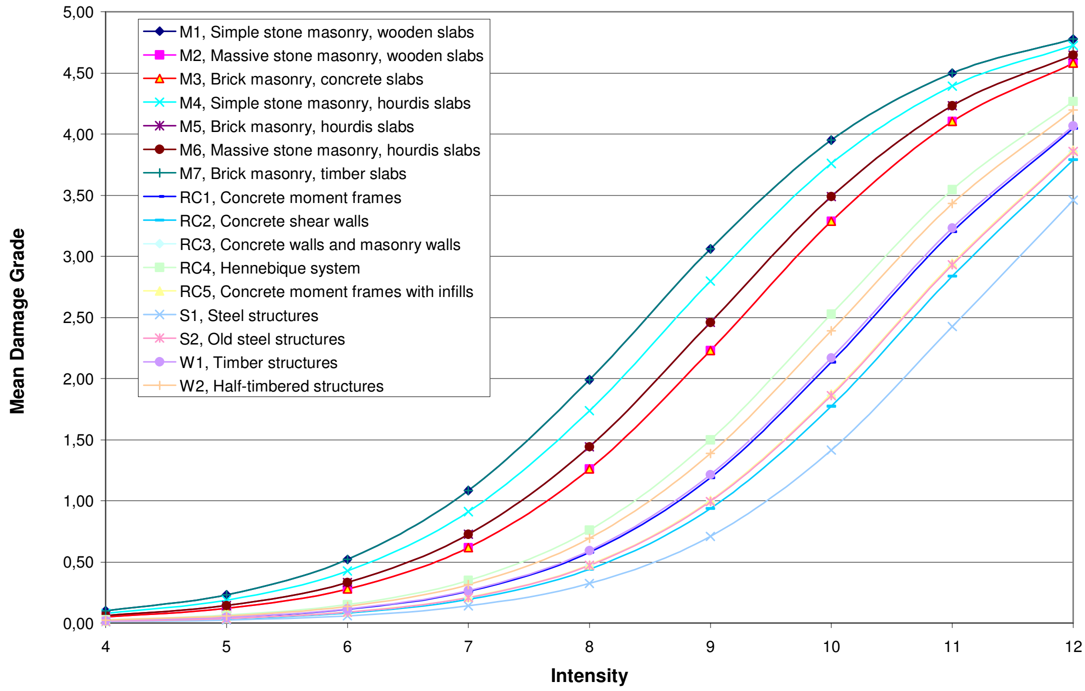


Figure 8: Seismic vulnerability curves for the SERIANEX project.

A preliminary calculation was carried out with the above vulnerability curves. When compared to the observation of damage due to the 2006 seismic event, this resulted in an overestimation of the number of damaged buildings (and economic losses) for low levels of intensity. Consequently, the vulnerability curves were modified accordingly for intensities between III. and VI.5. More precisely, the MDG was multiplied by a factor that was equal to 0 for 0 < I < III.5, linearly increasing from 0 to 1 for III.5 < I < VI.5 and equating to 1 from I = VI.5.

In order to increase precision as much as possible, vulnerability factors were taken into account. The selection of the vulnerability factors is based on the following criteria, which are:

- the possibility to easily and quickly identify the parameters during the survey
- the level of the factor influence

Consequently, the following vulnerability factors were applied for the project survey. The values corresponding to the parameters are taken from the Risk-UE study.

The vulnerability curves of French, German and Swiss buildings belonging to same vulnerability category are assumed to be the same.

Vulnerability factors

Table 2: Vulnerability factors and the associated modifying values

Vulnerability factors	Parameters	Values
Number of floors	Low (1-2)	-0.02
	Medium (3, 4 or 5)	+0.02
	High (6 and more)	+0.06
Soft-Story	Transformation, demolition	+0.04
Height of the building compared within the aggregate	Buildings of different heights	+0.04
	Staggered floors	+0.02
Building age	< 1919 (CH) or 1949 (F)	+0.02

In [GML 07], it is stated that the position of the building within the aggregate may have a certain influence on the seismic vulnerability of the given building. Because of the tall gables of the typical Basler houses, this statement is more likely to be true. However, the implementation of this factor in this study has proven to be too time-consuming given the limited budget; it was therefore not applied in the current study.

4 Observed damage after the 2006 seismic event

Damage due to the 2006 earthquake was reported by the engineering office Aegerter und Bosshardt AG. Around 2800 reported damage cases were paid out by the insurance. For every case, a description of the observed damage was presented; on the basis of the available description of 260 declared cases, it was possible to conclude that the most common type of damage was small cracks. The total cost of the repairs was around 6-7 millions CHF.

Additionally, the Swiss seismological service published a map (Figure 9) with the observed macroseismic intensity and an estimation of seismic intensity on the basis of measured ground motion [KF 07]. The distribution of the observed macroseismic intensity within the studied area was based on a collection of about 2000 reports satisfying the SED standard procedure. Ground motion data were recorded by different seismic stations that are situated in and close to the area of Basel city.

The following summary is based on the literature sources mentioned above.

4.1 Basel city

Reported damage was mainly concentrated in the middle of Basel city and in particular in the southern part of the Grossbasel district (around Stützen – and Steinengraben). Damage was also reported in the districts of St-Johann, Iselin, Gotthelf and Am Ring.

Most damage constituted of small cracks in the roughcast on walls; pre-existing cracks may have extended on the walls. In some cases, pieces of roughcast also fell off.

Buildings that were built before the 1950's were more affected than the ones built later. This is essentially due to the material of construction; buildings erected before 1950 have masonry walls (not always of good-quality), no basements, timber or hollow-core slabs and/or half-timbered structure with masonry infills. These structure types are particularly sensitive to movements (either vertical or horizontal).

Moreover, small cracks were also found on the walls of terraced-houses built in the beginning of the 20th century (around 1930).

Only a few cases of damage were reported for buildings that were built post 1950. They mostly included buildings that have either constructive features and/or an architectural design that are/is seismically unfavourable.

4.2 Basel country

Most reported damage was from areas within the neighbouring suburbs of Basel city, i.e. Binningen, Bottmingen und Allschwil. Less damage was apparently recorded in the farther areas such as the towns of Oberwil, Therwil, Reinach, Münchenstein, Arlesheim, Ettingen and Muttenz. Nevertheless, on the Swiss seismological service's map, only a few areas around the city of Basel were characterized by a higher intensity (I = V) than other parts within the city zone.

The type and grade of the reported damage is very similar to that observed in the city of Basel. Although the towns mentioned above are quite far from the borehole, the damage is actually not less severe than that reported in the area of Basel city.

4.3 Saint-Louis region

On French side, the cities of Saint-Louis and Huningue were the most damaged areas. The reported damage does not differ from the overall damage reported in the Basel area.

According to the Swiss seismological service map, a few parts of the city of Saint-Louis can be classified as intensity of V in the 2006 earthquake.

4.4 Lörrach region

The city of Weil am Rhein was affected by the earthquake as were Lörrach and Haltingen. Even in further away towns of Ötlingen, Binzen and Eimeldingen damage was reported.

The reported damage mainly consists of cracks within the roughcast of walls.

4.5 Discussion and proposed changes to vulnerability curves

When comparing the reported damage to the data from the Swiss seismological service, the maximum damage grade (i.e. D1) from both data sources is consistent. However, the geographical distribution of the seismic intensity V (which results into a damage grade D1 for buildings of vulnerability class A [Gr 01]) differs significantly.

The determination and observation of damage as well as of seismic intensity are subjective; this is an important point, since the insurance industry base pay outs on them. Consequently, the potential bias of misestimating damage should be accounted for, especially for low intensities such as IV, V and VI. However, if the definition of the cracks origin is complex, accounting for this potential misestimate becomes even more difficult. The assessment of this bias is beyond the scope of the present study. Therefore, this has not been quantified, though it is taken into account in the interpretation of results.

The observed cracks from 2006 earthquake (M = 3.2) cannot be considered to be structural failures. This type of damage typically corresponds to a damage grade lower[6] than or equal to D1 (EMS-98); damage grade D2 on the EMS-98 scale was not observed. Though the assignement of the correct percentage of D1 damage regarding the cases of lower damage grade than D1 is complex, a proportion of 10 % appears to be reasonable, which means that around 250 buildings could be considered as D1 on the EMS-98 scale .

[6] A damage grade D1 implies the presence of many cracks (though not structural) on walls. For almost every recorded case (at least for most of the 260 cases whose description is available), it has proved not to be the case; there were very few cracks. Consequently, such cases cannot be considered as D1 damage grade.

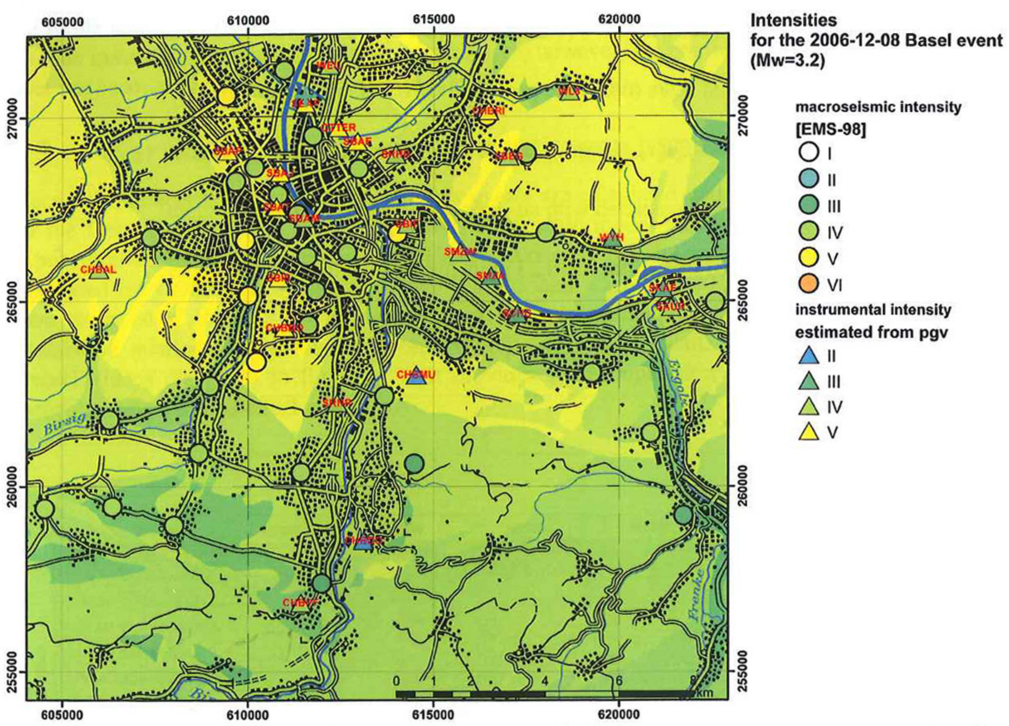


Figure 9: Comparison of the intensity prediction (background colour) to observed macroseismic intensities of medium and good quality (round symbols) and intensity estimated from recorded seismic ground motion (triangles, station names in red) for the December 8, 2006, M=3.2 event [KF 07].

5 Building inventory classification

According to the methodology presented in section 1.3, all buildings from the statistical records have to be associated with the corresponding vulnerability categories. It is achieved by using a building inventory classification system, which is defined on the basis of in-situ surveys, literature and also discussion with professionals in the field, as from the office for preservation of monuments and historic buildings of the canton Basel-city[7].

The investigated area is divided into smaller zones, which are the Basel city districts, the communes in France and Switzerland and groups of communes in Germany.

In order to take into account the technical development of civil engineering, the building inventory classification system is to be sub-divided into periods of time; they might be different for France, Germany and Switzerland.

[7] With this interlocutor, discussion was essentially about buildings in Basel-city.

Each vulnerability typology corresponds to a vulnerability index. The average value of the indices can be taken from Table 1 ; in order to refine the average value, modification factors are applied. These factors relate to the structure characteristics, such as the height, number of floors or age, for instance. The final vulnerability function can be described as:

$$V_i = V_i^* + \Delta V_{i,\text{number of floors}} + \Delta V_{i,\text{soft-story}} + \Delta V_{i,\text{age}} + \Delta V_{i,\text{irregularity of height}}$$

Where:

- V_i^* : average index of vulnerability of the corresponding type of structure,
- $\Delta V_{i,\text{number of floors}}$: modification factor for taking into account the number of floors,
- $\Delta V_{i,\text{soft-story}}$: modification factor for taking into account the presence of a soft-story,
- $\Delta V_{i,\text{age}}$ modification factor for taking into account the building age,
- $\Delta V_{i,\text{irregularity of height}}$: modification factor for taking into account the different heights of buildings within an aggregate.

Except for a few exceptions, the same modification factors can be applied to every single-residential-unit building and also for those with more than one residential unit.

It is very important to emphasize that for the three countries, the available official records only account for residential buildings. Industrial facilities and buildings for exclusive commercial use are not part of the statistics considered in this study. However, the potential impact of not considering this type of buildings is negligible as they occupy a very small portion of most towns in the area. For instance, industrial facilities corresponds to around 1 % of the building stock in case of most average towns (in Switzerland), 5 % for the southern side of the Rhine river and 8 % for its north bank.

