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AP 6000 Report

Report title:	**AP6000 Report – Technology Risk Comparison of the Geothermal DHM Project in Basel, Switzerland - Risk Appraisal including Social Aspects**
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Executive Summay

In order to deliver the study's mandate the following scope was developed:

- As AP 5000 was limited to characterising residential building damages, it was necessary to determine the cost of the loss to infrastructure and lifelines from the DHM project. This was done by way of a probabilistic risk assessment. The purpose was to finalise Frequency – Number of Fatalities (FN) curves and Frequency – Cost of Damage (FD) curves used for the risk appraisal.
- To derive with a risk appraisal from a local or regional viewpoint, both from lives risks and property damage point of view, all available Swiss data for the assessment of technical risk was reviewed, evaluated, and used as appropriate. As per the study's mandate, an assessment of the project against the Swiss Ordinance on Major Accidents (OMA) was made. For comparison the natural (background) seismic risk of the region was described and put into perspective. Other international guidelines were also used for orientation purposes.
- From a national perspective, attempts were made comparing the project's risk with other energy projects. Further, a comparison with other technologies in Switzerland was made. The project's risk cost was oriented against the gross domestic product (GDP) aimed at providing orientation for the government, to assess if such risk costs would be worthwhile to be invested. Additionally, new ways of comparing seismic risks were derived from mining projects from an amenity loss and tolerability of the affected population to vibrations viewpoint.
- As the above evaluations used largely technocratic approaches to assessing the project's risk, a sociological evaluation was conducted to reflect on the population's risk tolerability and acceptance of risk emanating from this new technology. It evaluated the project's acceptance from industry representatives' point of view and from a local population viewpoint

The following conclusions were derived:

- From an individual risk view: The project would be acceptable.
- From a risk to people view: the Swiss OMA ordinance rates the project acceptable, the ANCOLD guideline unfavourably or at most debatable.
- From a cost perspective:

  The Swiss OMA ordinance rates the project not acceptable. From a national perspective, most cost indicators are also unfavourably (e.g. chemical industry, natural flooding, technical risks).
- From an operator's perspective, the risk cost versus investment capital relation the project would rate unfavourably (ten times higher risk cost than profit).

- From a residents amenity view, and based on existing norms in Switzerland pertaining to vibrations the project would rate unfavourably.
- The overall amount of energy produced is small compared to energy gap to be filled, however, the project is a landmark project.
- As only 5,000 households would directly benefit from the DHM project compared to 542,000 residents who would be exposed to the tremors by feeling them in their daily life is not a favourable ratio. Further, as the area where the damage occurs does not necessarily correlate with the area of the planned heat distribution, inequity between benefactors and risk bearers is created.
- There are indications that future induced earthquakes will not be perceived by the population as reasonable, further the population feel a material, sanitary and mental threat from earthquakes.
- Business representatives generally have a positive attitude towards geothermal energy as it promises a sustainable energy generation. The business representatives conveyed a lack of acceptance for further earthquakes, however, they do not regard the earthquakes as an imminent threat to their businesses. In their companies, the business representatives did not observe significant damages and therefore would only be willing to accept a continuation of the project if:
  - technical progress is made,
  - plain accountability exists for the risks,
  - a clear legal foundation is provided for in the case of damages; and
  - a clear and open communication exists.

Overall, the application of the HFR technology based on the projects' original design at this particular site involves considerable financial risk, and a personal amenity loss associated with earthquakes.

The only potential way of pursuing the project would appear to rest on whether this project is considered important enough from a national perspective for following the national strategic energy supply program by supporting this new energy generating technology. Should the decision be to proceed with the project, it would seem necessary to have significant risk guarantees in place before starting.

In order to derive with a final decision the decision making process should be accompanied by a professional committee involving all stakeholders.

1 INTRODUCTION

1.1 Background

In response to its increasing energy demands, Switzerland launched a first decade energy supply program in 1990 (“Schweiz2000”), which was followed by the second program in 2000 covering the expected demand growth until 2010. A major goal of these programs (refer to Appendix 1 for objectives) is the avoidance of more fossil fuel and nuclear energy based supply, the result of which is a predicted “electrical energy gap” in the future unless alternative technologies can be proven and implemented.

One of the options for Switzerland is geothermal energy, the potential for which has been estimated between 1 and 24 TWh per year. Compared to the estimated electricity gap of between 5 and 13.5 TWh, it seems that geothermal energy could provide all of the energy needs within the EnergieSchweiz study timeframe while meeting the objectives for secure and renewable sources (Appendix 1).

The goal of the initiated geothermal project was the construction and operation of the world’s first geothermal heat power pilot plant using the Hot-Dry-Rock- or Hot-Fractured-Rock-technology (HDR/HFR). This project referred to as the DEEP HEAT MINING PROJECT (DHM) was regarded as a project of national importance by the Swiss Federal Department of Energy (BFE). An important stimulus to the local economy in the form of Know-How and an export-oriented technology was anticipated to result from the project.

The HFR process involves injecting water into a depth of approximately five kilometres, where the natural heat of the rock turns the water into steam that is extracted from a second bore and used to drive a turbine for electricity generation. The condensed water from the turbine is reticulated to industry and residences for heating. The initial set-up phase is called stimulation, and lasts for a period of several weeks until the connection between the first and second bore is established and water can be circulated. This circulation phase is when the plant is fully operative. It was planned to erect a pilot plant in Basel to supply about 5,000 households with electricity (3 MW_e) and heat (20MW_{th}) by employing an organic rankine cycle (ORC) technology.

The project was launched after an initial deep bore in Otterbach (approximately 2km away from the main bore in Kleinhüningen) has principally shown the technical suitability of the site for geothermal use.

During hydraulic stimulation of the subsurface, notable tremors occurred on 8 December 2006 (and thereafter) which caused damages in the order of 7 million CHF (Resonance AP 5000). The maximum of the tremors reached intensity V (refer to Figure 19 for an orientation). The damage type was restricted to the damage grade D1[1] or lower. A total of 2818 claims for damage were lodged (c.f. Tagesanzeiger Schweiz 19.07.2009). All damage claims in the area of influence, which is about 12 km around the bore, were accepted by Geopower AG (the operator of the DHM project).

[1] D1: Damage grade of buildings representing slight, mainly cosmetic damages (refer to AP 5000 for details)

The Canton Basel-City shut down the trial and initiated a risk assessment of the project, of which this report is a part, after the earthquakes occurred to determine whether it is safe to continue with the project. “There was no legal requirement for the Canton to undertake the risk assessment (Communiqué 15 March 2007 from Construction Department Canton Basel-City), but it chose to do so in order to determine whether or not it was safe to continue with the project. The Canton is able to undertake the risk assessment under the provisions of the Swiss Federal Environment Protection Act particularly the paragraph on disaster control (Art. 10 USG), which is also the basis for the Swiss Ordinance on Major Accidents (OMA).

At an international level, the technologies for HFR projects are developing, and it is expected that the associated risks will be evaluated and become more known and mitigated by technical solutions or covered by innovative insurance solutions. However, even if there are technical and insurance solutions that overcome the challenges of this emerging technology, public opinion that it poses an unacceptable level of perceived risk based on the Basel experience in 2006 may hamper or prevent further development and exploitation of the DHM project (“the project”).

1.2 Mandate and Scope

The entire study was divided up into six individual work packages (referred to as AP 2000 through AP 7000). This document represents the AP 6000 work package. It handles the project’s risk determination based on AP 5000, the risk appraisal, and outlines initial remarks on the communicative handling of these results as proposals for the further actions.

The applicable part for AP 6000 of the mandate of the risk assessment study (“the study”) based on description of services from 10 April 2007 by the construction department of the Canton of Basel-City was:

1. To develop a suitable way of illustrating the risk of the DHM project and to make proposals for a comparative appraisal of this risk (risk criteria).
2. Relevant damage indicators that need to be included in the risk analysis are: - damage to persons - damage to property.
3. The results of the risk analysis must be presented in a very clear and easily understandable form, supported by maps, graphs and tables.

In order to deliver the study’s mandate the following considerations were made and a scope developed:

5. As AP 5000 was limited to characterising residential building damages, it was necessary to determine the cost of the loss to infrastructure and lifelines from the DHM project. This was done by way of a probabilistic risk assessment. The purpose was to finalise Frequency – Number of Fatalities (FN) curves and Frequency – Cost of Damage (FD) curves used for the risk appraisal.
6. To derive with a risk appraisal from a local or regional viewpoint, both from lives risks and property damage point of view, all available Swiss data for the assessment of

technical risk was reviewed, evaluated, and used as appropriate. As per the study's mandate an assessment of the project against the Swiss Ordinance on Major Accidents (OMA; in German "StFV") was made using damage to persons and damage to property indicators from the viewpoint of the affected region. For comparison the natural (background) seismic risk of the region was described and put into perspective.

Other international guidelines were also used for orientation purposes.

For each indicator, conclusions were derived.

7. From a national perspective, attempts were made comparing the project's risk with other energy projects. Further, a comparison with other technologies in Switzerland was made. The project's risk cost was oriented against the gross domestic product (GDP) aimed at providing orientation for the government, to assess if such risk costs would be worthwhile to be invested. Additionally, new ways of comparing seismic risks were derived from mining projects from an amenity loss and tolerability of the affected population to vibrations viewpoint. As per the study's mandate several graphs, tables, and maps were prepared.
8. As the above evaluations used largely technocratic approaches to assessing the project's risk, a sociological evaluation was conducted to reflect on the population's risk tolerability and acceptance of risk emanating from this new technology. It evaluated the project's tolerability from industry representatives' point of view through a group interview and from a local population viewpoint from a desktop study and public hearing participation.
9. Recommendations for the project's risk appraisal and for further proceedings from a communication viewpoint were derived.

This work package addresses the technological risk aspects as well as the societal viewpoints emanating from the DHM project in Basel. Several assessments that were derived from this study are done for the first time in this context, including a property damage comparison with the risk criteria for installations subject to the OMA, a technology comparison with KATARISK, and an assessment with mining regulations.

It relies on the input and results from the previous work packages AP 2000 through AP 5000. AP 5000 covers the probabilistic seismic risk assessment.

The methodologies employed are described below.

1.3 Methodology

1.3.1 Risk to Infrastructure and Lifelines

In order to fulfil the scope of infrastructure risk cost determination, AP 6000 used a probabilistic model, which based on the RISQUE methodology as outlined in Bowden et al. (2001) and detailed in Appendix 2. Defining the model comprised the following steps:

First, a risk screening and risk identification by an intensive literature research on loss to infrastructure cost implications was conducted.

Secondly, an expert panel in a facilitated risk workshop was convened that draws on the panel members' expertise and study findings to define the likelihood, magnitude and consequence of infrastructure damage resulting from an earthquake associated with the DHM project. The panel consisting of members of AP 5000 was asked to define likelihood in terms of frequency (chances per year, refer to Table 14 in Appendix 3) and the consequences in terms of outage time or cost.

Thirdly, risk cost modelling was performed based on the results from the previous work packages only to maximum intensities of VI. For the assessment of earthquake damages from a range of larger intensities and magnitudes of natural earthquakes, the reader is referred to the results KATARISK (BABS 2003) study. The infrastructure risk cost determination would have been much more relevant if large earthquakes were to eventuate from the DHM project. However, during the public hearings it became obvious that the population was anxious about the basic services such as water and in-ground pipelines, thus an assessment was still considered as warranted.

The risk modelling used the consequential cost estimates not only associated with damage repair but also costs associated with business interruption. Two values of cost were sought for every input to the risk model; a Most Likely Case cost estimate (MLC) and the Reasonable Worst Case cost estimate (RWC). The MLC is represented by the mode (i.e., the highest point on a probability density function (PDF)) while the RWC is assumed to represent the 95% level of confidence, i.e. there is only a likelihood of 5 % that the RWC will be exceeded. The two values provide a quantitative measure of the uncertainty in the estimates. These estimates then formed the basis for assigning a lognormal cost distribution. The uncertainty inherent in each individual estimate of consequential cost is carried through the analysis and is included in the estimate of risk cost.

Using the likelihood estimates and the consequential cost PDFs, the risk modelling was the performed using a Monte Carlo Simulation (see Appendixes 2 and 3). The results of the infrastructure risk cost modelling are presented in chapter 2.4.

The results of the assessment were used to define the project's overall FD curve, which was then used for the risk appraisal.

1.3.2 Risk Appraisal and Technology Comparison

1.3.2.1 Risk Appraisal from a Local Viewpoint

To derive with a risk appraisal from a local or regional viewpoint, the FN curves of AP 5000 and the project's FD curve including the infrastructure risk cost was used an assessed against the indicators of OMA. The region's underlying natural earthquake risk was put into perspective using both, the results from AP 5000, and available Swiss wide data.

A desktop study on available other international guidelines outlining FN or FD criteria was conducted and appropriate guidelines were used orientation purposes. Appendix 6 details an overview.

1.3.2.2 Risk Appraisal and Technology Comparison from a National Perspective

Energy Projects

To derive with a comparison of the project's risk with other energy projects, a literature survey through the internet was conducted in German, English, and French.

The main literature of relevance that has been identified and subsequently reviewed was:

- NEEDS study quantification of risk indicators for sustainability assessment of future electricity supply options, PSI (2008);
- Ganzheitliche Betrachtung von Energiesystemen (GaBE) - (Comprehensive Evaluation of Energy Systems), PSI (2005);
- Severe Accidents in the Energy Sector (Project GaBE, first edition) PSI (1998).

Other Technologies

An intensive tri-lingual literature review was conducted establishing a data basis for the comparison with other technologies. Focus was placed on data related to Switzerland. If Swiss data were not available, data from Europe or from elsewhere in the world was researched drawing primarily on information produced for the energy and mining sectors.

The main literature of relevance that was identified of being of relevance was:

- Katarisk-Study (BABS 2003);
- Mining data related to explosions and vibrations from around the world.

It has been noted through the execution of the project that very little data from elsewhere in the world is available for deriving a direct technological comparison. The data, which is available, is mainly limited to FN curves, to assess projects' tolerability from a societal risk and individual risk of fatalities viewpoint. It was further noted that the KATARISK study (BABS 2003) appears to be the only study available, which derived FD curves for various technologies. The NEEDS and GaBE studies by PSI seem to be the only available studies comprehensively assessing the energy sector. FN and FD curves are a generally accepted method of describing and assessing risks of a project.

Therefore, significant efforts were made in an attempt to derive data of sufficient quality to make a comparison with KATARISK and NEEDS. In order to derive with this comparison from a fatality risk viewpoint, a FN curve was derived (refer to chapter 2.2.2). Using this data, backed by personal interviews with experts from the Swiss Paul Scherrer Institute (PSI) and the Swiss Federal Department for Civil Protection (BABS) in the relevant disciplines, the comparisons are given in chapter 3 of this report.

The data available to derive the technology risk comparison from a financial viewpoint was the total and annualised loss assessment and scenario study of AP 5000 and including the risk costs assessed by the infrastructure risk determination. It provides the basis for comparing the DHM project phases with KATARISK. Data details are outlined in chapter 2.5, results are described within chapter .

From a national viewpoint, the financial implications of performing the DHM project in Basel were benchmarked against general societal risks such as every day risks. Data from the Swiss consensus was researched and GDP data from the Canton Basel Statistical Office was obtained. This was done to provide an orientation for the government, to assess the range of risk cost from the DHM project, which would require investment when considering the Swiss Energy Supply program (Appendix 1). The results are outlined in chapter 3.4.3.3 and chapter 3.4.3.4.

An attempt was made to extend the technology risk comparison by comparing effects of conventional mining projects with the DHM project, as the DHM project is in fact a heat mining project. It could serve as the starting point for future guidelines on deep geothermal projects from an amenity loss and tolerability of the affected population to vibrations viewpoint (refer to chapter 3.4.4).

As per the study's mandate several graphs, tables, and maps were prepared as shown in chapter 3.

1.3.3 Social Aspects

The social aspects component of this work package sought to identify community perception and acceptance of, and reaction to, the DHM project. RiskCom in association with the Kommunikationsbüro Ulmer conducted a desktop research on publicly available documents such as press articles, internet blogs, and media releases, and conducted a series of interviews to establish inputs on public perception and the industry viewpoint of the geothermal project to the project.

Specifically, the following tasks were undertaken:

- Review of various internet blog entries, comments in the newspaper 'Basler Zeitung' (BaZ), the blog of the Office for Environment and Energy, and media releases about dialogue activities of the Stiftung Risikodialog as well as the EEG-EEG[2] position paper.
- A group interview was conducted with 15 representatives of companies from the industrial, commercial and service sector in the Basel region to analyse their risk perception. The group interview was held during a session of the Energy and Environment Commission (EUK) of the Chamber of Commerce in Basel on October 7,2009.

  The business representatives were split into three groups and interviewed about their

[2] Interessensgemeinschaft Erd- Erschütterungs- Geschädigte und Erd- Erschütterungs- Gerüttelten (EEG- EEG), a citizens' initiative.

perception of the temporarily suspended geothermal project. The statements made in this discussion were journalised and audio recorded.

- An interview with the head of the promotion office of economic development for the Canton Basel-Cit and Basel-Landschaft on October 2, 2009.

The findings for this component of AP 6000 are reported in chapter 5.

1.4 Report Structure

The report is structured to reflect the scope of work:

Chapter 2 – Determination of Risk Costs: handles the input into this work package. It mainly uses building risk cost data from AP 5000, outlines associated uncertainties, and information on the Basel specifics from AP 3000 and AP 4000. Furthermore, it summarizes the risk cost associated with infrastructure damage and determines the total risk cost of the project. It provides a link to Appendixes 2, 3, and 4, and also outlines the method used for the derivation of Frequency – Fatality (FN) curves suitable for the risk appraisal.

Chapter 3 - Risk Appraisal and Technology Comparison: describes, outlines, and evaluates the project's risks from a societal fatality and individual fatality viewpoint; and compares the project risks to other technologies and energy projects. It assesses the project's ranking against the OMA. It provides a possibility for developing risk acceptance criteria using vibration experience from mining examples.

Chapter 4 - Sociological study: describes the population's views and details the industry perception. It provides a framework, using risk classes, to assist with the development of a communication strategy.

Chapter 5 - Summary: summarizes the project acceptability based on the risk appraisal and the population's perception.

Chapter 6 - Recommendations: provides recommendations for future communication.

The chapters in **Appendix 1 (Geothermal Energy Considerations)** cover the energy considerations for the geothermal industry. They are aimed mainly for the information and benefit for political decision makers and related advisors. The content addresses the wider implications of energy generation based on a review of currently available information. It also puts into perspective the spatial distribution of risks from worldwide energy projects.

Appendix 2 – Methodology for Infrastructure Cost Determination covers the infrastructure risk assessment methodology.

Appendix 3-– Infrastructure Risk Results outlines the results from literature review and expert panel meetings, and provides a summary table of the panel's deliberations that are used in the quantitative risk assessment of the infrastructure risks.

Appendix 4 – Modelled Building Damage Distribution by Area provides a visual representation of the type of damages that would be expected if the project were to be re-initiated.

Appendix 5 – Social Assessment Questionnaire outlines the questionnaire used to interview industry representatives.

Appendix 6 – Risk Assessment Guidance Document and Background provides a brief overview on the ANCOLD guidelines and presents a selection of guidelines and relevant studies for this risk assessment.

Appendix 7 – References provides a list of literature used to compile and cited in this report.

Appendix 8 – Definitions provides a compilation of definitions used in this report.

Appendix 9 – Abbreviations provides a compilation of abbreviations used in this report.

2 DETERMINATION OF DHM PROJECT RISK

This chapter 2 outlines the relevant input information from previous work packages both from an earthquake occurrence viewpoint and from a cost viewpoint. The results of the infrastructure risk cost modelling are outlined, and the total project risk costs from the DHM project are derived. The earthquake effects are summarized for risk communication purposes. The chapter provides the background information for estimating the costs of potential infrastructure damage. Further, it serves as the basis for the quantitative risk appraisal.

For the benefit of the following discussion note that AP 5000 determined only the costs of building damage if the DHM project was to be re-initiated expressed as insured value loss. If these costs were to eventuate, they would fall under the responsibility of the project operator, unless the government provides financial backing. Those costs have a certain likelihood of occurrence; consequently they are termed risk costs. AP 5000 does not cover any further losses resulting from infrastructure and critical lifeline damages- this is covered in chapter 3. The infrastructure cost estimations are also expressed as risk costs (i.e. taking into account the probability of occurrence).

2.1 Summary of Earthquake Effects from AP 5000

The estimates from the previous work packages (AP 3000 through AP 5000) based the distribution laws considered in the models are that:

- The Basel situation is unique in that the Basel earthquake was stronger than could be expected from comparable projects (AP 3000, AP 4000, AP 7000).

If the project was to be resumed than the following effects will become evident:

- Between 8 and 90 earthquakes with $M_w \geq 2$ are possible during the 12-day stimulation phase of the reservoir of which between 2 and 30 could be felt by the residents. Of those felt between 0 and 9 could generate building damage mainly of damage grade D1 (slight or cosmetic damages).
- During the stimulation period, and according to the adopted models and associated uncertainties, it is likely (probability greater than 10%) that earthquakes with a magnitude M_w 3.7 eventuate (which is stronger than the Basel 2006 earthquake with moment magnitude of M_w of 3.2). This is equivalent to an intensity of about V. Earthquakes with a magnitude of M_w 4.1 or greater (i.e. intensity VI.5) are assessed as being not realistic. The probability of exceedance of intensity VI is close to 1:1000 during the stimulation period.
- During the 30 years of circulation between 40 and 500 earthquakes with $M_w \geq 2$ could be generated of which between 14 and 170 could be felt by the residents. Of those felt between 4 and 50 could generate building damage mainly of damage grade D1.

- During the 30 years of circulation between 3 and 30 earthquakes with $M_w \geq 3.3$ could occur (i.e. similar or stronger than the Basel 2006 earthquake), producing maximum intensities of less than VI.5 (VI-VII in intensity nomenclature, corresponding roughly to a magnitude M_w of 4.1) near the geothermal field and V.5 at 15 km distance. Events with VI.5 intensities have a 2:100 chance of occurring during any one year and create slight to medium damages (D1 to D2 with few D3 level damages).
- The distribution of the earthquakes is stochastic, meaning that there is no pattern to the mostly sudden but short events. A typical earthquake of that size does not last longer than 15 seconds.

The purpose of the previous work packages was also to assess if and how a geothermal activity could cause or exacerbate a natural earthquake of a larger magnitude. From the AP 5000 work package, it was concluded that this risk has a very low chance of occurring (1x10-7). For details, the reader is referred to AP 3000 and AP 4000.

Figure 30 of AP 5000 also outlines the comparison between the seismic hazard curves for the underlying earthquake risk (the normal or background risk), the stimulation period, and the circulation period. It is inferred that both, the stimulation period and the circulation period increase the natural background hazard, albeit only for intensities of less than VI.5.

Appendix 4 outlines the modelled damages on suburb scale for a re-initiation of the DHM project.

2.2 Lives Risks Data

2.2.1 Results from AP 5000

The results from the probabilistic seismic risk assessment of AP 5000 indicate there would be a small, almost non-quantifiable increase in potential human fatalities resulting from a re-initiation of the DHM project. This is a statistically derived number[3] of one to two human fatalities resulting from the geothermal project over the 30-year period (see Appendix 2 of AP 5000). This number is referred to as the most probable number. Taking into account the uncertainty in underlying seismic models the upper estimate of the most probable number of fatalities could also be seven as the uncertainty on this calculation is characterised by a factor of about four. Note also that it is the intensity VI earthquakes, which could have a detrimental effect on residents.

The analysis indicates a minimal increase in the frequency of intensity VI earthquakes that could, in some rare instances and given unfortunate circumstances, cause damage to a building, which could in turn cause severe injuries.

In addition, there is a high probability that an intensity VI earthquake would dislodge items such as roof tiles, flowerpots, parts from chimneys, etc. If these were to fall to the ground there is a change of injuring pedestrians or passers-by. In unfortunate circumstances, this

[3] A modelled number, which is totalled from risk increments for each individual modelled segment (i.e. towns or suburbs). For instance, suburb A might experience a 0.1 number of an additional fatality, suburb B is added which may have an increase of 0.01. The total from A+B would be 0.11. When summing up all fatalities from all suburbs the total is less than 2. Therefore any direct comparison with fatality guidelines can only be regarded as a general orientation.

could result in a very low number of people being injured or killed. There is a possibility that someone could experience a heart attack from sudden earthquakes of this intensity.

To put the number of fatalities into perspective, consideration needs to be given to the theoretical number of fatalities derived from natural seismicity. During the 30 year period over which a DHM project would be operating, the statistical number of fatalities from the natural seismicity is between 10 and 170 (as lower and upper bounds), with 48 being the most probable number. This represents a large uncertainty in the estimate. Therefore, the modelled fatalities from a potential DHM project are considered low when assessing uncertainty, and are not considered as a precise representation. Similarly, the number of injured people is also deemed low. Note that no injuries were reported from the December 2006 earthquake.

For benchmarking purposes with other technologies and other ubiquitous risks, the statistically derived number of fatalities from AP 5000 has been used in the remainder of the document. Note, that even if the numbers are quoted they are to be read and understood as small, almost non-quantifiable increase in potential human fatalities.

As the results from previous work packages suggest that the level of building damage would be low if the DHM project were to be re-initiated, i.e. could result in some potential cosmetic damage but insufficient to generate serious structural damage or collapse, it would be unnecessary to relocate people currently living close to the project area, and hence there is no requirement to provide additional public support to residents. Furthermore, no damage to natural resources is expected. The damage to critical infrastructure is considered to be low as outlined in Chapter 2.4.

2.2.2 Definition of an FN curve

As outlined in chapter 1.3.2 most of the publicly available data for making a technological assessment is through accidents and associated fatalities. In order to provide an assessment with other technologies deriving with some form of an FN curve for the DHM is warranted. Table 1 shows available data points from AP 5000. Considerable efforts went into defining this curve, however, the reader's attention is drawn to the discussion in the preceding section on the adoption of the statistically derived numbers of lives at risk. A further limiting factor is also the lack of evidence from other HFR projects. These limitations mean that care is required to avoid making an overly literal interpretation of the results of this assessment.

In general, it is reasonable to assume that it is more likely that the number of fatalities would be higher for a greater magnitude quake than for a lower magnitude quake. However, from the previous work package it became apparent that there is a maximum intensity earthquake (I = VI.5), which can be induced from the geothermal reservoir. During the 12-day stimulation period, the IV.5 earthquake has a 1:1000 chance of occurring (equivalent to a 3 x 10^{-5} chance for the year), whereas during the circulation period this has a 1:50 chance of occurring (equivalent to 0.6 chances per year).). The purpose of the previous work packages was also to assess if a large magnitude event could be initiated from a geothermal activity. From the AP 5000 work package, it was concluded that this risk has a very low chance of occurring (1x10-7). Consequently, no further considerations were made on this point in this work package.

While the likelihood of an intensity I=VI.5 earthquake may be 0.6 per year, earthquakes of this magnitude would not normally pose a serious lives risk and fatalities could only result in certain unfortunate circumstances (see chapter 2.2.1 above). It was postulated in AP 5000 that perhaps one (1) to seven (7) fatalities could occur during a single event during the30-year circulation period (refer Table 1). On this basis, the likelihood of a single fatality would be 1/30, or 0.03 p.a. This value, which serves as a point on the y-axis of the FN curve, is close to the cumulative probability of 0.021 as outlined in the Table 1 below. For the development of the FN curve, the variance in these two likelihood values is assumed to be the measure of uncertainty around this measure (F), while the AP 5000 estimate of one to seven is taken to represent the uncertainty around the numbers of fatalities (N).

Using this data, the following simplification for the FN curve was made:

- There is about a 1/1000 chance (or smaller i.e. 3×10^{-5}) for seven fatalities as an extreme case.
- A less extreme consideration is a 0.02 chance of 1 to 2 fatalities.

For simplification purposes and for deriving with a general representation of the DHM project, the FN curve was shown with a cloud that represents the estimate uncertainty in Figure 4 in chapter 3.

Table 1: Data basis for deriving with FN curve.

	Intensity at geothermal field	**Annual probability**	**Cumulative probability**	**OC**	**Fatality range MLC**	**PC**
Circulation Period	VI.5	0.02	0.021	0.4	1.7	6.8
Stimulation Period	VI.5	0.001 **(12 days)** 3×10^{-5} **(1 year)**	0.001 3×10^{-5}	0.4	1,7	6.8

MLC: most likely case: mean value,
OC: optimistic case: mean value minus total uncertainty,
PC: pessimistic case: mean value plus total uncertainty.

2.3 Summary of Building Damage Costs from AP 5000

Two processes are needed for developing the deep geothermal field- (1) a stimulation process, where the rock is hydraulically fractured (referred to as “fracing”) to create a pathway for the water to be circulated, and (2) the process of circulation where the water is injected with sufficient pressure to reach the extraction bore. The risk costs of the two periods were used for the determination of the project risk costs, and for orientation purposes when considering the GDP and the social risk spending.

2.3.1 Risk Cost in Stimulation Period

The most probable insured value loss for the stimulation period only (excluding natural earthquake risk costs) is about 41 million CHF (see Appendix 1 of AP 5000 and Table 2). It would represent 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 (AP 5000).

This most probable insured value loss has considerable uncertainties- there is a 15% chance that the number could be lower than 10 million CHF, but there is also a 15% chance that the cost could exceed 614 million CHF. There is 70 % chance that the cost is between 9 million CHF and 614 million CHF (see Table 2). The uncertainties largely result from the underlying seismic model and the data scarcity on geothermal reservoir stimulation.

2.3.2 Risk Cost in Circulation Period

The increment of seismic hazard during the circulation period has a lower variability than during the stimulation period, therefore the seismic vulnerability assessment for the circulation period derived much narrower cost ranges of the insured value loss (see Table 2). AP 5000 concluded that the most probable insured value loss during any one year of operation of the DHM project would be around 6 million CHF. In unfortunate circumstances, this number could be as high as 83 million CHF. The damage costs caused from natural earthquakes during any one year has been estimated to 89 million CHF (as the most probable number) and 192 million CHF in unfortunate circumstances. Over the lifespan of a re-initiated DHM project the losses from the geothermal project could reach 170 million CHF. AP 5000 concluded that a factor of close to three (3) governs the certainty of the most probable insured value loss for the circulation phase. The variation of the most probably affected number of buildings is between 0.6 and 1.5.

Table 2: Modelled Insured Value Loss from AP 5000.

Period	Insured value Loss Million CHF (rounded)			Percent of Basel GDP (rounded)
	OC	MLC	PC	
Stimulation Period (12 days) (including natural seismic activity)	10	45	620	0.02%- 0.1%- 1.3%
Stimulation Period (12 days) (without natural seismic activity)	9	41	614	0.02%- 0.1%- 1.3%
1st Year of Operation (1 year) (12 days of stimulation and 353 days of circulation, including natural seismic activity)	30	137	886	0.06%- 0.3%-1.9%
1st Year of Operation (1 year) (12 days of stimulation and 353 days of circulation, without natural seismic activity)	12	47	697	0.003%- 0.01%-1.5%
Year 2 to 30 Operation per annum (p.a.) (1 year of circulation, including natural seismic activity)	25	95	275	0.05% - 0.20%-0.6%
Year 2 to 30 Operation (p.a.) (1 year of circulation, without natural seismic activity)	3	6	83	0.006%- 0.01%- 0.2%
1 year of Normal Period (1 year of natural seismic activity)	25	89	192	0.05%- 0.19%- 0.4%
Maximum magnitude scenario: Mw=3.7-0.4	4	13	26	0.008%-0.03%-0.05%
Maximum magnitude scenario: Mw=3.7	16	54	108	0.03% -0.1% -0.2%
Maximum magnitude scenario: Mw=3.7+0.4	48	160	320	0.10% - 0.36%- 0.7%

MLC: most likely case: mean value,
OC: optimistic case: mean value minus total uncertainty,
PC: pessimistic case: mean value plus total uncertainty.
Maximum Magnitude Scenario: assumes an earthquake scenario of M_w=3.7± 0.4
Total uncertainty is the uncertainty in the hazard assessment and the vulnerability assessment.

2.4 Risks and Costs of Infrastructure Damage

The results presented herein should be regarded as a first estimate of infrastructure damage and associated socio-economic costs resulting from a potential re-initiation of the DHM project. To estimate the effects to specific infrastructure which could be affected by geothermally induced earthquakes an expert panel was established. A maximum intensity VI earthquake served as the basis for the estimation.The methodology is described in chapter 1.3.1 and Appendix 2.

The expert panel considered the likelihood of damage and the resulting costs associated with project-induced earthquakes on the following:

- Bridges
- Rail
- Airports
- Ship/barge transport on the River Rhine
- Dams
- Water supply
- Waste water treatment
- Hazardous waste storage areas
- Electricity system
- Gas distribution system
- Communications system
- Nuclear power plants
- Historic buildings

The results derived a total annual risk cost for all of these items of less than 0.1 million CHF (RWC). These estimates are considered immaterial as they are orders of magnitude less than the building damage estimates, and well within the uncertainty of the cost estimates produced in AP 5000.

The detailed basis for the estimation is included in Appendix 3.

With regard to damages to infrastructure, the expert panel concluded that:

- Overall electrical system will not be affected by the DHM project. However, damages to two existing transformer stations during the stimulation period are possible;
- A conceivable impact on the rail system would be that some trains would experience delays as the systems would require checking;
- It was estimated that less than 15 % of the historical buildings would receive minor damages incurring repair costs for each building between 0.02 million CHF and 0.1 million CHF if an intensity VI event was to occur. Moderate damages would only occur with a 1:100 chance, and have been accounted for with repair costs between 0.2 million CHF and 2 million CHF. The occurrence costs for repairing historical buildings in the event of an intensity VI earthquake are less than 4 million CHF. There is only a small chance (5%) of exceeding this occurrence cost.
- The infrastructure risk cost (i.e. accounting for the annual probability of an intensity VI event of 2:100) would be minor.

From a synthesis of relevant studies and available scientific literature the expert panel concluded that no or only negligible risk cost for the damage and repair of other infrastructure would occur, i.e. damages of bridges, airports, the inland water transport system, water supply infrastructure, waste water treatment plants, the natural gas distribution system, nuclear power plants, dams, and any secondary effects such as fires and explosions. These events were not further considered in the risk modelling.