5.1 Basel city

The building inventory classification is given per district or group of districts and these are:

1. Grossbasel and Kleinbasel
2. Vorstädte, Am Ring, Clara, St-Alban, Wettstein
3. Gundeldingen, St-Johann, Matthäus
4. Bachletten, Hitzbrunnen, Gotthelf
5. Iselin, Breite, Rosental
6. Klybeck, Kleinhüningen
7. Bruderholz

Firstly, the building inventory classification is presented, followed by the modification factors.

Notes:

- Along commercial streets, buildings built with a Hennebique system may have a ground floor without masonry infill because of shops. Consequently, the ground floor can exhibit a certain weakness at this level under seismic loading, the so-called soft-storey. For this reason, the vulnerability index must be modified accordingly.
- The vulnerability index of all buildings whose construction date is before 1919 were modified in order to account for the decreasing strength of materials with time [MT 03], [GML 07], [Mc 07].
- For a same period of time, the building inventory classification is in fact quite close amongst each group since the structure types of residential buildings usually change over time and not (or less) spatially.
- A residential-unit corresponds to a flat or a family house.

5.1.1 Building inventory classification

1. Grossbasel, Kleinbasel

Period of time	%	Comments, assumptions	Category
< 1919		• Buildings with one residential unit :	
	10 %	- Half-timbered structures	W2
	90 %	- Simple stone masonry walls, timber slabs	M1
		• Buildings with more than one residential unit or with commercial floors :	
	10 %	- Half-timbered structures, timber slabs	W2
	80 %	- Simple stone masonry walls, timber slabs	M1
	10 %	- Massive stone masonry, timber slabs	M2
1920 - 1945		• Buildings with one residential unit :	
	20 %	- Brick masonry walls, hollow-core slabs	M5
	20 %	- Brick masonry walls, timber slabs	M7
	60 %	- Hennebique system without openings at the ground floor level	RC4
		• Buildings with more than one residential unit or with commercial floors :	
	20 %	- Brick masonry walls, hollow-core slabs	M5
	20 %	- Brick masonry walls, timber slabs	M7
	60 %	- Hennebique system with openings at the ground floor level	RC4
1946 -1960		• Buildings with one residential unit :	
	100 %	- Brick masonry walls, reinforced concrete slabs	M3
		• Buildings with more than one residential unit or with commercial floors:	
	35 %	- Brick masonry walls, reinforced concrete slabs	M3
	20 %	- Concrete moment frames with regular infilled walls	RC5
	35 %	- Reinforced concrete walls, reinforced concrete slabs	RC2
	10 %	- Steel structures	S1
1961 - 1980		• Buildings with one residential unit :	
	80 %	- Brick masonry walls, reinforced concrete slabs	M3
	20 %	- Brick and reinforced concrete walls, concrete slabs	RC3
		• Buildings with more than one residential unit :	
	25 %	- Brick masonry walls, reinforced concrete slabs	M3
	5 %	- Brick and reinforced concrete walls, concrete slabs	RC3
	20 %	- Concrete moment frames with regular infilled walls	RC5
	45 %	- Reinforced concrete walls, reinforced concrete slabs	RC2
	5 %	- Steel structures	S1
1981 - 2000		• Buildings with one residential unit :	
	75 %	- Brick masonry walls, reinforced concrete slabs	M3
	15 %	- Brick and reinforced concrete walls, concrete slabs	RC3
	10 %	- Reinforced concrete walls, reinforced concrete slabs	RC2
		• Buildings with more than one residential unit :	
	10 %	- Brick masonry walls, reinforced concrete slabs	M3
	5 %	- Brick and reinforced concrete walls, concrete slabs	RC3
	20 %	- Concrete moment frames with regular infilled walls	RC5
	55 %	- Reinforced concrete walls, reinforced concrete slabs	RC2
	10 %	- Steel structures	S1

2. Vorstädte, Am Ring, Clara, St-Alban, Wettstein

Period of time	%	Comments, assumptions	Category
< 1919		• Buildings with one residential unit :	
	80 %	- Simple stone masonry walls, timber slabs	M1
	20 %	- Simple stone masonry walls, hollow-core slabs	M4
		• Buildings with more than one residential unit or with commercial floors :	
	70 %	- Simple stone masonry walls, timber slabs	M1
	25 %	- Simple stone masonry walls, hollow-core slabs	M4
	5 %	- Steel structures (old/ Belle Epoque)	S2
1920 - 1945		• Buildings with one residential unit :	
	20 %	- Brick masonry walls, hollow-core slabs	M1
	60 %	- Brick masrony, reinforced concrete slabs	M3
	20 %	- Hennebique system without openings at the ground floor slabs	RC4
		• Buildings with more than one residential unit or with commercial floors :	
	20 %	- Brick masonry walls, hollow-core slabs	M1
	60 %	- Brick masrony, reinforced concrete slabs	M3
	20 %	- Hennebique system with openings at the ground floor slabs	RC4*
1946 -1960		• Buildings with one residential unit :	
	100 %	- Brick masonry walls, reinforced concrete slabs	M3
		• Buildings with more than one residential unit or with commercial floors:	
	35 %	- Brick masonry walls, reinforced concrete slabs	M3
	20 %	- Concrete moment frames with regular infilled walls	RC5
	35 %	- Reinforced concrete walls, reinforced concrete slabs	RC2
	10 %	- Steel structures	S1
1961 - 1980		• Buildings with one residential unit :	
	80 %	- Brick masonry walls, reinforced concrete slabs	M3
	20 %	- Brick masonry and reinforced concrete walls, reinforced concrete slabs	RC3
		• Buildings with more than one residential unit :	
	25 %	- Brick masonry walls, reinforced concrete slabs	M3
	5 %	- Brick and reinforced concrete walls, concrete slabs	RC3
	20 %	- Concrete moment frames with regular infilled walls	RC5
	45 %	- Reinforced concrete walls, reinforced concrete slabs	RC2
	5 %	- Steel structures	S1
1981 - 2000		• Buildings with one residential unit :	
	70 %	- Brick masonry walls, reinforced concrete slabs	M3
	15 %	- Reinforced concrete walls, reinforced concrete slabs	RC2
	15 %	- Brick masonry and reinforced concrete walls, reinforced concrete slabs	RC3
		• Buildings with more than one residential unit :	
	10 %	- Brick masonry walls, reinforced concrete slabs	M3
	5 %	- Brick and reinforced concrete walls, concrete slabs	RC3
	20 %	- Concrete moment frames with regular infilled walls	RC5
	55 %	- Reinforced concrete walls, reinforced concrete slabs	RC2
	10 %	- Steel structures	S1

3. Gundeldingen, St-Johann, Matthäus

Period of time	%	Comments, assumptions	Category
< 1919		• Buildings with one residential unit :	
	10 %	- Half-timbered structures	**W2**
	90 %	- Simple stone masonry walls, timber slabs	**M1**
		• Buildings with more than one residential unit or with commercial floors :	
	10 %	- Half-timbered structures, timber slabs	**W2**
	80 %	- Simple stone masonry walls, timber slabs	**M1**
	10 %	- Massive stone masonry, timber slabs	**M2**
1920 - 1945		• Buildings with one residential unit :	
	20 %	- Brick masonry walls, hollow-core slabs	**M5**
	20 %	- Brick masonry walls, timber slabs	**M7**
	60 %	- Hennebique system without openings at the ground floor level	**RC4**
		• Buildings with more than one residential unit or with commercial floors :	
	20 %	- Brick masonry walls, hollow-core slabs	**M5**
	20 %	- Brick masonry walls, timber slabs	**M7**
	60 %	- Hennebique system with openings at the ground floor level	**RC4***
1946 -1960		• Buildings with one residential unit :	
	100 %	- Brick masonry walls, reinforced concrete slabs	**M3**
		• Buildings with more than one residential unit or with commercial floors:	
	5 %	- Brick masonry walls, reinforced concrete slabs	**M3**
	30 %	- Concrete moment frames with regular infilled walls	**RC5**
	45 %	- Reinforced concrete walls, reinforced concrete slabs	**RC2**
	20 %	- Steel structures	**S1**
1961 - 1980		• Buildings with one residential unit :	
	80 %	- Brick masonry walls, reinforced concrete slabs	**M3**
	20 %	- Brick masonry and reinforced concrete walls, reinforced concrete slabs	**RC3**
		• Buildings with more than one residential unit :	
	25 %	- Brick masonry walls, reinforced concrete slabs	**M3**
	5 %	- Brick and reinforced concrete walls, concrete slabs	**RC3**
	20 %	- Concrete moment frames with regular infilled walls	**RC5**
	45 %	- Reinforced concrete walls, reinforced concrete slabs	**RC2**
	5 %	- Steel structures	**S1**
1981 - 2000		• Buildings with one residential unit :	
	70 %	- Brick masonry walls, reinforced concrete slabs	**M3**
	15 %	- Reinforced concrete walls, reinforced concrete slabs	**RC2**
	15 %	- Brick masonry and reinforced concrete walls, reinforced concrete slabs	**RC3**
		• Buildings with more than one residential unit :	
	10 %	- Brick masonry walls, reinforced concrete slabs	**M3**
	5 %	- Brick and reinforced concrete walls, concrete slabs	**RC3**
	20 %	- Concrete moment frames with regular infilled walls	**RC5**
	55 %	- Reinforced concrete walls, reinforced concrete slabs	**RC2**
	10 %	- Steel structures	**S1**

4. Bachletten, Hirzbrunnen, Gotthelf

Period of time	%	Comments, assumptions	Category
< 1919		• Buildings with one residential unit :	
	10 %	- Half-timbered structures	W2
	90 %	- Simple stone masonry walls, timber slabs	M1
		• Buildings with more than one residential unit or with commercial floors :	
	10 %	- Half-timbered structures, timber slabs	W2
	80 %	- Simple stone masonry walls, timber slabs	M1
	10 %	- Massive stone masonry, timber slabs	M2
1920 - 1945		• Buildings with one residential unit :	
	20 %	- Brick masonry walls, hollow-core slabs	M5
	20 %	- Brick masonry walls, timber slabs	M7
	60 %	- Hennebique system without openings at the ground floor level	RC4
		• Buildings with more than one residential unit or with commercial floors :	
	20 %	- Brick masonry walls, hollow-core slabs	M5
	20 %	- Brick masonry walls, timber slabs	M7
	60 %	- Hennebique system with openings at the ground floor level	RC4*
1946 -1960		• Buildings with one residential unit :	
	100 %	- Brick masonry walls, reinforced concrete slabs	M3
		• Buildings with more than one residential unit or with commercial floors:	
	5 %	- Brick masonry walls, reinforced concrete slabs	M3
	30 %	- Concrete moment frames with regular infilled walls	RC5
	45 %	- Reinforced concrete walls, reinforced concrete slabs	RC2
	20 %	- Steel structures	S1
1961 - 1980		• Buildings with one residential unit :	
	90 %	- Brick masonry walls, reinforced concrete slabs	M3
	10 %	- Brick masonry and reinforced concrete walls, reinforced concrete slabs	RC3
		• Buildings with more than one residential unit :	
	10 %	- Brick masonry walls, reinforced concrete slabs	M3
	5 %	- Brick and reinforced concrete walls, concrete slabs	RC3
	30 %	- Concrete moment frames with regular infilled walls	RC5
	50 %	- Reinforced concrete walls, reinforced concrete slabs	RC2
	5 %	- Steel structures	S1
1981 - 2000		• Buildings with one residential unit :	
	70 %	- Brick masonry walls, reinforced concrete slabs	M3
	15 %	- Reinforced concrete walls, reinforced concrete slabs	RC2
	15 %	- Brick masonry and reinforced concrete walls, reinforced concrete slabs	RC3
		• Buildings with more than one residential unit :	
	10 %	- Brick masonry walls, reinforced concrete slabs	M3
	5 %	- Brick and reinforced concrete walls, concrete slabs	RC3
	20 %	- Concrete moment frames with regular infilled walls	RC5
	55 %	- Reinforced concrete walls, reinforced concrete slabs	RC2
	10 %	- Steel structures	S1

5. Iselin, Breite, Rosental

Period of time	%	Comments, assumptions	Category
< 1919		• Buildings with one residential unit :	
	10 %	- Half-timbered structures	W2
	90 %	- Simple stone masonry walls, timber slabs	M1
		• Buildings with more than one residential unit or with commercial floors :	
	10 %	- Half-timbered structures, timber slabs	W2
	80 %	- Simple stone masonry walls, timber slabs	M1
	10 %	- Massive stone masonry, timber slabs	M2
1920 - 1945		• Buildings with one residential unit :	
	20 %	- Brick masonry walls, hollow-core slabs	M5
	20 %	- Brick masonry walls, timber slabs	M7
	60 %	- Hennebique system without openings at the ground floor level	RC4
		• Buildings with more than one residential unit or with commercial floors :	
	20 %	- Brick masonry walls, hollow-core slabs	M5
	20 %	- Brick masonry walls, timber slabs	M7
	60 %	- Hennebique system with openings at the ground floor level	RC4*
1946 -1960		• Buildings with one residential unit :	
	100 %	- Brick masonry walls, reinforced concrete slabs	M3
		• Buildings with more than one residential unit or with commercial floors:	
	5 %	- Brick masonry walls, reinforced concrete slabs	M3
	30 %	- Concrete moment frames with regular infilled walls	RC5
	45 %	- Reinforced concrete walls, reinforced concrete slabs	RC2
	20 %	- Steel structures	S1
1961 - 1980		• Buildings with one residential unit :	
	90 %	- Brick masonry walls, reinforced concrete slabs	M3
	10 %	- Brick masonry and reinforced concrete walls, reinforced concrete slabs	RC3
		• Buildings with more than one residential unit :	
	10 %	- Brick masonry walls, reinforced concrete slabs	M3
	5 %	- Brick and reinforced concrete walls, concrete slabs	RC3
	30 %	- Concrete moment frames with regular infilled walls	RC5
	50 %	- Reinforced concrete walls, reinforced concrete slabs	RC2
	5 %	- Steel structures	S1
1981 - 2000		• Buildings with one residential unit :	
	70 %	- Brick masonry walls, reinforced concrete slabs	M3
	15 %	- Reinforced concrete walls, reinforced concrete slabs	RC2
	15 %	- Brick masonry and reinforced concrete walls, reinforced concrete slabs	RC3
		• Buildings with more than one residential unit :	
	10 %	- Brick masonry walls, reinforced concrete slabs	M3
	5 %	- Brick and reinforced concrete walls, concrete slabs	RC3
	20 %	- Concrete moment frames with regular infilled walls	RC5
	55 %	- Reinforced concrete walls, reinforced concrete slabs	RC2
	10 %	- Steel structures	S1

6. Klybeck, Kleinhüningen

Period of time	%	Comments, assumptions	Category
< 1919		• Buildings with one residential unit :	
	10 %	- Half-timbered structures	**W2**
	90 %	- Simple stone masonry walls, timber slabs	**M1**
		• Buildings with more than one residential unit or with commercial floors :	
	10 %	- Half-timbered structures, timber slabs	**W2**
	80 %	- Simple stone masonry walls, timber slabs	**M1**
	10 %	- Massive stone masonry, timber slabs	**M4**
1920 - 1945		• Buildings with one residential unit :	
	20 %	- Brick masonry walls, hollow-core slabs	**M5**
	20 %	- Brick masonry walls, timber slabs	**M7**
	60 %	- Hennebique system without openings at the ground floor level	**RC4**
		• Buildings with more than one residential unit or with commercial floors :	
	20 %	- Brick masonry walls, hollow-core slabs	**M5**
	20 %	- Brick masonry walls, timber slabs	**M7**
	60 %	- Hennebique system with openings at the ground floor level	**RC4***
1946 -1960		• Buildings with one residential unit :	
	100 %	- Brick masonry walls, reinforced concrete slabs	**M3**
		• Buildings with more than one residential unit or with commercial floors:	
	5 %	- Brick masonry walls, reinforced concrete slabs	**M3**
	30 %	- Concrete moment frames with regular infilled walls	**RC5**
	45 %	- Reinforced concrete walls, reinforced concrete slabs	**RC2**
	20 %	- Steel structures	**S1**
1961 - 1980		• Buildings with one residential unit :	
	90 %	- Brick masonry walls, reinforced concrete slabs	**M3**
	10 %	- Brick masonry and reinforced concrete walls, reinforced concrete slabs	**RC3**
		• Buildings with more than one residential unit :	
	5 %	- Brick masonry walls, reinforced concrete slabs	**M3**
	5 %	- Brick and reinforced concrete walls, concrete slabs	**RC3**
	35 %	- Concrete moment frames with regular infilled walls	**RC5**
	50 %	- Reinforced concrete walls, reinforced concrete slabs	**RC2**
	5 %	- Steel structures	**S1**
1981 - 2000		• Buildings with one residential unit :	
	70 %	- Brick masonry walls, reinforced concrete slabs	**M3**
	15 %	- Reinforced concrete walls, reinforced concrete slabs	**RC2**
	15 %	- Brick masonry and reinforced concrete walls, reinforced concrete slabs	**RC3**
		• Buildings with more than one residential unit :	
	5 %	- Brick masonry walls, reinforced concrete slabs	**M3**
	5 %	- Brick and reinforced concrete walls, concrete slabs	**RC3**
	30 %	- Concrete moment frames with regular infilled walls	**RC5**
	55 %	- Reinforced concrete walls, reinforced concrete slabs	**RC2**
	10 %	- Steel structures	**S1**

8. Bruderholz

Period of time	%	Comments, assumptions	Category
< 1919		• Buildings with one residential unit :	
	10 %	- Half-timbered structures	**W2**
	90 %	- Simple stone masonry walls, timber slabs	**M1**
		• Buildings with more than one residential unit or with commercial floors :	
	10 %	- Half-timbered structures, timber slabs	**W2**
	85 %	- Simple stone masonry walls, timber slabs	**M1**
	5 %	- Massive stone masonry, timber slabs	**M4**
1920 - 1945		• Buildings with one residential unit :	
	20 %	- Brick masonry walls, hollow-core slabs	**M5**
	20 %	- Brick masonry walls, timber slabs	**M7**
	60 %	- Hennebique system without openings at the ground floor level	**RC4**
		• Buildings with more than one residential unit or with commercial floors :	
	50 %	- Brick masonry walls, hollow-core slabs	**M5**
	50 %	- Brick masonry walls, timber slabs	**M7**
1946 -1960		• Buildings with one residential unit :	
	100 %	- Brick masonry walls, reinforced concrete slabs	**M3**
		• Buildings with more than one residential unit or with commercial floors:	
	50 %	- Brick masonry walls, reinforced concrete slabs	**M3**
	50 %	- Reinforced concrete walls, reinforced concrete slabs	**RC2**
1961 - 1980		• Buildings with one residential unit :	
	80 %	- Brick masonry walls, reinforced concrete slabs	**M3**
	20 %	- Brick masonry and reinforced concrete walls, reinforced concrete slabs	**RC3**
		• Buildings with more than one residential unit :	
	35 %	- Brick masonry walls, reinforced concrete slabs	**M3**
	15 %	- Brick and reinforced concrete walls, concrete slabs	**RC3**
	50 %	- Reinforced concrete walls, reinforced concrete slabs	**RC2**
1981 - 2000		• Buildings with one residential unit :	
	70 %	- Brick masonry walls, reinforced concrete slabs	**M3**
	15 %	- Reinforced concrete walls, reinforced concrete slabs	**RC2**
	15 %	- Brick masonry and reinforced concrete walls, reinforced concrete slabs	**RC3**
		• Buildings with more than one residential unit :	
	20 %	- Brick masonry walls, reinforced concrete slabs	**M3**
	20 %	- Brick and reinforced concrete walls, concrete slabs	**RC3**
	60 %	- Reinforced concrete walls, reinforced concrete slabs	**RC2**

5.1.2 Modification factors

1. Grossbasel, Kleinbasel

Buildings with one residential unit	Buildings with more than one residential unit or with commercial floors
- $\Delta V_{i,\text{number of floors}} = +0.01$ (4 st.-buildings) - $\Delta V_{i,\text{soft-story}} = 0$.-$\Delta V_{i,\text{irregularity of height}} = +0.02$.-$\Delta V_{age} = +0.02$ (<1919)	- $\Delta V_{i,\text{number of floors}} = +0.02$ (4-5 st.-buildings) - $\Delta V_{i,\text{soft-story}} = +0.02$ (for RC4* buildings) .-$\Delta V_{i,\text{irregularity of height}} = +0.02$.-$\Delta V_{age} = +0.02$ (<1919)

2. Vorstaedte, Am Ring, Clara St-Alban, Wettstein

Buildings with one residential unit	Buildings with more than one residential unit or with commercial floors
- $\Delta V_{i,\text{number of floors}} = 0$ (3 st.- buildings) - $\Delta V_{i,\text{soft-story}} = 0$.-$\Delta V_{i,\text{irregularity of height}} = +0.02$.-$\Delta V_{age} = +0.02$ (<1919)	- $\Delta V_{i,\text{number of floors}} = +0.01$ (4 st.-buildings) - $\Delta V_{i,\text{soft-story}} = +0.02$ (for RC4* buildings) .-$\Delta V_{i,\text{irregularity of height}} = +0.02$.-$\Delta V_{age} = +0.02$ (<1919)

3. Gundeldingen, St-Johann, Matthäus

Buildings with one residential unit	Buildings with more than one residential unit or with commercial floors
- $\Delta V_{i,\text{number of floors}} = 0$ (3 st.- buildings) - $\Delta V_{i,\text{soft-story}} = 0$.-$\Delta V_{i,\text{irregularity of height}} = +0.02$.-$\Delta V_{age} = +0.02$ (<1919)	- $\Delta V_{i,\text{number of floors}} = +0.03$ (4-6 st.-buildings) - $\Delta V_{i,\text{soft-story}} = +0.02$ (for RC4* buildings) .-$\Delta V_{i,\text{irregularity of height}} = +0.02$.-$\Delta V_{age} = +0.02$ (<1919)

4. Bachletten, Hirzbrunnen, Gotthelf

Buildings with one residential unit	Buildings with more than one residential unit or with commercial floors
- $\Delta V_{i,\text{number of floors}} = 0$ (3 st.- buildings) - $\Delta V_{i,\text{soft-story}} = 0$.-$\Delta V_{i,\text{irregularity of height}} = +0.02$.-$\Delta V_{age} = +0.02$ (<1919)	- $\Delta V_{i,\text{number of floors}} = +0.02$ (4-5 st. buildings) - $\Delta V_{i,\text{soft-story}} = +0.02$ (for RC4* buildings) .-$\Delta V_{i,\text{irregularity of height}} = +0.02$.-$\Delta V_{age} = +0.02$ (<1919)

5. Iselin, Breite, rosental

Buildings with one residential unit	Buildings with more than one residential unit or with commercial floors
- $\Delta V_{i,\text{number of floors}} = 0$ (3 st.- buildings) - $\Delta V_{i,\text{soft-story}} = 0$.-$\Delta V_{i,\text{irregularity of height}} = +0.02$.-$\Delta V_{age} = +0.02$ (<1919)	- $\Delta V_{i,\text{number of floors}} = +0.02$ (4-5 st.- buildings) - $\Delta V_{i,\text{soft-story}} = 0$.-$\Delta V_{i,\text{irregularity of height}} = +0.02$.-$\Delta V_{age} = +0.02$ (<1919)

6. Klybeck, kleinhüningen

Buildings with one residential unit	Buildings with more than one residential unit or with commercial floors
- $\Delta V_{i,\text{number of floors}} = 0$ (2-3 st.- buildings) - $\Delta V_{i,\text{soft-story}} = 0$.-$\Delta V_{i,\text{irregularity of height}} = + 0.02$.-$\Delta V_{age} = + 0.02$ (<1919)	- $\Delta V_{i,\text{number of floors}} = +0.02$ (4-5 st. buildings) - $\Delta V_{i,\text{soft-story}} = 0$.-$\Delta V_{i,\text{irregularity of height}} = + 0.02$.-$\Delta V_{age} = + 0.02$ (<1919)

7. Bruderholz

Buildings with one residential unit	Buildings with more than one residential unit or with commercial floors
- $\Delta V_{i,\text{number of floors}} = 0$ (2-3 st.- buildings) - $\Delta V_{i,\text{soft-story}} = 0$.-$\Delta V_{i,\text{irregularity of height}} = 0$.-$\Delta V_{age} = + 0.02$ (<1919)	- $\Delta V_{i,\text{number of floors}} = 0$ (2-3 st.- buildings) - $\Delta V_{i,\text{soft-story}} = 0$.-$\Delta V_{i,\text{irregularity of height}} = 0$.-$\Delta V_{age} = + 0.02$ (<1919)

5.2 Basel country

The percentage of each type of buildings is defined according to in-situ surveys.

5.2.1 Building inventory classification and modification factors

The towns in Basel country are gathered into groups according to the number of buildings in each category. The groups are as follows (2.2.2):

1. Small (rural) towns/ hamlets	< 500 buildings
2. Mid-size towns	500 < < 2000 buildings
3. Large towns	2001 < < 3000 buildings
4. Cities/suburbs	> 3001 buildings

1. & 2. Small (rural) towns, Hamlets, mid-size towns

Period of time	%	Comments, assumptions	Category
< 1919		• All kinds of buildings :	
	50 %	- Simple stone masonry walls, timber slabs	**M1**
	50 %	- Half-timbered houses	**W2**
		• Buildings with more than one residential unit or with commercial floors :	
	50 %	- Simple stone masonry walls, timber slabs	**M1**
	50 %	- Half-timbered houses	**W2**
1920 - 1945		• Buildings with one residential unit :	
	50 %	- Brick masonry walls, timber slabs	**M7**
	50 %	- Brick masonry, hollow-core slabs	**M5**
		• Buildings with more than one residential unit or with commercial floors :	
	50 %	- Brick masonry walls, timber slabs	**M7**
	50 %	- Brick masonry, hollow-core slabs	**M5**
1946 -1960		• Buildings with one residential unit :	
	100 %	- Brick masonry walls, reinforced concrete slabs	**M3**
		• Buildings with more than one residential unit or with commercial floors:	
	50 %	- Brick masonry walls, reinforced concrete slabs	**M3**
	35 %	- Reinforced concrete walls, reinforced concrete slabs	**RC2**
	15 %	- Concrete and masonry walls, concrete slabs	**RC3**
1961 - 1980		• Buildings with one residential unit :	
	70 %	- Brick masonry walls, reinforced concrete slabs	**M3**
	30 %	- Concrete and brick masonry walls structures	**RC3**
		• Buildings with more than one residential unit :	
	45 %	- Brick masonry walls, reinforced concrete slabs	**M3**
	35 %	- Reinforced concrete walls, reinforced concrete slabs	**RC2**
	20 %	- Concrete and masonry walls, concrete slabs	**RC3**
1981 - 2000		• Buildings with one residential unit :	
	55 %	- Brick masonry walls, reinforced concrete slabs	**M3**
	10 %	- Reinforced concrete walls, reinforced concrete slabs	**RC2**
	30 %	- Concrete and masonry walls structures	**RC3**
	5 %	- Timber structures	**W1**
		• Buildings with more than one residential unit :	
	40 %	- Brick masonry walls, reinforced concrete slabs	**M3**
	30 %	- Reinforced concrete walls, reinforced concrete slabs	**RC2**
	30 %	- Concrete and masonry walls structures	**RC3**

Modification factors:

Buildings with one residential unit	Buildings with more than one residential unit or with commercial floors
- $\Delta V_{i,\text{number of floors}} = -0.01$ (2 st.- buildings) - $\Delta V_{i,\text{soft-story}} = 0$ - $\Delta V_{age} = +0.02$ (< 1919)	- $\Delta V_{i,\text{number of floors}} = -0.01$ (2 st.- buildings) - $\Delta V_{i,\text{soft-story}} = 0$ - $\Delta V_{age} = +0.02$ (< 1919)

Note: the modification factor regarding the effect on vulnerability of the different height between two side-by-side buildings is no longer relevant in case of towns.