Consequently, the risk appraisal used only the results from the building loss assessment as derived from AP 5000.

2.5 Data used for Risk Appraisal and Technology Comparison

The results from the semi-probabilistic infrastructure risk cost modelling and the building damage assessment of AP 5000 were used to derive an assessment with other technologies. The semi-probabilistic cost modelling provided the only way to derive with an FD curve (refer to the data in Table 41 of AP 5000).

2.5.1 Data Uncertainty

As it is crucial for the risk appraisal especially to derive with useable comparisons with other technologies, a handle on the uncertainties is needed. The uncertainty of the data from AP 5000 is shown in Table 3. It can be seen that the background seismicity has the lowest uncertainty throughout the annual frequency rates. The stimulation period has the highest uncertainty at the high frequency rates. Here the cost uncertainty can skew the mean value by a factor of as much as 60. This skew decreases for the low frequency rates to a factor of 2. The circulation phase has a variance of factors between two and four. The uncertainty stems from the uncertainty on the hazard, the vulnerability functions as well as on the cost function. For a detailed discussion on uncertainties, refer to Section 9.3 of AP 5000.

Note that the KATARISK study has an uncertainty in cost of about one order of magnitude (pers.comm. J. Balmer, BABS). From an uncertainty point of view, the data from the probabilistic assessment are comparable with the KATARISK study.

2.5.2 Damage Cost Data

AP 5000 derived FD curves with uncertainty estimates based on different annual exceedance rates.

As derived in chapter 2.4, the infrastructure cost modelling results were assessed as being minor when compared to the building damage costs from AP 5000. Consequently, it was decided to use the building damage costs results as tabulated in Table 3 as the basis for the appraisal. The data in Table 3 are to be read as follows:

Assuming an exceedance rate of 0.01 p.a. for the 1st year of operation the resulting building damage cost is estimated to 2.364 million CHF. As this estimate includes the underlying natural background seismicity, for which the estimate is 2.035 million CHF, the result based on an exceedance rate of 0.01 for the first year of operation of a DHM project is 329 million CHF.

The results from Table 3 provided the basis for several of the key outputs of this AP 6000 study (refer Figure 7, Figure 8, Figure 12, Figure 13, Figure 14, and Figure 15). FD curves without uncertainties are shown in Figure 50 of AP 5000.

Table 3: Data for deriving the FD curves including uncertainties in million CHF, rounded.

Exceedance Frequency yr^{-1}	Background seismicity. Building Damage only Model Data	1st Year of Operation (incl. normal seismic activity) Model Data	1st Year of Operation (Geothermal Only)	Stimulation period. Excl background Model Data 12 days *	2nd to 30th Year of Operation (incl. normal seismic activity) Model Data	2nd to 30th Year of Operation (Geothermal Only).
	Column A	**Column B**	**Calculated Column B - Column A**	**Column C**	**Column D**	**Column D - Column A**
1	**0.6** OC = x 0.5 PC = x 2	**13** OC = x 0.2 PC = x 17	**13**	**3** OC = x 0.5 PC = x 60	**11** OC = x 0.08 PC = x 4.4	10
0.1	**73** OC = x 0.5 PC = x 2	**349** OC = x 0.4 PC = x 2.9	**276**	**122** OC = x 0.5 PC = x 4.8	**234** OC = x 0.4 PC = x 2.0	161
0.01	**2.035** OC = x 0.5 PC = x 2	**2.364** OC = x 0.5 PC = x 2.1	**329**	**390** OC = x 0.5 PC = x 2.7	**2.035** OC= x 0.5 PC = x 2.0	0
0.001	**11.888** OC = x 0.5 PC = x 2	**12.856** OC = x 0.5 PC = x 2.0	**968**	**968** OC = x 0.5 PC = x 2.0	**11.888** OC = x 0.5 PC = x 2.0	0

MLC: most likely case: mean value,
OC: optimistic case: mean value minus total uncertainty,
PC: pessimistic case: mean value plus total uncertainty.

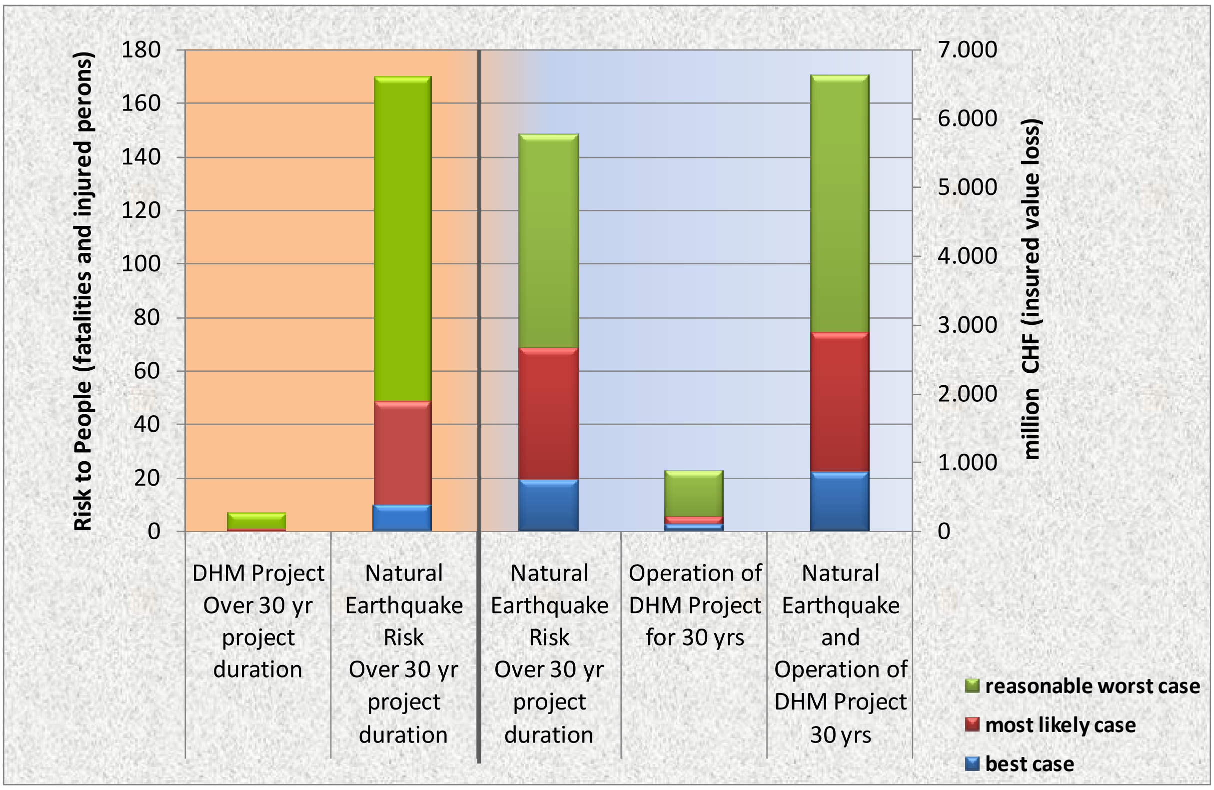
In order to derive with risk transfer solutions, it is necessary to compile the total project risk cost. The data as outlined in Table 3 was used to derive an estimate of the additional levy on energy costs by the total risk cost (see chapter 3.5.2).

Table 4: Most Likely Total Project Risk Costs (without consideration of uncertainties.

Insured Value Loss	**Approximate Cost (million CHF) MLC**
Stimulation period	40 (insured value loss)
Circulation period (30 years)	170 (insured value loss)
Other Infrastructure damage	Minor (see Chapter 3.2)
APPROXIMATE TOTAL PROJECT RISK COST	**210** (for benchmarking purposes)

A graph summarising the total project from a risk to people and insured value loss point of view compared with the underlying earthquake risk point of view is shown in Figure 1. It results from data stated in Table 2.

Figure 1: Project Summary Graph.



Note that the cost shown are insured value losses, which are relevant for insurance considerations; the costs are risk costs. It is a statistical representation of costs that could eventuate due to natural earthquakes in the next 30 years

3 RISK APPRAISAL

This chapter outlines the risk appraisal process. The total project risk is summarised in chapter 2.5.

From a local perspective, and as per the projects scope, the Basel DHM project was compared against the risk to person and risk of damages indicators stated in the OMA ordinance (see chapter 3.2.2). Because the population may wish to know what additional personal risk they would face should the DHM project be re-initiated, an assessment of the individual fatality risk posed by the project was made (see chapter 3.2.4).

From a national perspective, there is a need that technological advancements are viewed from a variety of angles to prevent premature criticism of the technology in general, especially after an unfortunate start to the DHM project trial. Therefore and because of the project's pilot character, the results from the probabilistic seismic risk assessment (PRA) were compared with results of studies on other technologies in Switzerland, and with guidelines of existing technologies, which may have similar effects but in a slightly different context (see chapters 3.4.1, 3.4.2.1, and 3.4.3.2). The energy and mining industries are examples. Guidelines exist for mining projects, which create vibrations that may have an impact on buildings and/or residents by blasting activities and other construction related activities such as pile driving, detonation works etc (see chapter 3.4.4). Consequently, it was decided to use those guidelines also for an evaluation of the residents' amenity loss and tolerability to vibrations viewpoint.

Further, a comparison with other technologies in Switzerland was made. The project's risk cost was oriented against the Basel gross domestic product (GDP) aimed at providing orientation for the government, to assess if such risk costs would be worthwhile to be invested. Also, this spending indicates the risks, which society is prepared to accept (chapters 3.4.3.3 and 3.4.3.4). Interestingly, this type of benchmarking was specifically asked for by the residents participating in the communication session conducted by the Stiftung Risikodialog.

The following chapters describe and assess the DHM project from various angles to provide perspective and improved understanding of the project within the context of other common and commonly accepted activities.

3.1 Risk Evaluation Criteria

In order to evaluate the risks from this geothermal project, risk acceptance criteria need to be screened for usefulness and appropriateness as they form the basis for decision-making. Several international bodies have established criteria. Risk criteria are categorised according to the consequences they consider. In general, these main categories exist:

1. Human fatalities: the risk measures are either based on individual (life) risk or societal (lives) risk;
2. Economic damage, including property damage;
3. Environmental damage.

Several guidelines provide criteria for the assessment of those categories. Table 5 provides an overview of the selected guidelines for assessing the DHM project. Other internationally available guidelines were reviewed and an overview is provided in Appendix 6. Selected background information on the guidelines of the Australian National Committee on Large Dams (ANCOLD) is also provided therein.

Table 5: Risk Categories and Guidelines.

Societal Lives Risk		**Individual Life Risk**		**Property Damage**	
OMA Guideline	Chapter 3.2.2	Swiss Guidelines	Chapter 3.2.4	OMA	Chapter 3.2.2
ANCOLD Guideline	Chapter 3.2.3	Germany Guidelines	Chapter 3.2.4		
KATARISK*	Chapter 3.4.2.2	Dutch Guidelines	Chapter 3.2.4	KATARISK*	Chapter 3.4.3.2
Energy Projects*, PSI	Chapter 3.4.2.1	UK Guidelines	Chapter 3.2.4		

*= studies used for comparison purposes.

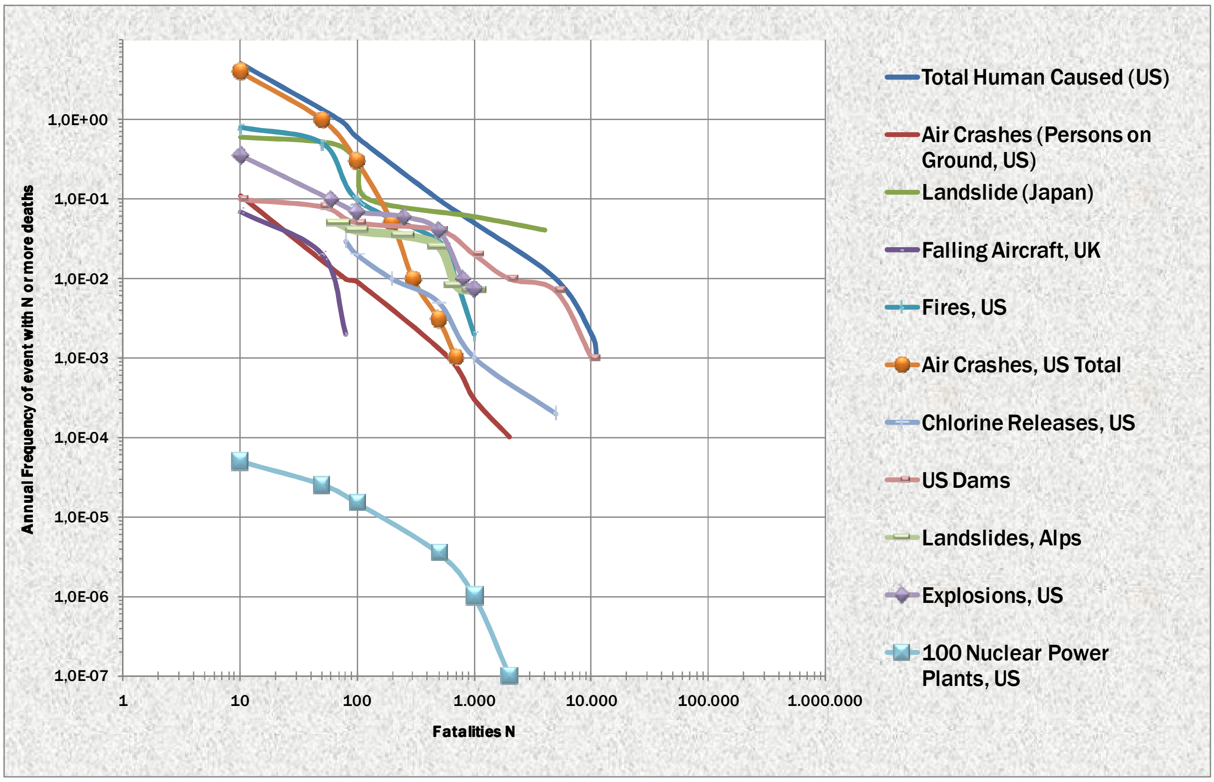
Further, there are general principles on risk tolerability and acceptability from a social acceptance viewpoint (German Advisory Council on Global Change – WBGU, 1998) against which the DHM project was assessed.

3.1.1 Human Fatalities – Societal Live Risk

The development of human fatality criteria is based largely on statistical data relating to fatalities associated with common activities such as smoking, driving, and flying. The assumption is that people continue to engage in these activities knowing that by doing so they are placing themselves at risk and that therefore the levels of risk posed by these activities are generally acceptable (i.e. as such define acceptable levels of societal risks). One of the methods that has been used to establish a socially acceptable level of lives risk is the FN (Frequency – Number of Fatalities) curve.

These criteria outline the annual frequency (F) of certain activities causing a number of fatalities (N). The general trend of the curves is shown in Figure 2. The curves are dipping to the right indicating that that it becomes less likely to have accidents which large number of fatalities.

Figure 2: Example of international FN curves (from Bowden et al, amended).



As fatalities are often associated with disasters, counting fatalities that result from incidents has become a standard practice. A monetary value can be assigned for the loss of a life (Value of Statistical Life, VSL) or a value of cost of saving a statistical life (CSSL). The VSL concept is a standard practice by health departments, insurance companies, and economists. Further, adverse health effects are believed to be predictable. An example is the modelling of additional cancer risks from living nearby a nuclear power plant (NPP). Therefore, while the practice of assigning a value to a life is commonly applied, it can still be controversial particularly to lay people who struggle to understand the concept. The individual living close to a NPP may be concerned with his individual risk of being killed by an incident.

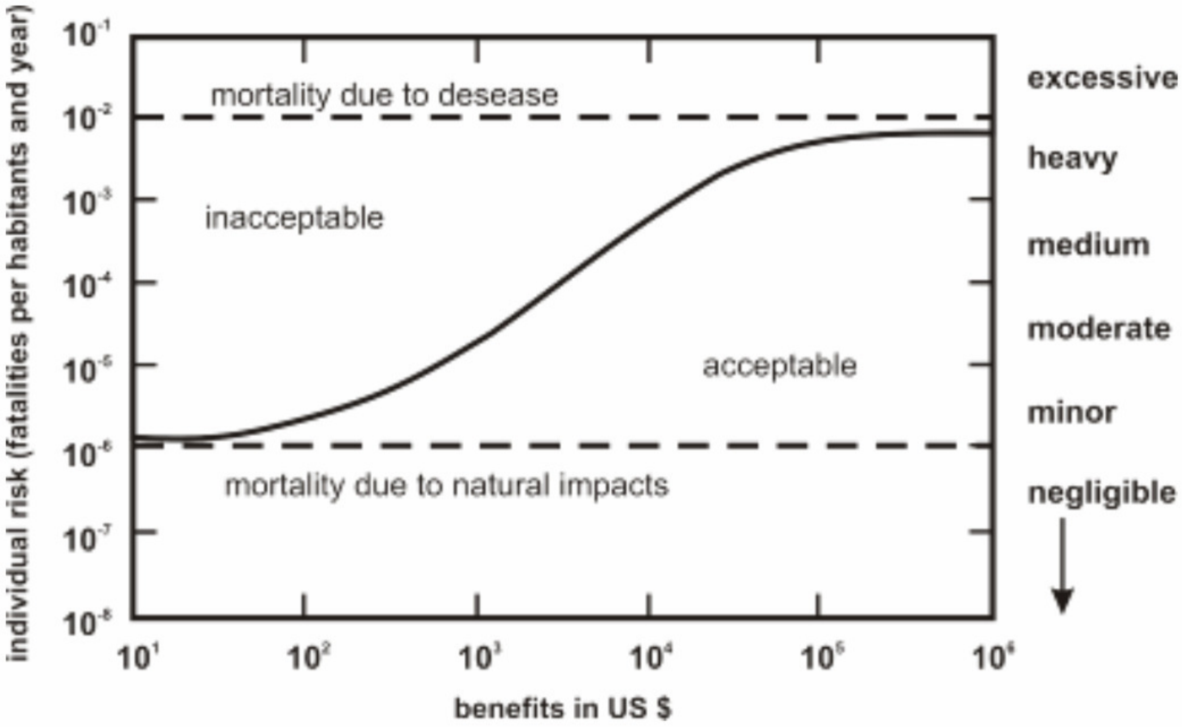
3.1.2 Individual Risk

Individual risk is defined as the probability that an average unprotected person, permanently present at a permanent location is killed due to an accident resulting from a hazardous activity.

When assessing this individual risk, one has to account for the involuntary nature of the exposure and the fact that there is very little, if any, personal influence on the initiating event or the follow-on chain events possible. Further, there might be very little personal gain immediately associated with a geothermal energy project.

The Figure 3 below outlines this general concept. On the left axis, the individual risk in fatalities per year is shown. The bottom axis displays the individual benefit gained in US $. The axis on the right describes the subjective risk estimation (from negligible to moderate to excessive). One can see from Figure 3 that for an increase in benefit, the risk acceptance increases.

Figure 3: Individual Risk and Benefit Concept.



Cited in Traite de Génie Civil Vol 21- Systèmes Énergétiques, L'école Polytechnique Fédérale de Lausanne. Translated.

3.1.3 Property Damage

Acceptability criteria for property damage have been proposed in the past (Jansen, 1998), but only the OMA ordinance appears to provide actual threshold values.

The Swiss KATARISK study appears to be the only study on industrial facilities and natural events assessing several factors including number of fatalities in FN curves, as well as number of evacuees, people needing subsistence, destruction of environmental resources in terms of financial consequences and associated FN curves, and property damage in FD curves (frequency damage). However, guiding limit values for acceptability were not developed in KATARISK.

3.1.4 Social Acceptance Principles

The German Advisory Council on Global Change (WBGU, 2000) and the International Risk Governance Council (IRGC, 2005) have developed general principles on risk tolerability and acceptability from a social acceptance viewpoint, but have not provided specific (financial) values for practical use. However, one advantage is evident, the work provides linkage to risk communication.

- Factors also contributing to social acceptance of a project include:
- Damage to individuals (in terms of being subject to an evacuation, or needing subsistence, or experiencing other bodily harm) or animals (e.g. loss of a species);
- Property damage (including buildings or material values, infrastructural losses and repair costs, and loss of the ability to generate economical value);
- Environmental damage (environmental impairment costs, loss of resources, etc);
- Social damage (e.g. loss of quality of life, loss of social engagement).

3.2 Risk for People from a local perspective

3.2.1 Comparison with natural earthquake fatality risk

As described in chapter 2.2.1 and visualised in Figure 1, during the 30 year period over which a DHM project would be operating, the statistical number of fatalities from the natural seismicity is between 10 and 170 (as lower and upper bounds), with 48 being the most probable number. This represents a large uncertainty in the estimate.

The results from the probabilistic seismic risk assessment indicate there would be a small, almost non-quantifiable increase in potential human fatalities resulting from a re-initiation of the DHM project. This is a statistically derived number of one to two human fatalities resulting from the geothermal project over the 30-year period. Taking into account the uncertainty on this estimate the total number of fatalities could be seven. Therefore, the modelled fatalities from a potential DHM project are considered low when assessing uncertainty, and are not considered as a precise representation. Similarly, the number of injured people is also deemed low.

Further, when comparing the fatality increment per year of the DHM project of around 0.05 (i.e. 1 to 2 additional fatalities over 30 years) to the underlying natural tectonic risk which is between 0.3 (10 fatalities in 30 years) and 5.7 (170 fatalities in 30 years), the DHM would only add a small fraction of this risk.

3.2.2 Comparison with Swiss Ordinance on the Prevention of Major Accidents (OMA)

As per the projects' scope, the Basel DHM project was compared against the Swiss OMA ordinance. The OMA ordinance addresses major accidents related to sites storing and handling substances exceeding specified amounts. The OMA also covers transportation of hazardous materials. For these sites, its goal is the safety of residents and the environment outside such a site. For other sites, it refers to Article 10 of the Swiss Environmental Protection Act (USG), which extends its application to "any person who operates or intends to operate installations which, in exceptional circumstances, could seriously damage persons or the environment shall take proper steps to protect the population and the environment". For those sites "the required safety distances must be observed, technical safety measures must be taken and supervision of the installation and organization of the alarm system must be ensured" (from Art 10 of USG). The OMA also regulates the level risk for the sites that fall under Art. 10 of the USG (pers. comm. D. Bonomi, BAFU).

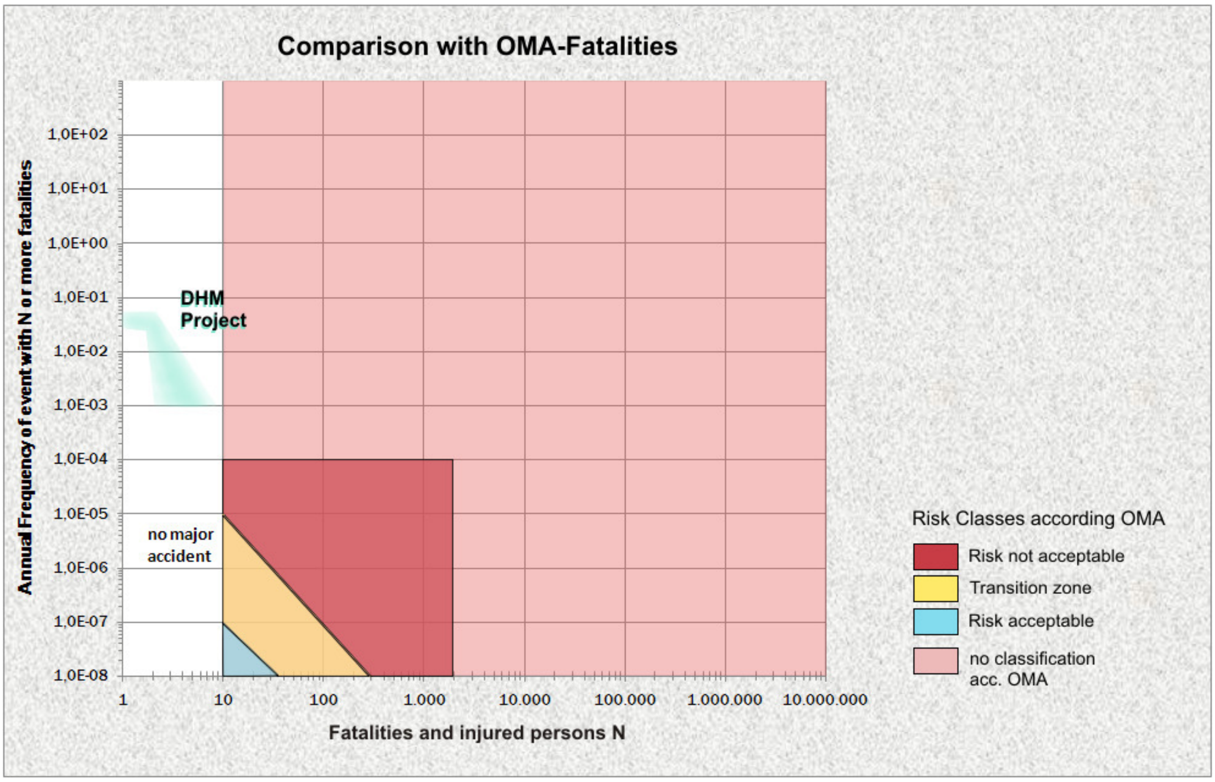
The OMA applies thresholds for defining a major accident, which are outlined in Table 6 and compared against the modelled values from AP 5000.

Table 6: OMA Thresholds and modelled values from the DHM project.

Parameter	Threshold	DHM modelled values
Fatalities	10	small, almost non-quantifiable increase in potential human fatalities
Contaminated surface waters in m^3 volume	10^6	0
Contaminated surface waters in km^2 area	1	0
Contaminated groundwater for a specific time measured in person months	10^4	0
Reduced fertility of topsoils in km^2 a	0.02	0
Property Damage In million CHF (basis 1996)	50 (1996) 71 (2009)	50 million p.a. Year 1 (2009 valuation) 6 million p.a. Years 2- 30 Possible total 200+ million (2009 valuation)

In order to derive a comparison with the OMA the fatality estimates from chapter 2.2.2 were used and for the cost comparison, the data from chapter 2.3 and AP 5000 (section 10.3.3) was used. Figure 4 shows the potential location of an FN curve of the DHM project for orientation purposes. The curve is blurred to reflect the small, almost non-quantifiable increase in potential human fatalities, and the large associated uncertainty.

Figure 4: Swiss Ordinance on Major Accidents – Fatalities.



From a fatality point of view, the OMA is only applicable for accidents with more than ten fatalities. The DHM project would be located outside this range. Further, when comparing the thresholds for major accidents with the DHM project (see Table 6), the DHM project would be classified as an accident and not classified as a large accident or a catastrophe, due to the low numbers of people at risk from the project.

For an overall rating against the OMA, please refer to section 3.3.2.

3.2.3 Societal Risks Comparison with ANCOLD guidelines

ANCOLD guidelines (refer to Appendix 6 for a background information) were also used for comparison. The guidelines have been developed for large dams, i.e. for water storage sites, which might have a catastrophic impact when bursting. As the DHM project is a single project, consequently similar to a dam, it is justifiable for using the guidelines for comparison. Note that both, the ANCOLD and the societal criteria from Australian New South Wales planning guidelines start at one fatality. This is a difference to the OMA. Figure 5 outlines the comparison.

Figure 5: Societal Risk Comparison with ANCOLD guidelines.

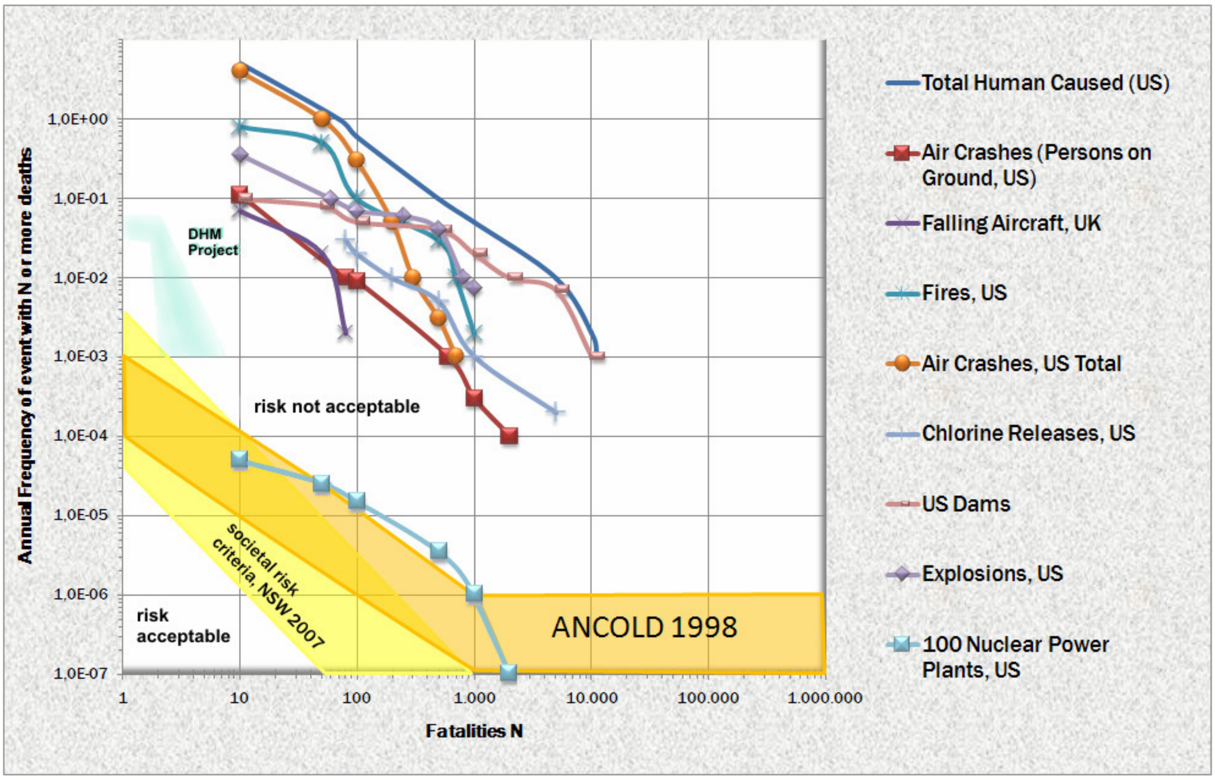


Figure 5 shows the DHM project being located well toward the left of other technologies and facilities in terms of its risk to life. The curve is blurred to reflect the small, almost non-quantifiable increase in potential human fatalities, and the large associated uncertainty. More importantly, the DHM project is significantly (perhaps a hundred times) safer than air travelling in the US or being caught by a fire. Chlorine releases or explosions cause at least ten times more fatalities than a DHM project. It is evident from Figure 5 that the DHM project may pose a higher risk than dams, which were constructed or upgraded to the ANCOLD 1998 and ANCOLD 2003 standards, but certainly only at the low N end of the curve.

The DHM project in its present design would rate above the yellow shaded area (i.e. in the intolerable area) of the ANCOLD guidelines of 1998 and would rate inacceptable (ALARP[4]) when using the ANCOLD 2003 guidelines.

Consideration needs to be given to the fact that all other activities outlined in Figure 5 would not rate acceptable, albeit they are largely tolerated by virtually all societies. Therefore, it may be debatable to rate the DHM project as marginally tolerable with respect to the societal risk guidelines by ANCOLD in conjunction with FN curves for other industries/activities.

[4] ALARP= as low as reasonably practicable. This takes into account a cost benefit of actions taken, where as the ALARA principle ("as low as reasonably achievable") is a technical measure.

3.2.4 Individual risk

As outlined in chapter 2.2 the DHM project has a small, almost non-quantifiable increase in potential human fatalities. For orientation purposes, a number between one and seven fatalities have been used to assess the individual risk.

Therefore, if the project were to proceed, each resident in the area of consideration (Basel and a 12 km radius) would face an increased **annual risk** from an induced seismic event of:

1 - 7 fatalities / 542,000 residents / 30 years = **6×10^{-8} to 5×10^{-7}**.

As the earthquakes are sudden erratic events which cannot reasonably be predicted, except that during the stimulation period, there is a higher frequency of events, the calculation assumes that the residents are physically present in the Basel region. Unlike for chemical or other production facilities workers or employees are only exposed to risks from these facilities at certain times.

In Switzerland, the PLANAT study (BAFU 2009) has yielded a guidance value for natural catastrophes. For earthquakes a guidance value of $\leq 1 \times 10^{-5}$ was developed.

Internationally there are several guidelines providing threshold values for tolerability of individual risks (per year):

- Germany railway safety guideline value (Bohnenblust): 1×10^{-6}
- Dutch TAW threshold: 1×10^{-6}
- UK HSE threshold: 1×10^{-6}
- Australia (Queensland state) different threshold values depending on the facility in which the individual is located: from 5×10^{-7} (hospitals), 1×10^{-5} for sporting complexes, for workers within industrial sites 5×10^{-5}.

Putting the individual risk of about 1×10^{-7} into perspective- it is about ten times more likely for an individual to be killed in an accident while working in the service industry (3×10^{-6} chance, HSE 2000) and a hundred times more risky than working as a self-employed person (2×10^{-5} chance, HSE 2000).

When considering these threshold values, the risk from a geothermal plant in Basel is acceptable from an individual risk perspective. The DHM project would also be acceptable from an individual risk perspective when the benefit concept as outlined in Figure 3 would be applied.

Therefore, the individual risk from the DHM project can be considered as being acceptable.

3.3 Financial risks from a local perspective

Background information on natural earthquake occurrences and costs in Basel and Switzerland is provided in chapter 3.3.1. In chapter 3.3.1.4 a comparison of the DHM projects induced costs with background seismic costs is made.

3.3.1 Natural Earthquakes

3.3.1.1 Damages from Past Events

There is an underlying natural earthquake risk in Basel, which manifested itself in the occurrence of a magnitude M_w6.5 earthquake in 1356, destroying most of the city. This earthquake is believed to have a return period between 1000 and 3000 years, with considerable margins for error. Over the past 100 years, the maximum intensity earthquake in Basel reached VI.