3. Large towns

Period of time	%	Comments, assumptions	Category
< 1919	 45 % 10 % 45 %	• All buildings : - Simple stone masonry walls, timber slabs - Massive stone masonry - Half-timbered houses	 M1 M2 W2
1920 - 1945	 50 % 50 % 50 % 50 %	• Buildings with one residential unit : - Simple stone masonry walls, timber slabs - Simple stone masonry walls, hollow-core slabs • Buildings with more than one residential unit or with commercial floors : - Mid quality stone masonry walls, hollow-core slabs - Brick masonry walls, hollow-core slabs	 M1 M4 M4 M5
1946 -1960	 100 % 50 % 35 % 15 %	• Buildings with one residential unit : - Brick masonry walls, reinforced concrete slabs • Buildings with more than one residential unit or with commercial floors: - Brick masonry walls, reinforced concrete slabs - Reinforced concrete walls, reinforced concrete slabs - Concrete and masonry walls, concrete slabs	 M3 M3 RC2 RC3
1961 - 1980	 70 % 30 % 40 % 30 % 5 % 20 % 5%	• Buildings with one residential unit : - Brick masonry walls, reinforced concrete slabs - Concrete and brick masonry walls structures • Buildings with more than one residential unit : - Brick masonry walls, reinforced concrete slabs - Reinforced concrete walls, reinforced concrete slabs - Concrete and masonry walls, concrete slabs - Concrete moment frames with regular infilled walls - Steel structures	 M3 RC3 M3 RC2 RC3 RC5 S1
1981 - 2000	 60 % 10 % 30 % 30 % 28 % 30 % 5 % 2 %	• Buildings with one residential unit : - Brick masonry walls, reinforced concrete slabs - Reinforced concrete walls, reinforced concrete slabs - Concrete and masonry walls structures • Buildings with more than one residential unit : - Brick masonry walls, reinforced concrete slabs - Reinforced concrete walls, reinforced concrete slabs - Concrete and masonry walls structures - Concrete moment frames with regular infilled walls - Steel structures	 M3 RC2 RC3 M3 RC2 RC3 RC5 S1

Modification factors:

Buildings with one residential unit	Buildings with more than one residential unit or with commercial floors
- $\Delta V_{i,\text{number of floors}} = 0$ (3-4 st.- buildings) - $\Delta V_{i,\text{soft-story}} = 0$ - $\Delta V_{age} = +\ 0.02$ (< 1919)	- $\Delta V_{i,\text{number of floors}} = +0.01$ (3-4 st.- buildings) - $\Delta V_{i,\text{soft-story}} = 0$ - $\Delta V_{age} = +\ 0.02$ (< 1919)

4. Cities/ suburbs

Period of time	%	Comments, assumptions	Category
< 1919	 40 % 20 % 40 %	• <u>All buildings</u> : - Simple stone masonry walls, timber slabs - Massive stone masonry - Half-timbered houses	 **M1** **M2** **W2**
1920 - 1945	 30 % 35 % 35 % 30 % 70 %	• <u>Buildings with one residential unit</u> : - Simple stone masonry walls, timber slabs - Simple stone masonry walls, hollow-core slabs - Brick masonry walls, hollow-core slabs • <u>Buildings with more than one residential unit or with commercial floors</u> : - Simple stone masonry walls, hollow-core slabs - Brick masonry walls, hollow-core slabs	 **M1** **M4** **M3** **M4** **M5**
1946 -1960	 100 % 30 % 45 % 25 %	• <u>Buildings with one residential unit</u> : - Brick masonry walls, reinforced concrete slabs • <u>Buildings with more than one residential unit or with commercial floors</u> : - Brick masonry walls, reinforced concrete slabs - Reinforced concrete walls, reinforced concrete slabs - Concrete and masonry walls, concrete slabs	 **M3** **M3** **RC2** **RC3**
1961 - 1980	 70 % 30 % 28 % 45 % 20 % 5 % 2 %	• <u>Buildings with one residential unit</u> : - Brick masonry walls, reinforced concrete slabs - Concrete and brick masonry walls structures • <u>Buildings with more than one residential unit</u> : - Brick masonry walls, reinforced concrete slabs - Reinforced concrete walls, reinforced concrete slabs - Concrete and masonry walls, concrete slabs - Concrete moment frames with infilled walls - Steel structures	 **M3** **RC3** **M3** **RC2** **RC3** **RC5** **S1**
1981 - 2000	 60 % 10 % 30 % 23 % 40 % 30 % 5 % 2 %	• <u>Buildings with one residential unit</u> : - Brick masonry walls, reinforced concrete slabs - Reinforced concrete walls, reinforced concrete slabs - Concrete and masonry walls structures • <u>Buildings with more than one residential unit</u> : - Brick masonry walls, reinforced concrete slabs - Reinforced concrete walls, reinforced concrete slabs - Concrete and masonry walls structures - Concrete moment frames with infilled walls - Steel structures	 **M3** **RC2** **RC3** **M3** **RC2** **RC3** **RC5** **S1**

Modification factors:

Buildings with one residential unit	*Buildings with more than one residential unit or with commercial floors*
- $\Delta V_{i,\text{number of floors}} = 0$ (2-3 st.buildings) - $\Delta V_{i,\text{soft-story}} = 0$ - $\Delta V_{age} = + 0.02$ (< 1919)	- $\Delta V_{i,\text{number of floors}} = +0.01$ (3-4 st. buildings) - $\Delta V_{i,\text{soft-story}} = 0$ - $\Delta V_{age} = + 0.02$ (< 1919)

5.2.2 Application to communes

Small (rural) towns, Hamlets :	- Bättwil - Bettingen - Kaiseraugst - Schönenbuch - Witterswil
Mid-size towns :	- Aesch - Arlesheim - Biel – Benken - Birsfelden - Bottmingen - Dornach - Ettingen - Frenkendorf
Large towns :	- Binningen - Münchenstein - Oberwil - Pratteln - Therwil
Cities/ suburbs :	- Allschwil - Muttenz - Reinach - Riehen

5.3 French side

The French statistics also group buildings according to their date of construction; however, the periods of time that are considered differ from the ones used in Switzerland.

As for Switzerland, the distribution of building types is different when comparing a city (and its suburbs) with a rural town. The following groups were identified:

1. Small (rural) towns/ hamlets	< 500 buildings
2. Mid-size towns	500 < < 2000 buildings
3. Large towns	2001 < < 3000 buildings
4. Cities/suburbs	> 3001 buildings

5.3.1 Building inventory classification

1. Small (rural) towns, hamlets

Period of time	%	Comments, assumptions	Category
< 1949	 25 % 25 % 25 % 25 %	• All buildings : - Simple stone masonry walls, timber slabs - Simple stone masonry walls, hollow-core slabs - Half-timbered houses - Brick masonry structures	 **M1** **M4** **W2** **M5**
1950- 1974	 90 % 10 % 50 % 50 %	• Buildings with one residential unit : - Brick masonry walls, reinforced concrete slabs - Concrete and brick masonry walls structures • Buildings with more than one residential unit or with commercial floors : - Brick masonry walls, reinforced concrete slabs - Reinforced concrete moment frames with infilled walls	 **M3** **RC3** **M3** **RC5**
1975 -1989	 80 % 20 % 55 % 45 %	• Buildings with one residential unit : - Brick masonry walls, reinforced concrete slabs - Concrete and brick masonry walls structures • Buildings with more than one residential unit or with commercial floors : - Brick masonry walls, reinforced concrete slabs - Reinforced concrete moment frames with infilled walls	 **M3** **RC3** **M3** **RC5**
1990 - 2008	 60 % 30 % 10 % 28 % 70 % 2 %	• Buildings with one residential unit : - Brick masonry walls, reinforced concrete slabs - Concrete and brick masonry walls structures - Timber structures • Buildings with more than one residential unit : - Brick masonry walls, reinforced concrete slabs - Reinforced concrete moment frames with infilled walls - Steel structures	 **M3** **RC3** **W1** **M3** **RC5** **S1**

Modification factors:

Buildings with one residential unit	Buildings with more than one residential unit or with commercial floors
- $\Delta V_{i,\text{number of floors}} = -0.02$ - $\Delta V_{i,\text{soft-story}} = 0$ - $\Delta V_{age} = +0.02$ (< 1949)	- $\Delta V_{i,\text{number of floors}} = +0.01$ (2-3 storey buildings) - $\Delta V_{i,\text{soft-story}} = 0$ - $\Delta V_{age} = +0.02$ (< 1949)

2. Mid-size towns

Period of time	%	Comments, assumptions	Category
< 1949	 25 % 20 % 5 % 25 % 25 %	• All buildings : - Simple stone masonry walls, timber slabs - Simple stone masonry walls, hollow-core slabs - Massive stone masonry - Half-timbered houses - Brick masonry structures	 **M1** **M4** **M2** **W2** **M5**
1950 - 1974	 80 % 20 % 50 % 50 %	• Buildings with one residential unit : - Brick masonry walls, reinforced concrete slabs - Concrete and brick masonry walls structures • Buildings with more than one residential unit or with commercial floors : - Brick masonry walls, reinforced concrete slabs - Reinforced concrete moment frames with infilled walls	 **M3** **RC3** **M3** **RC5**
1975 -1989	 80 % 20 % 50 % 50 %	• Buildings with one residential unit : - Brick masonry walls, reinforced concrete slabs - Concrete and brick masonry walls structures • Buildings with more than one residential unit or with commercial floors : - Brick masonry walls, reinforced concrete slabs - Reinforced concrete moment frames with infilled walls	 **M3** **RC3** **M3** **RC5**
1990 - 2008	 60 % 30 % 10 % 28 % 70 % 2 %	• Buildings with one residential unit : - Brick masonry walls, reinforced concrete slabs - Concrete and brick masonry walls structures - Timber structures • Buildings with more than one residential unit : - Brick masonry walls, reinforced concrete slabs - Reinforced concrete moment frames with infilled walls - Steel structures	 **M3** **RC3** **W1** **M3** **RC5** **S1**

Modification factors:

Buildings with one residential unit	Buildings with more than one residential unit or with commercial floors
- $\Delta V_{i,\text{number of floors}} = 0$ - $\Delta V_{i,\text{soft-story}} = 0$ - $\Delta V_{age} = + 0.02$ (< 1949)	- $\Delta V_{i,\text{number of floors}} = +0.01$ (2-3 storey buildings) - $\Delta V_{i,\text{soft-story}} = 0$ - $\Delta V_{age} = + 0.02$ (< 1949)

3. Large towns

Period of time	%	Comments, assumptions	Category
< 1949	 25 % 20 % 5 % 25 % 25 %	• All buildings : - Simple stone masonry walls, timber slabs - Simple stone masonry walls, hollow-core slabs - Massive stone masonry - Half-timbered houses - Brick masonry structures	 M1 M4 M2 W2 M5
1950 - 1974	 80% 20% 50 % 50 %	• Buildings with one residential unit : - Brick masonry walls, reinforced concrete slabs - Concrete and brick masonry walls structures • Buildings with more than one residential unit or with commercial floors : - Brick masonry walls, reinforced concrete slabs - Reinforced concrete moment frames with infilled walls	 M3 RC3 M3 RC5
1975 -1989	 80 % 20 % 50 % 50 %	• Buildings with one residential unit : - Brick masonry walls, reinforced concrete slabs - Concrete and brick masonry walls structures • Buildings with more than one residential unit or with commercial floors : - Brick masonry walls, reinforced concrete slabs - Reinforced concrete moment frames with infilled walls	 M3 RC3 M3 RC5
1990 - 2008	 50 % 40 % 10 % 18 % 80 % 2 %	• Buildings with one residential unit : - Brick masonry walls, reinforced concrete slabs - Concrete and brick masonry walls structures - Timber structures • Buildings with more than one residential unit : - Brick masonry walls, reinforced concrete slabs - Reinforced concrete moment frames with infilled walls - Steel structures	 M3 RC3 W1 M3 RC5 S1

Modification factors:

Buildings with one residential unit	Buildings with more than one residential unit or with commercial floors
- $\Delta V_{i,\text{number of floors}} = 0$ - $\Delta V_{i,\text{soft-story}} = 0$ - $\Delta V_{age} = + 0.02$ (< 1949)	- $\Delta V_{i,\text{number of floors}} = +0.01$ (2-3 storey buildings) - $\Delta V_{i,\text{soft-story}} = 0$ - $\Delta V_{age} = + 0.02$ (< 1949)

4. Cities

Period of time	%	Comments, assumptions	Category
< 1949		• All buildings :	
	18 %	- Simple stone masonry walls, timber slabs	M1
	17 %	- Simple stone masonry walls, hollow-core slabs	M4
	15 %	- Massive stone masonry	M2
	25 %	- Half-timbered houses	W2
	25 %	- Brick masonry structures	M5
1950 - 1974		• Buildings with one residential unit :	
	60 %	- Brick masonry walls, reinforced concrete slabs	M3
	30 %	- Concrete and brick masonry walls structures	RC3
	10 %	- Reinforced concrete moment frames with infilled walls	RC5
		• Buildings with more than one residential unit or with commercial floors :	
	20 %	- Brick masonry walls, reinforced concrete slabs	M3
	10 %	- Concrete and brick masonry walls structures	RC3
	70 %	- Reinforced concrete moment frames with infilled walls	RC5
1975 -1989		• Buildings with one residential unit :	
	70 %	- Brick masonry walls, reinforced concrete slabs	M3
	15 %	- Concrete and brick masonry walls structures	RC3
	15 %	- Reinforced concrete moment frames with infilled walls	RC1
		• Buildings with more than one residential unit or with commercial floors :	
	15 %	- Brick masonry walls, reinforced concrete slabs	M3
	10 %	- Concrete and brick masonry walls structures	RC3
	70 %	- Reinforced concrete moment frames with infilled walls	RC5
	5 %	- Steel structures	S1
1990 - 2008		• Buildings with one residential unit :	
	40 %	- Brick masonry walls, reinforced concrete slabs	M3
	40 %	- Concrete and brick masonry walls structures	RC3
	10 %	- Timber structures	W1
	10 %	- Reinforced concrete moment frames with infilled walls	RC5
		• Buildings with more than one residential unit :	
	15 %	- Brick masonry walls, reinforced concrete slabs	M3
	10 %	- Concrete and brick masonry walls structures	RC3
	70 %	- Reinforced concrete moment frames with infilled walls	RC5
	5 %	- Steel structures	S1

Modification factors:

Buildings with one residential unit	Buildings with more than one residential unit or with commercial floors
- $\Delta V_{i,\text{number of floors}}$ = +0.01 - $\Delta V_{i,\text{soft-story}}$ = 0 - ΔV_{age} = + 0.02 (< 1949)	- $\Delta V_{i,\text{number of floors}}$ = +0.02 (4-5 storey buildings) - $\Delta V_{i,\text{soft-story}}$ = 0 - ΔV_{age} = + 0.02 (< 1949)

5.3.2 Application to communes

Small (rural) towns , hamlets :

- Attenschwiller
- Brinckheim
- Buschwiller
- Folgensbourg
- Hagenthal–le–Bas
- Hagenthal–le–Haut
- Helfrantzkirch
- Kappelen
- Michelbach-le-Bas
- Michelbach-le-Haut
- Neuwiller
- Ranspach
- Stetten
- Uffheim
- Wentzwiller

Mid-size towns :

- Bartenheim
- Blotzheim
- Hégenheim
- Hésingue
- Kembs
- Rosenau
- Sierentz
- Village - neuf

Large towns :

- Huningue

Cities :

- Saint - Louis

5.4 German side

Compared with the French and Swiss statistics, German ones only give the number of buildings that have been inventoried since 1986. Moreover, they are often given for large administrative areas that include more than one town. Consequently, there are areas that include rural towns and others just a city, as is the case for Lörrach for instance. In order to be able to take the differing types of urbanization into account, five inventory categories according to the building types are proposed (here below). Distributions are defined on the basis of in-situ surveys.

The groups are:

1. Small (rural) towns/ hamlets	< 500 buildings
2. Mid-size towns	500 < < 2000 buildings
3. Group of mid-size and small (rural) towns	2001 < < 3000 buildings
4. City (suburbs included) and mid-size towns	> 3001 buildings

5.4.1 Building inventory classification

1. Small (rural) towns/ Hamlets

Period of time	%	Comments, assumptions	Category
< 1986		• Buildings with one residential unit :	
	20 %	- Simple stone masonry, timber slabs	**M1**
	10 %	- Simple stone masonry, hollow-core slabs	**M4**
	30 %	- Brick masonry walls, reinforced concrete slabs	**M5**
	30 %	- Concrete and brick masonry walls structures	**RC3**
	10 %	- Half-timbered structures	**W2**
		• Buildings with more than one residential unit or with commercial floors :	
	5 %	- Simple stone masonry, hollow-core slabs	**M1**
	10 %	- Brick masonry walls, hollow-core slabs	**M5**
	30 %	- Brick masonry walls, reinforced concrete slabs	**M3**
	20 %	- Concrete and brick masonry walls structures	**RC3**
	30 %	- Reinforced concrete shear walls	**RC2**
	5 %	- Reinforced concrete moment frames with infilled walls	**RC5**
1987 - 2008		• Buildings with one residential unit :	
	50 %	- Brick masonry walls, reinforced concrete slabs	**M5**
	50 %	- Concrete and brick masonry walls structures	**RC3**
		• Buildings with more than one residential unit or with commercial floors :	
	30 %	- Brick masonry walls, reinforced concrete slabs	**M3**
	40 %	- Concrete and brick masonry walls structures	**RC3**
	30 %	- Reinforced concrete shear walls	**RC2**

Note: it is assumed that the configuration of small rural towns and hamlets is the same.

Modification factors:

Buildings with one residential unit	Buildings with more than one residential unit or with commercial floors
- $\Delta V_{i,\text{number of floors}} = -0.02$ - $\Delta V_{i,\text{soft-story}} = 0$	- $\Delta V_{i,\text{number of floors}} = +0.01$ (2-3 storey buildings) - $\Delta V_{i,\text{soft-story}} = 0$

Note: there is no longer a modification factor that accounts for the building age.

2. Mid-size towns

Period of time	%	Comments, assumptions	Category
< 1986		• Buildings with one residential unit :	
	20 %	- Simple stone masonry, timber slabs	**M1**
	10 %	- Simple stone masonry, hollow-core slabs	**M4**
	30 %	- Brick masonry walls, reinforced concrete slabs	**M5**
	30 %	- Concrete and brick masonry walls structures	**RC3**
	10 %	- Half-timbered structures	**W2**
		• Buildings with more than one residential unit or with commercial floors :	
	5 %	- Simple stone masonry, hollow-core slabs	**M1**
	5 %	- Brick masonry walls, hollow-core slabs	**M5**
	30 %	- Brick masonry walls, reinforced concrete slabs	**M3**
	5 %	- Massive stone masonry, timber slabs	**M2**
	20 %	- Concrete and brick masonry walls structures	**RC3**
	30 %	- Reinforced concrete shear walls	**RC2**
	5 %	- Reinforced concrete moment frames with infilled walls	**RC5**
1987 - 2008		• Buildings with one residential unit :	
	50 %	- Brick masonry walls, reinforced concrete slabs	**M5**
	50 %	- Concrete and brick masonry walls structures	**RC3**
		• Buildings with more than one residential unit or with commercial floors :	
	20 %	- Brick masonry walls, reinforced concrete slabs	**M3**
	40 %	- Concrete and brick masonry walls structures	**RC3**
	30 %	- Reinforced concrete shear walls	**RC2**
	10 %	- Reinforced concrete moment frames with infilled walls	**RC5**

Modification factors:

Buildings with one residential unit	Buildings with more than one residential unit or with commercial floors
- $\Delta V_{i,\text{number of floors}} = 0$ - $\Delta V_{i,\text{soft-story}} = 0$	- $\Delta V_{i,\text{number of floors}} = +0.01$ (2-3 storey buildings) - $\Delta V_{i,\text{soft-story}} = 0$

3. Group of mid-size and small (rural) towns

Period of time	%	Comments, assumptions	Category
< 1986		• Buildings with one residential unit :	
	20 %	- Simple stone masonry, timber slabs	**M1**
	10 %	- Simple stone masonry, hollow-core slabs	**M4**
	30 %	- Brick masonry walls, reinforced concrete slabs	**M5**
	30 %	- Concrete and brick masonry walls structures	**RC3**
	10 %	- Half-timbered structures	**W2**
		• Buildings with more than one residential unit or with commercial floors :	
	6 %	- Simple stone masonry, hollow-core slabs	**M1**
	6 %	- Brick masonry walls, hollow-core slabs	**M5**
	30 %	- Brick masonry walls, reinforced concrete slabs	**M3**
	3 %	- Massive stone masonry, timber slabs	**M2**
	20 %	- Concrete and brick masonry walls structures	**RC3**
	30 %	- Reinforced concrete shear walls	**RC2**
	5 %	- Reinforced concrete moment frames with infilled walls	**RC5**
1987 - 2008		• Buildings with one residential unit :	
	50 %	- Brick masonry walls, reinforced concrete slabs	**M5**
	50 %	- Concrete and brick masonry walls structures	**RC3**
		• Buildings with more than one residential unit or with commercial floors :	
	20 %	- Brick masonry walls, reinforced concrete slabs	**M3**
	40 %	- Concrete and brick masonry walls structures	**RC3**
	30 %	- Reinforced concrete shear walls	**RC2**
	10 %	- Reinforced concrete moment frames with infilled walls	**RC5**

Modification factors:

Buildings with one residential unit	Buildings with more than one residential unit or with commercial floors
- $\Delta V_{i,\text{number of floors}} = 0$ - $\Delta V_{i,\text{soft-story}} = 0$	- $\Delta V_{i,\text{number of floors}} = +0.01$ (2-3 storey buildings) - $\Delta V_{i,\text{soft-story}} = 0$

4. City (suburbs included) and mid-size towns

Period of time	%	Comments, assumptions	Category
< 1986		• Buildings with one residential unit :	
	16 %	- Simple stone masonry, timber slabs	**M1**
	8 %	- Simple stone masonry, hollow-core slabs	**M4**
	33 %	- Brick masonry walls, reinforced concrete slabs	**M5**
	33 %	- Concrete and brick masonry walls structures	**RC3**
	10 %	- Half-timbered structures	**W2**
		• Buildings with more than one residential unit or with commercial floors :	
	2.5 %	- Simple stone masonry, hollow-core slabs	**M1**
	2.5 %	- Brick masonry walls, hollow-core slabs	**M5**
	20 %	- Brick masonry walls, reinforced concrete slabs	**M3**
	2.5 %	- Massive stone masonry, timber slabs	**M2**
	20 %	- Concrete and brick masonry walls structures	**RC3**
	30 %	- Reinforced concrete shear walls	**RC2**
	20 %	- Reinforced concrete moment frames with infilled walls	**RC5**
	2.5 %	- Steel structures	**S1**
1987 - 2008		• Buildings with one residential unit :	
	50 %	- Brick masonry walls, reinforced concrete slabs	**M5**
	50 %	- Concrete and brick masonry walls structures	**RC3**
		• Buildings with more than one residential unit or with commercial floors :	
	15 %	- Brick masonry walls, reinforced concrete slabs	**M3**
	40 %	- Concrete and brick masonry walls structures	**RC3**
	30 %	- Reinforced concrete shear walls	**RC2**
	10 %	- Reinforced concrete moment frames with infilled walls	**RC5**
	5 %	- Steel structures	**S1**

Modification factors:

Buildings with one residential unit	Buildings with more than one residential unit or with commercial floors
- $\Delta V_{i,\text{number of floors}} = +0.01$ - $\Delta V_{i,\text{soft-story}} = 0$	- $\Delta V_{i,\text{number of floors}} = +0.02$ (4-5 storey buildings) - $\Delta V_{i,\text{soft-story}} = 0$

5.4.2 Application to communes and to group of communes

Small (rural) towns / hamlets :	- Rümmingen - Schallbach - Wittlingen - Fischingen
Mid-size towns :	- Binzen - Eimeldingen - Grenzbach/ Wyhlen
Group of mid-size and small (rural) towns :	- Efringen-kirchen - Inzlingen - Steinen
City (suburbs included) and mid-size towns :	- Lörrach - Weil am Rhein

Note: the towns of Hagenbach, Degerfelden and Herten could not have been taken into account because they are administratively included in the commune of Rheinfelden which is well outside the 12 km radius boundary that is considered in the framework of this study.

6 Financial losses

Insurers have also studied the impact of potential earthquakes in the area of buildings. However, it is not the structural behaviour of structures that interests them but rather the monetary aspects – the costs to repair the resulting damage. Whereas structural engineers have focused on the development of design methods for new buildings, members of the insurance profession have worked on ways to use statistics about financial losses due to past seismic events in refining their earthquakes insurance pricing.