In Switzerland there were 34 earthquakes with an intensity of V or larger over the past 25 years. Statistically Switzerland should experience a Magnitude 4 earthquake (Intensity V to VI, minor building damage) once a year.

- An intensity VI-VII earthquake (i.e. similar to an induced earthquake from geothermal activities) hit Yverdon in 1898. The associated building damage is estimated between 55 and 110 million CHF (in 2002 valuation). In
- An intensity VII earthquake in Glarus in 1971 caused building damages between 31 and 160 million CHF.
- A natural earthquake occurred in Bern which was hit with an intensity VII quake in 1881 causing damages between 280 million CHF (optimistic estimate) and 1250 million CHF (conservative estimate).
- An M_L 5.3 earthquake occurred on 1996 July 15 in the vicinity of Annecy (French Alps). It was the strongest event to shake southeastern France in the last 34 years. Moderate to serious damage in the Annecy area was seen consistent with intensities of VII-VIII,
- An earthquake struck Nidwalden in 1601 with an intensity VIII (Magnitude 6.2) causing a building damage between 760 million CHF (optimistic estimate), and 8,960 million CHF (conservative estimate).
- Other intensity VIII earthquakes hit Altdorf (1774) and Rawil (1946) causing similar damages (optimistic estimate around 450 million CHF and conservative estimate around 2,000 to 3,000 million CHF).
- The strongest earthquake in the past 25 years in Switzerland occurred on 20 November 1991 with an epicentre between Thusis and Lenzerheide (referred to as the Vaz earthquake). It reached intensities between V and VI (Magnitude 5.1) and caused cracks in buildings and a power failure in the region. The earthquakes hypocentre was at 12 km depth, a depth significantly deeper than the recent geothermally induced quakes in Basel.

Worldwide there are about 50,000 earthquakes annually with magnitudes between 3 and 3.9.

All data sources are from “Risikoanalyse Schweiz XXI, 2003” and Weidmann, 2002.

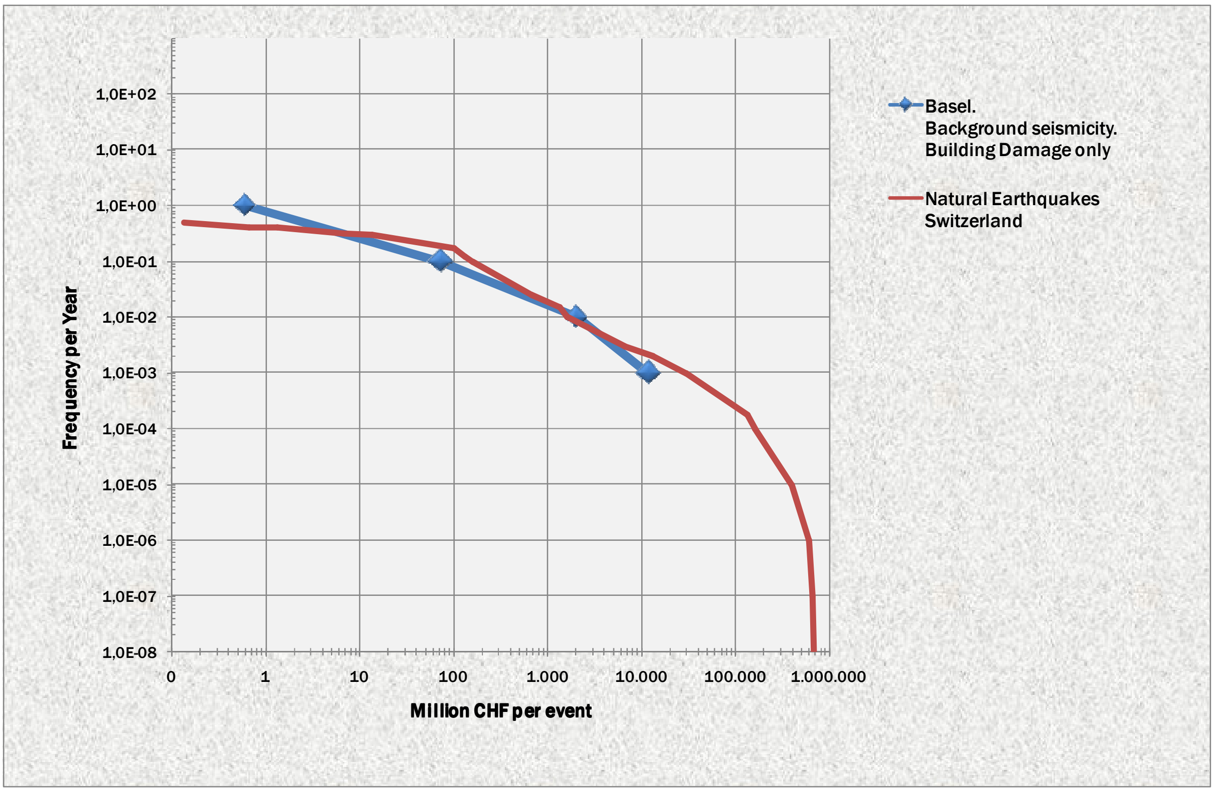
3.3.1.2 FD Cost Curves

The KATARISK study (BABS 2003, refer to chapter 3.4.1 for details) derived an FD curve for the risk of natural earthquakes in Switzerland (red curve in Figure 6). AP 5000 has also modelled the background earthquake risk in Basel. Both are shown in Figure 6. Note that these curves were not paint-brushed to allow a better visualisation.

When comparing these two curves it becomes evident that the underlying earthquake risks in Basel follow the earthquake curve for Switzerland. Note that AP 5000 did not model the costs (as insured value loss) associated with annual frequencies below 10^{-3}, because there is no more risk increment from a re-initiated DHM project at lower frequencies, hence the curve stops there.

One could intuitively expect that the earthquake risk in Basel would be a subset of the total earthquake risk in Switzerland. For reference, Basel and the Valais region are the two most earthquake prone regions in Switzerland. But as the curve describes the earthquake risks in Switzerland and the Valais region has much less industrial properties than Basel, it is clear that the natural earthquake curve for Basel needs to follow the Swiss curve. Any impreciseness may be due to: a) different cost damage functions might have been applied; b) the inflation rate is not applicable to building values, and c) the house prices have possibly risen by more than the average cost of living in the past 11 years or so, etc. may explain why the curves are not identical.

Figure 6: Comparing Modelled Natural Earthquake Cost in Basel with Natural Earthquake Costs for Switzerland.



3.3.1.3 Geothermally Induced Damages

To obtain FD curves, a semi-probabilistic was developed in AP 5000, and the results are displayed in the following sections. Due to this limitation, the Figure 13 to Figure 15 below are useable only as a general estimation.

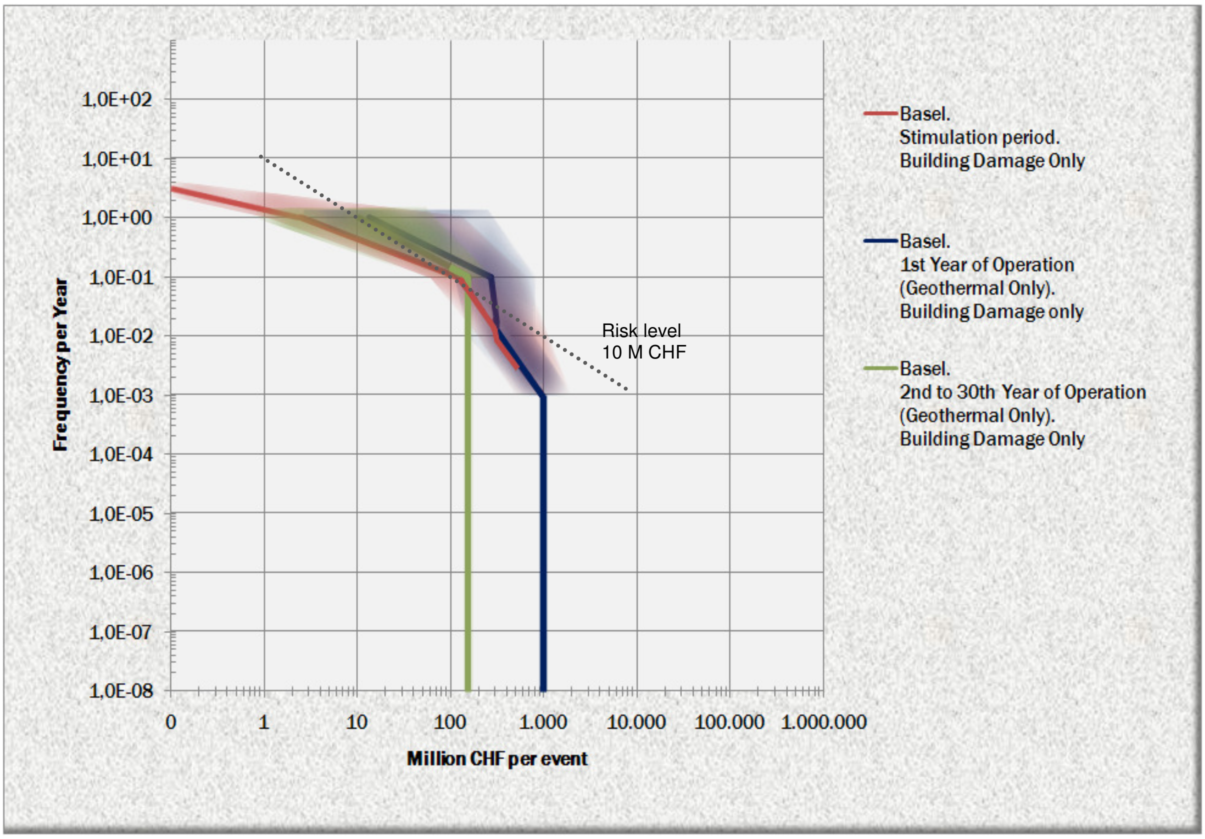
The results of AP 5000 (Table 41) are presented in a graphical form in Figure 7. In addition to AP 5000 this figure shows the confidence intervals determined by AP 5000. The figure shows that the stimulation period (red line) has the potential to produce higher costs than the circulation (i.e. operational) period (green line). The stimulation curve stops at likelihoods of 10^{-3} p.a., which represents the model results below which the annual frequency poses no further risk increment above the natural system (i.e. the underlying natural earthquakes in Basel). Figure 7 also shows that the first year of operation (blue line) is the most costly year as it covers the short stimulation period(s) with circulation occurring for the remainder of that first year.

The figure also shows that significant costs could eventuate when operating the system in its original design (refer to AP 3000-AP 4000 for details). The FD curve for both the first year and every subsequent year of operation lies approximately on a line of equal risk of 10 million CHF per year.

This indicates that the DHM project is likely to incur an annual cost of roughly 10 million CHF per year, and has a 10% chance of incurring costs in the order of 100 million CHF in any year.

From an investor's perspective, over the life of the project the expected costs are higher than the original investment costs of about 80 million CHF, and may exceed the investment in a single year. More importantly, with a risk cost of roughly 6 million CHF per annum (Table 2), the expected annual costs are significantly higher than the 0.6 million in projected annual profit.

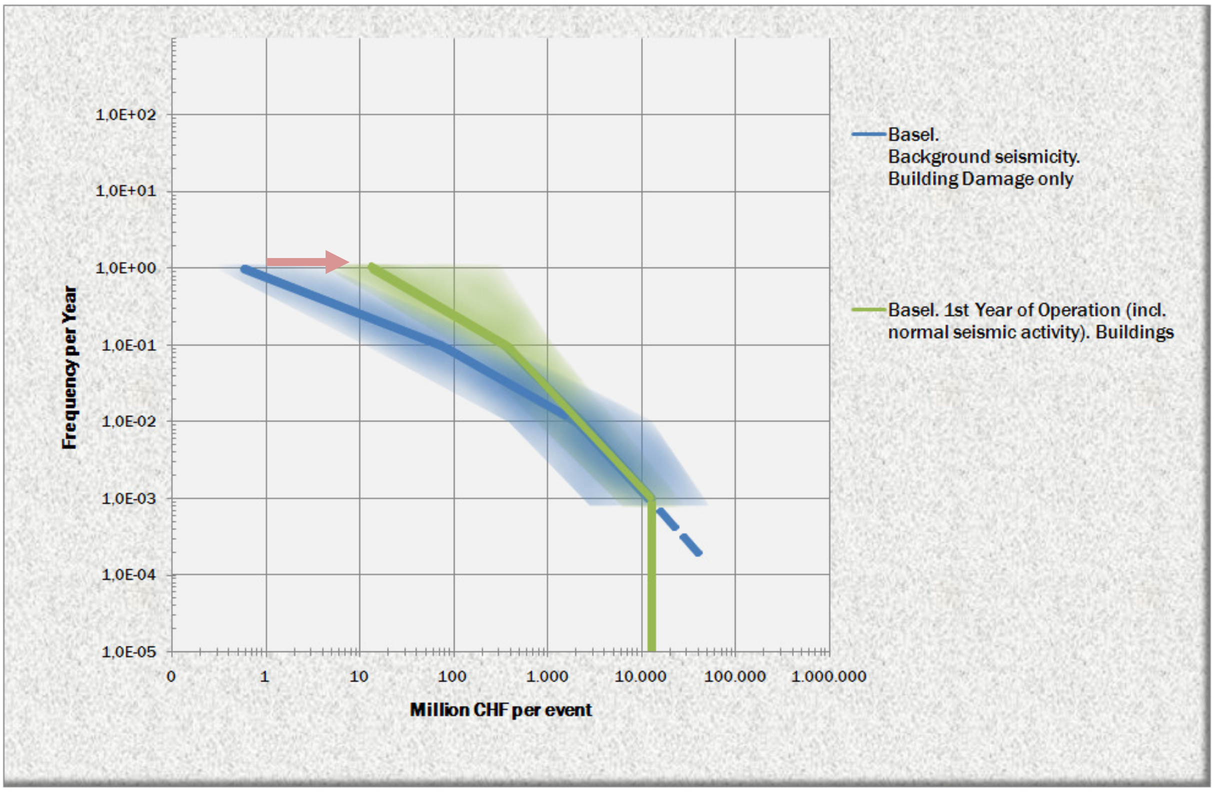
Figure 7: FD curve of the geothermal field in Basel.



3.3.1.4 Comparison of DHM Project risk cost with background seismic costs

The Figure 8 shows the natural earthquake risk and the first year of operation of the DHM project in its original design. It can be seen that the increment by which the earthquake risk is increased in the study area is evident in the lower cost and higher frequency end of the curve (i.e. the beginning of the blue and green curves on the left). The green vertical line indicates that there is no additional cost at frequencies below 10^{-3}, as there is no adjunct in hazard. The lower end of the blue line is dashed to indicate the presumption that the curve is likely to reflect to some extend the natural earthquake curve of Figure 6. For further details, refer to AP 5000.

Figure 8: Natural Earthquake risks versus induced earthquake risk.



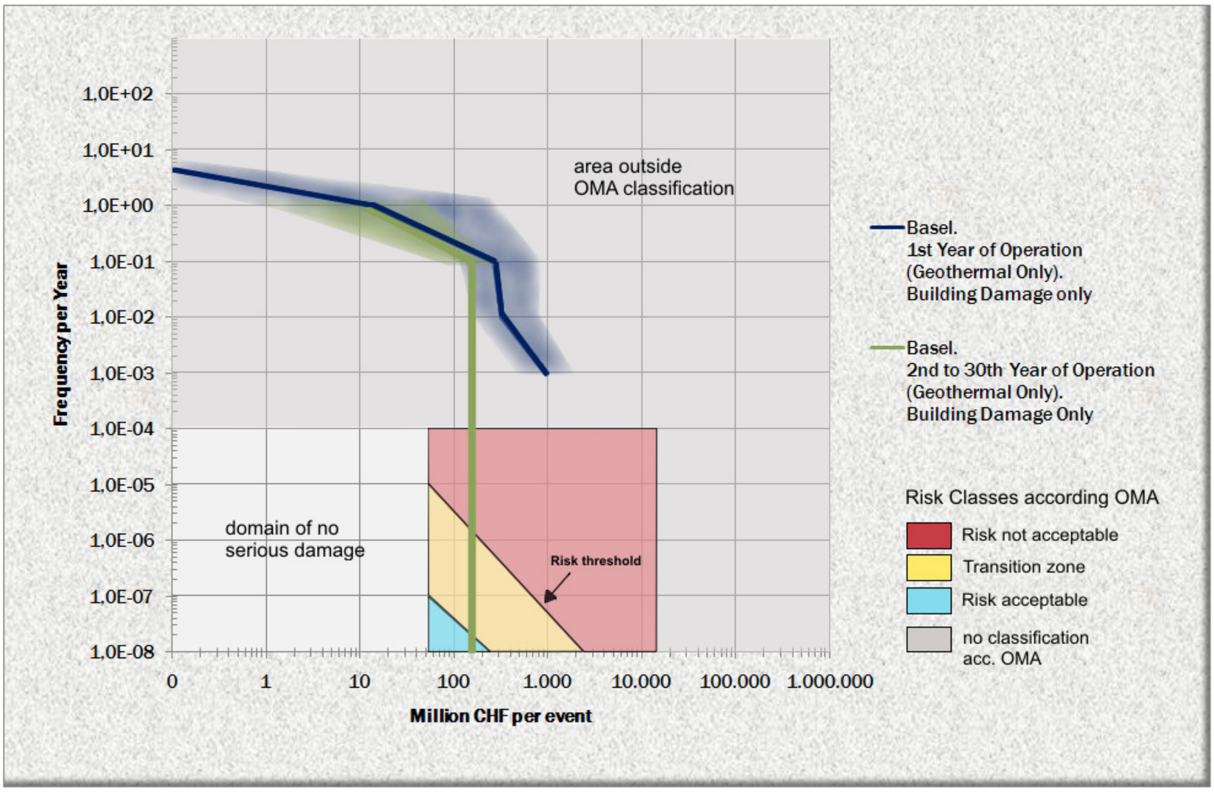
3.3.2 Comparison with Swiss Ordinance on Major Accidents (OMA)

Figure 9 outlines the associated property damage as a FD curve of the stimulation period and the circulation period compared to the OMA. In addition, this figure shows the confidence intervals determined by AP 5000 (also see chapter 2.5.1 for a discussion on uncertainties).

Figure 9 was amended to reflect the inflation of the property damage indicator to a CHF $_{2009}$ valuation. Note that up now the property damage index has never been applied for a risk determination of installations subject to the OMA in Switzerland (pers. comm. D. Bonomi, BAFU).

Further, the OMA in its present version does not cover annual frequencies above 10^{-4} p.a. The darker red area covers the area where risks would not be acceptable. When extending the red shaded area vertically (grey shaded area) one could infer that any project located above would also be rated as not acceptable. Note that the boundary where the unacceptable area starts has a risk threshold of about 500 CHF per year only. The FD curve for every year of operation lies approximately on a line of equal risk of 10 million CHF per year. Consequently, the DHM project in its original design would rate as not acceptable from a property damage cost viewpoint.

Figure 9: Swiss Ordinance on Major Accidents – Property (Damages).



Overall rating according to the OMA:

Although from a fatality viewpoint the risk would be acceptable, but from the property damage indicator, the DHM project would have to be classed as not acceptable. Note that there has been no previous case where a project was assessed against the property damage indicator.

3.4 National Considerations of Risk

This chapter provides an overview of a nationwide study conducted by the Swiss Federal Department for Civil Protection (BABS). The study assessed the impacts from technologies and industries as well as from natural disasters, both from a risk of lives perspective and from a financial risk perspective. The study provides a comparison of the DHM project from a national perspective.

The following chapters first handle the risk to people (chapter 3.4.2) and secondly the financial risk perspective (chapter 3.4.3).

3.4.1 KATARISK Study

3.4.1.1 General Remarks and Results

The KATARISK study (BABS 2003) evaluated all known natural and man-made (technical) incident and accident cases by statistical damage expectation values for physical damage to human life. The general results are inferred from Figure 10 show for Switzerland (in order of risk of fatalities):

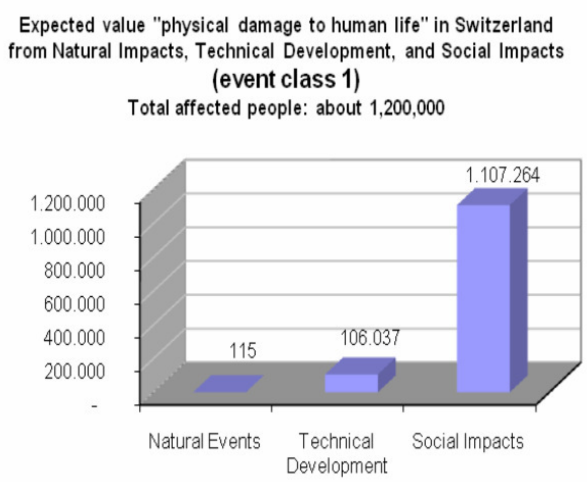
I. Social impacts (e.g. leisure and sports activities, working accidents, epidemics, migrations) are the highest cause for fatalities;

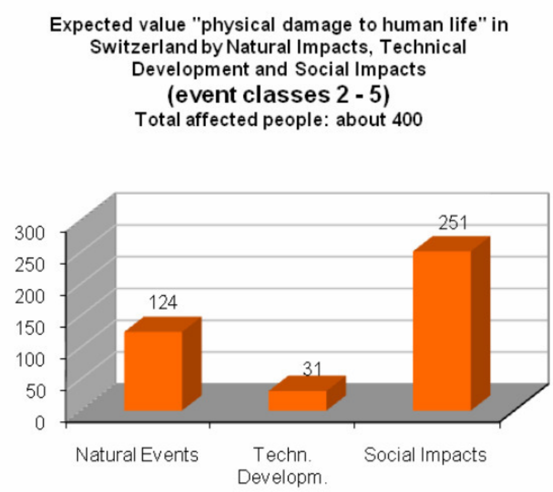
II. Technical hazards are the second highest cause for accidents.

Examples include: nuclear power plant incident Lucerns/Switzerland 1969 with local radioactive fallout; chemical plant incidents like Schweizerhalle 1986, accidents with trains transporting hazardous goods at Zurich-Affoltern in March 1994 and Lausanne in June 1994; several major fire incidents with fatalities; several train accidents with fatalities; aircraft accidents with fatalities; and the highest figure for car accidents);

III. Natural hazards (with highest figures for avalanches, lightning, earthquake, heat/drought, and forest fires).

Figure 10: Statistical number of people severely affected by natural events, social impacts, and technical development (from Katarisk, graphically amended).





It is much more likely to die from social impacts than as a result from technological developments, even for more severe accidents which are classed into class 2 to 5, with 5 being most severe. Therefore, the risk of dying from a DHM project is by far smaller than dying from a common flu or from skiing.

3.4.1.2 Methodology of KATARISK study

The accident and property damage (FN / FD) curves used as a basis for this assessment were derived using data from Switzerland and where appropriate data was missing accidents from elsewhere in the world. The curves derived by the KATARISK study are based on a review of actual accidents. Clustering of similar accidents and similar industries was done. For events that have not yet been observed in Switzerland, accidents from other countries and facilities were used or credible scenarios for Switzerland were developed. The lower right end of the curves are derived from those scenarios.

Therefore, the curves (irrespective of the consequence they assess) are representative of accidents in a particular industry, anywhere in Switzerland. The inclusion of facilities from elsewhere simply mean that the curve is better defined but not moved in parallel upwards or sideways. It is therefore not warranted to scale down the frequencies to a city or regional scale. The curves do not sum up all technical facilities either. The curves were constructed by adding up frequencies (not costs). A curve representing the chemical industry, therefore provides an estimate of the potential (cost or fatality) risks a resident is exposed to somewhere close to a chemical facility. Such a facility however, may not have all the features, which the curve represents, as it may not be handling certain chemicals or processes that could lead to a catastrophic event. But this particular facility may well be subject to frequent minor incidents. For a city like Basel, it is reasonable to assume that from all the facilities present, much of the curve is actually covered.

The data derived for this project is of a slightly different nature as it encompasses a very detailed probabilistic safety assessment (PSA) which to our knowledge has not been done in a similar depth for other technologies except for the nuclear industry. Hence, the existing data is considered to provide a reasonable comparison between the risk posed by this project and by other technologies.

The KATARISK study and the AP 5000 results cover both only direct losses, whereas indirect losses and secondary costs have been omitted. Therefore, the comparison between the KATARISK study results and the DHM project is valid.

The KATARISK curves were developed to gain an order of magnitude understanding of technological and natural risks in Switzerland. To pay tribute to this circumstance the curves were “paint brushed”, where necessary, to reflect the inherent uncertainty. All costs in the KATARISK publication were inflated (using the average annual inflation rate of 2.7%) to 2009 valuation to make them comparable with this project. The uncertainty in the estimates from AP 5000 has been similarly accounted for (“paint brushing”).

3.4.2 Risk to People

3.4.2.1 Risk Comparison with Energy Projects

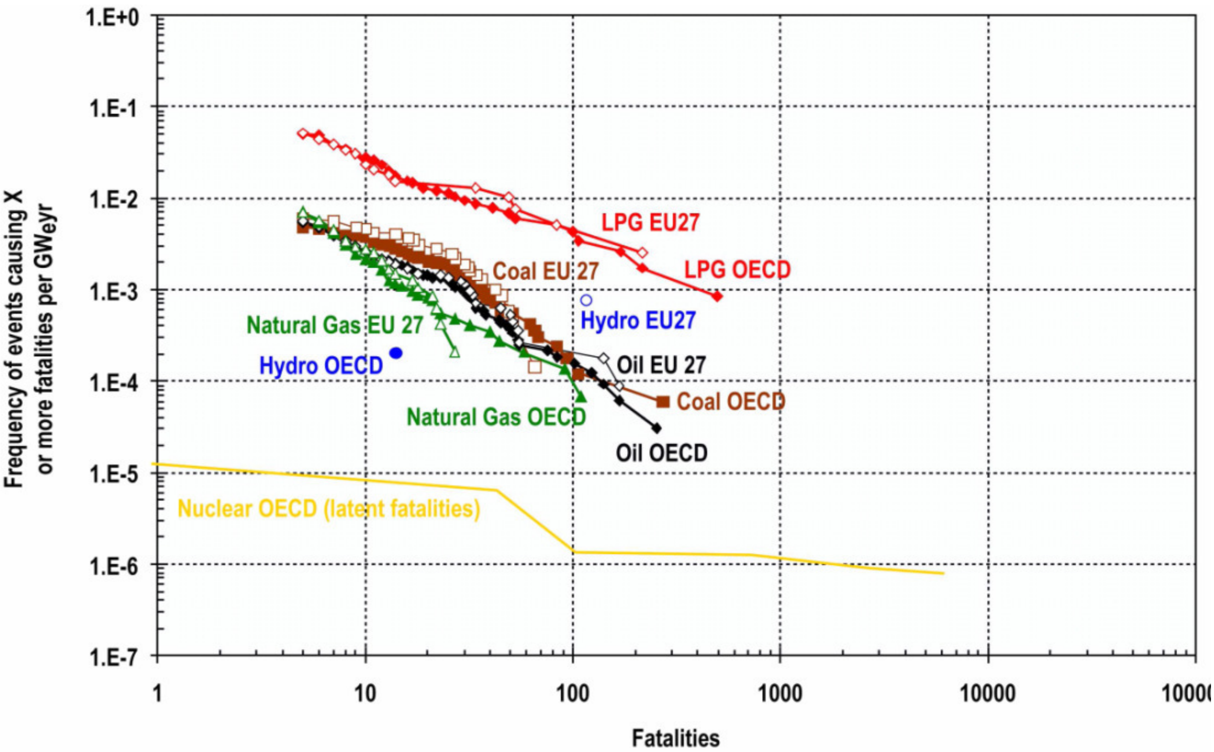
The PSI has developed the largest database (energy related severe accident database - ENSAD) on fatalities and accidents of energy projects worldwide (see Figure 11). It is relevant to know that the data basis for the figure below is from actual fatalities. Only the curve for the nuclear energy projects has been determined by probabilistic safety analyses (pers. comm. Dr. Stefan Hirschberg, PSI). As for data availability and consistency reasons, much of the interpretations are only valid when comparing fatalities.

For a discussion on the limitations of the fatality determination refer to chapter 2.2 and footnote 3. The following limitations and particularities of Figure 11 have to be recognised:

- The projects shown in the ENSAD database include all upstream, transport and downstream activities, whereas the DHM project only consists of a portion of an upstream activity (i.e. fracing the reservoir and circulating water). The drilling risks and distribution activities are considered to be negligible.
- It uses normalized data from technologies that are used extensively throughout the world and have been operating for many decades. The statistics from which the curves are drawn therefore reflect significant energy production over a significant period (for example, energy produce by coal in the 27 years between 1969 and 1996 totalled more than 24,000 $GW_e yr$). By comparison, the energy production from the Basel DHM is inconsequential; 0.09 $GW_e yr$ over the 30 year operating period. This huge discrepancy makes a meaningful comparison between DHM and other traditional energy projects impossible.
- Data exists for about 30 years or more. There is hardly any data on HFR projects as the technology is still in its infancy.
- PSI interpreted only accidents with more than 5 fatalities from their ENSAD database. Because the DHM project has only small, almost non-quantifiable increase in potential human fatalities, a direct comparison cannot be easily drawn. For example, if the assumption is that there are no fatalities resulting from the DHM project, which is a reasonable assumption for this single, small-scale pilot project, then there are no data on which to make a comparison. However, assuming a single fatality, which while unlikely is conceivable, that single value will grossly overstate the lives risk as there is so little energy being produced by the project.
- The curves on Figure 11 would increase steeply to the left (the low N end of the curve), if all accidents with 1 to 5 fatalities were to be incorporated and shown.

Overall, there are too many limiting factors for a credible comparison of the DHM project with other energy projects to be made.

Figure 11: Fatalities from Energy Projects in EU and OECD (excl. China)- societal risk comparison (from PSI 2008)



3.4.2.2 Comparison with Technical Risks

The modelled fatalities of the DHM project in Basel could also be compared with the summation curves of individual industries/technologies – either voluntarily taken by individuals or involuntarily taken - in Switzerland (see below).

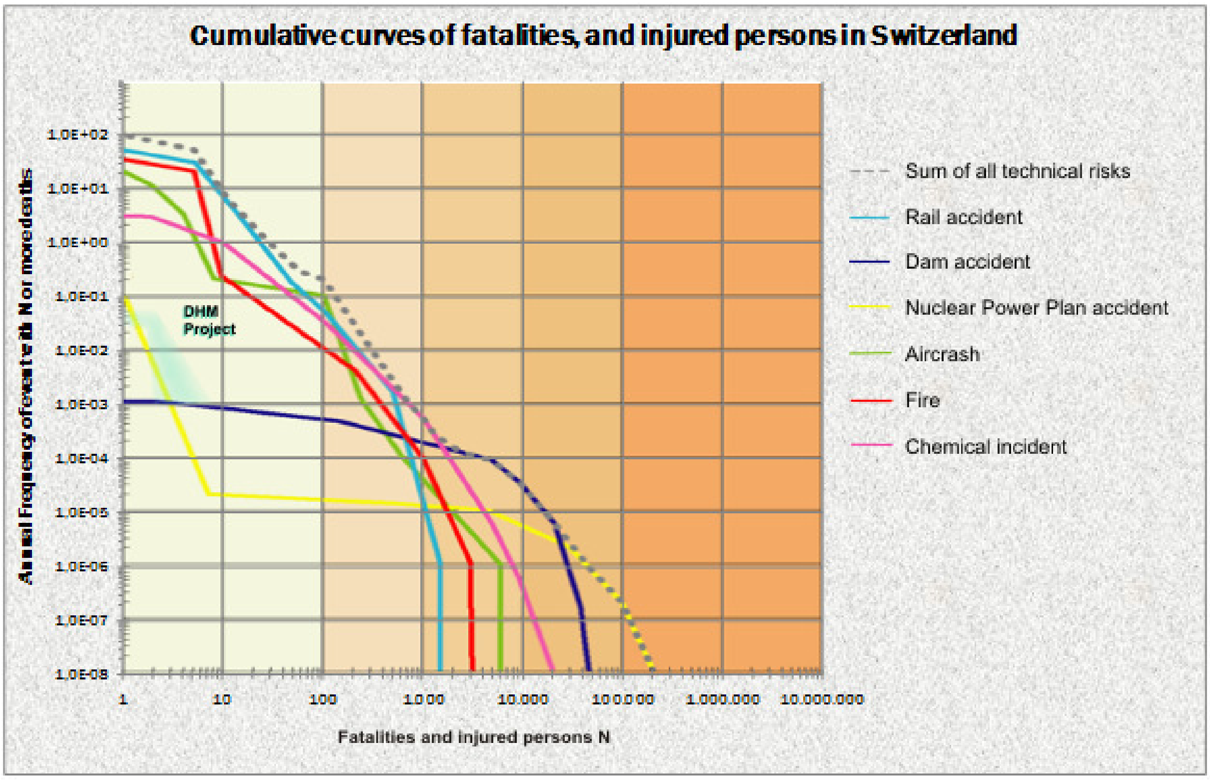
Figure 3-11 shows a comparison of the number of fatalities Basel DHM project with other technical facilities, industries or means of transportation in Switzerland. Although the curves shown are for Switzerland, any of those facilities could be present in Basel. Hence, a comparison is valid (see also chapter 3.4.1.2 for details). The DHM curve is blurred to reflect the small, almost non-quantifiable increase in potential human fatalities, and the large associated uncertainty. All colour lines with the exception of the Basel DHM line are from the KATARISK study. Note that for clarity purposes the KATARISK graph was not spray-painted.

The graph shows that incidents from fires, airplane crashes train accidents or an incident at a chemical facility somewhere in Switzerland are a) more risky and b) are likely to kill by far more people than a re-initiation of the DHM project. The DHM project is probably about 10 or more times safer than trains, flying, fire, and chemical installations. Dams in Switzerland seem to be designed to standards close to ANCOLD, and therefore are safer than if the DHM project was to be re-initiated from a fatality viewpoint.