6.1 State of the art

Based on past damage statistics and also on the building characteristics that can be easily recorded, Swiss Re insurers have derived curves that give the mean damage ratio as a function of the MM (Modified Mercalli Scale[8]) intensity. Each curve corresponds to a type of structure; there are 10 typologies, each corresponding to a structure type:

Table 3: Identified typologies and their description [CS 92]

Typology	Description
1A	Wood frame with light exterior wall finish (plaster, stucco, etc.)
1B	Wood frame with brick veneer finish
2A	Steel frame with bracing or reinforced concrete shear walls or with light-weight cladding systems
2B	Steel frame without bracing or reinforced concrete shear walls and with non-load bearing walls of reinforced concrete, brick, etc.
3A	Reinforced concrete frame with reinforced concrete or brick shear walls
3B	Reinforced concrete frame without shear walls and with load or non-load bearing walls or precast concrete, brick, etc.
3C	Precast concrete frame with or without shear walls
4A	Reinforced concrete, precast tilt-up, reinforced masonry or reinforced hollow block bearing (or non-bearing with pilasters)
4B	Unreinforced brick or solid block bearing walls
4C	Unreinforced hollow block bearing walls

[8] The Modified Mercalli Scale (MM) is comparable to the Medvedev-Sponheuer-Karnik scale (MSK); the former is used in USA whilst European rather use the latter. The EMS-98 scale is based on the MSK scale.

The curves that were developed in [CS 92] are given below:

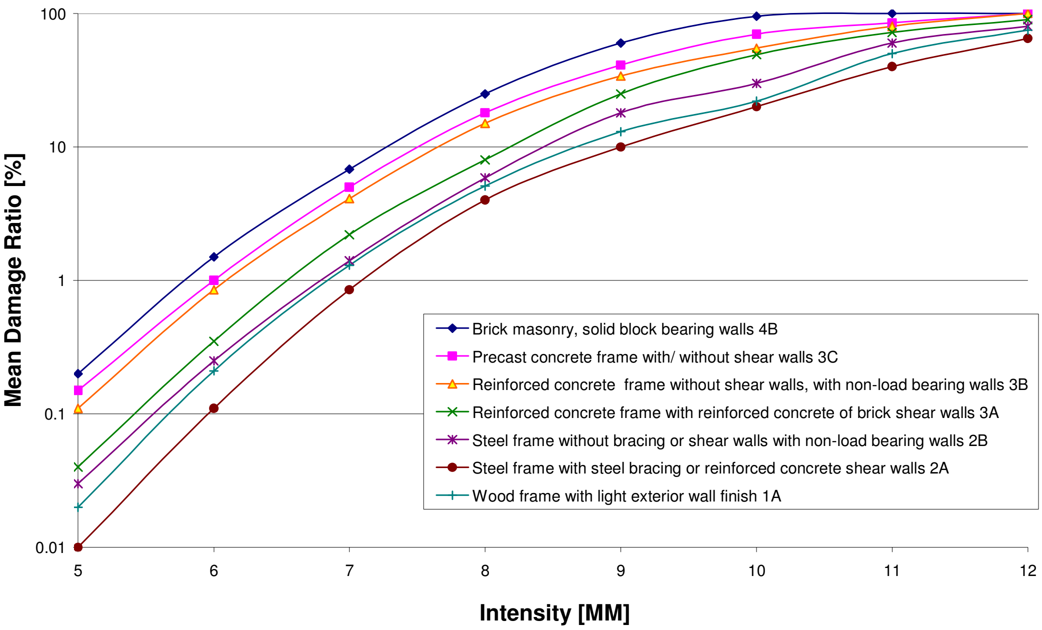


Figure 10: Mean Damage Ratio [%] as a function of the MM Intensity.

Note: according to [CS 92], the above curves have to be slightly modified as a function of the building age.

The graph shown above is taken from [CS 92]; however, the portions of the curves in the area between intensity IV and V and between X and XII are an estimate. These curves must also be modified by a factor to account for the age influence.

When considering the Mean Damage Ratio as a function of the Mean Damage Grade, it is evident that the cost curve for most construction types (without accounting for the age influence), is higher than this of masonry buildings for the portion between damage grades D0 and D2. By contrast, for higher values of damage grade, the costs are higher for masonry buildings. There are no explanations for these differences except for the uncertainties in the official statistics. Consequently, it was decided to use, as a basis, only one cost curve for every construction type corresponding to the average curve (figure 11) of the graph in Figure 10.

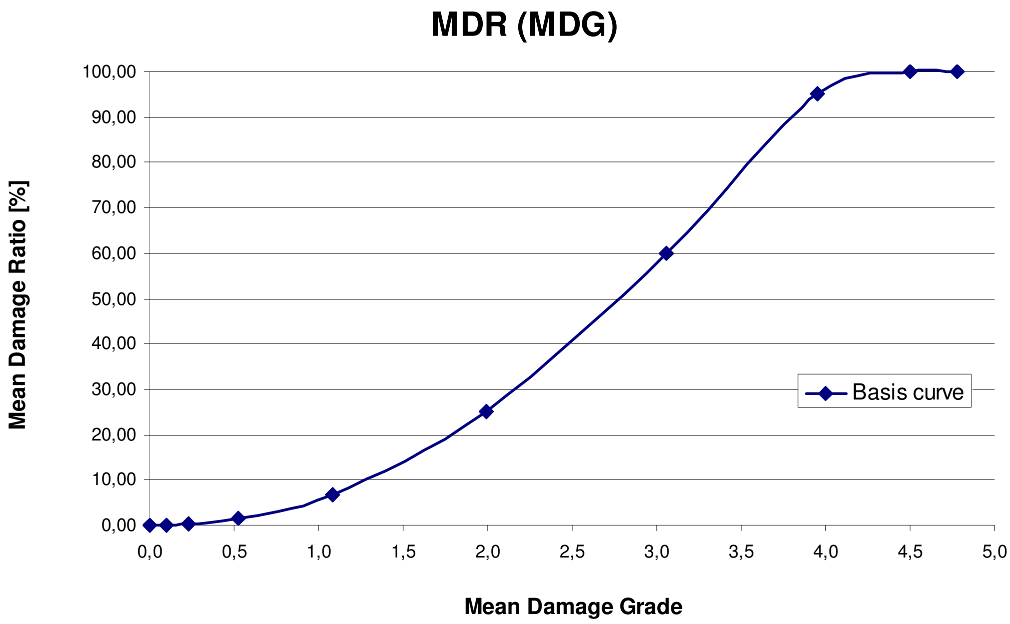


Figure 11: Average curve of Mean Damage Ratio deduced from [CS 92].

Since this curve was determined on the basis of payouts after earthquakes that happened during the second half of the 20th century, the obtained curve must be adapted to the current context of the Basel. This is achieved by expert-judgment which is based on the payouts of damage resulting from the 2006 Basel earthquake.

The curve was refined on the basis of a simple calculation that takes into consideration a building whose insured value is 500’000 CHF; this corresponds to a simple individual residential house. Based on the observed damage after the 2006 seismic event on this type of building, the costs for repairing damage due to earthquakes for a damage grade of D1 are assessed to be 2 % of the insured value of the building. For a mean damage grade of D2, the costs of repairs are about 15 % of the insured value (usually equal to the replacement costs) and when the damage grade is D3, D4 and D5, they are about 55 %, 91 % and 100 % respectively. It is considered reasonable to assume that the building is almost totally destroyed for a mean damage grade of D4 (figure 12).

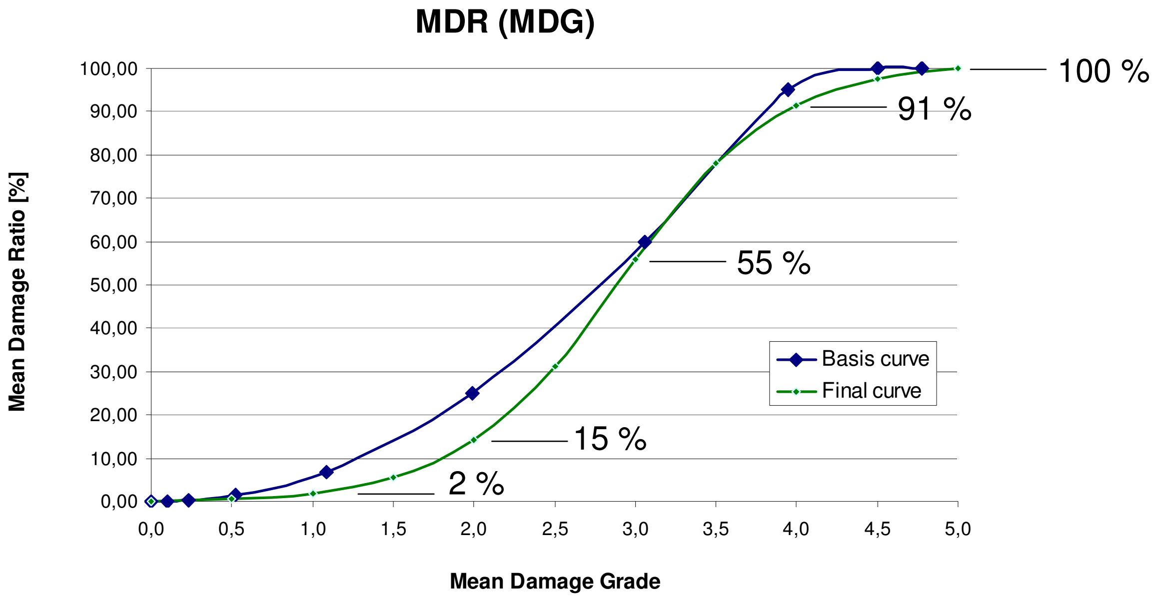


Figure 12: Basis curve taken from [CS 92] and final curve for financial losses defined on the basis of observations recorded after the 2006 seismic event.

The final cost curve includes the costs of repairs and the all associated costs (administrative, etc.).

Calculation done with the curve resulting from the expert-judgement have shown reasonable values, matching real payouts after the 2006 seismic event.

Note: it should be noted that the final curve shown in the Figure 12 is valid for residential buildings with at least one residential-unit.

6.2 Insured buildings

6.2.1 Basel city

The insured values have been obtained for the area on the left bank of the Rhine river and also for the right bank. The values are given for five classes, namely the residential dwelling (A), industrial (B) and commercial (C) buildings. They are:

Table 4: Insured values for buildings of Basel city

	Number of buildings	Insured value (CHF)
Left bank (south)	20'757	48'065'762'000
Class A	18'766	33'983'379'000
Class B	1'023	10'303'164'000
Class C	968	3'779'219'000
Right bank (north)	7'478	19'952'639'000
Class A	6'446	10'418'323'000
Class B	450	4'288'513'000
Class C	582	5'245'803'000

Notes :

- hospitals are included within the Class B.
- insured value was then distributed into districts proportional to the number of buildings.

The sum of the insured values for the city of Basel is 68'018'401'000 CHF.

6.2.2 Basel country

For each town, it has been possible to obtain the insured value of every building.

Table 5: Insured value of buildings in Swiss towns that are enclosed within the 12 km boundary.

Town name	Number of buildings	Insured value [CHF]
Aesch	1891	2’482’556’000
Allschwil	3131	4’642’731’000
Arlesheim	1756	2’672’989’000
Bättwil	268	*469’857’332*
Bettingen	276	483’883’000
Biel-Benken	841	862’700’000
Binningen	2652	3’879’930’000
Birsfelden	1072	2’444’026’000
Bottmingen	1464	1’575’029’000
Dornach	1418	*2’230’884’058*
Ettingen	1125	1’038’284’000
Frenkendorf	1058	1’375’505’000
Kaiseraugst - Augst	468	820’497’132
Münchenstein	2514	3’891’378’000
Muttenz	3453	6’441’873’000
Oberwil	2233	2’605’762000
Pratteln	2322	4’353’187’000
Reinach	3889	4’791’266’000
Riehen	3894	5’592’363’000
Schönenbuch	1218	*696’020’003*
Therwil	8180	2’128’635’000
Witterswil	1264	*748’615’973*

Note: the values in italic are assumptions, which are based on known values for other towns.

The sum is 56’227’971’498 CHF.

6.2.3 Saint-Louis region

The insured value of the buildings in France is not known. It is assumed that, for a town with the same number of buildings, the insured value in France corresponds to similar sized towns in Switzerland.

Table 6: Assumed insured values for the French towns and city.

Town name	Number of buildings	Insured value [CHF]
Attenschwiller	339	594’334’461
Bartenheim	1402	2’205’711’882
Blotzheim	1567	2’465’299’943
Brinckheim	129	226’162’671
Buschwiller	368	645’177’232
Folgensbourg	288	504’921’312
Hagenthal-le-bas	399	699’526’401
Hagenthal-le-haut	173	303’303’427
Hégenheim	1291	2’031’079’914
Helfrantzkirch	298	468’831’770
Hésingue	966	1’519’770’099
Huningue	2981	4’090’917’829
Kappelen	193	338’367’407
Kembs	1579	2’484’179’074
Michelbach-le-Bas	284	497’908’516
Michelbach-le-Haut	188	329’601’412
Neuwiller	220	385’703’780
Ranspach-le-Bas	271	475’116’929
Ranspach-le-Haut	177	310’316’223
Rosenau	794	1’392’040’006
Saint-Louis	8889	13’370’317’186
Sierentz	1032	1’623’605’323
Stetten	111	194’605’089
Uffheim	335	587’321’665
Village-neuf	1475	2’320’559’933
Wentwiller	226	396’222’974

The sum is 40’460’902’458 CHF.

6.2.4 Lörrach region

As for France, the insured value of buildings is unknown for Germany. Consequently, it is therefore assumed that these values are similar to the ones in Switzerland.

Table 7: Assumed insured values for the German towns and city.

Town name	Number of buildings	Insured value [CHF]
Binzen	778	1’223’997’036
Efringen-Kirchen	3530	5’309’620’842
Eimeldingen	510	802’363’096
Fischingen	201	316’225’455
Granzach-Wyhlen	2929	4’019’556’632
Inzlingen	657	1’033’632’458
Lörrach	7730	11’627’016’745
Rümmingen	452	792’445’948
Schallbach	203	355’899’397
Steinen	2342	3’213’998’509
Weil am Rhein	5284	7’947’885’702
Wittlingen	261	457’584’939

The sum is 37’100’226’760 CHF.

The total sum of the insured value for the considered building stock is 174’955’537’491 CHF.

7 Discussion

The main objective of this study was to provide a tool to assess the seismic vulnerability of the building stock in the area of Basel. Furthermore, the scope also includes presenting a method of calculating the financial losses to assess pay outs. To achieve this, an inventory of the building stock was elaborated, representative typologies were identified with corresponding vulnerability curves and a cost curve was also defined.

The building stock inventory was created for the entire area around Basel city, on the basis of national statistics. However, statistics from the three considered countries, only included residential buildings, though hotels and hospitals were also taken into account. Consequently, religious, museum, city halls, commercial and industrial buildings, if they do not consist of any residential component, are not included in the inventory. However, with input from other literature, it has been possible to determine that these types of buildings correspond to 8 % of the total number of buildings in the Swiss area north to the Rhine and 5 % of the area south to the Rhine. For villages, the percentage is even lower and is around 1 %. Based on these findings, it can be assumed that the contribution from these other buildings is probably around 5 % at the most, which corresponds to about 5000 buildings.

The next step was to classify the inventory into groups; each building of the inventory was categorised in a group. Since the categorization was based on in-situ visits and literature, it is likely that this could bring uncertainties. Nevertheless, no other choice was available since more than 50’000 buildings must be considered. For this reason, the distribution of the types of buildings in the building stock was discussed with local professionals of the Basler area. With the definition of the vulnerability curves, this approach constitutes probably the largest component of uncertainty.

The vulnerability curves, which are proposed in this report, were defined by Risk-UE, though a few types of buildings were however not listed in Risk-UE, for example, the half-timbered structures. For each of these types, a vulnerability curve was defined by expert judgment. Moreover, the value of every seismic vulnerability curve for low-level intensities was calibrated with the observed damage after the 2006 seismic event. This calibration contributes to increase the accuracy of seismic vulnerability curves for this segment of the curve.

About 2800 cases were taken into account by the insurance and paid out; this corresponds to 2.6 % of the entire building stock under consideration. The observed damage, which was mostly cracks in walls, corresponds to a maximum damage grade of D1 on the EMS-98 scale. We assume that 10 % of buildings were characterized by D1 damage grade. However, when comparing the distribution of intensity given by the SED [KF 07] with the 2800 damage cases, the damage locations do not match the area characterized by an intensity for which damage D1 was expected. This observation proved that there could be a subjective bias in the assessment of damage. This bias was shown to be most significant for the low intensities because the damage for such level of intensity mainly consists of small cracks, origins of which are difficult to assess. However, it is difficult to adapt the vulnerability curves to account for this potential subjective bias and this was therefore not taken into account.

In 1992, Swiss-Reinsurance published cost curves [CS 92] on the basis of damage observed over a ten year history of earthquakes; however, none of the seismic events considered for this publication occurred in Europe. After comparison with the financial losses resulting from the damage due to the 2006 seismic event, the average cost curve deduced from the Swiss-Reinsurance values proved to be an overestimate. Though not that different from the Swiss-Reinsurance cost curve, the one defined for this study by expert-judgment on the basis of the 2006 seismic event payouts is consistent with what happened in 2006. It was therefore concluded that the modified cost curve will derive realistic values for the financial losses for simulations of case scenarios.

8 Conclusion

Thanks to national building statistics from the three countries and to the on-site visits, it has been possible to draw an inventory of the building stock within the considered area around the geothermal site. The determination of the type of structure for each buildings included in this building stock turned out to be a complex task since the structure is not always easily readable from the pavement. This step consequently involved a large uncertainty as often expressed in literature [St 04].

Uncertainties are also found in the definition of the vulnerability curves; every effort has therefore been made to make use of the most up-to-date research in this study [MT 03]. Since the most likely seismic scenarios in the study area would generate small intensities, this seismic intensity range was studied in detail. The comparison between the reported damage after the 2006 seismic event and the results obtained with the Risk-UE curves shows that these curves overestimate damage for low intensities. This is probably due to the fact that these curves were derived based on data recorded after seismic events that were characterized by higher intensities from VII to IX (EMS-scale). The derivation of damage grade for the low intensities range was less reliable owing to the shortage of data for small-intensity earthquakes. Therefore, the segment of vulnerability curves for low intensities (III.5 to VI.5) consists of an extrapolation instead of statistics-stated values. In order to match observations at lower intensities, the vulnerability curves were calibrated for low-level intensities (I = III.5 to VI.5) on the basis of the data recorded after the 2006 seismic event. This calibration ensures that the calculation for other earthquakes with low-level intensities is reliable.

The definition of the costs curve is based both on literature and expert judgment; consequently, there are uncertainties associated with this curve. However, the implementation of the curve in the calculation has given results that are comparable to the observations for the 2006 seismic event.

In closing, it is worth noting that only the buildings with at least one residential dwelling-unit have been taken into account. The costs for industrial, administrative and cultural heritage buildings are likely to be different from those for residential building, though negligible in comparison with the global uncertainty component of the whole loss estimation.

Cultural losses are not accounted for in the present study.

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APPENDIX

A.1 BUILDING STOCK DATA

A.1.1 France

The statistics about buildings for France are taken from the INSEE website. The distinction between the single residential dwellings (H in the following tables) and the multi-storey apartment blocks (written F in the following tables) was based on a published graph.

Attenschwiller

	<-1949		1950-1974		1975-1989		1990 ->	
	H	F	H	F	H	F	H	F
339	90	2	58	7	73	7	87	15

June 2009.

-> 308 houses and 31 multi-storey apartment blocks.

Bartenheim

	<-1949		1950-1974		1975-1989		1990 ->	
	H	F	H	F	H	F	H	F
1402	242	42	278	48	233	50	245	264

June 2009.

-> 998 houses and 404 multi-storey apartment blocks.

Blotzheim

	<-1949		1950-1974		1975-1989		1990 ->	
	H	F	H	F	H	F	H	F
1568	240	74	267	50	315	200	277	145

June 2009.

-> 1099 houses and 469 multi-storey apartment blocks.

Brinckheim

	<-1949		1950-1974		1975-1989		1990 ->	
	H	F	H	F	H	F	H	F
130	33	2	21	0	37	0	36	1

June 2009.

-> 127 houses and 3 multi-storey apartment blocks.

Buschwiller

	<-1949		1950-1974		1975-1989		1990 ->	
	H	F	H	F	H	F	H	F
367	72	15	67	13	81	13	80	26

June 2009.

-> 300 houses and 67 multi-storey apartment blocks.

Folgensbourg

	<-1949		1950-1974		1975-1989		1990 ->	
	H	F	H	F	H	F	H	F
287	54	6	60	9	51	9	58	41

June 2009.

-> 223 houses and 65 multi-storey apartment blocks.

Hagenthal-le-Bas

	<-1949		1950-1974		1975-1989		1990 ->	
	H	F	H	F	H	F	H	F
399	67	21	63	14	103	18	56	57

June 2009.

-> 289 houses and 110 multi-storey apartment blocks.

Hagenthal-le-Haut

	<-1949		1950-1974		1975-1989		1990 ->	
	H	F	H	F	H	F	H	F
173	50	10	26	3	48	1	35	0

June 2009.

-> 159 houses and 14 multi-storey apartment blocks.

Hégenheim

	<-1949		1950-1974		1975-1989		1990 ->	
	H	F	H	F	H	F	H	F
1084	213	110	245	56	190	40	135	95

December 2008.

-> 783 houses and 301 multi-storey apartment blocks.

Helfrantzkirch

	<-1949		1950-1974		1975-1989		1990 ->	
	H	F	H	F	H	F	H	F
297	90	3	40	1	94	1	61	7

June 2009.

-> 285 houses and 12 multi-storey apartment blocks.

Hésingue

	<-1949		1950-1974		1975-1989		1990 ->	
	H	F	H	F	H	F	H	F
786	175	42	190	20	147	50	92	70

December 2008.

-> 604 houses and 182 multi-storey apartment blocks.

Huningue

	<-1949		1950-1974		1975-1989		1990 ->	
	H	F	H	F	H	F	H	F
2981	200	394	350	1098	95	368	50	426

June 2009.

-> 695 houses and 2286 multi-storey apartment blocks.

Kappelen

	<-1949		1950-1974		1975-1989		1990 ->	
	H	F	H	F	H	F	H	F
194	43	5	35	1	39	6	43	22

June 2009.

-> 160 houses and 39 multi-storey apartment blocks.

Kembs

	<-1949		1950-1974		1975-1989		1990 ->	
	H	F	H	F	H	F	H	F
1579	196	32	298	29	400	50	450	124

June 2009.

-> 1344 houses and 235 multi-storey apartment blocks.

Michelbach-le-Bas

	<-1949		1950-1974		1975-1989		1990 ->	
	H	F	H	F	H	F	H	F
284	36	6	62	6	91	0	80	3

June 2009.

-> 269 houses and 15 multi-storey apartment blocks.

Michelbach-le-Haut

	<-1949		1950-1974		1975-1989		1990 ->	
	H	F	H	F	H	F	H	F
188	40	9	39	2	60	7	24	7

June 2009.

-> 163 houses and 25 multi-storey apartment blocks.

Neuwiller

	<-1949		1950-1974		1975-1989		1990 ->	
	H	F	H	F	H	F	H	F
219	47	9	44	9	59	4	46	1

June 2009.

-> 196 houses and 24 multi-storey apartment blocks.

Ranspach-le-Bas

	<-1949		1950-1974		1975-1989		1990 ->	
	H	F	H	F	H	F	H	F
271	58	14	58	1	52	0	51	37

June 2009.

-> 219 houses and 52 multi-storey apartment blocks.

Ranspach-le-Haut

	<-1949		1950-1974		1975-1989		1990 ->	
	H	F	H	F	H	F	H	F
177	49	4	20	3	49	0	51	1

June 2009.

-> 169 houses and 8 multi-storey apartment blocks.

Rosenau

	<-1949		1950-1974		1975-1989		1990 ->	
	H	F	H	F	H	F	H	F
793	81	11	161	9	226	5	190	110

June 2009.

-> 658 houses and 136 multi-storey apartment blocks.

Saint-Louis

	<-1949		1950-1974		1975-1989		1990 ->	
	H	F	H	F	H	F	H	F
8889	700	933	950	3127	788	1100	250	1041

June 2009.

-> 2688 houses and 6201 multi-storey apartment blocks.

Sierentz

	<-1949		1950-1974		1975-1989		1990 ->	
	H	F	H	F	H	F	H	F
1032	186	60	150	28	175	78	119	236

June 2009.

-> 630 houses and 402 multi-storey apartment blocks.

Stetten

	<-1949		1950-1974		1975-1989		1990 ->	
	H	F	H	F	H	F	H	F
111	34	7	10	2	34	0	20	4

June 2009.

-> 98 houses and 13 multi-storey apartment blocks.

Uffheim

	<-1949		1950-1974		1975-1989		1990 ->	
	H	F	H	F	H	F	H	F
335	63	15	47	6	105	5	65	29

June 2009.

-> 280 houses and 55 multi-storey apartment blocks.

Village-neuf

	<-1949		1950-1974		1975-1989		1990 ->	
	H	F	H	F	H	F	H	F
1475	323	48	321	52	166	146	150	269

June 2009.

-> 960 houses and 515 multi-storey apartment blocks.

Wentzwiller

	<-1949		1950-1974		1975-1989		1990 ->	
	H	F	H	F	H	F	H	F
226	63	7	52	4	42	0	46	12

June 2009.

-> 203 houses and 23 multi-storey apartment blocks.

A.1.2 Germany

The statistics only include the residential buildings.

Binzen

	<-1919		1920-1945		1946-1960		-1986		1986-2000	
	H	F	H	F	H	F	H	F	H	F
778							308	209	280	40

-> 588 (75.6 %) houses and 249 (24.4 %) multi-storey apartment blocks.

Efringen-Kirchen

	<-1919		1920-1945		1946-1960		-1986		1986-2000	
	H	F	H	F	H	F	H	F	H	F
2229							1215	522	277	215

-> 1492 (66.9 %) houses and 737 (33.1 %) multi-storey apartment blocks.

Eimeldingen

	<-1919		1920-1945		1946-1960		-1986		1986-2000	
	H	F	H	F	H	F	H	F	H	F
510							200	121	130	59

-> 330 (64.7 %) houses and 180 (35.3 %) multi-storey apartment blocks.

Fischingen

	<-1919		1920-1945		1946-1960		-1986		1986-2000	
	H	F	H	F	H	F	H	F	H	F
201							104	39	40	18

-> 144 (71.6 %) houses and 57 (28.4 %) multi-storey apartment blocks.

Grenzach-Wyhlen

	<-1919		1920-1945		1946-1960		-1986		1986-2000	
	H	F	H	F	H	F	H	F	H	F
2929							1234	955	532	208

-> 1766 (60.3 %) houses and 1163 (39.7 %) multi-storey apartment blocks.