Note the DHM project is almost similar to the nuclear power technology from a fatality point of view, with the exception that the DHM project is unlikely to create a large earthquake, which would result in similar deaths as a large NPP incident. Hence, the paint brushed line for the DHM stops. In fact, a re-initiated DHM project poses a similar level of risk as are expected to emanate from infrequent, minor incidents of Swiss NPPs. However, the energy benefit from a NPP is significantly (a hundred times or more) greater than from the DHM project.

Figure 12 shows that based on fatalities the geothermal project would be positioned favourably compared to many other technological risks.

Figure 12: Comparison with technical risks in Switzerland.



3.4.3 Financial Risks

When assessing a new technology it is warranted to assess potential damage costs resulting from this technology. Ideally, FD curves for other technologies would already exist, however, specific FD curves are hard to establish for a number of reasons. Governments usually action measures to protect the country's population, and determine the costs of protecting a human life in terms of Willingness-To-Pay (WTP). All other issues are usually dealt with by doing an economic benefit cost study. For environmental projects, the US government prescribes to have a benefit/cost ratio (BCR) of greater than 1 before financing a new project.

The question there is whether secondary effects are measured or not. Private companies usually would like to see BCR's much greater than 1, before taking on projects. Overall, there are no published studies to the author's knowledge that outline technology or risk based comparisons in the form of FD curves.

The following sections will primarily compare the costs of socially accepted technologies in Switzerland from the KATARISK study (BABS 2003) using FD curves with the FD curves derived from the DHM project.

3.4.3.1 Energy Projects

The ENSAD database by PSI contains only a few reports on monetary damages for past accidents, with no data on likelihoods of occurrence. Also the extent of damage which is included in the monetary summation for each case might vary depending on data sources, etc. Some data may reside within re-insurance companies and may cover direct losses, indirect losses, and secondary costs, or any portion of the three costs types. Therefore, a cost comparison with the DHM project is not credible.

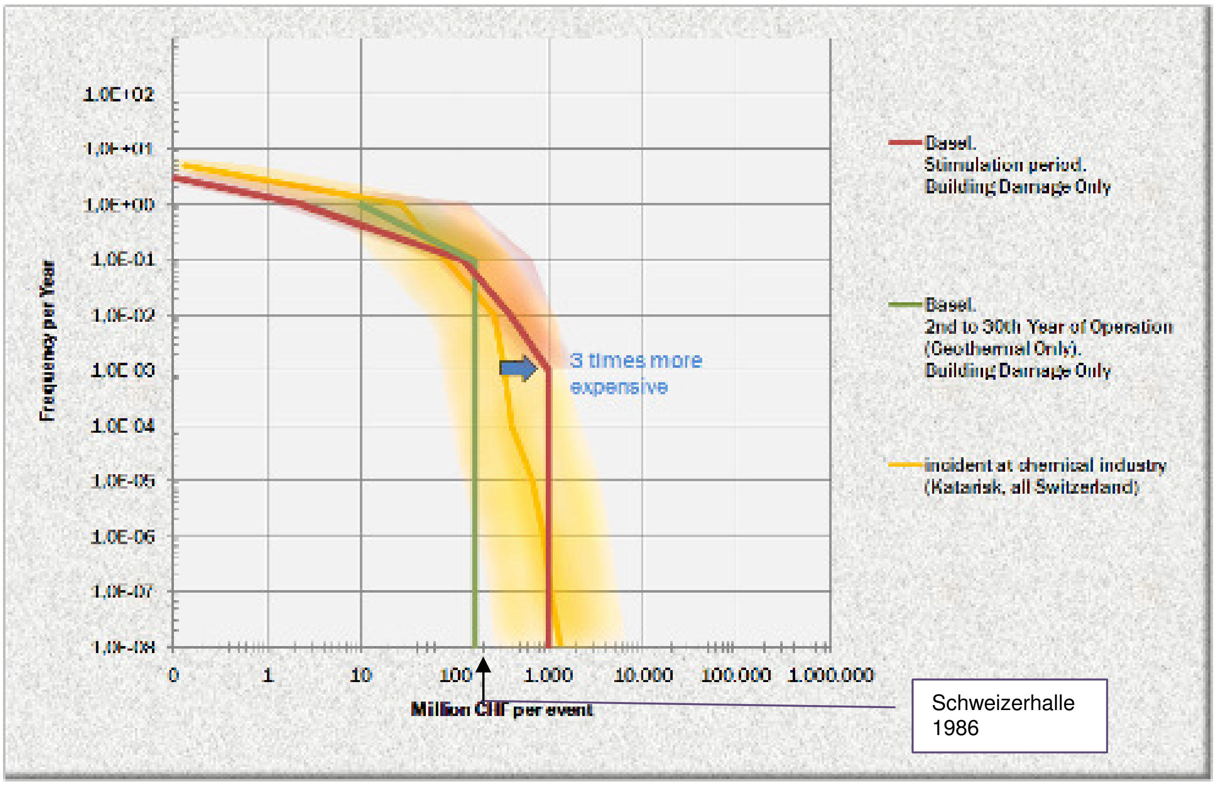
3.4.3.2 KATARISK

3.4.3.2.1 Comparison with Chemical Industry Risks

As Basel is Switzerland's centre for the chemical industry and contains about 25% of all chemical plants in Switzerland, the risk of the geothermal project was compared to the risks caused by the chemical industry.

Figure 13 shows FD curves for the chemical industry in Switzerland and the geothermal project. One can infer that the costs derived from risks of the chemical industry are similar to the costs derived from installing and operating the DHM project in its original design. The Schweizerhalle event in 1986 which polluted 5km² of the Rhine River, 0.5 km² of groundwater resources, killed 50 tons of fish, and caused dread in the residents (50,000 people were alarmed) is also shown on the graph. In today's valuation its cost would amount to about 230 million CHF.

Figure 13: Chemical Industry risks versus DHM Project.



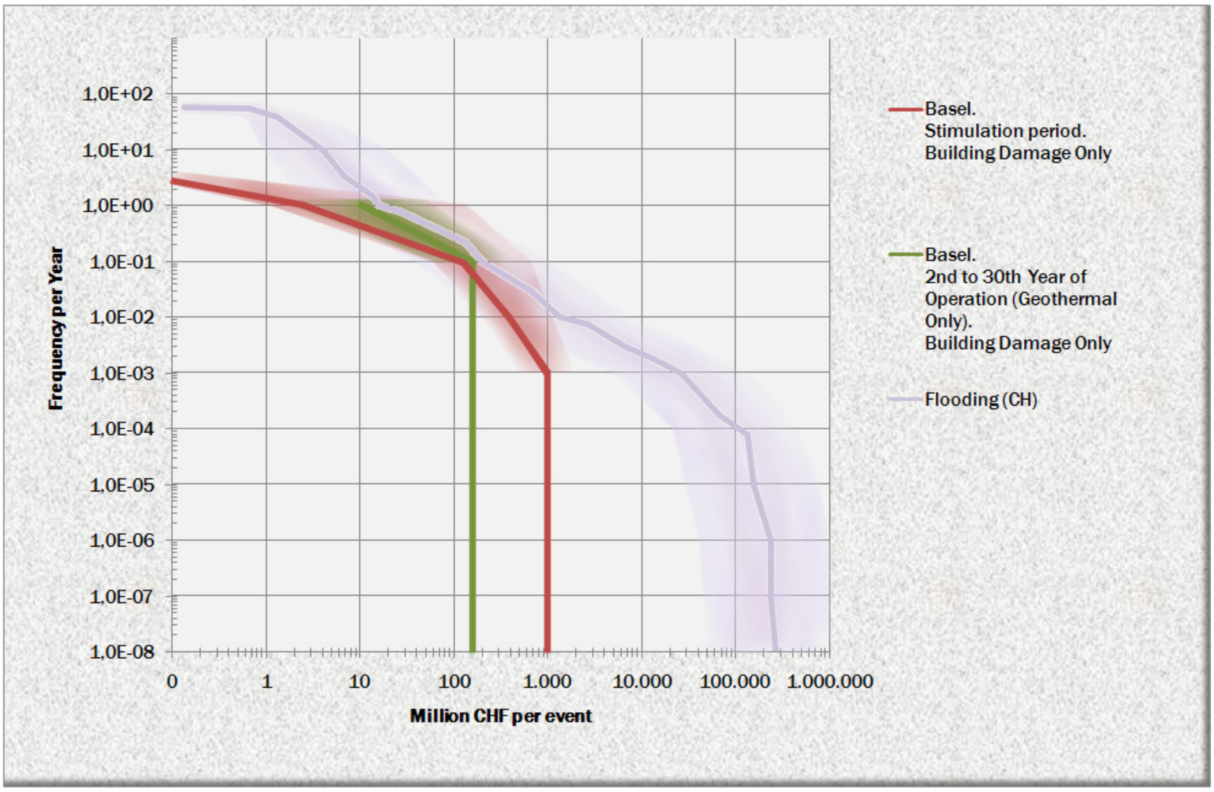
The FD curve of the DHM project indicates that re-initiating the DHM project in its original design has a 10% chance of producing similar costs as the Schweizerhalle event. During the stimulation period, the DHM risk cost is even more expensive than all risk costs from a cross-section of facilities in the chemical industry. This is explainable as the chemical plants only rarely cause widespread damage to buildings beyond the chemical facility.

3.4.3.2.2 Comparison with Flooding Risks

Switzerland is subject to recurring flooding events due to snowmelts and significant rain events. This is a risk that is easily comprehended and widely understood. Hence, the comparison of the geothermal project was made, albeit knowing that flooding is considered as an Act of God and only partially caused by man-made activities such as erecting cities near rivers. This comparison is also derived to demonstrate the order of costs, which would be derived from a DHM project.

From Figure 14 it can be seen that the costs associated with flooding are significantly higher than the costs associated with the DHM project in its original design, however only at frequencies above 1 p.a. and at frequencies below 0.1 p.a. The comparison shows on the other hand it shows that there is an expected annual risk cost of about 20 million due to flooding in Switzerland, and a 10% p.a. chance that the risk cost could be above 200 million CHF. This means that the flooding risk curve from Switzerland follows a line of equal risk with a risk level of about 20 million CHF, which when compared to the risk level of the DHM project of 10 million CHF is only about twice as expensive in the 100% to 10% annual frequency range.

Figure 14: Flooding risks versus DHM Project.



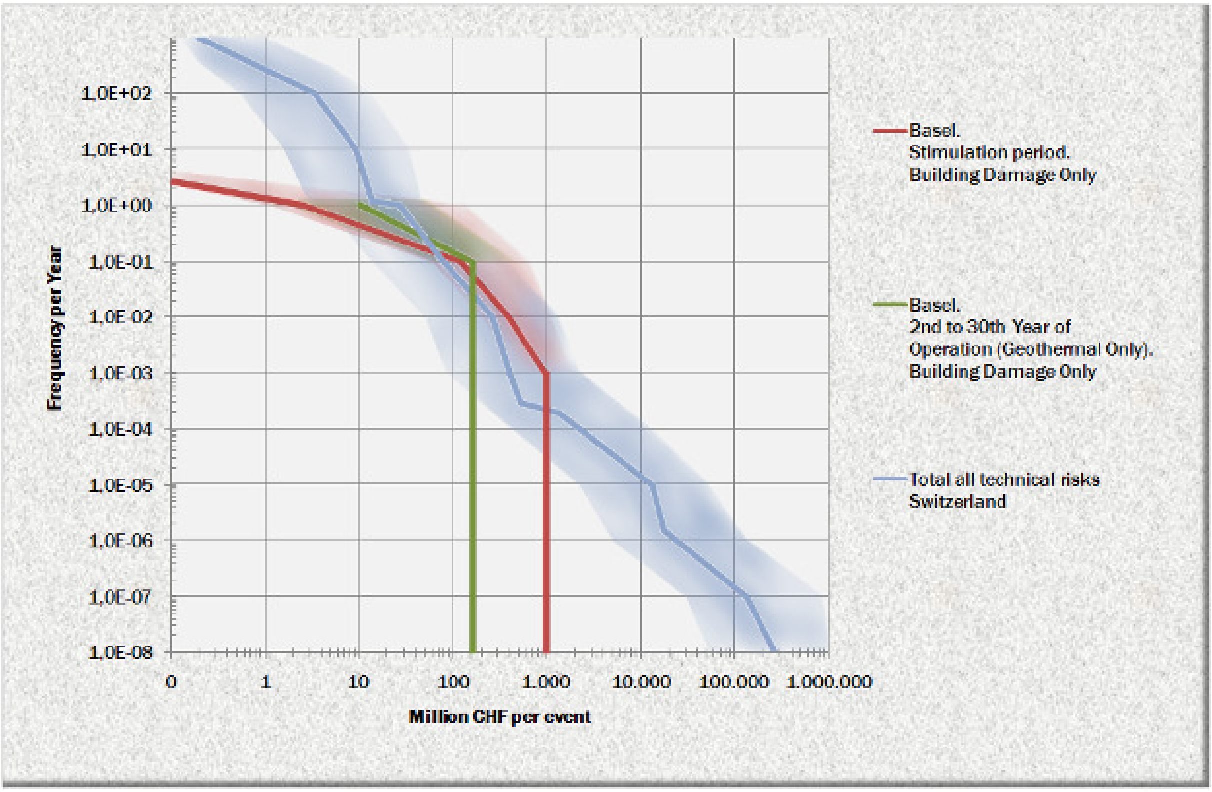
3.4.3.2.3 Comparison with Technical Risks

KATARISK also provides a summary FD curve covering the vast majority of industrial facilities and transportation related infrastructure, including railway accidents, emergency at dams, nuclear incidents, air traffic incident, fire, and chemical incidents (in KATARISK referred to as technical risks) in Switzerland. This can interpreted as being in a city, which has all of those facilities. This FD curve is shown in the graph below (Figure 15).

We can also see that the risks associated with the short stimulation period for the geothermal project and in parts for the operation phase fall outside the technical risk cost “envelope” in a range between a one in 10 chance of occurring and a 1 in a thousand chance of occurring. In this range, the costs of the geothermal project would be 2 to 5 times higher than all costs caused by the technical risks considered by KATARISK. The operational risk cost is similar to that for technical risks over the range of 0.1-1 p.a. (10% to 100% p.a.). We see that only for the high frequency events, the costs related to the technical risks are significantly higher compared to the costs that would be caused by the geothermal energy project. The same conclusion can be drawn for rare events (below frequencies of 10^{-4} p.a.; i.e. events that have a 1:10,000 chance of occurring annually).

Figure 15 indicates that all technical risks, covering a wide range of industries and facilities, frequently cause similar, and potentially lower costs than the DHM project in its original design.

Figure 15: DHM project versus a summation of technical risks Switzerland.



Chapter 3.4.3 demonstrates that

- The FD curve for the DHM project lies approximately on a line of equal risk of 10 million CHF per year. This indicates that the DHM project has a 10% chance per annum of incurring costs in the order of 100 million CHF, which is higher than the original investment costs of about 80 million CHF, and significantly higher than the 0.6 million in projected annual profit.
- The damage costs associated with the DHM project are likely to be similar or greater than that associated with a wide range of technical facilities.
- The FD curve of the DHM project indicates that re-initiating the DHM project in its original design has a 10% chance of producing similar costs as the Schweizerhalle event.

It is important to understand that there may be lost opportunity costs in not proceeding with the DHM project that have not been accounted in the above assessment. However, as the previous chapters outlined and based on the cost data that is available, from a commercial viewpoint the DHM project could be financially fatal for any investor. The only potential way of pursuing the project would appear to rest on whether this project is considered important enough from a national perspective for following the national strategic energy supply program by supporting this new energy generating technology. Should the decision be to proceed with the project, it would seem necessary to have significant risk guarantees in place before starting.

The following two chapters provide an orientation for the government from a national perspective whether the DHM project should be supported. First, a benchmark with the Basel GDP is provided, followed by a benchmarking with social spending against with to gauge the tolerance of society to everyday risks.

3.4.3.3 Benchmarking with Basel GDP

"Table 2: Modelled Insured Value Loss from AP 5000." in chapter 2.3 tabulates the cost benchmarking with the Basel GDP. It is evident that when having a pessimistic view on the project (especially when considering the stimulation phase) the insured building value loss associated with the project could be as high as 1.5% of the GDP of Basel, which is significant, even to the wider tri-national region. However, it must be noted that a 600+ million CHF damage to buildings with a 15% of not being exceeded.

The ratio of the most probable insured value loss and the GDP of both Cantons of Basel (about 46 billion CHF in 2008) is estimated 0.1% for the stimulation period, and about 0.01% for the circulation or operational period. Note numbers are neither discounted nor inflated.

It is beyond the scope of this study to assess the impact from the DHM project risks on a cross section of the region's employers and the economic activity.

3.4.3.4 Benchmarking with Social Spending

To express the modelled risk costs (as insured value loss) arising from an induced earthquake in a more understandable form (i.e. to make those numbers more comprehensible), such costs were compared with general societal costs. Note that those costs are occurrence costs, i.e. they have a likelihood of one or close to one to eventuate. Further, due to the uncertainties contained, the benchmarking provided gives a general indication only.

Societal costs may be caused by smoking, work-related impairment of health, road accidents, recreational accidents, sport injuries, etc. These examples are for benchmarking as they are an immense cost factor for the public and social systems of any country.

The societal costs for Switzerland are presented in Table 7. Costs include tangible (material) costs and intangible costs (e.g. pain, consumption losses, etc.) where available. Please note that intangible costs are highly uncertain and some estimates were developed based on WTP studies. An inflation rate of 2.7% p.a. was applied to the conclusions from earlier studies to produce 2009 costs that might be benchmarked against the insured values losses associated with a potential re-initiation of the DHM project.

Table 7: Tangible and intangible socio-economic costs in Switzerland [in billion CHF; numbers are rounded].

Year of study	Impacts	Tangible costs (year of study)	Total costs (tangible + intangible; year of study)	Tangible Costs in 2009 valuation	Total costs (tangible + intangible; in 2009 valuation)
2004	Work-related impairment of health (1 year)	1.6 (estimated)	10	1.8 (estimated)	11.4
2004	*- hereof occupational accidents*	*no data*	*1.7*		*1.9*
2003	Road accidents (1 year)	6.5	14	7.6	16.4
2003	Sport injuries (1 year)	2.1	13.1	2.5	15.4
2003	Home and recreational accidents (1 year)	4.5	27.2	5.3	31.9
1995	Smoking (1 year)	5	10	7.3	14.5
2003	Alcoholism (1 year)	1.5	6.9	1.8	8.1
Total				**26.3**	**97.9**

To adjust those costs to the study region, the following assumptions were made:

- The population in the region of Basel (incl. German and French side) is about 542,000 which was used for calculation purposes as representing a 6.8% portion of the population of Switzerland;
- The social structure is similar in the region as in Switzerland; therefore the German and French areas can be treated similarly;
- An inflation rate of 2.7% was used for the calculation to compare the 2009 earthquake estimates results to the originally reported costs at the time of study.

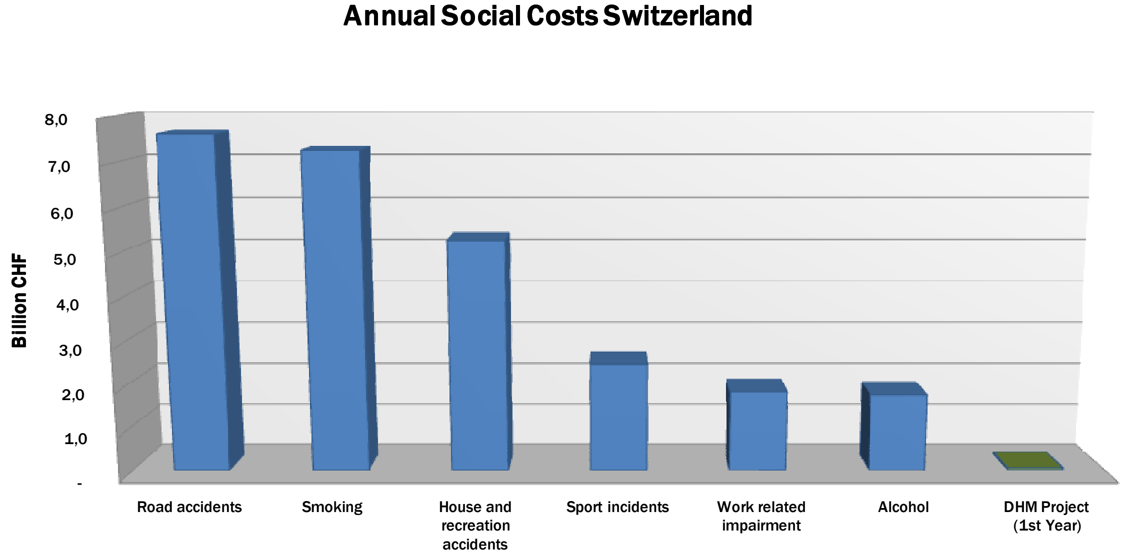
The total social costs for Basel expressed in 2009 CHF, pro-rated on population in accordance with these assumptions, are presented in Table 8.

Table 8: Pro-rata adjusted tangible and intangible socio-economic costs for the study area from Switzerland data [in billion CHF, numbers are rounded].

Impacts	**Tangible costs**	**Total costs (tangible + intangible**
Work-related impairment of health (1 year)	no data estimate: 0.12	0.57
- hereof occupational accidents	*no data*	*0.13*
Road accidents (1 year)	0.52	1.11
Sport injuries (1 year)	0.17	1.04
Home and recreational accidents (1 year)	0.36	2.17
Smoking (1 year)	0.49	0.99
Alcoholism (1 year)	0.12	0.55

The following diagrams show the proportion of induced earthquake risk costs for the first year of operation benchmarked against Swiss and Basel region social costs (1-year-consideration, tangible costs):

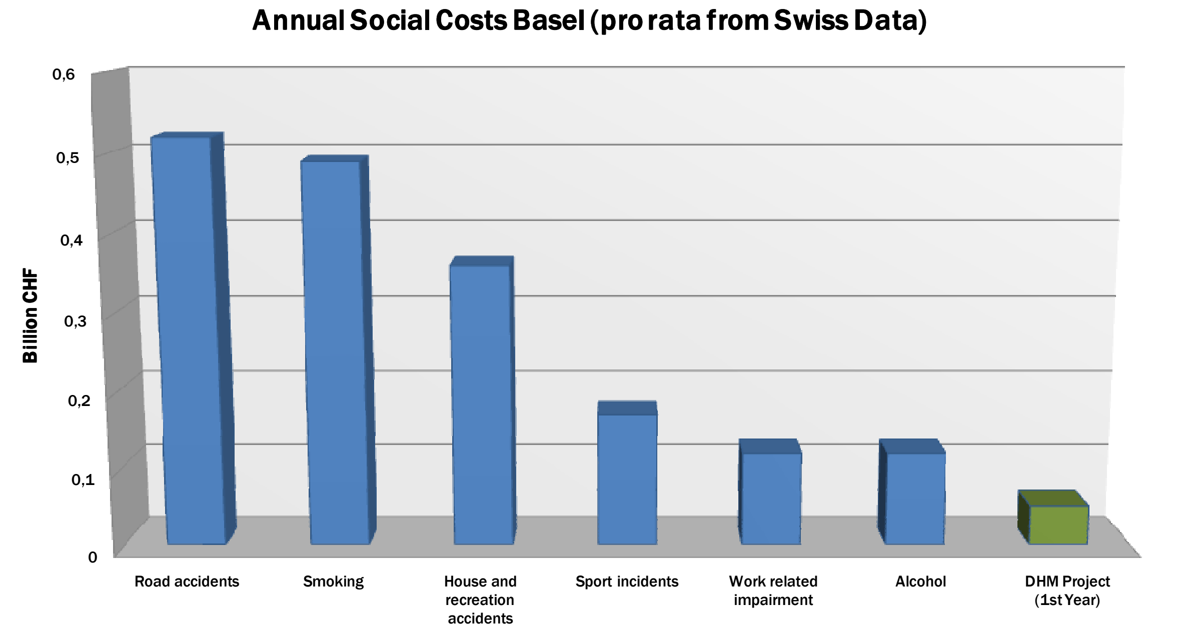
Figure 16: Social Costs Switzerland benchmarked against most probable insured value loss.



	Road accidents	Smoking	House and recreation accidents	Sport incidents	Work related impairment	Alcohol	DHM Project (1st Year)
Swiss Capital Expenditure	7,6	7,3	5,3	2,5	1,8	1,8	0,05

In summary, Switzerland is spending about 5% of its GDP (26 billion of 520 billion) for social costs related to work-related impairment of health, road accidents, sport injuries, home and recreational accidents, smoking, and alcoholism. The comparable Basel expenses are estimated to 1.8 billion CHF (pro rata adjustment). As can be seen from Figure 17 alcohol related costs or costs associated with work accidents are at least twice as costly for the society compared with one year of operating the DHM project. Societal costs for smoking or road accidents are tenfold the costs of operating the DHM project.

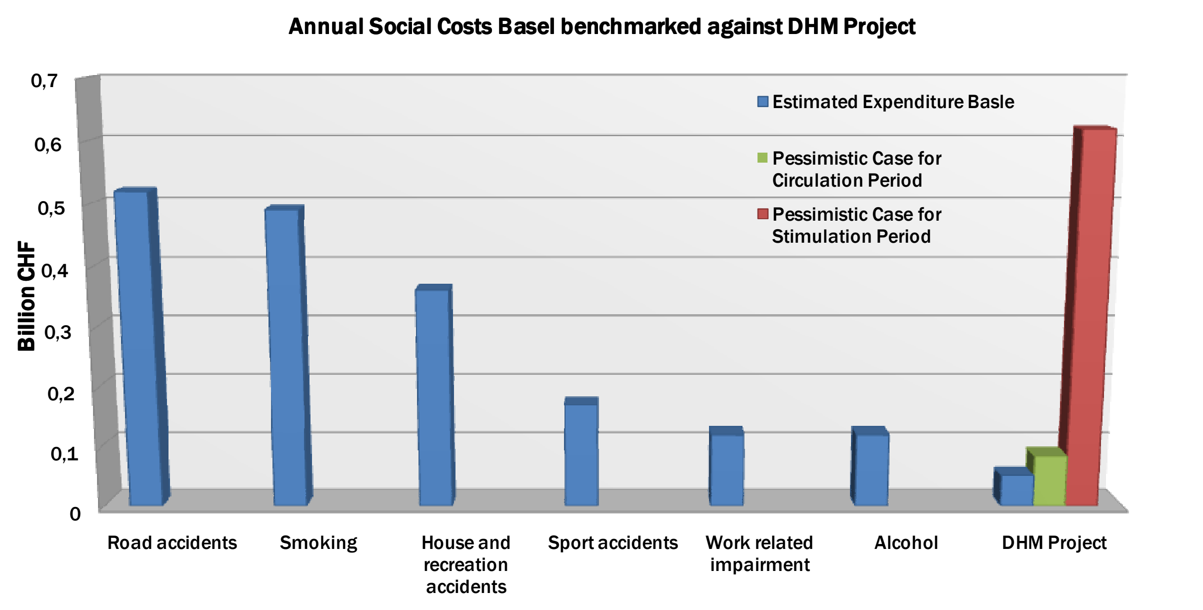
Figure 17: Basel Apportion of Social Spending benchmarked against DHM Project.



	Road accidents	Smoking	House and recreation accidents	Sport incidents	Work related impairment	Alcohol	DHM Project (1st Year)
Estimated Expenditure Basel	0,52	0,49	0,36	0,17	0,12	0,12	0,05

When considering a pessimistic case for the stimulation period of the DHM project using a risk cost of about 620 million CHF, the project would benchmark unfavourably against the social costs (they have a likelihood of 1). This is because the high risk costs associated with the stimulation phase, which have a 15% chance of not being exceeded. Note that the benchmarking against the GDP and the societal spending does not by itself justify any decision on the projects acceptability. Figure 18 outlines this concept.

Figure 18: Apportion of Social Spending benchmarked against Pessimistic Case of DHM Project.



	Road accidents	Smoking	House and recreation accidents	Sport accidents	Work related impairment	Alcohol	DHM Project
Estimated Expenditure Basle	0,52	0,49	0,36	0,17	0,12	0,12	0,05
Pessimistic Case for Circulation Period							0,083
Pessimistic Case for Stimulation Period							0,62

3.4.4 Extractive Industries for Comparison

A comparison with extractive industries is warranted as the DHM project is in fact a heat mining project. It has usually a limited lifetime until the reservoir is depleted. For deep geothermal projects, this time frame is estimated to about 30 years. After that time, the reservoir is depleted. Therefore, recent mining related accidents are cited and existing guidance on mining projects has been used as an aid for orientation purposes until such time when governing documents are developed.

Earthquakes are not the result of geothermal technologies only. As described above, most technologies which influence the deeper underground by destabilizing the pre-existing physical balance may cause seismic events. Underground mining of coal, minerals, and ores can also induce earthquakes from various activities such as blasting, or collapsing voids or shafts from which the materials have been extracted.

3.4.4.1 Earthquakes from Mining Activities in Germany

In Germany, mining of black coal is currently performed in a few mines in North Rhine-Westphalia and in the Saarland. Mining in those areas leads to subsidence (i.e. depressions created at surface from collapse of underground voids) as well as seismic events.

In February 2008, a magnitude M_L 4.0 earthquake occurred near Saarlouis in the German state of Saar as result of coal mining processes (Primsmulde mine). Previous earthquakes were not that strong. This particular event damaged more than 100 buildings; nobody was injured. Some chimneys collapsed and a car was hit by rubble. About 300,000 to 400,000 people live in the region. As a direct consequence of this event, the coal mining activities were reduced to a minimum level, and the closure of the mine was brought forward in time.

A magnitude 2.8 event also resulted from coal mining processes occurred in North Rhine-Westphalia near Moers on October 7, 2009. Minor damages were reported. This particular mining field is subject to frequent tremors. Earlier tremors with appreciable magnitudes (2.7 and 3.1) were measured in September 2009, and July 2009. The area around Moers is populated with about 174,000 inhabitants.

3.4.4.2 Comparable Effects from Mining Activities

As there are no guidelines in Switzerland regulating effects from subsurface stimulation such as fracing a reservoir, this chapter describes how other countries are dealing with mining related activities. Although in this study the diagram (Figure 19) serves for orientation purposes, it may be considered useful by the government for deriving guidelines for geothermal projects.

As a reference, the Basel 2006 earthquake by the DHM project reached intensities of V, which would correspond to a peak ground velocity (pgv) value of about 25 mm/sec and therefore being rated strongly perceptible in Figure 19. Should the DHM project be re-initiated, further tremors of at least an intensity IV could be expected. There is a 10% chance of an intensity V.2 to V.5 event, and there is a 2% chance during the circulation period of experiencing an intensity VI.5 event.

3.4.4.2.1 Resident Amenity Considerations

Extractive mining activities may have an impact on residents resulting from their blasting activities and other construction related activities such as pile driving, which generate relatively low levels vibrations. Many towns were originally constructed close to mining sites, but as the mining operations grew, the direct impacts on the residents increased. Research and regulations followed and comparisons to the present “deep heat mining project” can be drawn.

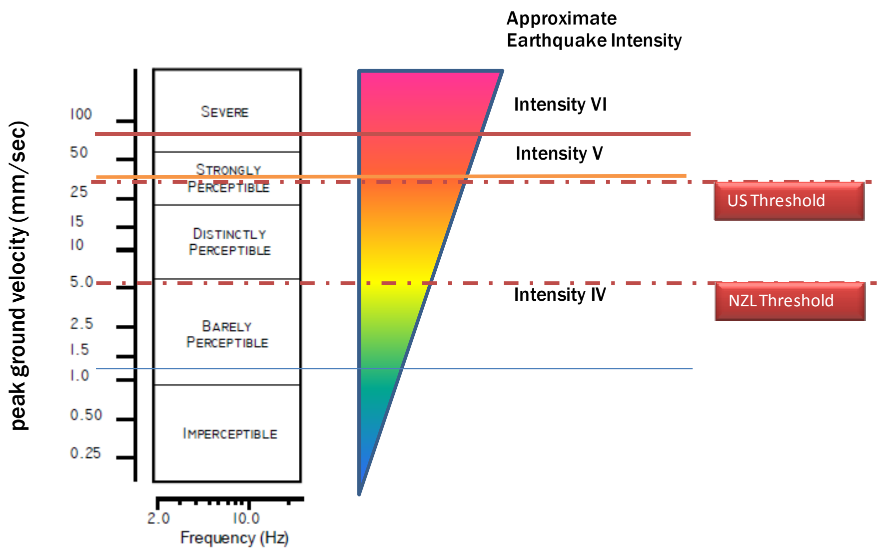
The vibrations are assessed in peak particle velocity (referred to as peak ground velocity, pgv). This is a measure related to the ground surface velocity and is dependent on the frequencies of the vibrations caused (in Hertz) and the peak acceleration. The 2004 US Federal Office of Surface restricts ground vibration at any dwelling, public building, etc to less than 32 mm/sec. If a proponent wants to propose an alternative limit, he must include information that affirmatively demonstrates that ground vibrations above or at the proposed alternative peak particle velocity level will not damage the building or structure. Historic buildings may only tolerate lower pgv’s where as bridges may tolerate higher pgv’s.

Australia and New Zealand have typically much lower tolerable limits of 5 to 10 mm/sec near populated areas, the limits being set to protect the population’s amenity, which is significantly lower than that required to protect structures from either cosmetic or structural damage. In

Switzerland, there is no regulation, which covers the impact on people. As a reference, the German norm DIN 4150/2 can be used. It prescribes that rare events can have a maximum pgv of 6mm/sec in a residential area.

Figure 19 below outlines the respective threshold values, and parallels those with earthquake intensities. An approximation of the earthquake peak velocities as stated in the earthquake monitoring and vulnerability analysis (ETH, SED 2008) was used. The underlying Wiss diagram also outlines the perception on the vibrations by the residents. The 2006 Basel earthquake would fall into the strongly perceptible class.

Figure 19: Mining Related Vibrations compared to Earthquakes.



3.4.4.2.2 Building Damage Considerations

In the Swiss norm on vibration effects on buildings (SN 640 312 a, 1992), a pgv of 15mm/s for frequencies below 30 Hz is provided as a guidance value. Depending on the frequency of occurrence of the vibrations, this value should be further reduced. No further guideline was available for an assessment of building effects.

3.4.4.3 Summary

- When assessing the residents' amenity, the guideline and threshold values generally applied in other countries would rate the levels of vibration associated with the DHM tremors as unacceptable. For example, the guideline values for Germany (6mm/sec), Australia and New Zealand (5-10 mm/sec) would be exceeded at least twofold.

- From the Swiss norm on vibration effects on buildings, a similar earthquake would not be tolerable when considering the guidance value of 15 mm/sec.
- The above demonstrates that any project, which would generate intensity V earthquakes, would not be acceptable from a social amenity perspective in many countries.

3.5 Risk versus Benefits

3.5.1 Risk Cost versus Profit

When stimulating the reservoir the most probably risk cost is about 40 million CHF. During the circulation period, the DHM project produces an annual cost of about 5.6 million CHF. Further, the DHM project has a 10% chance to produce costs in the order of 100 million CHF.

In any case all those risk costs are higher than the 0.6 million in planned annual profit. Further, there is a 10% chance that costs of 100 million CHF eventuate, which are higher than the original investment costs of about 80 million CHF.

It is important to understand that there may be lost opportunity costs in not proceeding with the DHM project that have not been accounted in this assessment. This starts with pure energy supply costs for energy derived from other technologies, but may go as far as a signalling effects for other geothermal projects.

3.5.2 Risk Cost Effect on Energy Cost

When apportioning the mean total risk cost of about 210 million CHF to the energy produced, the effect on the total energy produced over the 30 years would be around 0.05 CHF/KWh. When apportioning the risk cost only to the amount of electricity produced this additional external cost would be around 0.4 CHF/KWh.

Reportedly, there are plans to switch off parts of the heat distribution system in Basel-Kleinhüningen in the not too distant future. But the in-ground heat distribution system must be maintained if the project was to go ahead. Otherwise, additional costs will incur.

3.5.3 Social considerations

For heat and electricity supply of 5000 households, it is expected that during the stimulation period a total of 1,000 ± 50% houses might experience damage in one form or another (see Appendix 3). As only 5,000 households would directly benefit from the DHM project compared to 542,000 residents who would be exposed to the tremors by feeling them in their daily life is not a favourable ratio. Further, as the area where the damage occurs does not necessarily correlate with the area of the planned heat distribution, inequity between benefactors and risk bearers is created.

4 SOCIOLOGICAL STUDY

This chapter provides a description of the general risk perception of the DHM project in Basel. In the following, certain influencing social factors will be examined in detail and their importance for risk perception of HFR projects will be specified.

The sociological study focussed on the perception from the industry viewpoint and assessed only the general viewpoint of the population for a variety of different reasons. A lower emphasis was placed on community perception as a concurrent communication project focused on this area and had been launched and performed by the Stiftung Risikodialog ("Trust for Risk Communication"). The publicly available results from the study by the Stiftung Risikodialog were available for inclusion in this study.

Our observations were derived from interviews and participation in the public hearings (at the time of funding of study and participation in one session of the public consultation hearings). Further as described in chapter 1, a meeting with business representatives was conducted at the premises of the Chamber of Commerce in Basel. A questionnaire was prepared for gathering information from the meeting attendees (refer to Appendix 4). In section 4.3 below, statements of representatives of all three groups are presented conjointly. As deemed appropriate, the quotes have been completed with single words for the sake of comprehensibility. The authors assume responsibility for the exact repetition of the statements.

4.1 Past Events

Public reaction to the DHM-induced earthquakes in December 2006 and January 2007 was influenced by worry and fright. Immediately after the tremors, numerous calls reached the control rooms of the police and fire service. The tremors had aroused Basel's population, reminding it of the region's elevated natural earthquake risk. Unsurprisingly, the quakes were the hot topic of numerous letters to the editor, blog entries, and discussions among the population. The tremors and resulting damage motivated people to form a citizens' initiative "EEG-EEG ". This organisation campaigns for reasonable compensation for all damage resulting from the project, and calling for more transparency in the decision-making process on how to proceed with the geothermal plant at the location of Basel (cf. position paper www.eeg-eeg.ch).

To support risk competent decision-making in politics, the government authorised the Stiftung Risikodialog to enter into a dialogue with the population. Therefore, in May 2008 several dialogue events took place with the participation of members of the Grosser Rat (Great Council of the Canton Basel City), political parties, and the Commission for Risk Evaluation. Those events were held in June 2009.

Those people directly affected by the project-related tremors have a high interest in the DHM project and form the foundation of EEG-EEG as demonstrated by those meetings. However, based upon the meetings, it appears that the people from Basel have not finally formed their opinion about the project. Moreover, they show interest in gaining a broader understanding of the associated risks through various assessments of the project. Based on the media-related communication about the drillings and the quakes, one might reasonably assume that population's current negative attitude towards the project may be caused by a lack of information and involvement in the project in the forefront.

4.2 General Findings on Risk Perception in Basel

4.2.1 General Risk Perception

The intuitive perception of risks is determined not only by rational calculation of probabilities and the costs for (if any) occurrence of damage (Slovic 1987; Böhm 2008). Among the other factors that influence risk perception is how equitably people perceive the distribution of a risk's cost and benefits, how capable they feel in personally exercising control over this risk, how acquainted they are with the risk, and if they have the chance to hold a person or institution liable for possible damages (Renn 1992).

In the following chapter, certain influencing factors will be examined in detail and their importance for risk perception of the previous planning process will be specified.

Apart from the costs and-benefits of a given technology, risk perception also depends on the value ascribed to the potential personal benefits and losses. Further, it depends how their distribution is perceived by the people involved. Often-mentioned in relation to geothermal energy is the benefit of holding a sustainable source of energy. That raises the question of whether, in the opinion of the population, this benefit can be derived solely from the given technology or if there are alternatives with less negative impacts and similar benefits.

The perception of costs varies depending on the perceived severity, the reversibility, and the probability of the occurrence of damages. The essential question with respect to the DHM project is: what likelihood of reversible damages or large earthquakes do the residents expect?

Worry and fright as reported in several blog entries, letters to the editor, and media releases and the high level of interest in the dialogue events indicate significant concern among the population. The concerns are less about the tremors that have already occurred than they are about apprehension of a potentially hazardous quake in the future. The uncertainty of estimates by experts as revealed in the media gave an additional boost to those fears.

If the population ascribes the ability to cause a disaster to a technology, the perceived risk is increased. For the implementation of such a technology to gain wide acceptance there has to be, trust in the public institutions responsible for the project. It is important to assure people that these public institutions can do handle the associated risk with reasonable care and in a manner that minimises the probability of loss occurrence to its lowest.

The issue of using Basel as the location for the pilot trial not only has to be resolved for the scientific community, but also has to be convincingly communicated to the general population. It will be necessary to convince people of the economic benefit of the DHM project for Basel, while also convincing them that their vulnerability to the negative effects of the project can be minimised.

If the issue of location cannot be resolved or communicated satisfactorily, it could raise suspicion that in addition to the stated objective of obtaining a sustainable source of energy, other unknown interests may exist that favour the location and/or specific groups.

4.2.2 General Prerequisites for Decisions by the Population

Public participation in decision-making processes is essential for gaining wide acceptance that risk has been adequately accounted for in the decision. The feedback at the public meetings confirms that the population is seeking such an exchange. In the EEG-EEG position paper, a transparent, widely accepted decision-making process is demanded as well as a neutral and independent point of contact for handling any and all questions and problems that may arise during the project. As indicated above, there has to be room to exchange information about costs and benefits of a technology and their fair distribution for the technology to be able to gain the favour of the citizens, thus enabling the implementation of the project.

The process for damage compensation therefore has to be reconciled with the population. Furthermore, transparent communication and mutual exchange can improve the trust in public authorities and their regulation of risks. Besides, the ambiguity and reliability of sources of information has to be emphasised. This is the only way to provide trust in the responsible institutions. How far this trust persists cannot be stated at this point. This could be subject of further empirical studies.

4.3 Findings from Interviews with Industry Representatives

4.3.1 Personal Perception

Industry representatives operate as human beings as well as businessmen. In this chapter, they depict only their personal impressions and do not take an industry viewpoint. This view will be shown in chapter 4.3.3.

Concrete indications of the importance of public information and public participation resulted from group interviews with business representatives from the Basel region. They were asked to give their personal assessment while particularly addressing the issue of communication before the quakes on the one hand and the communication after the quakes on the other. The majority of them had been sufficiently informed although some individuals were critical that they had not been adequately informed of the whole extent of the project.

“Everyone who was interested knew that there were drillings, and that they were drilling down to 5,000 metres. Everyone who wanted to know could read it in the BaZ. Thus, no one can say it was not communicated. But the problem is, people are not interested till something goes wrong and then there is a great hullabaloo about it. But it had been communicated.”

”It is exceedingly deficient for somebody who lives here […], I had known that there is a geothermal project, but I had no idea in which depths it was taking place and which technology was applied, that is the main criticism.”

The interviewees' personal impression was that after the quakes the communication on the part of both, the project leaders and the government, was perceived as deficient. The feeling of not having been sufficiently informed aggravated the negative effects of the quakes significantly for some individuals and severely impaired their acceptance of the whole project.

"After the bang I took a guided tour to the site and was very surprised at first that no project manager was there to respond to the numerous questions. There was a complete absence of risk dialogue, which in my opinion jeopardised the people's acceptance for the project."

Another relevant parameter for the geothermal project is the possibility of personal risk control. Obviously, the impression of lacking information before the project contributed to the public indignation as criticised on various occasions. Lacking information prior to significant, negative consequences may give the impression to the affected persons that decisions were made without their inclusion and that they have no influence on the proceedings. This impression can be met with comprehensive information in the forefront of quakes or better still by involving the affected people in specifying the date of the drillings. Another possibility of participation is the civil right of co-determination by holding a principle vote on the further proceedings. This increases the perceived personal risk control and further contributes to considering the risk assumption as unsolicited.

4.3.2 Risk Perception from Industry Viewpoint

4.3.2.1 General Perception

Generally, geothermal energy is perceived as a sustainable and promising technology. Geothermal energy is not only being compared with sustainable technologies such as utilization of solar power including photovoltaic but also to other large-scale technologies such as nuclear energy. The potential success of geothermal energy depends on the future acceptance or the refusal of nuclear energy. Geothermal energy is considered an additional source of energy with a lot of development potential. Thus, the industry representatives generally look favourably upon geothermal energy, which was certified by the interviews held at the Chamber of Commerce in Basel

"[Geothermal energy] is the only additional source of energy. Hydro power is depleted and the remaining sources are prohibited. Nuclear power [gesture expressing doubts], wind power does not apply to the location of Switzerland, geothermal energy has the greatest potential."

"Geothermal energy will profit from anti-nuclear activists becoming more important."

For the interviewees the importance of geothermal energy is not only restricted to the DHM project in the Basel region; it influences the energy scene throughout Switzerland, regardless of the geothermal plant's location.

"It's not only [important] for the region. It [geothermal energy] has great importance for the whole energy scene, throughout Switzerland."

According to the business representatives, unlike nuclear and gas-fired power plants, the negative outcomes of geothermal energy are immediately perceptible in form of ground tremors and therefore can trigger off immediate and stronger reactions and fears. They did not mention that their businesses were linked to geothermal energy in any way, for instance via CO2-tax. They regard geothermal energy as an innovative and sustainable technology that is eligible for funding.

"With a nuclear power you have an ultimate storage in the ground, with gas-fired power you have the terminal storage in the air, and here [with geothermal energy] you directly feel the consequences. That's the difference."

In means of risk perception, according to the business representatives, fear and insecurity about further consequences play a decisive role within the population. Against the background of the big Basel quake in 1356, the insecurity is considered to be great. From the point of view of the business representatives this insecurity may be compared to reactions to other widely accepted technologies such as genetic engineering. From a natural scientific perspective, these technologies are acceptable hence, the risk involved is reasonable. The businessmen consider the public to be too terrified of a hazardous quake to gain acceptance among a majority of the people to continue the drillings. Although the disaster in Schweizerhalle in 1986 had far more serious consequences and the chemical industry regained its acceptance in the aftermath, this seems unlikely in the case of the DHM project from an industry viewpoint.

"As a scientist you are used to living with uncertainties. Personally, I am in favour of geothermal energy. But in my opinion the ground motions are not maintainable although I personally would accept them. This discussion reminds me of genetic engineering and other fields of research. There are uncertainties, but as long you can deal with them, it's okay."

"The chemical industry then [Schweizerhalle] made lots of efforts and took measures to regain acceptance, but the same thing all over again, I think that would not work. Of course things could have been resolved, but I am not sure if you can create acceptance."

Many voices were raised in favour of the DHM project, however they argued with the fear of a huge quake against the location of Basel.

Although the vibrations did not provoke fear of death, they were compared to the reactions after the disaster in Schweizerhalle in 1986. This comparison also raised awareness of the great Basel earthquake in 1356 and hence the generated fears were far beyond any actual levels of damages that occurred.

"The physical effects were relatively small; however it is not acceptable that it will continue in this spirit. Nevertheless, the main topic is fear and reactions resemble those after the catastrophe in Schweizerhalle, which was a lot bigger, but still, the pattern was about the same."

"There is a subliminal fear, that [this project] will trigger the next big quake, in Basel we are already waiting for the next big quake. Man is playing with forces [of nature] he cannot control. And we are given scientific explanations, that are incomprehensible, to justify this."

4.3.2.2 Earthquake Impacts on the Companies

The business representatives agree upon that the quakes did not cause any serious physical damages directly. If any cracks were found, it could not be judged if they originated from the recent quakes from previous earthquakes. Companies that owned operations that would present a serious danger to the whole population in the event of an earthquake that caused damage designed and built their premises to be earthquake-proof. Thus, the low-intensity induced earthquakes did not cause any damage to these facilities.

"In the chemical industry everything is earthquake-proof and is constructed for significantly stronger quakes."

In contrast, companies with operations that pose a far less risk from earthquake damage consider potential damages from the project to be more likely, especially if a company resides in older, multi-story buildings.

The emotional impacts however were of greater significance. Many interviewed representatives reported people at work expressed fear, anxiety, surprise, or sometimes even disappointment. These reactions were reinforced by the unusual bang accompanying the earthquake.

"Our staff was frightened, but we did not sustain any material damages."

"The consequences were above all fears and no structural damages." "Never before in my life had I experienced such a strong feeling like this angst. I am sure a lot of other people who did not know about the drillings in these immense depths made the same experience."

4.3.3 Communication Rating

The company representatives in general see high potential in geothermal energy. The points of criticism they mentioned mainly refer to the implementation process of this technology in Basel. Their statements make clear that communication policy and public information should be expanded and consecutively improved to successfully utilise geothermal energy in Basel. The following voices clearly point out the need for intense communication:

"No further field test without clear communication."

"Furthermore, communication has to be clear. That is a crucial point."

"The advantages for the society have to pinpointed."

"General acceptance has to be created via the framework. This has to be talked over. The chemical industry also survived the Schweizerhalle disaster, but this has to be handled differently. A consensus has to be reached in society and then it is feasible. But it has to be clear what will be done in a different way."

"Both have to change, research and clean communication, but first of all there has to be clarified: what do we want and which way do we go – and then we have to stick to this approach and have to communicate this in a clear and competent way."

"I don't think that geothermal energy is regarded as reasonable. For me it is conceivable, if you point out the alternatives of geothermal energy, that there will be a critical discussion about advantages and disadvantages. This would be desirable. The alternative is nuclear energy, I guess. You have to weigh risks against benefits, nuclear energy against geothermal energy. With hydropower we barely have a chance that anything can be added and those few wind power stations in the Black Forest will not be able to outweigh that."

The businessmen were discordant at issue how promising good communication might be. It is clear though that a lot of efforts have to be taken in communication to create wide acceptance.

"Efforts for research and communication should amount to 50 percent, each."

To enable the project's re-initiation the interviewees mentioned – apart from improved communication processes - mutual decision-making, taking responsibility and a precise legal foundation as further prerequisites.

"There has to be an open discussion. The project should be approved by the majority of the population, otherwise it is dead. There is a need for reliable statements about the magnitude and for clear announcements in means of insurance to cover losses."

"Generally we are absolutely positive about geothermal energy, but we have to know who will take responsibility for an OK."

"If a political consensus is reached, we would endure the quakes. But there has to be a legal basis that provides the necessary framework. Then details such as the question of liability insurance and compensation are secondary."

"Claims for compensation have to be accepted without the onus of proof."

4.3.4 Acceptance Rating of Geothermal Energy in Basel

The chances of geothermal energy are generally regarded as better, if the option of breaking the rock is abandoned and alternative exploitabilities with a considerably lower earthquake risk should are expanded.

"Geothermal energy is a double-edged either the variant including fracing [breaking up the stone] or other alternative application possibilities. It would be difficult to enforce fracing."

„If the project shall be continued it has to be a Basel specific, pared-down version, a stepwise approach."

[The project could fail due to social reasons], "unless its size is significantly reduced or [the project] will be implemented with the associated risks somewhere else."

Although the majority of business representatives regarded the project as reasonable from the business perspective, they assume a termination of the project given the fears among the population.

"I think in Basel it is dead. There is no use in all that communication, people don't believe anything anymore."

"For my company geothermal energy is no problem, but it is another question if it is a problem for the staff, for their homes and families. For my company this is no problem, we would do that right away, but the people also have a private life and are humans who are terribly scared."

"In my point of view that's the end of this issue here in Basel, but there still is a last flicker of hope, especially with regard to the political forces in Basel (red-green). The policy-makers are against nuclear power and thus cannot oppose to everything else. Hence, there is a chance for the location of Basel. But the shock has occurred and there is no balanced evaluation on the part of the population, which makes communication very difficult. The natural ground motions make it even more difficult."

From the sociological study, evidence exists that:

1. from a business representatives perspective, there appears to be support for the project, if

    a. technical progress is made,

    b. plain accountability exists for the risks,

    c. a clear legal foundation is provided for in the case of damages; and

    d. a clear and open communication exists.

The business representatives show the complexity of risk perception.

2. from a population viewpoint there appears to be strong resistance to the project. Improvements can be made if:

    a. there is a clear and open communication including reliable statements b.
    b. about the expected magnitudes;

    c. there is a public participation in decision-making,

    d. awareness is raised;

    e. there are advance warnings before quakes occur.

For the population it is essential to know how a decision in favour of or against the technology was reached. In case of continuation, the public has to be aware of the project's importance for the national power sector. The central issues from an industrial viewpoint are the responsibility and clear claim settlement.

Note that studies on risk perception provide important indications for risk communication. For the development of a specific risk communication concept decisions by politics (i.e. the risk managers) have to be made based on the strategic goals to be reached.

As this report only provides the basis for this decision, the communicative aspects covered herein and in chapter 6, can only derive with initial suggestions.

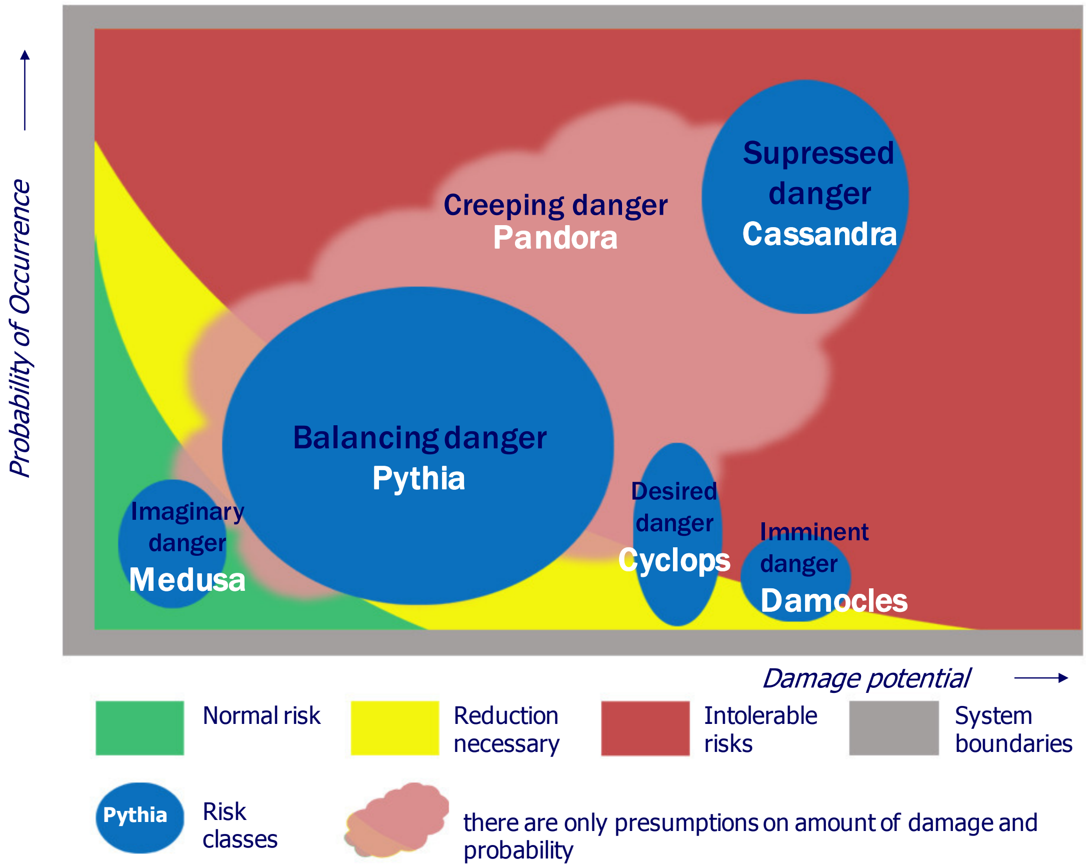
4.4 Societal Risk Classification

Risks can be assessed by their damage potential, their consequences and the associated uncertainties. The WBGU risk classification approach (outlined in WBGU 2000, IRGC 2005, Renn 2008) reflects additionally the public concerns. The classification provides a tool for developing risk communication measures.

The WBGU based its approach on a literature research, several expert surveys, and empirical data. The list of criteria that were selected were: extent of damage, probability of occurrence, incertitude, ubiquity, persistency, reversibility, delay effect, violation of equity, potential of mobilization.

From this, six characteristic risk classes were developed lending their names from the Greek mythology (Figure 20).

Figure 20: Risk Classification by WBGU, IRGC, Renn (slightly amended by the author).



Excluded were activities that reflect everyday events such as car accidents, household accidents, common flu and others. Also it was stated that risks with a high potential of damage and a probability of close to one are located in the intolerable area. For details the author refers the reader to Renn (2008). The boundaries between the red, yellow, and green areas were not defined by the authors (WBGU, IRGC, Renn).

The risk classes reflect different risk perception clusters.

Table 9: Risk Classes.

Risk Class and Description	Probability	Consequence	Examples
The Sword of Damocles	Low	High	The stochastic nature of an event determines the risk- includes nuclear energy, dams, large scale chemical facilities
Cyclops	Indecisive	High	Natural catastrophes earthquakes, volcanic eruptions, new infectious diseases
Pythia	Large uncertainty intervals	Potentially High	BSE, nanotechnology
Pandora	Unknown	Potentially High	POPs, endocrine disruptors high persistence
Cassandra	High	High	Anthropogenic climate change, destabilisation of terrestrial ecosystems, salinity effects, threat to biodiversity long delay until consequences eventuate
Medusa	Low	Low	Electromagnetic fields, high mobilisation potential

Source: Renn, 1998 page 52, amended

We have classed the Basel DHM project into the category of Pythia, because:

1. The HFR technology can be described as a technology, which does not have a catastrophic damage potential, however, there is considerable cost involved in a re-initiation of the project;
2. The risk is imposed, unfairly distributed, and is regarded as inadequately controllable;
3. It is typically associated with imperceptibility, as long as no earthquakes eventuate.

In the event the project was to be re-initiated this classification assists in developing the risk communication strategy (see chapter 6).

5 SUMMARY

5.1 Technological Viewpoint

5.1.1 Energy Summary

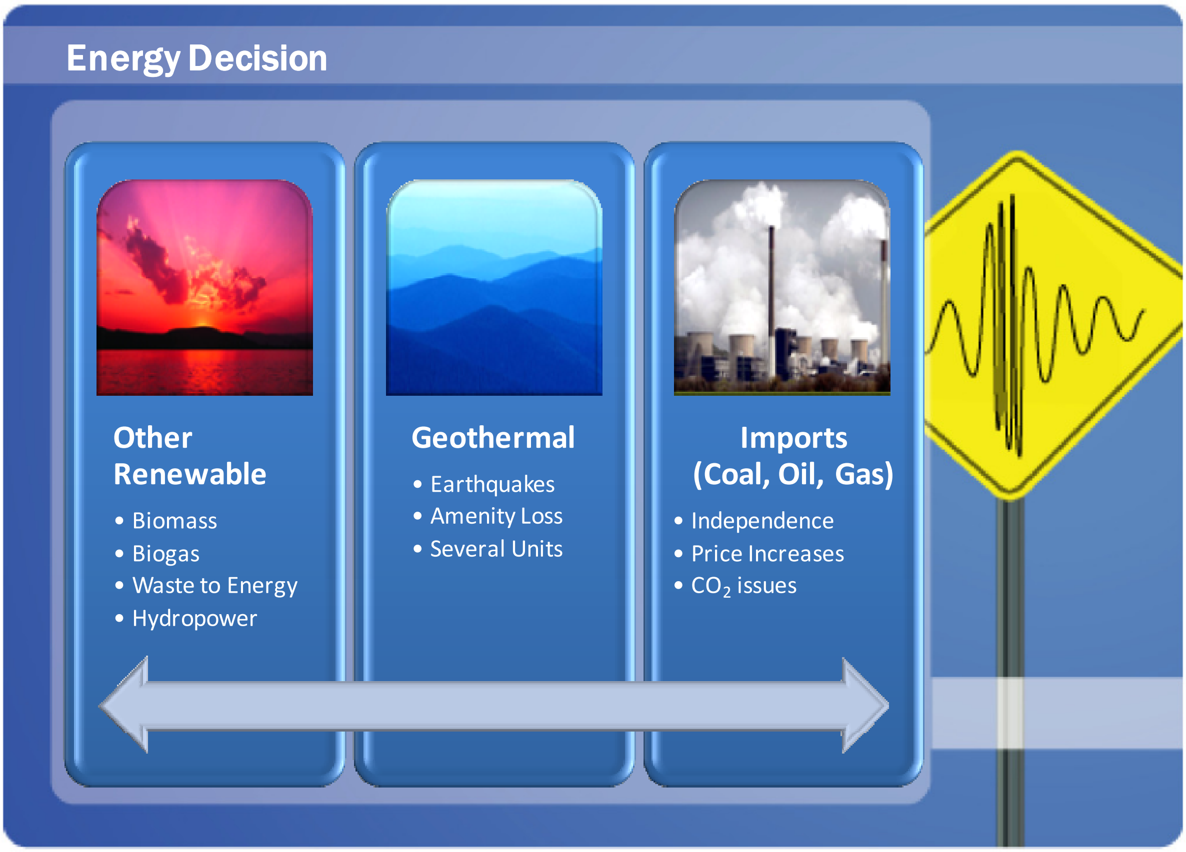
In summary, estimates of the potential for geothermal power generation in Switzerland range from 1 to 25 TWh per annum. Compared to an electricity gap between 5 and 13.5 TWh it seems that geothermal energy could fill the identified gap. BFE concludes that it would be a real success if 5-10% of total energy supply would be provided by geothermal sources until 2050. Geothermal energy provides base load power, an advantage, which can only be achieved by waste to energy, biomass, biogas projects, and water projects in the renewable energy field. Wind energy and photovoltaic energy provide peak load capacity, which are available at certain times.

According to the Basel energy law, the Canton needs to find sustainable energy sources and in particular needs to reduce the Canton's dependency of imported energy. Canton Basel-City currently obtains 93% of its electricity from hydropower with the capacity limit almost reached. To close the energy gap with renewable energy projects numerous of such power plants or units are necessary.

According to the national energy supply program, the 2,000 Watt society will govern the developments in energy efficiency, as large energy savings can be achieved through more efficient technology.

Therefore, a decision has to be made between the remaining renewable energies, a prolonged period of energy import dependency (from coal, oil, and gas) or geothermal power (see Figure 21) In any case, trade-offs are necessary.

Figure 21: Energy Decision Graphic.



5.1.2 Risk Appraisal Summary

The risk of the DHM project was assessed from a local; i.e. the Basel region's perspective, and from a national; i.e. Swiss wide viewpoint. For both levels, the indicators used were risk to people ("societal risk") and property damage ("financial risk").

5.1.2.1 From a local perspective

From a local perspective, and as per the study's scope, the Basel DHM project was assessed against the risk criteria of the Swiss OMA ordinance. Additionally, the project was rated against the Australian ANCOLD guidelines. Because the population would need to know which additional personal risk they would face if the DHM project would be re-initiated, an assessment of the individual fatality risk was made. Further, a comparison with the underlying natural earthquake risk with the induced risk by the DHM project was prepared.

The following is concluded:

- From a risk to people viewpoint: the DHM project may produce a small, almost non-quantifiable increase in potential human fatalities. In unfortunate circumstances associated with intensity VI events dislodged items such as roof tiles, flower pots, parts from chimneys could result in a very low number of pedestrians or passers-by being injured or killed.

- From a regulatory viewpoint, based on the OMA ordinance:

  From the risk to people indicator, the risk would be acceptable, but from the property damage indicator the project is rated as not acceptable as the DHM risk costs exceed the threshold.

- From a regulatory viewpoint, based on the ANCOLD 1998 and 2003 guidelines: Using the risk to people indicator, the DHM project in its original design would rate as inacceptable. However, consideration needs to be given to the fact that all other voluntary or involuntary technologies and activities would not rate acceptable, albeit they are largely tolerated by virtually all societies. Therefore, it may be debatable to rate the DHM project as marginally tolerable with respect to the societal risk guidelines by ANCOLD in conjunction with FN curves for other industries/activities.

- From an individual risk perspective, the DHM project can be considered as being acceptable.

- From earthquake considerations: there is an increment by which the earthquake risk is increased in the study area as during the operation of the DHM project additional small earthquakes will occur (for details refer to AP 5000). The cost increment is minimal compared to the underlying earthquake risk. From risk to people considerations, the increment is also minimal.

- Cost considerations: The infrastructure risk cost caused from re-initiation of the DHM project would be minor. The project's overall risk costs could be exceeding 210 million CHF. Considerable cost uncertainty is in the stimulation period.

- For heat and electricity supply of 5000 households, it is expected that during the stimulation period a total of 1,000 ± 50% houses might experience mostly cosmetic damage across the tri-national region (see Appendix 4). As only 5,000 households would directly benefit from the DHM project compared to 542,000 residents who would be exposed to the tremors by feeling them in their daily life is not a favourable ratio. Further, as the area where the damage occurs does not necessarily correlate with the area of the planned heat distribution, inequity between benefactors and risk bearers is created.

5.1.2.2 From a national perspective

From a national perspective, there is a need that technological advancements are viewed from a variety of angles to prevent premature decisions on projects, especially after an unfortunate start to the DHM project trial.

Therefore, attempts were made comparing the project's risk with other energy projects. Further, a comparison with other technologies in Switzerland was made. The project's risk cost was oriented against the GDP aimed at providing orientation for the government, to assess if such risk costs would be worthwhile to be invested. Additionally, new ways of comparing seismic risks were derived from mining projects from an amenity loss and tolerability of the affected population to vibrations viewpoint.

From a risk to people viewpoint:

- Overall, there are too many limiting factors for a credible comparison of the DHM project with other energy projects to be made.
- A re-initiated DHM project in its original design would pose a similar level of risk as are expected to emanate from infrequent, minor incidents of Swiss NPPs. However, the energy benefit from a NPP is significantly (a hundred times or more) greater than from the DHM project.
- The DHM project would be positioned favourably compared to many other technological risks, such as fires, airplane crashes train accidents or an incident at a chemical facility.

Cost comparisons yielded that:

- The damage costs associated with the DHM project are likely to be similar or greater than that associated with a wide range of technical facilities, including industrial facilities and transportation related infrastructure (e.g. railway accidents), emergency at dams, air traffic incidents, fires, and chemical incidents.
- The FD curve of the DHM project indicates that re-initiating the DHM project in its original design has a 10% chance of producing similar costs as the Schweizerhalle event in 1986.

From a governmental point of view the following orientation can be drawn:

- The DHM project's risk cost in the first year could amount to 0.003% to 1.5% of the Basel GDP, with the most likely percentage being about 0.01%.
- For Basel, alcohol related costs or costs associated with work accidents are at least twice as costly for the society compared with one year of operating the DHM project. Societal costs for smoking or road accidents are tenfold the costs of operating the DHM project. However, when considering a pessimistic case for the stimulation period using a risk cost of about 620 million CHF, the project's risk cost would exceed the spending for road accidents or smoking (about 500 million CHF each).

Further regulatory comparisons indicate:

- When comparing to international mining regulations the DHM project would rate unfavourably and that any project which would generate intensity V earthquakes would not be acceptable in many countries:
  - From a residents' amenity view, the guideline values for Germany (6mm/sec), Australia and New Zealand (5-10 mm/sec) would be exceeded at least twofold (Basel 2006 earthquake 25mm/sec, with several of such events expected when re-initiating the DHM project).
  - From the Swiss norm on vibration effects on buildings, a similar earthquake would not be tolerable when considering the guidance value of 15 mm/sec.

5.1.2.3 Operator Viewpoint

From an operator viewpoint the following is evident:

- From a financial consideration the DHM project's risk costs are significantly higher than the 0.6 million in planned annual profit. Further, there is a 10% chance that costs of 100 million CHF eventuate, which are higher than the original investment costs of about 80 million CHF. Consequently, DHM project is a financial fatality for any investor.

Table 10 summarizes the results of the comparative assessment of the Basel DHM.