Inzlingen

	<-1919		1920-1945		1946-1960		-1986		1986-2000	
	H	F	H	F	H	F	H	F	H	F
657							335	203	60	59

-> 395 (60.1 %) houses and 262 (39.9 %) multi-storey apartment blocks.

Lörrach

	<-1919		1920-1945		1946-1960		-1986		1986-2000	
	H	F	H	F	H	F	H	F	H	F
7730							2805	3294	929	702

-> 3734 (48.3 %) houses and 3996 (51.7 %) multi-storey apartment blocks.

Rümmingen

	<-1919		1920-1945		1946-1960		-1986		1986-2000	
	H	F	H	F	H	F	H	F	H	F
452							186	119	118	29

-> 304 (67.3 %) houses and 148 (32.7 %) multi-storey apartment blocks.

Schallbach

	<-1919		1920-1945		1946-1960		-1986		1986-2000	
	H	F	H	F	H	F	H	F	H	F
203							105	42	40	16

-> 145 (71.4 %) houses and 58 (28.6 %) multi-storey apartment blocks.

Steinen

	<-1919		1920-1945		1946-1960		-1986		1986-2000	
	H	F	H	F	H	F	H	F	H	F
2342							1052	765	347	178

-> 1399 (59.7 %) houses and 943 (40.3 %) multi-storey apartment blocks.

Weil am Rhein

	<-1919		1920-1945		1946-1960		-1986		1986-2008	
	H	F	H	F	H	F	H	F	H	F
5278							2531	1779	736	232

-> 3267 (61.9 %) houses and 2011 (38.1 %) multi-storey apartment blocks.

Wittlingen

	<-1919		1920-1945		1946-1960		-1986		1986-2000	
	H	F	H	F	H	F	H	F	H	F
261							105	56	78	22

-> 183 (70.1 %) houses and 78 (29.9 %) multi-storey apartment blocks.

A.1.3 Switzerland

Swiss statistics do not include administrative and commercial buildings (buildings which only are devoted to commercial activities) as well as schools and religious buildings.

BASEL CITY: DISTRICTS

Grossbasel

	<-1919		1920 -1945		1946 -1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
491	39	334	0	34	0	22	3	28	4	27

-> 46 (9.4 %) of buildings with only one residential-unit and 445 (90.6 %) are buildings with at least one residential-unit.

Kleinbasel

	<-1919		1920 -1945		1946 -1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
282	24	142	1	25	2	32	1	41	1	12

-> 29 (9.4 %) of buildings with only one residential-unit and 253 (90.6 %) are buildings with at least one residential-unit.

Vorstädte

	<-1919		1920 -1945		1946 -1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
565	28	272	3	53	3	63	1	86	3	53

-> 38 (6.7 %) of buildings with only one residential-unit and 527 (93.3 %) are buildings with at least one residential-unit.

Am Ring

	<-1919		1920 -1945		1946 -1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
1174	172	485	14	95	2	114	1	209	1	81

-> 190 (16.2 %) of buildings with only one residential-unit and 984 (83.8 %) are buildings with at least one residential-unit.

Breite

	<-1919		1920 -1945		1946 -1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
653	33	117	39	145	8	161	0	96	0	54

-> 80 (12.3 %) of buildings with only one residential-unit and 573 (87.7 %) are buildings with at least one residential-unit.

St - Alban

	<-1919		1920 -1945		1946 -1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
1190	112	164	202	195	27	234	17	135	13	91

-> 371 (31.2 %) of buildings with only one residential-unit and 819 (68.8 %) are buildings with at least one residential-unit.

Gundeldingen

	<-1919		1920 -1945		1946 -1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
1411	26	526	5	349	1	88	0	314	1	101

-> 33 (2.3 %) of buildings with only one residential-unit and 1378 (97.7 %) are buildings with at least one residential-unit.

Bruderholz

	<-1919		1920 -1945		1946 -1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
2031	52	32	660	214	519	205	185	104	18	42

-> 1434 (70.6 %) of buildings with only one residential-unit and 597 (29.4 %) are buildings with at least one residential-unit.

Bachletten

	<-1919		1920 -1945		1946 -1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
2467	196	226	914	481	194	276	4	138	6	32

-> 1314 (53.3 %) of buildings with only one residential-unit and 1153 (46.7 %) are buildings with at least one residential-unit.

Gotthelf

	<-1919		1920 -1945		1946 -1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
968	76	244	250	216	0	33	1	127	1	20

-> 328 (33.9 %) of buildings with only one residential-unit and 640 (66.1 %) are buildings with at least one residential-unit.

Iselin

	<-1919		1920 -1945		1946 -1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
1444	108	251	118	396	4	313	2	196	2	54

-> 234 (16.2 %) of buildings with only one residential-unit and 1210 (83.8 %) are buildings with at least one residential-unit.

St - Johann

	<-1919		1920 -1945		1946 -1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
1520	87	394	222	325	4	160	8	216	4	100

-> 325 (21.4 %) of buildings with only one residential-unit and 1195 (78.6 %) are buildings with at least one residential-unit.

Clara

	<-1919		1920 -1945		1946 -1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
251	2	107	0	25	0	21	0	73	0	23

-> 2 (0.8 %) of buildings with only one residential-unit and 249 (99.2 %) are buildings with at least one residential-unit.

Wettstein

	<-1919		1920 -1945		1946 -1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
673	38	139	123	182	4	93	1	32	25	36

-> 191 (28.4 %) of buildings with only one residential-unit and 482 (71.6 %) are buildings with at least one residential-unit.

Hirzbrunnen

	<-1919		1920 -1945		1946 -1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
1524	8	23	897	208	97	185	3	90	2	11

-> 1007 (66.1 %) of buildings with only one residential-unit and 517 (33.9 %) are buildings with at least one residential-unit.

Rosental

	<-1919		1920 -1945		1946 -1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
255	1	59	0	86	0	29	0	40	0	40

-> 1 (0.4 %) of buildings with only one residential-unit and 254 (99.6 %) are buildings with at least one residential-unit.

Matthaeus

	<-1919		1920 -1945		1946 -1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
1116	64	517	10	97	0	87	0	232	0	109

-> 74 (6.6 %) of buildings with only one residential-unit and 1042 (93.4 %) are buildings with at least one residential-unit.

Kleinhüningen

	<-1919		1920 -1945		1946 -1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
164	4	22	9	27	1	42	0	46	0	13

-> 14 (8.5 %) of buildings with only one residential-unit and 150 (91.5 %) are buildings with at least one residential-unit.

Klybeck

	<-1919		1920 -1945		1946 -1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
437	19	108	6	124	1	86	0	66	1	26

-> 27 (6.2 %) of buildings with only one residential-unit and 410 (93.8 %) are buildings with at least one residential-unit.

BASEL COUNTRY

Aesch

	<-1919		1920 -1945		1946 -1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
1891	100	66	120	39	219	36	642	168	365	136

-> 1446 (76.5 %) of buildings with only one residential-unit and 445 (23.5 %) are buildings with at least one residential-unit.

Allschwil

	<-1919		1920-1945		1946-1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
3131	223	130	544	195	275	227	530	329	530	148

-> 2102 (67.1 %) of buildings with only one residential-unit and 1029 (32.9 %) are buildings with at least one residential-unit.

Arlesheim

	<-1919		1920-1945		1946-1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
1756	167	93	236	74	267	60	317	169	278	95

-> 1265 (72 %) of buildings with only one residential-unit and 491 (28 %) are buildings with at least one residential-unit.

Bättwil

	<-1919		1920-1945		1946-1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
268	14	10	5	4	4	0	49	15	150	17

-> 222 (83 %) of buildings with only one residential-unit and 46 (17 %) are buildings with at least one residential-unit.

Bettingen

	<-1919		1920-1945		1946-1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
276	15	8	19	9	34	10	93	20	58	10

-> 219 (79.3 %) of buildings with only one residential-unit and 57 (20.7 %) are buildings with at least one residential-unit.

Biel-Benken

	<-1919		1920-1945		1946-1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
841	55	20	13	10	25	6	368	27	284	96

-> 745 (88.6 %) of buildings with only one residential-unit and 96 (11.4 %) are buildings with at least one residential-unit.

Binningen

	<-1919		1920-1945		1946-1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
2652	183	167	358	121	390	168	609	198	298	160

-> 1838 (69.3 %) of buildings with only one residential-unit and 814 (30.7 %) are buildings with at least one residential-unit.

Birsfelden

	<-1919		*1920-1945*		*1946-1960*		*1961-1980*		*1981-2000*	
	H	F	H	F	H	F	H	F	H	F
1072	104	113	189	123	112	137	34	149	42	69

-> 481 (44.9 %) of buildings with only one residential-unit and 591 (55.1 %) are buildings with at least one residential-unit.

Bottmingen

	<-1919		*1920-1945*		*1946-1960*		*1961-1980*		*1981-2000*	
	H	F	H	F	H	F	H	F	H	F
1464	68	27	77	17	154	35	567	85	369	65

-> 1235 (84.4 %) of buildings with only one residential-unit and 229 (15.6 %) are buildings with at least one residential-unit.

Dornach

	<-1919		*1920-1945*		*1946-1960*		*1961-1980*		*1981-2000*	
	H	F	H	F	H	F	H	F	H	F
1418	98	71	165	76	175	63	350	93	252	75

-> 1040 (73.3 %) of buildings with only one residential-unit and 378 (26.7 %) are buildings with at least one residential-unit.

Ettingen

	<-1919		*1920-1945*		*1946-1960*		*1961-1980*		*1981-2000*	
	H	F	H	F	H	F	H	F	H	F
1125	81	34	23	9	53	11	503	100	237	74

-> 897 (79.7 %) of buildings with only one residential-unit and 228 (20.3 %) are buildings with at least one residential-unit.

Frenkendorf

	<-1919		*1920-1945*		*1946-1960*		*1961-1980*		*1981-2000*	
	H	F	H	F	H	F	H	F	H	F
1058	63	50	87	33	152	33	232	126	227	55

-> 761 (71.9 %) of buildings with only one residential-unit and 297 (28.1 %) are buildings with at least one residential-unit.

Kaiseraugst

	<-1919		1920-1945		1946-1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
468	30	24	29	14	40	20	53	58	125	75

-> 277 (59.2 %) of buildings with only one residential-unit and 191 (48.8 %) are buildings with at least one residential-unit.

Münchenstein

	<-1919		1920-1945		1946-1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
2514	178	107	532	108	422	155	384	120	402	106

-> 1918 (76.3 %) of buildings with only one residential-unit and 596 (23.7 %) are buildings with at least one residential-unit.

Muttenz

	<-1919		1920-1945		1946-1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
3453	161	105	542	123	698	167	659	252	561	185

-> 2621 (75.9 %) of buildings with only one residential-unit and 832 (24.1 %) are buildings with at least one residential-unit.

Oberwil

	<-1919		1920-1945		1946-1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
2233	128	62	109	25	241	51	852	163	435	167

-> 1765 (79 %) of buildings with only one residential-unit and 468 (21 %) are buildings with at least one residential-unit.

Pratteln

	<-1919		1920-1945		1946-1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
2322	202	125	300	100	268	119	453	288	384	83

-> 1607 (69.2 %) of buildings with only one residential-unit and 715 (30.8 %) are buildings with at least one residential-unit.

Reinach

	<-1919		1920-1945		1946-1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
3889	91	54	234	41	502	87	1412	433	840	195

-> 3079 (79.2 %) of buildings with only one residential-unit and 810 (20.8 %) are buildings with at least one residential-unit.

Riehen

	<-1919		1920-1945		1946-1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
3894	185	101	756	152	908	389	520	275	428	180

-> 2797 (71.8 %) of buildings with only one residential-unit and 1097 (28.2 %) are buildings with at least one residential-unit.

Schönenbuch

	<-1919		1920-1945		1946-1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
397	28	4	11	3	6	2	129	19	177	18

-> 351 (88.4 %) of buildings with only one residential-unit and 46 (11.6 %) are buildings with at least one residential-unit.

Therwil

	<-1919		1920-1945		1946-1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
2031	78	30	62	10	135	21	822	175	615	83

-> 1712 (84.3 %) of buildings with only one residential-unit and 319 (15.7 %) are buildings with at least one residential-unit.

Witterswil

	<-1919		1920-1945		1946-1960		1961-1980		1981-2000	
	H	F	H	F	H	F	H	F	H	F
427	31	12	10	4	13	2	180	15	151	9

-> 385 (90.2 %) of buildings with only one residential-unit and 42 (9.8 %) are buildings with at least one residential-unit.

A.2 EUROPEAN MACROSEISMIC INTENSITY SCALE 1998

Intensity degree	Description of the ground shaking
I	Not perceptible
II	Hardly perceptible
III	Weak
IV	Largely observed
V	Fairly strong
VI	Strong
VII	Very strong
VIII	Damaging
IX	Destructive
X	Devastating
XI	Catastrophic
XII	Very catastrophic

A.3 GLOSSARY

Hennebique system : Construction system developed by the French engineer, François Hennebique (1842-1921), that is composed of a form of reinforced concrete frames (kind of) with steel bars and hooked connections enclosed within concrete. This system belongs to the first generation of reinforced concrete structures, the first was erected in 1892.

Heimatstil : Describes an architectural style that takes its origins in the regional and/or local architectural traditions (country architecture). First applied at the beginning of the 20th century, it was transformed over the years and was still applied until the mid-20th century (*source: Historisches Lexikon der Schweiz*).