Table 10: Summary of Risk Comparisons

Risk Comparison	Measurement	Acceptability / Tolerability
Societal Risks - Swiss Ordinance on Major Accidents based on Art 10 of USG	Fatalities Costs	Acceptable Not acceptable
Societal Risks – ANCOLD Guideline	Fatalities	not acceptable, but debateable
Societal Risks - Worldwide Energy Risks	Fatalities	favourably
Societal Risks – Technical Risks Switzerland	Fatalities	tolerable, but not when compared to NPPs
Societal Risks – Energy Projects	Fatalities	Not possible to compare
Individual Risks – Various Guidelines	Fatalities	acceptable
Damage Costs – Natural Earthquakes	Costs	tolerable/comparable
Damage Costs – Chemical Industry	Costs	unfavourably due to excessive costs
Damage Costs – Natural Flooding	Costs	unfavourably due to excessive costs
Damage Costs – Technical Risks	Costs	unfavourably due to excessive costs

It can be seen that DHM project in its original design would rate:

- From an individual risk view: This is the only distinct positive indicator.

- From a risk to people view: the Swiss OMA ordinance rates the project acceptable, the ANCOLD guideline unfavourably or at most debatable.
- From a cost perspective: The Swiss OMA ordinance rates the project not acceptable. From a national perspective most cost indicators are also unfavourably (e.g. chemical industry, natural flooding, technical risks). From an operator's perspective, the risk cost versus investment capital relation the project would rate unfavourably (ten times higher risk cost than profit).
- From a residents amenity view, and based on existing norms in Switzerland pertaining to vibrations the project would rate unfavourably.
- The overall amount of energy produced is small compared to energy gap to be filled, however, the project is a landmark project.
- As only 5,000 households would directly benefit from the DHM project compared to 542,000 residents who would be exposed to the tremors by feeling them in their daily life is not a favourable ratio. Further, as the area where the damage occurs does not necessarily correlate with the area of the planned heat distribution, inequity between benefactors and risk bearers is created.

From the previous work packages (AP 3000, AP 4000, and AP 7000) it was determined that:

- The geological setting is not explicitly favourable as the project is located in an area with a high tectonic activity rate, and an increase in the earthquake frequency from induced activity is associated with the project. Further, it became evident that the Basel situation is unique in that the Basel earthquake of 2006 from the DHM project was stronger than could be expected from comparable projects.

Overall, the application of the HFR technology based on the projects' original design at this particular site involves considerable financial risk, and a personal amenity loss associated with earthquakes.

5.2 Social Viewpoint

5.2.1 Public Perception

There are indications that future induced earthquakes will not be perceived by the population as reasonable. There are indications that the people in Basel feel a material, sanitary and mental threat from earthquakes. The usual fears concerning earthquakes hang in the air (cf. Renn, Ulmer, Grobe 2006). In the worst case this might lead to symptoms such as powerlessness, rage, and aggression as well as fear and panic. These symptoms were not perceived in Basel though but were perceived in other cases and regions (i.e. mining in Saar state, Germany).

During public events, in e-mails and letters to the editor, citizens pointed out that from their point of view the vitiations of their lives' quality as well as their physical and psychic health exceeded the limits of what is reasonable. All those expressions of concern are not a matter of the actual earthquake experience, more crucial is the fear that the situation might worsen in the future.

It is the population's risk perception that determines people's further actions and emotions and governs their behaviour. With geothermal energy, people are lacking a direct sensory experience with the risk. People derive their assessment of the risk from the information accessible to them. Here the discussion about the risks alone could increase the perceived probabilities. The people in Basel cannot have own sensory experience prior to upcoming quakes – as they have no sensory noticeable impression how strong it will be. That is one reason why the requirements for risk communication in Basel are high. For comparison, the population can permanently make own judgements on risks like cancer from air pollution (smog), but with the risk from a geothermal plant they are dependent on the communication about the technology. This information is communicated via science, politics, and mass media. Being used to a situation or having the impression of knowing a technology helps to minimise the perceived risks. Deep geothermal energy in particular is novel and not a trivial technology. The dimension of the perceived risk steadily increases if the scientific context is insufficiently explored yet and is afflicted with uncertainties (WBGU 2000). This equates to the risk perception factor "unfamiliar".

The people's attitudes towards risk issues are, among others, results of social communication processes. Laymen have difficulties to distinguish between well and badly conducted studies (Wiedemann 2001). On the one hand citizens draw upon media coverage on the other hand a regional or local opinion network is formed. Both developments build upon and reciprocally fuel each other. Hence, risk issues are not static; they rather possess a dynamic history (Wiedemann 2001). The sources of information (every organisation or medium) have different motivations to present an environmentally danger in a certain way. While experts and citizens groups pick out the riskiness of an incident as a central theme, the industry or public agencies tend to avoid those issues. A great majority of action groups emphasise the risks of environmental influences in contrast to sources from the industry or the economy (Sandmann 1994).

Another factor that probably led to the present discussion about the DHM project is that the local population regarded themselves as excluded from the site selection. This is a crucial factor in risk perception and equals the perception factor *(personally) uncontrollable* (Renn 2008). If the population has the impression of not being able to prevent large-scale technologies in the proximity of their residential environment, recreational areas, and school grounds, the emanating risks generally are estimated higher. So the public mostly is not risk-avers or technophobic.

5.2.2 Industry Perception

In summary, the business representatives generally have a positive attitude towards geothermal energy. Geothermal energy is considered to hold a high potential for development and promises a sustainable energy generation. The business representatives conveyed a lack of acceptance for further earthquakes, however, they do not regard the earthquakes as an imminent threat to their businesses. In their companies, the business representatives did not observe significant damages and therefore are willing to accept a continuation of the project if:

a) technical progress is made,

b) plain accountability exists for the risks,

c) a clear legal foundation is provided for in the case of damages; and

d) a clear and open communication exists.

In their view, resistance against the project is growing among the population. The citizens of Basel have been scared by the earthquakes, and the uncertainty about further impacts and the background of the Basel earthquake in 1356 aggravate those fears. Hence, the probability of continuing the project is considered to be low. In their opinion, a re-initiation of the project will only meet with acceptance if communication is further improved. They admit better chances to a project that is based on a broad consensus, which could be achieved through information policy.

In general, innovative projects should be promoted, for which the business representatives are willing to support geothermal energy projects in the future.

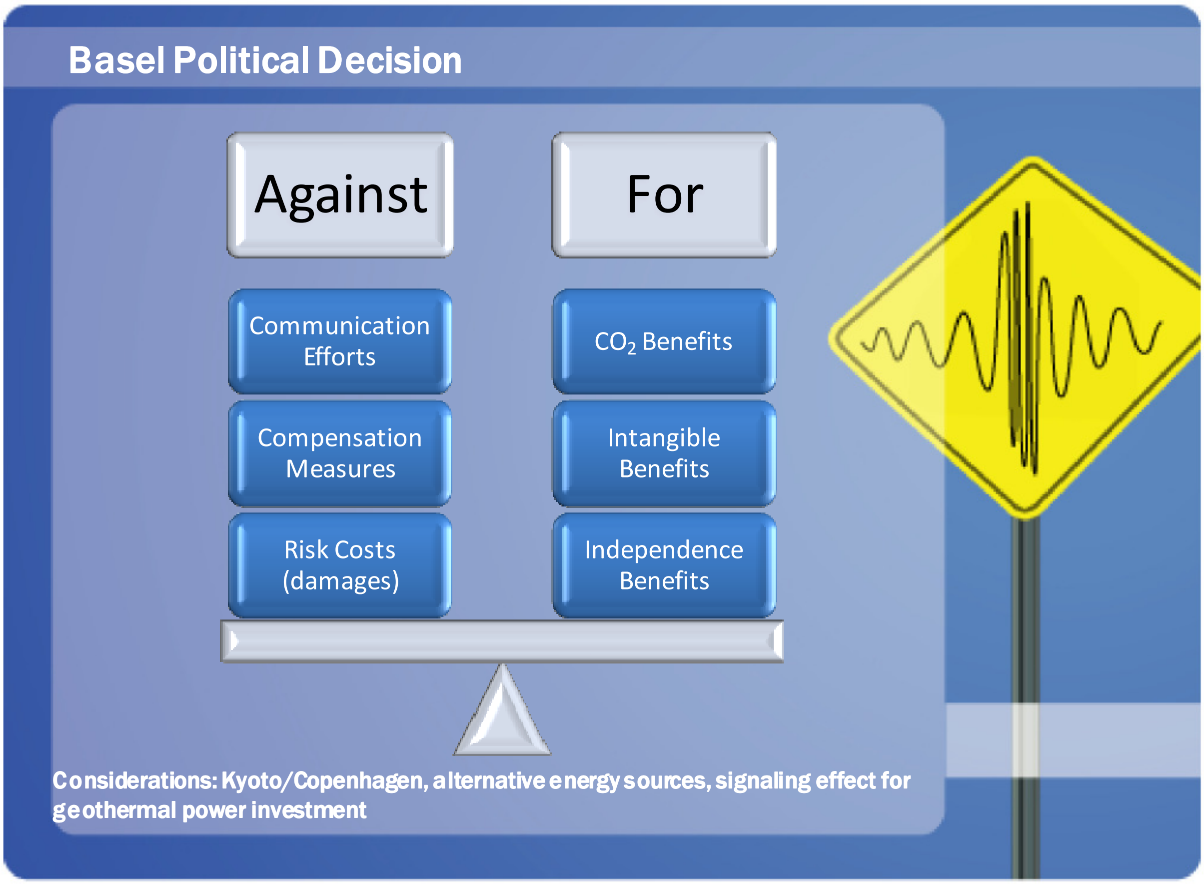
5.3 Final Remarks

From this study, it became evident that the earthquake hazards or perceived risks by the population are significant as the technology is relatively new, not enough known to the general public, and not comprehensively communicated with all benefits and hazards to the area where such plants will be installed. Therefore, the successful experiences from other countries (e.g. use of best suited HFR technology applications, complete understanding of geological conditions, community right to know about benefits compared to related risks, new insurance products to cover potential damages, a clear communication strategy, tolerability of amenity loss from (in-)frequent earthquakes, and a legal framework for use of renewable energy supply sources like geothermal plants) may play a pivotal role in acceptability of a new technology. If there is no political commitment on local and national level, then the Canton of Basel will be forced to offset the energy supply from other sources (with other disadvantages and risks), may miss an attractive market development for energy efficiency and renewable energy technology export, and finally maybe faced with more stringent climate protection requirements due to international developments.

The only potential way of pursuing the project would appear to rest on whether this project is considered important enough from a national perspective for following the national strategic energy supply program by supporting this new energy generating technology. Should the decision be to proceed with the project, it would seem necessary to have significant risk guarantees in place before starting.

In order to derive with a final decision the decision making process should be accompanied by a professional committee involving all stakeholders.

Figure 22: Basel Political Decision.



6 RECOMMENDATIONS

6.1 Risk Reduction and Risk Transfer

Technical risk reduction measures and recommendations are made in AP 7000.

AP 6000 reviewed the alternative scenarios from AP 7000 and states that:

Alternative 1 -Initial Stimulation and Reduced Circulation Rates thereafter: Although the stimulation period only lasts for a period of 12 days, there is still a considerable financial risk associated with alternative 1. The property damage indicator of the OMA ordinance would be exceeded. The societal acceptance would be more favourable compared to the original design, as with the reduced circulation rates the risk of earthquakes is reduced. However, as AP 7000 states this option might not be economically feasible.

Alternative 2 – Multi-Fracture system: In principle, the magnitude of the induced seismicity would most probably be in such a range that the population would not realise any ground movements or vibrations. This would eventuate if a sufficiently large number of parallel fractures can be stimulated. The empirical relationship between maximum magnitude and reservoir size derived in AP3000 may serve as a guideline when designing a multi-fracture system. The technical risks associated with developing such a system, however, may be significant and cannot be judged here (compare AP7000).

Alternative 3 – Triplet system: The stimulation period lasts for a period of 18 days, increasing at least the risk for financial losses even further. The property damage indicator of the OMA ordinance would be exceeded. The societal acceptance would be more favourable compared to the original design, as the induced seismicity might decrease considerably during circulation.

Further recommendations for decision makers:

1. To reduce the potential of fatalities, cost efforts could be as high as 20 to 100 million CHF based on willingness to pay studies carried out in Switzerland and elsewhere. This means that those amounts could be used for project redesigning efforts or development of alternatives.
2. As no earthquake insurance is currently available for a project like this, it seems warranted that a risk transfer solution needs to be developed with all insurance companies. This should provide coverage for geothermally induced earthquakes and natural earthquakes. Refer to Figure 1.
3. From a financing point of view, the project's risk cost could be apportioned to the final price of energy. When apportioning the mean total risk cost of about 210 million CHF to the energy produced, the effect on the total energy produced over the 30 years would be around 0.05 CHF/KWh. When apportioning the risk cost only to the amount of electricity produced this additional external cost would be around 0.4 CHF/KWh.

6.2 General Recommendations with the Public from a Communication Viewpoint

Irrespective of the decision, the following recommendations are derived from the present situation:

1. In any case, a clear communication has to be initiated.
2. Evidence suggests that the region expects a clear and definite signal from politics. The technology should be favoured by politics and evaluated as favourable or, in contrast, there have to be good reasons to refuse it. There are indications for accumulated frustration even up to more conservative levels of the population who traditionally are more open to economic arguments. Therefore, the local population should be included in shaping the further proceedings.
3. In general, innovative projects demonstrating technological progress should be promoted, for which the Canton Basel is willing to provide support in the future.
4. A deep understanding of the content of the citizens' sources of information could yield important indications. This involves both indirect sources such as mass media and direct sources, which generate know-how. Risk perception does not evoke spontaneously in a person's head; it is rather based upon a social process integrating different sources of information.

6.2.1 In case of a positive decision

For landmark projects like the DHM project in Basel the function (e.g. procedural strategy) and impact (e.g. signalling effect) for Europe must be kept in mind and should be communicated. If the population evaluates the benefit of the project only based on the local context – i.e. the local benefit – and does not see the way to an European society with more peripheral and renewable energy sources - the technology would probably not be accepted in Basel.

On the one hand, Basel has the opportunity of utilising a promising technology, which a lot of the affected citizens of Basel would consider as such when it comes to establishing a CO_2 neutral energy supply in Europe. Especially business representatives perceive this technology with all its advantages as worthwhile. The Basel region could position itself as "pioneer of technology" and profit from the positive image associated with it. On the other hand, a lot of people do not foresee any other resort than abandoning the geothermal project. This is due to the quake experienced and the fear of future quakes.

The authorities should continue with a risk dialogue using Figure 22. Moreover, the dialogue needs to be intensified. It is of utmost importance to believably demonstrate that the concerns are acknowledged and understood. The government should also acclaim -in public- that the people in Basel would incur heavy cost burdens from a new technology, which is able to be a key-technology for a sustainable energy supply in the future. Overall, people expect a clear and open communication, public participation in the decision-making process, plain accountability for the risks, and a clear legal foundation in the case of damages.

The attitude of both the government and the operator in terms of communication for the future should be „Wer Akzeptanz will, darf sie nicht wollen“ - meaning: avoid monologues to enhance public understanding and avoid recurring the positive facts of geothermal energy. We would recommend offering telephone hotlines for residents to obtain more comprehensive information and to respond to the different and individual concerns.

More details on the communication strategy for Basel must be developed depending of the actual situation, aims, and needs, because obviously there is no king’s road when it comes to dealing with public concerns. Every possible solution might involve tangible and intangible costs and disadvantages. Hence, only a procedural approach/method might be helpful. This could be accessed in form of mediation including the most important stakeholders or via direct participation by establishing public forums.

The results of such an approach might be general conditions under which the technology is accepted. This could entail compensation payments.

6.2.2 In case of a negative decision

In case there is a negative decision on the DHM project, the residents should be informed about the essential reasons in a dialogue situation. A decision against the DHM project would however be viewed as an example of good governance addressed to the population, because it would be regarded as a decision in favour of safety - although the risk is arguably mostly financial. A termination of the project would bring the Canton government and the plant operator in a position of trust and the people will have more confidence for the next decision regarding public matters, which will be taken by the government. However, it needs to be ascertained that the decision is not against the HFR technology. The public should not perceive the termination of the project as failure of the technology, rather the implementation into society failed because of the local situation and geographical setting.

The discussion about the DHM project in Basel by now involves all social groups such as the responsible authorities, citizen groups, businesses, science, the media, and politics. The media, local groups, and the scientific community have been strongly committed for quite some time, and during hearings and public discussions called the broad public’s attention to this subject. These actors have to obtain all the information needed and inquired at an early stage.

Further, it is recommended to set the path for finding alternative sites, subsiding technological advances or provide funding of alternatives.

The content to be communicated should encompass:

1. A diagram showing the variety and complexity of aspects considered.
2. The cradle to grave path the DHM project took over time – showing the main occurrences, developments, and current status.
3. It is recommended to focus on the research necessary for employing HFR projects, the necessity to find alternative sites with the background of climate change.

7 LIMITATIONS

RiskCom prepared this report in accordance with the usual care and thoroughness of the consulting profession for the use of the Canton of Basel and only those third parties who have been authorised in writing by RiskCom to rely on the report. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in such a report. It is prepared in accordance with the scope of work and for the purpose outlined in the proposal dated 5 December 2007.

The methodology adopted and sources of information used by RiskCom are outlined in this proposal. RiskCom is not in a position to make an independent verification of the information of the underlying data of the expert panel or the partner companies or any statements beyond the agreed scope of works. RiskCom assumes no responsibility for any inaccuracies or omissions.

RiskCom conducts the development of the final criteria main risk analysis at a stage where the specialist studies were available mainly as final documents. Any risk assessment workshops to derive the criteria were held in an open and constructive manner, allowing all opinions to be heard. Where uncertainties existed the members were allowed to come back with better estimates.

All reports prepared for the Canton of Basel should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

To the extent that the services require judgment, no assurance can be provided that fully definitive or desired results will be obtained, or if any results are obtained, that they will be supportive of any given course of action. The services may include the application of judgment to scientific principles, to that extent certain results of this work may be based on subjective interpretation.

8 APPENDIX

Appendix 1: Geothermal Energy Considerations

Appendix 1-1. Basel Economic Importance

The Basel region - Canton Basel City and Canton Basel Landschaft - gross domestic product (GDP) is in the order of 46.4 billion CHF (2008). The largest contributors to the GDP are the manufacturing industry, the coke and refined petroleum products, the chemicals and chemical products, pharmaceutical industry, business services, real estate services, trade and repair services, and banking and insurance (Source Statistics Department Basel). About 190,000 people are directly employed in this region supporting these industries (as of Feb 2009). The energy producers contribute about 1.3% of the GDP or less than 600 million CHF. For comparison, the national GDP of Switzerland is about 520 billion CHF in 2007.

Figure 23: Tri-national region around Basel (from Wikipedia)

The study area (12 km around Basel) is home to about 540,000 inhabitants reside in the tri-national region. For the purposes of this study they were accounted for as Swiss nationals, thereby representing just under 7% of the Swiss population. It is one of Europe's most densely populated area.

The Swiss pharmaceuticals and specialty chemicals industry operates largely from Basel, with Novartis, Syngenta, Ciba Specialty Chemicals, Clariant, and F. Hoffmann-La Roche headquartered there. The finance and insurance industry (UBS and National Swiss insurance) plays a pivotal role in the local economy.

Swiss International Air Lines, the national airline of Switzerland, is headquartered on the grounds of EuroAirport Basel-Mulhouse-Freiburg near Saint-Louis (Haut-Rhin, France) northwest of Basel.

Major industries are also present in the nearby area of Lörrach and Weil am Rhein (e.g. GABA/Colgate-Palmolive, Kraft Foods).

The wider region Canton Basel Landschaft was selected for erection of a nuclear power plant in Kaiseraugst. Severe protests in 1975 have forced the government to drop their plans for erecting the 1000 MW plant in 1989. The financial loss incurred was between 1.1 and 1.3 billion CHF. Switzerland has currently five NPPs with an installed capacity of about 3,300 MW. In neighbouring France, the NPP Fessenheim (northwest of Basel) has an installed capacity of 900MW.

Appendix 1-2. Geothermal Energy Production

This chapter cover the energy considerations for the geothermal industry. They are aimed mainly for the information and benefit for political decision makers and related advisors. The content addresses the wider implications of energy generation based on a review of currently available information.

Geothermal energy is a base load energy that can be generated from different depths and consequently requires different processes - shallow geothermal energy generation, and deep geothermal energy generation can be distinguished. Both processes are briefly outlined in following sections.

1. Shallow Sources

Shallow geothermal energy generation is generally limited to depths of about 100 m below ground. Low temperatures in such depths across most of Central Europe only allow the generation of heat, normally used for domestic heating purposes and warm water generation. Electrical power cannot be produced by shallow geothermal bores. However the vast majority of the geothermal energy currently in use is produced from numerous, small, shallow operations.

This technology is usually not associated with measureable earthquakes.

2. Deep Sources

a) Exploitation of Hydrothermal Sources

Naturally occurring hot groundwater in deep groundwater bearing layers (aquifers) can be used to generate both heat and power. For economic project realisation groundwater temperatures in excess of 100℃ are required, which usually occurs at depths deeper than 1,000 m to 3,000 m. Typically two or more wells will be installed within the same aquifer at proximity. Groundwater is extracted from one bore, used for energy generation, and reinjected through the second bore back into the aquifer.

By way of example, this type of geothermal power generation is for instance used in Landau/Germany with an output of 3 MW_{el} for about 6,000 households and 6-8 MW_{th} (heating) for about 300 households. Its annual reduction of CO_2 emissions is about 6,000 tons. It went into operation in 2007 and it is the first industrial geothermal plant. However, at the time of writing, this project is currently placed on hold due to seismic risk concerns.

b) Exploitation of Deep Basement Sources

The HDR (Hot Dry Rock), Hot Fractured Rock (HFR), or EGS (Enhanced Geothermal System) process is used when hydrothermal aquifers are not available, but a high geothermal gradient and some pre-existing zones of weakness paired with pre-existing natural geological forces exists in deep (>4 km) basement rock formations. The terms HDR, HFR, EGS refer to the same process.

To extract hot water for energy generation purposes at a HDR system, two (or more) boreholes (injection well/extraction wells) at depths of between 3,000 m and 6,000 m below ground are necessary. The wells are hydraulically connected by fracing[5] the intermediary rock zone (referred to as the stimulation period) by water injection at high pressure. This stimulation enhances or creates permeability in this rock system, which will be used to circulate water between the boreholes. Circulating water is naturally heated through the underground passage of the fracture system thus created, extracted for heat and power generation and then reinjected to repeat the circulation process.

3. Seismic Risks from Deep Geothermal Projects

Seismic risks from deep geothermal projects are referenced and presented in a tabular format in work package AP 3000. Therefore, no further statements are made in this report.

Appendix 1-3. Energy Policy Considerations

The purpose of this chapter is to present in general the comparative advantages and benefits of geothermal power supply with regard to other established energy supply technologies as well as the related risk events and risk perceptions.

1. Swiss market

[5] Hydraulic fracturing, creating factures through which the water travels from the injection to extraction bore(s).

As a main source of information, the BFE (2007) report on energy perspectives which details background and basic assumptions and is available from the Swiss Federal Government website (www.energie-perspektiven.ch) was reviewed. In addition, the PSI (2005) report on renewable energy projects and new nuclear power plants was reviewed.

According to the BFE 2007 report (see BFE Figure 2.6-1), the primary energy supply sources in Switzerland until the beginning of the 21st Century were CO_2 emitting fossil energy supplies (coal, gas) as well as non-CO_2 emitting uranium (for nuclear power plants), water (hydro power plants), and –increasingly during the last decades- renewable energy sources (e.g. biogas, biomass, waste, wind).

According to the Swiss Energy Newsletter (2009), the total consumption per final type of energy reached a historical high of about 900.000 TJ (equaling 250 TWh), increasing by 4.1% in 2008 compared to 2007. The increase is mostly caused by demands from services and households. The per capita consumption in Switzerland is now higher than the average consumption of the EU's 15 members.

Switzerland launched a first decade energy supply program in 1990 ("Schweiz2000"), which was followed by the second program ("EnergieSchweiz") in 2000 lasting until 2010. The energy supply program has four main targets:

- Supply Security (no imports);
- Environmentally acceptable (less emissions and nuclear waste);
- Economically acceptable (energy costs);
- Socially acceptable (country-wide same conditions).

Avoiding more fossil and nuclear energy based supply is a major goal to comply with the four targets.

Resulting from this there will be an electrical energy supply gap. While electricity represents only a quarter of the total energy need, it cannot be replaced by other types of energy, and is therefore a major focus for development of renewable energy sources. A time frame of more than 50 years is considered to be realistic by experts for meeting the total energy demand using renewable sources.

The proposed new targets for the next program (2010-2020) are presently under review, and were not available at the time of this report preparation.

As there are national regulations for CO_2 restrictions based on international agreements (Kyoto Protocol), some cantons agreed on a phase out of nuclear plants (e.g. City of Basel), and as fossil energy sources are limited on the planet earth, water and renewable energy sources are becoming major long term sources for energy supply in developed countries like Switzerland. All future energy supply scenarios of the referenced report have their advantages and disadvantages with regard to all evaluated criteria (for details see BFE report).

The most challenging <u>Scenario IV</u> addresses the "2000 Watt Society" (represents annual average consumption per capita worldwide in 2006, compared with Switzerland being at 5000 Watt, among them are 3000 Watt based on fossil sources) until year 2100. This scenario requires a significant energy reduction in all private, public, and commercial activities (31% less energy consumption per capita and 48% fewer CO_2 emissions) as well as a massive development of renewable energy sources for electricity and heat supply (e.g. breakthrough of geothermal plants as a main source for electricity generation) in order to complete the supply deficiencies. These deficiencies are estimated to 5 TWh (Total production from all power plants between 2000-2035), due to lower electricity consumption and higher electricity efficiency) until 2035.

Scenario III ("new priorities") is presenting the instruments and techniques to achieve the commonly accepted targets (see above). This Scenario requires further extension of hydropower plants or a breakthrough of geothermal energy sources for the national electricity generation to complete the 22% electricity deficiency (total of 13.5 TWh estimated until 2035) within the coming 10-20 years.

Scenario I ("continue as it is") and Scenario II ("enforced cooperation between public organisations and the industry") evaluated the present technical, energetic, economical and ecological consequences of different political constellations, but stated that either climate change protection targets will be failed, or energy prices will raise due to necessary electricity import.

The BFE report states that the missing energy sources of Scenario IV (focus on renewable energy sources) until 2020 need elevated electricity production by geothermal sources between 0.8 up to 2 TWh (Section 2.6.4). If not feasible, a focus on photovolatics must be initiated. The summary of the report notes (page Z-4) that "the contribution of geothermic sources to heat and electricity supply is uncertain as it is depending on not enough known technical factors". This statement is assumed to be made on the fact that although Switzerland conducted several deep geothermal installations in the past decade (including Basel –Kleinhüningen as a major national deep heat mining project/ DHM based on hot fractured rock (HFR) process), none of them could be turned into reliable and sustainable energy supply service installations or plants.

BFE concludes that it would be a real success if 5-10% of total energy supply were provided by geothermal sources by 2050. Based on a yearly total consumption of 250 TWh this would require approximately 12 to 25 TWh per annum from geothermal sources. The BFE report states that the missing energy sources of Scenario IV (focus on renewable energy sources) until 2020 need elevated electricity production by geothermal sources of between 0.8 and 2 TWh .

Based on the results of the two reports and the goals of the present EnergieSchweiz program, Scenario III ("new priorities") is likely to receive high priority in the next two decades. BFE presented seven options (A-G) for electricity supply to close the identified electricity gaps. In the course of future oil supply reduction, a basic political decision is necessary about the proportion of renewable, nuclear, and fossil energy supply sources as well as about electricity imports. BFE concludes that Scenario III (and also IV) is attractive for investment into energy efficiency and renewable energy sources as they will reduce operational costs for households, industry, and services in the long-term, and these costs will be lower than the required capital costs. The consequences for energy prices and total gross domestic product (GDP) are considered to be minor. There is however a need for international harmonisation of energy politics.

The PSI study emphasizes that although Switzerland is among the top three countries in terms of per capita use of geothermal resources (after Iceland and New Zealand), the focus of the Swiss Geothermal Program is on heat and not on electricity production. This focus is considered by PSI as the right utilization of this resource as heat supply with fossil fuels is associated with high CO_2 emissions compared to the almost CO_2-free Swiss electricity generation by water and nuclear power plants.

The PSI report notes (page 307) that geothermal resources can be considered as sustainable and economical if the produced heat is used at a defined location for a long period of time. The potentially available heat amount for Switzerland is estimated at 1.5 $x10^7$. TWh. However, only a small proportion of it can be utilized as only the fractured rock can be used for heat generation, and the amount of usable heat depends on the successful rock fracturing. In addition, heat exploitation can only be done up to a certain temperature, and electricity production depends on thermal efficiency connected to the fluid temperature (electricity efficiency grade between 9-13%). PSI presented two tables about the physical potential for geothermal heat and for geothermal electricity generation (Tab. 9.2 and Tab. 9.3) based on the methodology of a German study (Jung et al. 2002). The so-called heat in place is significantly higher than the maximum usable energy for electricity generation.

The German government hopes that up to 3.4 TW of geothermal power can be installed by 2020. The main incentive for that goal is the funding via a national law (EEG) issued by the former government, which now grants 20 Cent per kWh electricity from geothermal plants (15 Cent/kWh until 2009). For comparison, the installed capacity in 2007 is a mere 8 MW (i.e only a small portion of the targeted 3.4 TW). Significant annual growth rates of 200% are hoped for in heat generation with geothermal plants. It is however not clear during the time of this project if the new German government (effective November 2009) will continue the funding levels of the EEG due to national budget constraints.

In Switzerland about 0.15 CHF/kWh for electricity generation, and in addition about 0.023 CHF/kWh for heat are refunded (as of 2004).

For comparison, the production costs are calculated by PSI for

- PV based electricity: between 0.34 – 0.89 CHF/kWh (average of northern and southern part of Switzerland);
- electricity imported from solar power plants in the Mediterranean area between 0.14 – 0.26 CHF/kWh;
- wind energy plants between 0.13 – 0.14 CHF/kWh (by 2020);
- small water based power plants between 0.10 – 0.25 CHF/kWh.

No such data were provided for biomass, waste to energy plants, and import from wave power plants.

PSI concluded that all renewable sources have the theoretical potential to grow, but each of them needs specific political (financial) or technical support.

1. Small water power plants apply state-of-the-art technology but need some financial support such as an eco label fee;
2. Wind energy plants are subject to environmental impact assessments and do not have a high acceptance within the Swiss population;
3. PV based electricity needs timely limited public funded investments and an amendment of the electricity generation law (higher fees);
4. Administrative and financial engagement of Switzerland for solar power plants in the Mediterranean area;
5. Geothermal electricity supply has such a high potential that the related uncertainties (geological data, boring costs) need to be addressed, and administrative support be ensured to increase public awareness, reduce related risks and production costs.

PSI summarized the optimistic – realistic potential of 10% electricity supply by renewable energy sources in Switzerland by 2035 as technically feasible if there are substantial contributions from small water power plants, wind power, biomass and geothermal power plants, and a small contribution by photovoltaic (PV, solar panel) based electricity. However, the geothermal contribution is considered to be speculative due to the technology being in the development phase. The total potential for renewable energy by 2035 is estimated by PSI at around 5.5 TWh per annum, which is less than the half of the potential estimated to be achievable by electricity efficiency and saving measures. The realisation of these latter measures however is considered rather difficult.

Acknowledging the limitations of fossil sources, implementing the international CO_2 restrictions, maintaining the high level of hydropower supply and supporting more the renewable energy sources will be the main future tasks in order to cover the estimated electricity deficiencies in an environmentally sound manner. Above all, renewable energy sources (especially geothermal plants) have additional unique advantages for the country:

I. Contribute to the independence of energy/electricity supply from off-country sources (an “EnergieSchweiz” goal) – geothermal energy, biogas and biomass, and waste to energy processes supply base load energy;

II. Geothermal plants need a very low specific surface area per produced energy unit (see Figure 24);

III. The users are within the vicinity of the geothermal power station, which is likely for a relatively small but highly populated country like Switzerland. According to the geothermal generation map of Switzerland (PSI report section 9 Geothermie Fig. 9.12 page 312), the main known, geologically interesting and economically feasible resources are found in the strip between Lake Constance and Lake Geneva (and that is the most populated part of Switzerland (“Mittelland”);

IV. The innovative Swiss energy research market is a valuable platform for commercial business applications, and thus a basis for export technologies and jobs;

V. Energy efficiency technologies and renewable energy supply techniques are highly attractive for investors from all over the world as sustainable energy supply is a worldwide challenge.

The worldwide potential of geothermal energy (up to 3,000 m depth) is estimated at 1.2 x 10^{10} TWh (most of it below 100°C), while the energy consumption in 1987 was at 8.3 x 10^{4} TWh (40% of it below 100°C), according to KONSENS KG (2008). Based on these theoretical calculations, the energy supply from geothermal sources could last for thousands of years.

The worldwide installed capacity for geothermal plants based electricity generation is about 9.000 MW_e (0.009 TW_e). The most important countries where electricity is generated by geothermal plants are USA (>2000MW_e), Philippines, Mexico, Indonesia, and Italy (700 MW_e) (in decreasing order; BMU 2007).

About 28,000 MW of thermal power from geothermal sources is installed worldwide (2008); the Swiss portion being only a mere 582 MW_{th}, producing heat of 1,175 GWh/a.

In summary, estimates of the potential for geothermal power generation in Switzerland range from 1 to 25 TWh per annum. Compared to an electricity gap between 5 and 13.5 TWh it seems that geothermal energy could fill the identified gap. For comparison, one nuclear power plant produces at least as much energy as 15-30 DHM projects together.

Other new research projects such as DINAR (performed by Institute for Solar Energy Supply Technology and funded by the German Ministry for the Environment) focused on decentralised energy management for the low voltage grid as a value to future electricity supply for households and industry compared to the present centralised feed-in at the high voltage level (the “virtual power plant concept”). A major precondition however is that virtual power plants are developed with suitable interfaces for grid operation, and that the grid operator strategies are open to their use. This requires another political decision. Further information is found at:

www.bine.info/fileadmin/content/Publikationen/Englische_Infos/projekt_0208_engl_internetx.pdf

2. Basel Situation

According to the Basel energy law, the Cantons need to find sustainable energy sources and in particular needs to reduce the Canton’s dependency of imported energy. Canton Basel-City currently obtains 93% of its electricity from hydropower.

Basel was chosen because of a series of factors:

a. Geology - The high geothermal gradient in the region. Note that two zones in Switzerland are particularly suitable –Valais and Basel;

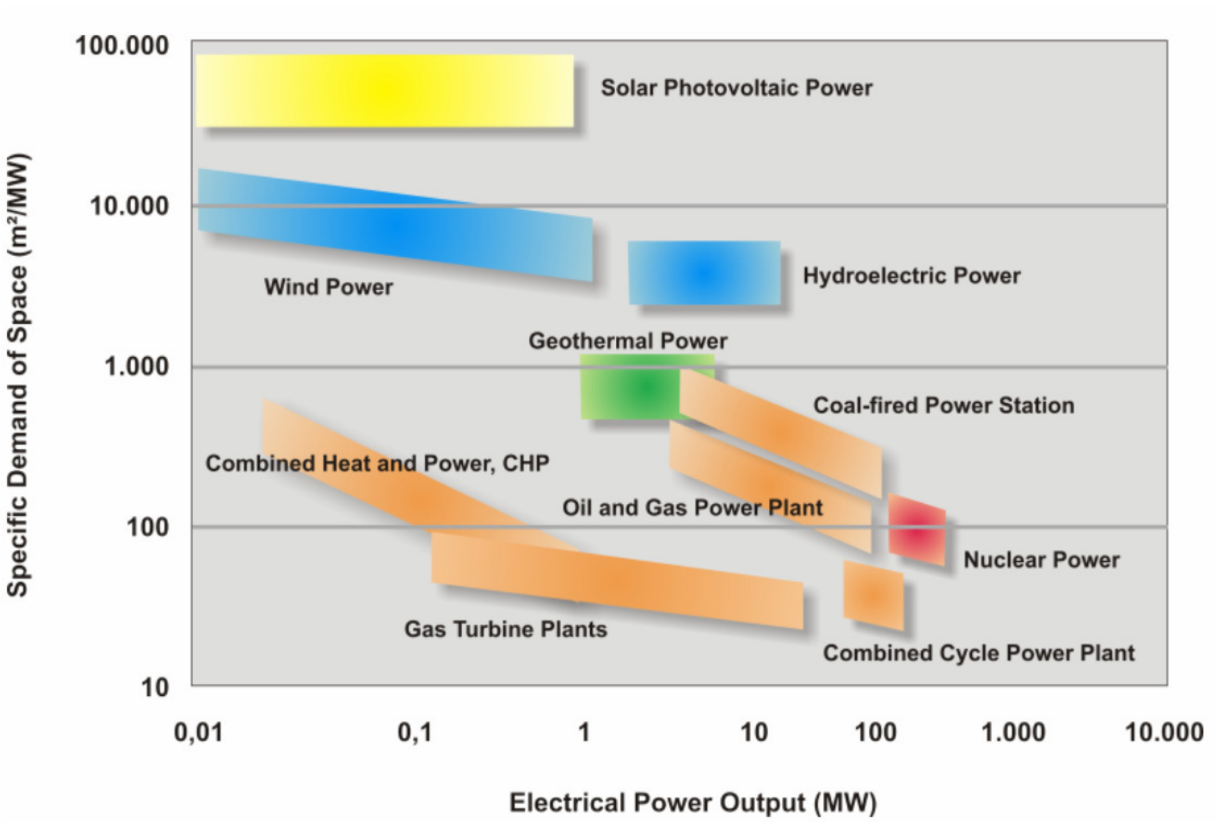
b. The existing heat distribution system for about 5,000 households, which is currently used by the waste incinerator and the waste water treatment plant (together about 50%) and four natural gas heat plants;

c. The proximity of heat users;

d. Low normative space requirements.

The following chart presents the specific space requirement (m^2/MW) for different energy generation plants compared with a geothermal plant:

Figure 24: Space requirements for various power sources.



Source: Siemens (1997).

Note: The Basel DHM project was originally designed to primarily produce heat with electricity production occurring at times of low heat demand.

Appendix 1-4. Regulations, Risks, and Technological Advancements

The Canton of Basel, based on grounds of frightening the population due to earthquakes, stopped the DHM project6.

[6] The legal basis for this action is provided in Article 10 of the Swiss Environmental Protection Law (Art 10, USG)

In Germany for instance, the Federal Mining Act chiefly regulates geothermal projects. In particular, this Act aims at preventing adverse impact on the health and safety of the population and the environment. A geothermal bore can be stopped if the Agency is satisfied that the impact would have a general impact on the population.

The projects' location in a tri-national region might raise the issue of globalisation, especially since all three neighbouring countries are not part of the EU. What might be permissible in one country might not be allowed in another country. Hence, it is advisable to develop internationally accepted guidelines for geothermal projects, so that as this case one country may permit a project, but the effects be felt across the border too.

Therefore considering only probabilities and damage functions is not sufficient as additional ripple effects may promulgate secondary and tertiary impacts. On the other hand, the violation of equity (between those who benefit and those who bear the risks) paired with adverse public perception is a delicate balancing act. This balance is not easy to find as opportunities and risks emerge in a cloud of uncertainties and ambiguities. The hunt for opportunities and associated technological advancements implies risk taking.

The PSI (2005) concluded that the potential benefit of geothermal energy is significantly larger than the existing uncertainties, and that it provides a viable and practical alternative energy source unless CO2 emissions cease to be internationally relevant and at the same time nuclear energy can be endorsed.

Appendix 1-5. Costs of Energy

1. Electricity Production Costs from Geothermal Plants

The costs of producing electrical energy from geothermal plants in Germany are estimated to around 0.3 ± 0.05 CHF[7]/KWh (Rogge 2003). This is above the costs from other technologies such as wind farms, biogas, natural gas, coal and potentially even water (around 0.05 CHF/KWh). No data for Switzerland is available (Roth et al 2009).

PSI (2005) estimated future electricity production costs from geothermal plants to be in a range between 0.07 – 0.15 CHF/kWh. Hirschberg et al. (2008) estimated full costs of electricity generation by geothermal sources to be around 0.10 CHF/kWh by 2030.

a) Electricity Production Costs from Renewables

The portion of biogas and wind production are relatively small in Switzerland and contribute together only 0.5% of the energy use. The cost for Swiss wind energy is provided in Roth et al (2009) with about 0.12 €$_{2000}$ / KWh. The cost of electricity generation from photovoltaic panels (PV) is between 0.5 and 0.7 €/KWh (0.8 to 1.1 CHF /KWh) in Germany and around 0.8 CHF/KWh in Switzerland. As the costs for PV was initially very high and Switzerland did not actively subsidise its usage, it is hardly used (173 TJ -equalling 48 GWh)- representing 0.02% of the Swiss energy use in 2005). PV usage is space intensive and in Germany this

[7] A conversion factor of 1.5CHF per € was used throughout the document

has been overcome to some extent by installing PVs on farmland and closed landfills. Technological advancements such as ultra-thin PVs may stimulate its use in future.

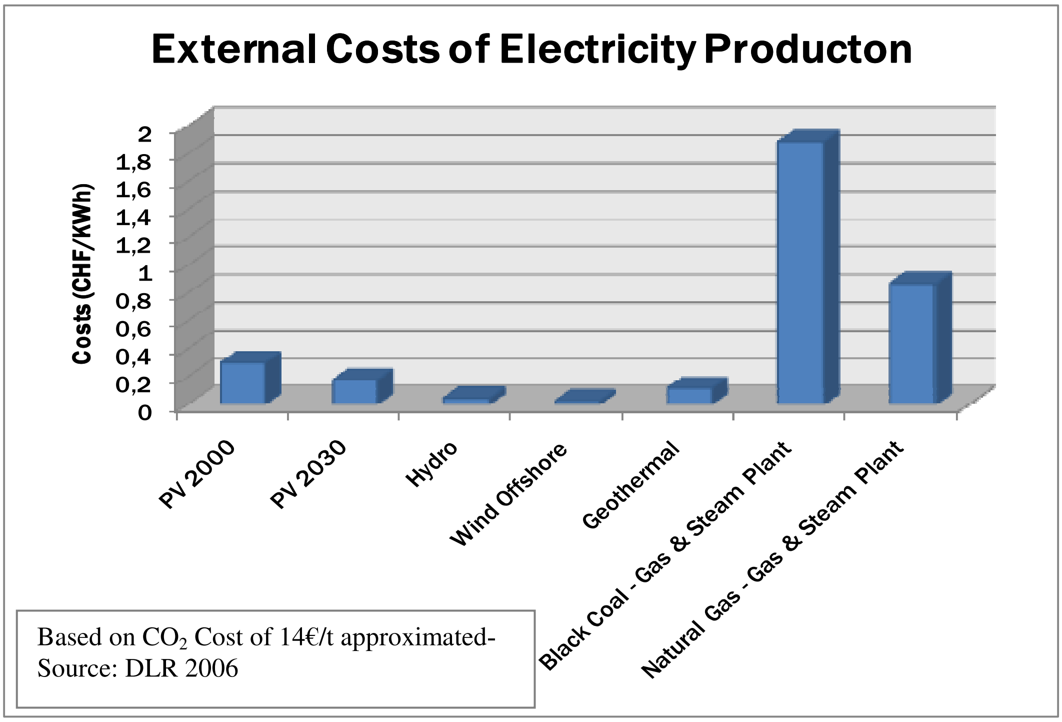
b) External Costs of Renewables

In order to evaluate the economic aspects of renewable energies, it is important to assess the different available technologies holistically. One method is to calculate external costs of the technologies used. External costs are costs that arise through the use of a technology that are not typically accounted for e.g. by energy companies. An example of an external cost associated with the generation of electricity is the CO_2 produced from fossil fuel plants. The emissions have negative effects, e.g. results of climate change, that are not paid or accounted for by the generating companies. External costs therefore include not only the use of a technology and its related emissions, but should also take into account energy used for constructing the plant, disposal, etc.

To assess the full cost of a technology and to enable a fair comparison between technologies, the total costs, and the external costs, should be accounted for.

The following graph compares external costs without risk considerations for electricity generation through different sources in CHF/kWh. The calculation combines different surveys and adds up resulting damages to the climate, health, ecosystems, materials, crops, etc. Using geothermal energy for generation of electricity instead of conventional fuels, such as lignite, black coal or natural gas reduces external costs by 87% to 95%.

Figure 25: External Costs of Electricity Production.



Kaltschmitt (2003) assessed the climate change related emissions (i.e. CO_2) from geothermal energy as being about 80t per GWh based on a limited life cycle analysis. This is a tenth of traditional black coal (see Figure 26).

Figure 26: Greenhouse Gas Emissions per Energy Generation Type.

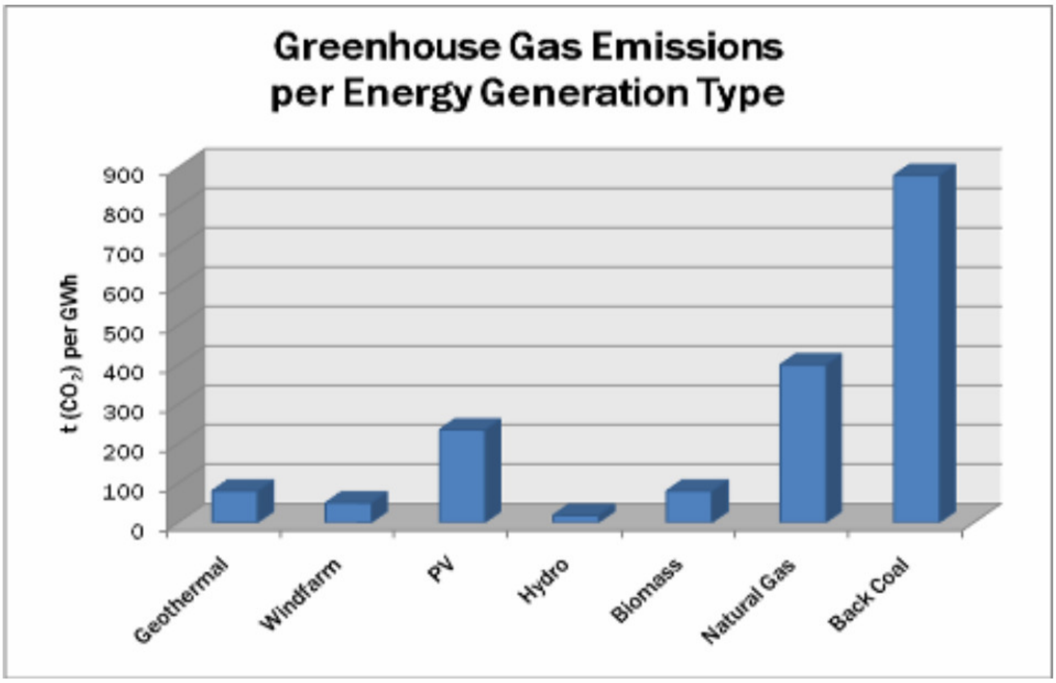


Table 11 (Ingenieurbüro für neue Ideen, 2009) details the amount of emissions, such as CO_2 that can be saved through the use of renewable energies. The figures encompass the upstream chains and the whole life cycle of different energy sources. The results show, that by using geothermal energy instead of the conventional mix of energy sources, 835t of CO_2 can be saved for each GWh electricity produced.

Table 11: Avoided emissions from renewable energies in consideration of upstream chains.

Energy Source	CO_2	SO_2	NO_x	Dust
	t/GWh	mg/KWh	mg/KWh	mg/KWh
Hydropower	851	544	685	-11
Wastewater treatment off gas	780	398	-43	25
Biogas	688	230	-1320	-301
Biomass (solid)	819	337	-1832	-7
Biomass (liquid)	570	1	-5505	-857
Geothermal	835	518	703	30
Wind	753	451	607	-3
Photovoltaic	591	106	492	-52

Appendix 1-6. Risk Insurance Considerations for Geothermal Project Developments

As a consequence, the further development of energy supply plants based on exploitation of deep geothermal energy sources requires a more detailed view on the associated risks and /or risk perceptions in order to prevent or mitigate the potential physical, technical, public, and reputation damage.

According to the GGA Institute (2008), the major exploration risk is the risk of penetrating a geothermal reservoir with one (or more) borehole(s) with inadequate quantity (defined by energy output) or quality (e.g. aggressiveness of the water). Therefore, the new Swiss Electricity Supply Decree (SVV 743.71, 14 March 2008) stipulates that geothermal power projects may apply for a risk coverage under specific conditions (e.g. 50% risk coverage for drilling and testing if the electricity usage is above 1.5%).

In Australia for example, HFR is considered as future competitive alternative when comparing it with hydrothermal systems, and because of the availability of remote project locations, potential earthquake effects at those locations may not be perceived as significant. As Geodynamics & Q-con (2008), point out insurance is provided for well drilling only. The HFR related risks are considered by the public to be low compared with the associated benefits from such projects for the Australian country.

France provides a national geological risk insurance system in order to generally provide coverage for the HDR projects (Presentation at Geofund Risk Conference in Karlsruhe, 2009). However, they are not on a high priority agenda as long as other energy supply sources are in a more favoured position by the government and the national energy supply company.

HDR projects in Germany are covered to date by an exploration risk insurance, albeit mainly focussed on the downhole drilling and installations. Few companies offer an insurance covering volume or heat flux, which appear to be the most critical parameters. According to KONSENS KG (2008), it is however discussed that a larger number of geothermal projects may be covered by a productivity guarantee insurance (PGI). The PGI would cover the following risks:

I. property damages;

II. catastrophic incidents for the operator;

III. operational and environmental liabilities for the operator;

IV. infrastructure damages (e.g. turbines);

V. business interruption.

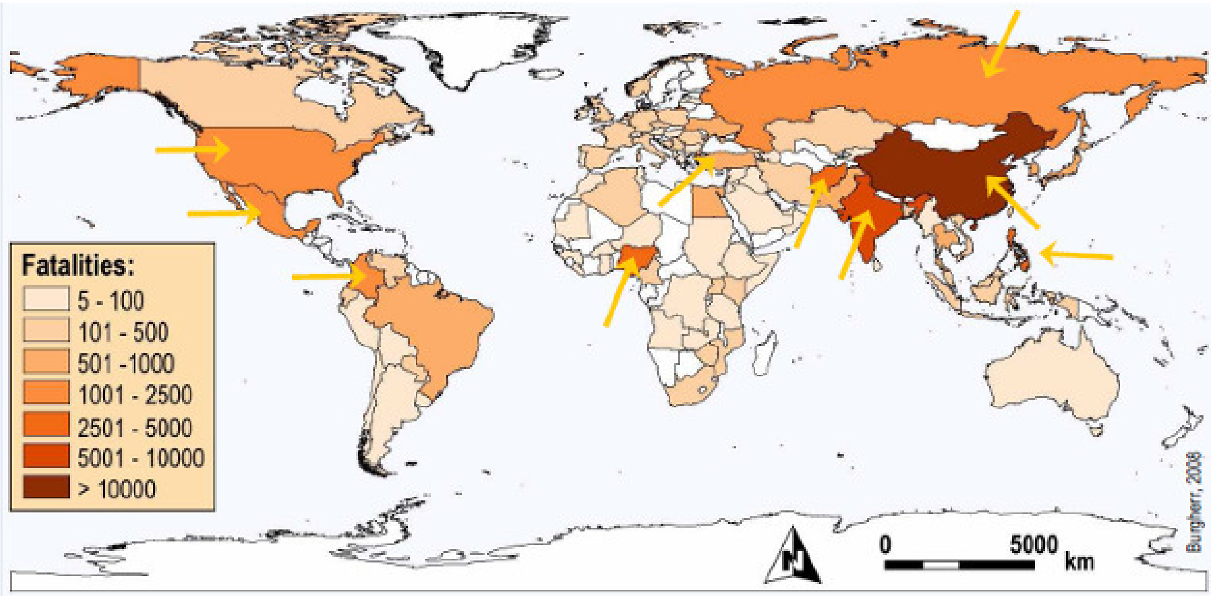
The PGI as an example for one insurance product is not common yet as there are still some conditions to be cleared and experience to be gained in the coming years. It does demonstrate that the insurance market is developing creatively together with the emerging renewable energy supply market, and it may be just a matter of time for the insurance market reaching a greater level of maturity before appropriate policies are available.

Appendix 1-7. Worldwide Risk Comparison

In order to compare the worldwide distribution of risks, a closer look on the potential risks for Switzerland and the urban area of Basel with surroundings is presented based on an evaluation of international risk maps (e.g. Risk Map 2007 prepared by Control Risk Insurance) and the Swiss KATARISK Report (BABS 2003).

According to the 2007 world map on general and political risks for the public, Switzerland is classified with the lowest risk category (= irrelevant) for both risks. There are only two other countries in the same category (Finland, Norway).Figure 27 outlines the worldwide fatalities between 1969 and 2000 associated with Energy Projects (PSI 2008). It describes Switzerland as a very low risk country, whereas the rest of Europe has a higher ranking. China, India, and even the United States and Russia have higher risk rankings.

Figure 27: World Wide Fatalities associated with Energy projects (from PSI 2008).



According to the Munich Re World of Natural Hazards (2004), Swiss rivers cause flooding in about 10% of country area, thus this is considered to present a very high degree of exposure.

A high degree of exposure for about 60% of the Swiss country's area is related to earthquake and winter storms.

A low degree of exposure for the Swiss country is related to hailstorms, lightning, frost, tornados, and drought.

The most severe historical incidents for the Swiss population were the Basel earthquake with 1,500 fatalities (in 1356) and the Valais earthquake with 250 fatalities (in 1855). Major flooding incidents were recorded for 1343, 1570, 1852, and 1910. Other major incidents were based on geological movements after extreme weather conditions including two landslides in central Switzerland in 1806 (457 fatalities) and in 1881 (115 fatalities). Heavy thunderstorms with lightning caused 6 deaths in 1992 and 14 deaths in 1999. Several avalanches resulted in 94 deaths in 1749, 98 deaths in 1951, and 17 deaths in 1999.

Appendix 2: Risque assessment methodology

Appendix 2-1. Methodology for Infrastructure Risk Cost Determination

In order to fulfil the scope of infrastructure risk cost determination, AP 6000 used a probabilistic model, which based on the RISQUE methodology as outlined in Bowden et al. (2001). Defining the model comprised the following steps:

1. Risk screening and risk identification
2. Determination of the probability of an impact and the consequences by an expert panel to :
    - Establishing likelihood of an impact on the selected infrastructure;
    - Determining the consequences if the impact were to occur.
3. Risk cost modelling

The infrastructure risk cost determination would have been much more relevant if large earthquakes were to eventuate. However, during the public hearings it became obvious that the population was anxious about the basic services such as water and in-ground pipelines, thus an assessment was warranted.

1. Risk Screening and Identification

A review of critical industry and infrastructure sectors in Switzerland was performed initially, adjusted to the projects' scope and considering the local situation, followed by a detailed review on infrastructures and lifelines. It resulted in a selection of most relevant infrastructures, which required a quantitative assessment. A table providing an overview is appended as Appendix 3.

The screening exercise has been conducted through literature review. The following documents acted as the main sources of information:

1. Criticality Study (BABS, VBS 2009);
2. Earthquake preparation studies for Switzerland (e.g. PLANAT 2005, summary of PEGASOS 2007, Risikoanalyse Schweiz XXI 2003, Leuschner Thesis 2008);
3. Earthquake prevention & lifeline study (BAFU, UVEK 2008, Basler&Hoffmann 2004);
4. Earthquakes in Switzerland (Weidmann 2002);
5. US and NZ studies on socio-economic earthquake impacts.

Focus was put on the infrastructures in Switzerland. This was done, as it was expected from the AP 5000 results that the expected damages would be minor.

2. Expert Panel

As soon as the results from AP 5000 were available, the expert panel was formed. The expert panel consisted chiefly of Mr Christophe Martin (Chief Seismologist from Geoter) and Mr. Martin Koller (President of Resonance, and Head of Switzerland's Earthquake Engineers and Construction Dynamics - SGEB). Their judgement was largely based on the numerous meetings and internal discussions within the entire working group. The discussions were supported by the review of the studies as outlined in 1 and reviews of former earthquake occurrences and damages.

The expert panel determined the probabilities of the infrastructures and critical lifelines to be affected. Independent estimates were initially derived and when the probabilities were more than one order of magnitude apart, either consensus was tried to be derived or the more conservative probability estimate was used. The probability determination was done using the following table:

Table 12: Likelihood Guide.

Qualitative Description	Order of Magnitude Probability per year	Frequency	Basis
Certain -occurs in the next year			Certain, or as near to as makes no difference
Almost certain - has a 50% chance of occurring	1 >50%		One or more incidents of a similar nature has occurred here
Highly probable - has a 10% chance or 1 in 10 years	>10%	once in 10 years	A previous incident of a similar nature has occurred here
Possible - 1% chance of occurring or 1 in a 100 yrs	> 1%	once in 100 years	Could have occurred already without intervention
Unlikely - once in a 1000 years	> 0.1%	once in 1000 years	Recorded recently elsewhere
Very unlikely - has happened elswhere or 1 in	> 0.01%		It has happened elsewhere
Highly improbable - published information exists	>1E-5		Published information exists, but in a slightly different context
Almost impossible - 1 in a million chance	>1E-6		No published information on a similar case

from Bowden et. al (2001, amended)

For crucial structures such as bridges, AP 5000 developed a probabilistic seismic risk model to determine the possibility of an impact on those structures.

If the probability of any selected structure being affected was determined to have a 1 in 1000 chance (10^{-3}) it was included in the cost modelling.

The determination of the cost impact was derived from various sources- either own data was available for specific infrastructure repair costs, or data was available from other studies on values of infrastructure per unit length, or in case of transportation related costs the Swiss Trakos study (Swiss Statistical Office 2006) was used, or other publicly available data sources were consulted. This research was well done before the actual results of AP 5000 became available in order to be able of modelling the cost implications with a minimal lead time.

3. Risk Cost Modelling

The table in Appendix 3 outlines the general procedure:

a. it shows the list all of the credible infrastructure which were considered

b. it shows the assessment of the likelihood of the selected infrastructure being affected.

The cost modelling was the performed using a Monte Carlo Simulation. A Most Likely Case cost estimate (MLC) and the Reasonable Worst Case cost estimate (RWC) of the estimated financial implications associated with the project was defined. In this approach, the MLC is represented by the Mode (i.e., the highest point on the probability density function [PDF]). The Reasonable Worst Case is associated with a likelihood of 5 % that the estimated costs will be exceeded (i.e., a confidence level of 95% that these costs will not be exceeded). These estimates then formed the basis for assigning a lognormal cost distribution. As risk is defined as an intrinsic combination of cost and likelihood, several ways present itself to analyse the total risk exposure. The chance method approach as outlined in the risk management methodology section (referred to as the RISQUE method) in Bowden et al (2001) truly models the risk cost.

The chance method creates random numbers that are compared to the assigned probability of damage. When a generated random number exceeds the probability criteria, a cost from the probability density function is used. In general, 20,000 model runs, reflecting the drawing of 20,000 numbers were made. From past experience, it was decided to only model probabilities greater than about 10^{-3}. Lower probabilities were only modelled if the was the expectation that very high occurrence or damage costs would be possible

Appendix 3: Infrastucture Risk

Appendix 3-1. Bridges

Highway transportation systems generally consist of roadways, bridges, and tunnels. Road damage only occurs due to surface fault ruptures or extreme soil failure. Bridge damage can occur due to extreme ground shaking and or site soil failure. Generally, such failures occur with earthquakes greater than magnitude 6 (about intensity VII+). Tunnels are amongst the safest structures in the event of an earthquake; hence no damage is expected resulting from geothermally induced earthquakes.

Loss of bridge function usually results in significant disruption to the transportation network, and this is a key component to reliability of lifelines. The potential regional economic impact can be estimated considering the likely bridge/highway segment outage time, associated increased travel times, and the resulting impact on a cross section of the region's employers.

The reliability of bridge structures was derived by AP 5000 using the Risk_ue (2004) methodology based on the seismic hazard from the geothermal plant, the bridge structural design characteristics, and performance of similar structures in previous earthquakes.

Six bridges and nine viaducts exist in Basel. Details of bridges built before 1989 are provided in Table 7.

Table 13: Bridges in Basel.

Bridge / Viaduct	Type	Construction period	Estimated vehicle traffic (cars and trucks) per day
Mittlere Rheinbrücke	Bridge across river Rhine	1903 - 1905	5.000-10.000
Johanniterbrücke	Bridge across river Rhine	1965 - 1967	20.000
Schwarzwaldbrücke	Motorway bridge across river Rhine	1970 - 1973	20.000*/80.000
Verbindungsbahnbrücke	Railway bridge across river Rhine	1959 - 1961	---
Viaduktstrasse	Bridge in Basel downtown	1901 - 1903	10.000
Dorenbachviadukt	Bridge in Basel downtown	1932 - 1934	20.000
Luzemerringbrücke	Bridge in Basel downtown	1962 - 1965	10.000
Birsbrücke Autobahn A2	Motorway bridge	1966 - 1970	120.000
Heuwaageviadukt	Bridge in Basel downtown	1969 - 1970	30.000-40.000
Singerbrücke A2	Motorway bridge	1970 – 1973	120.000
Bäumlihofbrücke A2	Motorway bridge	1971 - 1974	100.000
Wiesebrücke A2	Motorway bridge	1975 - 1980	40.000**
Grenzbrücke A2	Motorway bridge	1976 - 1980	40.000**

(Data from Statistical Office Canton Basel City)

No specific information was collated for bridges in nearby Germany (Weil am Rhein) or France. From an initial review no critical bridges with respect to transportation capacity were identified.

Until 1970s no guidelines existed for earthquake safety of bridges. In 1970, the SIA 160 guideline was implemented which contained regulations that from today's perspective are inappropriate. Since the new inception of guidelines in 1989 only few bridges were built in accordance with the new SIA 160 norm in Switzerland. Overall 95% of the bridges in Switzerland were built without adequate protection against earthquakes. Bridges including autobahn bridges are therefore considered vulnerable even against medium strong earthquakes intensities (e.g. VII to VIII). Furthermore, no current vulnerability classification exists, although plans exist by the Swiss Traffic Authority (ASTRA) for a classification of 781 bridges. For this reason, AP 5000 modelled the seismic vulnerability of the bridges.

The PSA assessment of the bridges showed that the chance of even having minor damages to the existing bridges is less than 10^{-5}. Therefore, no cost estimates of repair costs and associated delay costs were derived.

Appendix 3-2. Rail

The railway system and tracks are more vulnerable than roads because of their complex and technically advanced infrastructure (Basler & Hofmann, 2004). An interruption of railway connections is possible for strong earthquakes. However, because of the large network of tracks compensating possibilities exist. Because of this, the railway system was not classified as a lifeline by the Swiss earthquake vulnerability study. Also, the study concluded that it would be disproportional to protect those structures under the given redundancies of transporting goods.

The Basel railway system is a centrepiece as it comprises one of Europe's main switching stations. The Swiss National Rail (SBB) does not have a program set-up for assessing the earthquake protection systematically (Report to Swiss Government, 2008). Generally, severe failures of rail systems occur with earthquakes greater than magnitude 6 (about intensity VII+).

The expert panel estimated that even at intensities of around VI (which have a 1 in 1000 chance of occurring in the event of a re-initiation of the DHM project), a conceivable impact on the rail system would be that some trains would experience delays as the systems would require checking. Consequently, output losses would be negligible. Based on an average daily number of travellers of about 200,000 in Basel (data from SBB for Basel Swiss Railway Station) and another 200,000 travellers elsewhere in the tri-national region, an average delay cost of about 0.08 CHF/journey (data from TRAKOS, 2006), the associated delay costs would be in the order of 100,000 CHF, when considering one intensity VI tremor per year. The risk cost adjusted for the likelihood of an intensity VI earthquake of about 10^{-3}, is minor.

Appendix 3-3. Airports

The Swiss working group on earthquake protection and lifelines concluded that measures to protect airports are not deemed necessary as road or helicopters can serve as back-up. Further, given the low intensity earthquakes associated with the DHM project, and the low vulnerability of the runway(s), the risk is deemed very low (less than 10^{-4}). Consequently, impacts resulting from airport interruptions were not quantified in this study.

Appendix 3-4. Ship / Barge Transport on the River Rhine

Basel has four harbours, of which two are located in Basel-City (Kleinhüningen and St. Johann). The other two harbours are jointly owned by Basel-City and Basel Landschaft (Birsfelden and Muttenz). The ports were constructed between 1906 and 1950.

93% of the products shipped on the Rhine river by about 180 barges are for the refining and coke industries. It accounts for about 10-15% of the exported tonnage of Switzerland. About 6 to 9 million tonnes of goods are transported per annum.

It is not considered that a re-initiation of the geothermal project would have impacts on this industry.

Appendix 3-5. Water Supply

Due to the fact that the water supply of Basel is mainly facilitated through infiltration galleries (excavated in-ground drains fed by water from the River Rhine at about 1000 L/sec), it is not expected that damages to the source area will be generated given the low intensities resulting from geothermally induced earthquakes.

As the water is distributed by in-ground pipelines, the risk of outages to this important lifeline system is regarded by the expert panel as being negligible (10^{-5}). Groundwater bores not deeper than 100m are also not expected to experience adverse effects as the seismic motion decreases with depth.

Appendix 3-6. Hazardous Waste Storage Areas

A study on the hazardous waste and material storage areas has recently been conducted (Leuschner 2008, Masters Thesis). However, the study excluded earthquake risks and concentrated on flooding and other natural disasters. The Canton of Basel-City has also reviewed the earthquake safety of the hazardous waste and material storage sites and passed a law that requires upgrading measures when new plants are planed or old plants are subject to renovation.

As the Swiss Ordinance on Major Accidents, OMA, regulates those structures, and an additional agreement was passed in 1999 between Roche, CIBA, Novartis, and the Canton Basel-City on their facilities, it was concluded by the expert panel that the structures would only experience damages in case of earthquakes with intensities greater or equal than VII. As the DHM related seismic activity does not generate intensities greater than VI.5, the probability of observing damage from geothermally induced earthquakes is low (10^{-4}).

Appendix 3-7. Electricity System

Both Basel cantons have an electricity network covering several hundreds of kilometres. The Swiss Federal Department for the Environmental (BAFU) initiated a study in association with the Swiss High Voltage Inspection Agency (ESTI) to assess the vulnerability of elements of the electricity supply system recently. It concluded that critical elements are the local transformer stations, subordinate power stations and in particular the outdoor switching stations with porcelain insulators and not the high voltage power lines themselves. It is noteworthy that the power supply for industry, the public buildings, and the residential houses can not be replaced by generators.

The expert panel assessed that the electricity system is not significantly affected by the geothermal project. Power outages are not expected. The only conceivable damage scenario is that some damages to two existing high voltage switching stations could result as a consequence of intensities ≥ VI. The probability of exceedance of intensity VI is close to 1/1000 during the stimulation period and 2/100 during the circulation period. The cost for repair was estimated to be between 0.2 million CHF and 0.6 million CHF, if the intensity VI event were to occur.

Appendix 3-8. Gas Distribution System

In Switzerland there are some main transit pipelines for natural gas, which could influence the gas supply over many regions in Europe. Several pipelines are present in the Basel region. In an event of significant disruption of supply of fuels the Swiss Risk study emphasises that the supply can be substituted from neighbouring areas. The greater risk stems from the secondary risks of storage facilities of those fuels (refer to chapter Appendix 3-14).

Note that there is virtually no oil pipeline distribution system in Switzerland.

The expert panel assessed that the pipeline system is not significantly affected by the re-initiation of the DHM project.

Appendix 3-9. Nuclear Power Plants

The PEGASOS study on nuclear power plants (NPPs) was conducted in 2007. It concluded that all Swiss NPPs are seismically designed and withstand ground motions corresponding to at least intensity VII.

Consequently, there will be no detrimental impacts on the NPPs from a re-initiation of the DHM project.

Appendix 3-10. Waste Water Treatment

The Swiss study on earthquake risks to lifelines identified that critical elements of the waste water treatment plants are the pumps and the treatment units itself which can be interrupted due to power outages. Although there are at present no alternatives or back-up solutions readily available, the expert panel assessed that due to the low intensity earthquakes and associated ground movements by a potential re-initiation of the DHM project, there is no significant risk of outages of these structures. Consequently, no quantification was deemed necessary.

Appendix 3-11. Dams

There are no storage dams on the Swiss side near Basel. The dams in the neighbouring Black Forest are not deemed to be affected (10^{-6}) by the low intensities. Consequently, the impact was not quantified.

Appendix 3-12. Historical Buildings

Historical buildings were not accounted for in the work performed in AP 5000. Historical buildings outside Switzerland were not accounted for.

Basel (City and Landschaft, within the 12km radius) has about 85 historical buildings which are identified as cultural heritage sites by the Cantonal Building Department of Basel in November 2008. During the Basel 1356 earthquake (M_w 6.5) about 11 of those suffered severe damages (e.g. Münster, Barfüsser, Steinen-Kloster, Predigerkirche). The review of available data indicates that not all buildings were destroyed many only suffered medium damages, some only minor damages (e.g. Spalentor, St Johann-Tor).

It was estimated that less than 15 % of the historical buildings would receive minor damages incurring repair costs for each building between 0.02 million CHF and 0.1 million CHF if an intensity VI event was to occur. Moderate damages would only occur with a 1:100 chance, and have been accounted for with repair costs between 0.2 million CHF and 2 million CHF. The occurrence costs for repairing historical buildings in the event of an intensity VI earthquake are less than 4 million CHF. There is only a small chance (5%) of exceeding this occurrence cost. The risk cost (i.e. accounting for the probability of an intensity VI event of 10^{-3}) would be minor.

Appendix 3-13. Communication Systems

Communication systems today rely on functionality of computers and partly on transmitter masts. These structures are vulnerable to significant ground movement or power failures without adequate back-up systems. The induced earthquakes from a geothermal project are not considered strong enough to cause those failures and the likelihood is estimated to be below 10^{-4}. However, it is probable that in an event of an intensity VI quake some roof tiles would loosen and selected TV satellite dishes would dislodge and reception be interrupted.

Appendix 3-14. Secondary effects

Secondary effects of earthquakes are fires and explosions, flooding from burst or otherwise polluted drinking water pipelines, and subrosion[8] endangering foundations of buildings, landslides and road blockages, which may also affect emergency lifelines (e.g. hospitals becoming dysfunctional). The expert panel assessed the risks of secondary effects as being negligible, based also on experience from similar earthquakes. As for fires, these could be caused, albeit not from the earthquakes itself, but from people disturbed by the quake, leaving their homes without first turning off their stoves (Weidmann 2002).

[8] Technical term for sub-surface erosion

Appendix 3-15. Results

The results from the infrastructure risk cost modelling and the building damage assessment of AP 5000 were then used for deriving an assessment with other technologies.

Table 14: Risk to Infrastructure – Results.

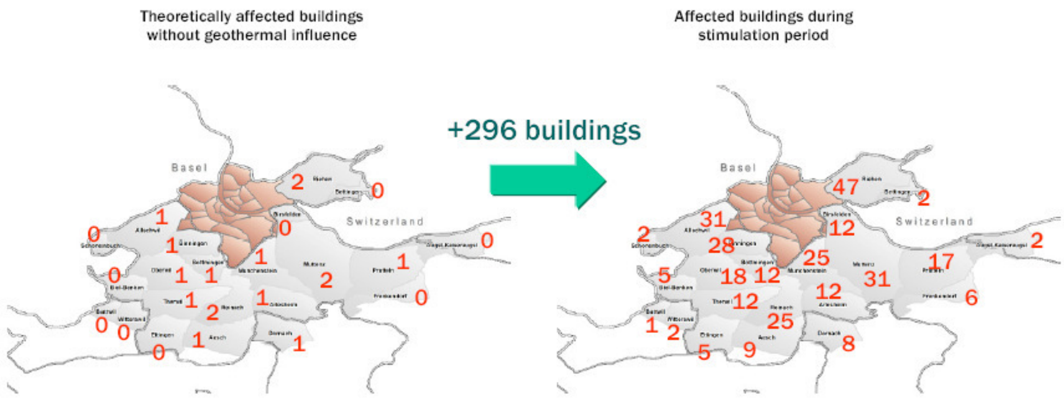
INFRASTRUCTURE DAMAGE	Intensity 6
Stimulation period in frequency (yr-1)	**1E-03**
Circulation period in fFrequency (yr-1)	**2E-02**
	combined probability
PIPELINES	
Pipeline - Major (national) Natural Gas	2E-06
Pipeline - Drinking Water	2E-06
Pipeline - Sewer	2E-06
Pipeline - central heating	2E-06
Waste Incinerator damage (KVA)	2E-06
ROADS & BRIDGES	
Probability of repair to Autobahn Bridge or Dreirosen bridge causing traffic interruption (<2 days)	2E-05
Probability of repair to Autobahn Bridge or Dreirosen bridge causing traffic interruption (<1 week)	2E-06
Probability of repair to Autobahn Bridge or Dreirosen bridge causing traffic interruption (<1 month)	2E-07
Probability of main road closure and repairs of less than two days	2E-06
Probability of main road closure and repairs of less than one week	2E-06
Probability of main road closure and repairs of less than one month	2E-07
TRAIN	
Percentage of affected travellers [%]	50-80%
Number of affected travellers	75000 - 200000
Number of Outages per Year lasting about 2 hours	1-4
HARBOURS	
Probability of harbours being affected (i.e. ships can not dock or even manoeuvre on the Rhine)	2E-06
AIRPORT	
likelihood of airport interruption	2E-05
ELECTRICITY	
probability of widespread grid failure leading to business interruption longer than 4 hours but less than one day	2E-05
power stations (Birsfelden), outage time (<1 day)	2E-04
failure of several local transformer stations and outdoor switching stations with porcellain insulators - outage time more than 4 hours, but less than one day	4E-04
failure of several local transformer stations and outdoor switching stations with porcellain insulators - outage time less than two days	2E-07
HAZARDOUS WASTE AND STORAGE	
likelihood of sinificant damages to storage areas	2E-05
WASTE WATER	
likelihood of significant waste water treatment plants interruption	2E-06
DRINKING WATER SUPPLY	
likelihood of damage of network	2E-05
NUCLEAR POWER PLANTS	
likelihood of damage to a NPP in the area	2E-08
HISTORICAL BUILDINGS	
likelihood of minor damages	3E-03
likelihood of moderate damages	2E-04
SECONDARY NATURAL ISSUES	
likelihood of significant effects on dams in the black forest	2E-07

Appendix 4: Modelled Building Damage by area

SWITZERLAND

D1 earthquake bldg damages without geothermal influence (12 days) vs.
D1 earthquake bldg damages during stimulation period (12 days)

Swiss side (BL, SO, AG)– D1 building damages during stimulation period

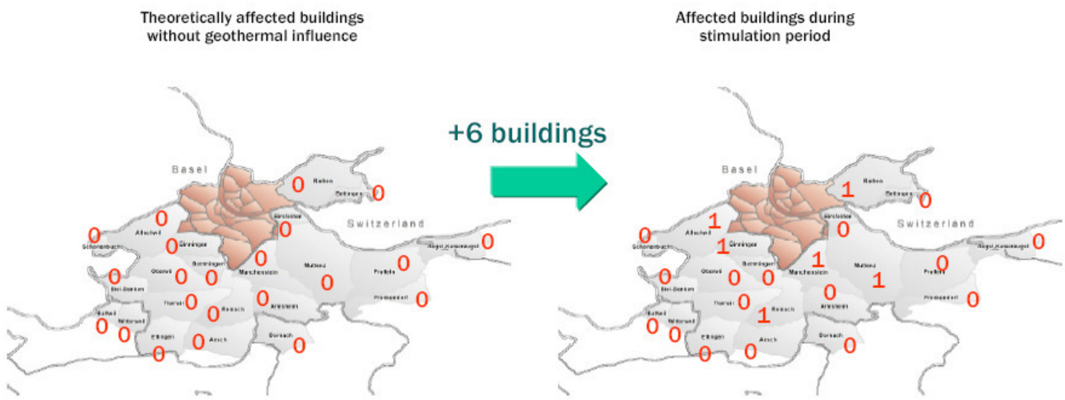


D1: slight damages (approximate value loss (avl): 2%)
D2: moderate damages (avl: 15%)
D3: substantial to heavy damage (avl: 55%
D4: very heavy damage (avl: 91%)
D5: destruction (avl: 100%)

1 Number of affected buildings

D2 earthquake bldg damages without geothermal influence (12 days) vs.
D2 earthquake bldg damages during stimulation period (12 days)

Swiss side (BL, SO, AG)– D2 building damages during stimulation period



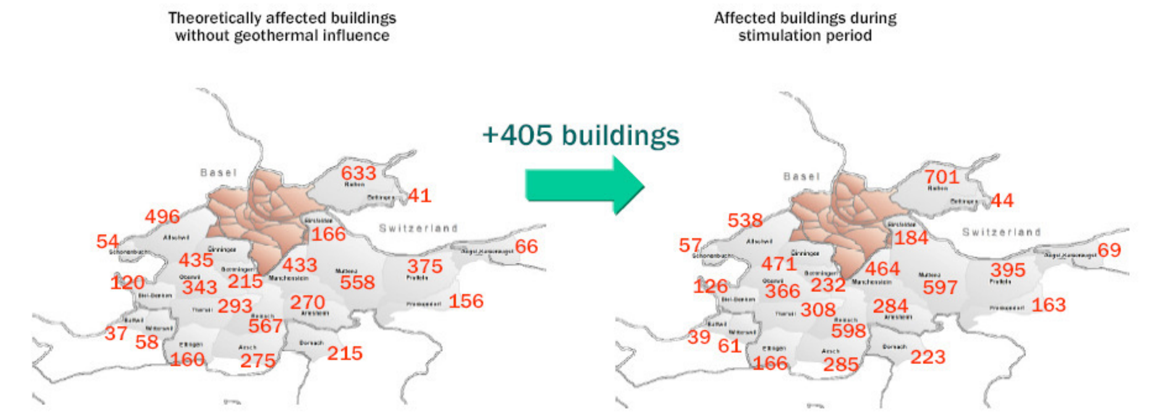
D1: slight damages (approximate value loss (avl): 2%)
D2: moderate damages (avl: 15%)
D3: substantial to heavy damage (avl: 55%
D4: very heavy damage (avl: 91%)
D5: destruction (avl: 100%)

1 Number of affected buildings

No buildings are affected in damage grades D3-D5 (12 days period)

D1 earthquake bldg damages without geothermal influence (30 ys) vs. D1 earthquake bldg damages during circulation period (30 ys)

Swiss side (BL, SO, AG)– D1 building damages during circulation period

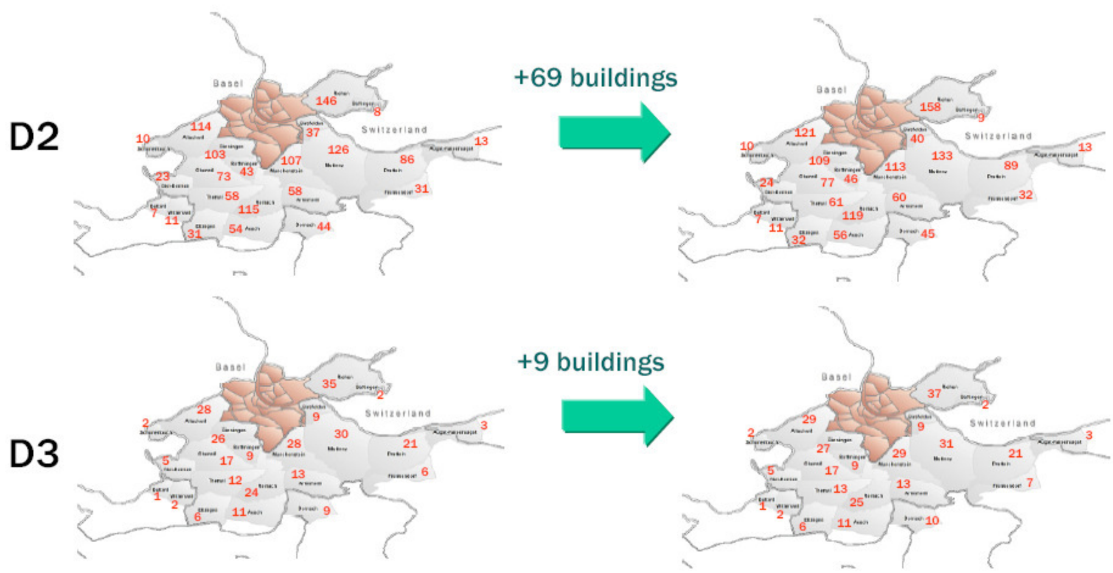


D1: slight damages (approximate value loss (avl): 2%)
D2: moderate damages (avl: 15%)
D3: substantial to heavy damage (avl: 55%
D4: very heavy damage (avl: 91%)
D5: destruction (avl: 100%)

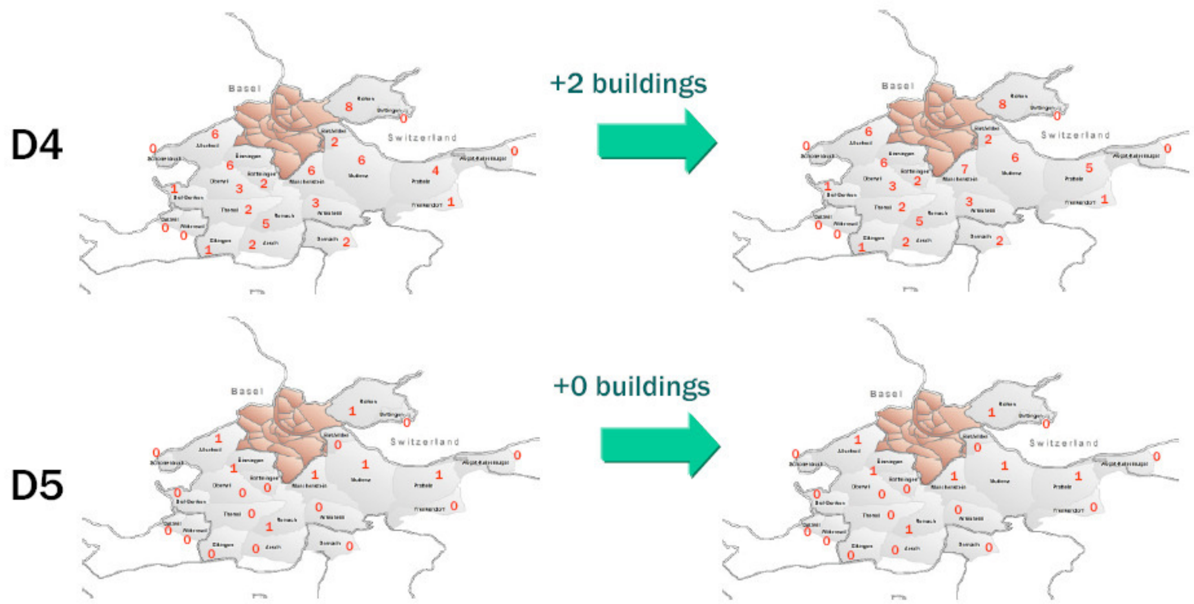
1 Number of affected buildings

D2 and D3 earthquake bldg damages without geothermal influence (30 ys) vs. D2 and D3 earthquake bldg damages during circulation period (30 ys)

Swiss side (BL, SO, AG) – D2 and D3 building damages during circulation period



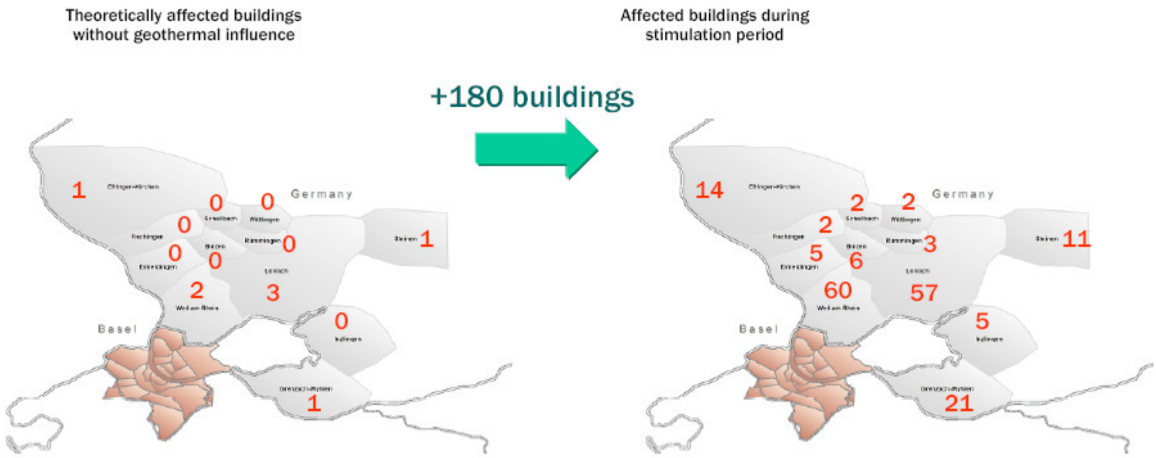
D4 and D5 earthquake bldg damages without geothermal influence (30 ys) vs.
D4 and D5 earthquake bldg damages during circulation period (30 ys)



GERMANY

D1 earthquake bldg damages without geothermal influence (12 days) vs.
D1 earthquake bldg damages during stimulation period (12 days)

German side – D1 building damages during stimulation period



D1: slight damages (approximate value loss (avl): 2%)
D2: moderate damages (avl: 15%)
D3: substantial to heavy damage (avl: 55%
D4: very heavy damage (avl: 91%)
D5: destruction (avl: 100%)

1 Number of affected buildings

D2 earthquake bldg damages without geothermal influence (12 days) vs. D2 earthquake bldg damages during stimulation period (12 days)

German side – D2 building damages during stimulation period

Theoretically affected buildings without geothermal influence

Affected buildings during stimulation period

+3 buildings

D1: slight damages (approximate value loss (avl): 2%)
D2: moderate damages (avl: 15%)
D3: substantial to heavy damage (avl: 55%
D4: very heavy damage (avl: 91%)
D5: destruction (avl: 100%)

1 Number of affected buildings

No buildings are affected in damage grades D3-D5 (12 days period)

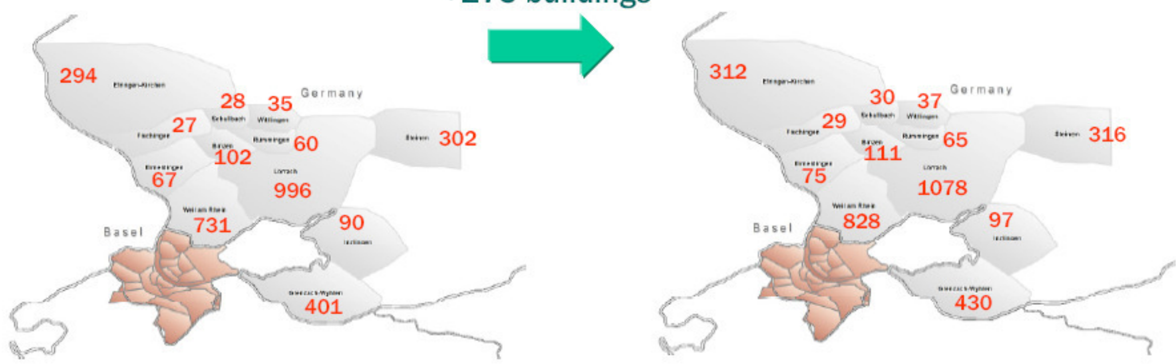
D1 earthquake bldg damages without geothermal influence (30 ys) vs. D1 earthquake bldg damages during circulation period (30 ys)

German side – D1 building damages during circulation period

Theoretically affected buildings without geothermal influence

Affected buildings during stimulation period

+275 buildings



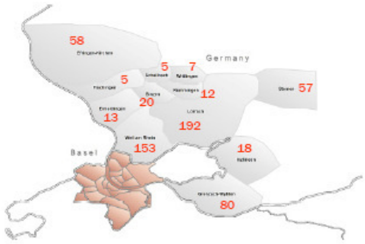
D1: slight damages (approximate value loss (avl): 2%)
D2: moderate damages (avl: 15%)
D3: substantial to heavy damage (avl: 55%
D4: very heavy damage (avl: 91%)
D5: destruction (avl: 100%)

401 Number of affected buildings

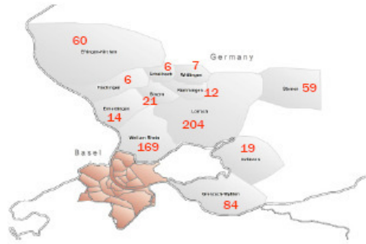
D2 and D3 earthquake bldg damages without geothermal influence (30 ys) vs.
D2 and D3 earthquake bldg damages during circulation period (30 ys)

German side – D2 and D3 building damages during circulation period

D2



+41 buildings



D3

+6 buildings

D4 and D5 earthquake bldg damages without geothermal influence (30 ys) vs.
D4 and D5 earthquake bldg damages during circulation period (30 ys)

German side – D4 and D5 building damages during circulation period

D4

+0 buildings

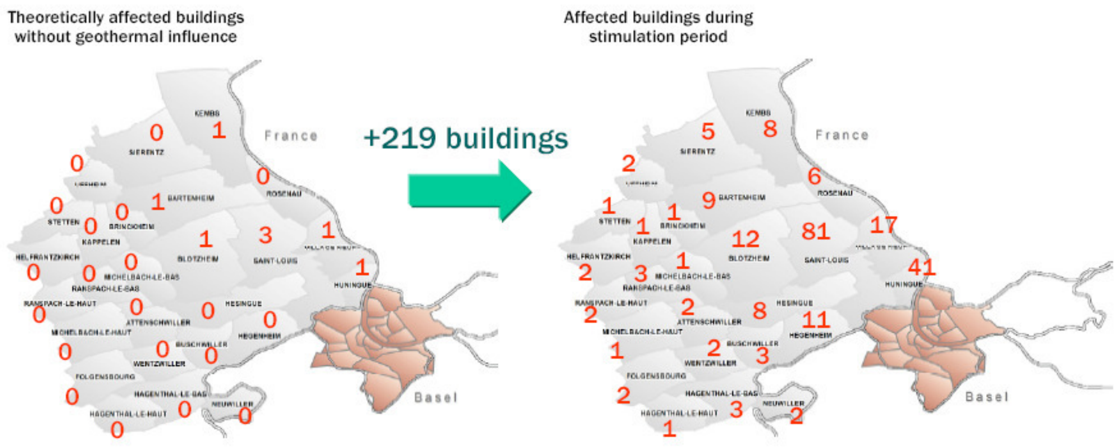
D5

+0 buildings

FRANCE

D1 earthquake bldg damages without geothermal influence (12 days) vs.
D1 earthquake bldg damages during stimulation period (12 days)

French side – D1 building damages during stimulation period

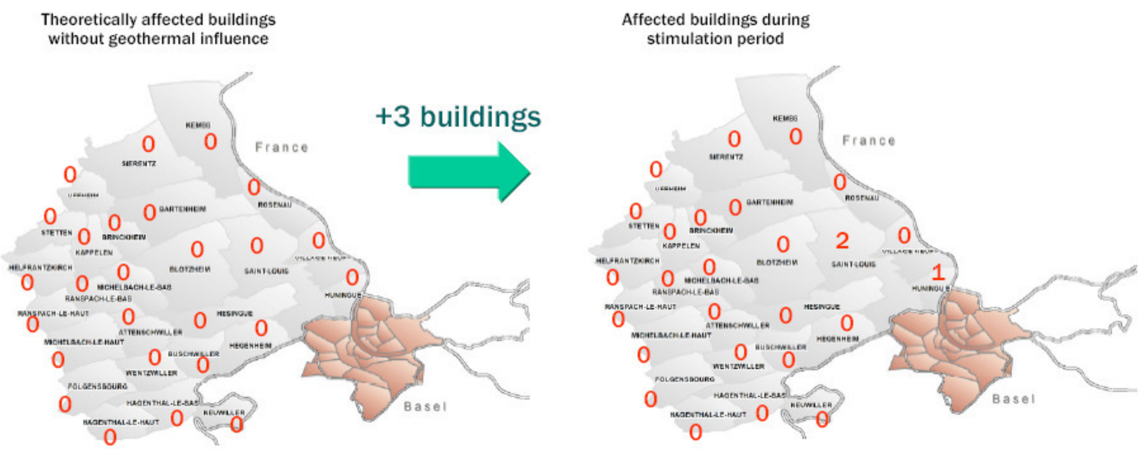


D1: slight damages (approximate value loss (avl): 2%)
D2: moderate damages (avl: 15%)
D3: substantial to heavy damage (avl: 55%
D4: very heavy damage (avl: 91%)
D5: destruction (avl: 100%)

1 Number of affected buildings

D2 earthquake bldg damages without geothermal influence (12 days) vs.
D2 earthquake bldg damages during stimulation period (12 days)

French side – D2 building damages during stimulation period



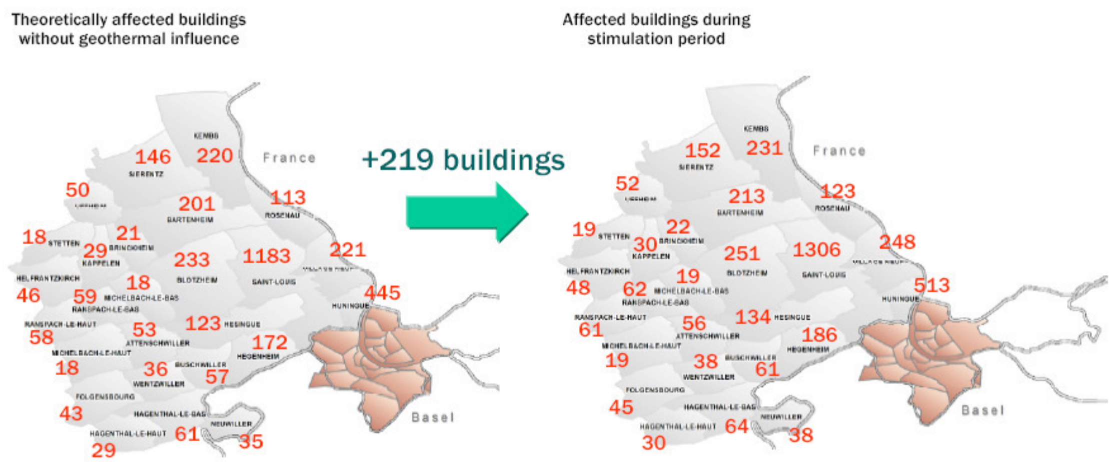
D1: slight damages (approximate value loss (avl): 2%)
D2: moderate damages (avl: 15%)
D3: substantial to heavy damage (avl: 55%
D4: very heavy damage (avl: 91%)
D5: destruction (avl: 100%)

1 Number of affected buildings

No buildings are affected in damage grades D3-D5 (12 days period)

D1 earthquake bldg damages without geothermal influence (30 ys) vs. D1 earthquake bldg damages during circulation period (30 ys)

French side – D1 building damages during circulation period



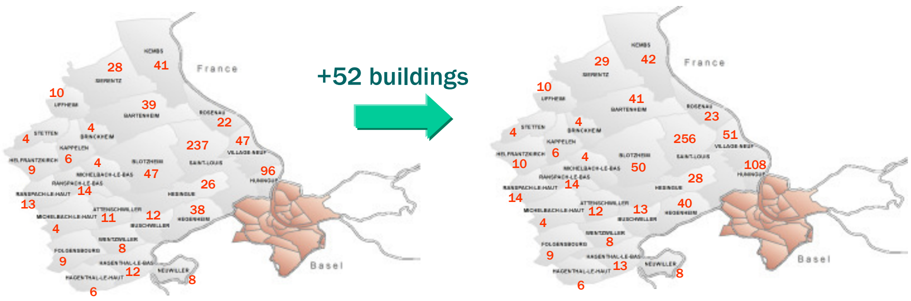
D1: slight damages (approximate value loss (avl): 2%)
D2: moderate damages (avl: 15%)
D3: substantial to heavy damage (avl: 55%
D4: very heavy damage (avl: 91%)
D5: destruction (avl: 100%)

18 Number of affected buildings

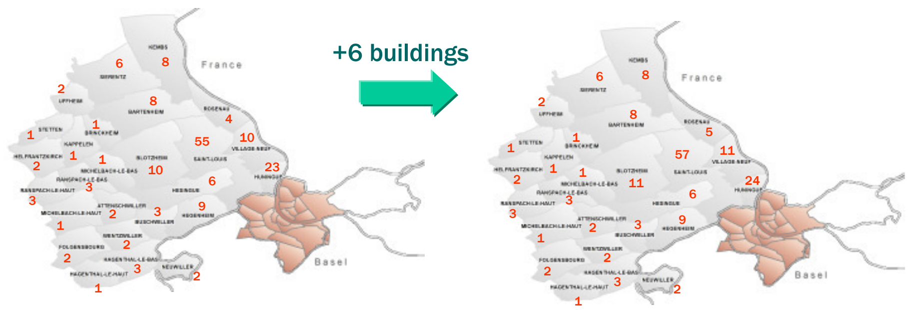
D2 and D3 earthquake bldg damages without geothermal influence (30 ys) vs. D2 and D3 earthquake bldg damages during circulation period (30 ys)

French side – D2 and D3 building damages during circulation period

D2



D3

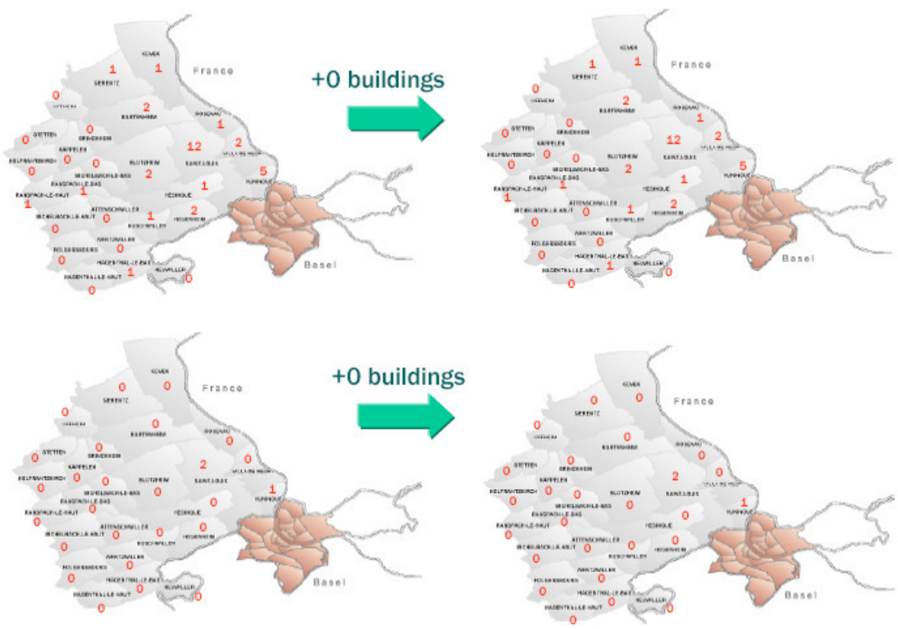


D4 and D5 earthquake bldg damages without geothermal influence (30 ys) vs.
D4 and D5 earthquake bldg damages during circulation period (30 ys)

French side – D4 and D5 building damages during circulation period

D4

D5



Appendix 5: Social Assessment Questionnaire

Fragenkatalog für Unternehmens- und Wirtschaftsvertreter am Standort Basel

Derzeit wird das Thema Geothermie als Energiequelle und mit den damit verbunden möglichen Beben diskutiert.

Als aller erstes interessiert uns: Haben Sie die Beben in Basel erlebt und wenn ja, wie haben Sie diese erlebt?

Was denken Sie persönlich über Geothermie im Allgemeinen? Denken Sie dabei an besondere Chancen und Risiken?

Wenn man davon ausgeht, dass die Geothermie ab und an kleinere Beben mit sich bringen könnte: Gibt es Rahmenbedingungen, unter denen Sie mögliche weitere Beben erdulden würden, um die Vorteile der Geothermie zu nutzen?

Jetzt möchten Sie wir Sie als Unternehmens- bzw. Interessenvertreter befragen:

Hatte das Beben auf Ihr Unternehmen Auswirkungen? Falls ja, welche? (Mitarbeiterschreckung, Risse, etc.)

Welche Bedeutung könnte die Geothermie für Ihr Unternehmen oder Interessensverband am Standort Basel haben? Gibt es spezielle Chancen und Risiken, die Sie damit verbinden? Falls Sie es als Risiko einstufen, hat es eine außerordentliche Bedeutung für Ihr Unternehmen?

Gibt es Rahmenbedingungen unter denen Ihre Unternehmung am Standort Basel mögliche leichte Beben erdulden würden?

(Hinweis für den Befragten: Das könnte zum Beispiel ein spezieller technischer oder auch organisatorischer Rat zur Schadensbegrenzung sein sowie eine spezielle Kommunikationsmaßnahme.)

Noch eine Frage zur Bedeutung der Geothermie für Basel: Halten Sie oder Ihr Unternehmen die Geothermie für förderungswürdig?

Nun möchten wir Ihnen noch einige Infos zum Rahmen der Energiepolitik in der Schweiz geben. Im Anschluss diskutieren wir noch einige Fragen zur strategischen Bedeutung der Geothermie. (Vortrag von 10 min)

Im Anschluss an den Vortrag:

1. Kann Geothermie eine große Bedeutung für die Region bekommen im Hinblick auf Arbeitsplätze, Tourismus, Image, bedeutender Energielieferant?

2. Welche zentralen Maßnahmen zur Erschließung der Geothermie als Energiequelle müssten hierfür konkret ergriffen werden?

Appendix 6: Risk Assessment Guidance Documents and Background

Appendix 6-1. Background to ANCOLD

The Australian National Committee on Large Dams (ANCOLD) defined very conservative set of acceptability criteria, which formed the basis for many institutions to adopt similar values and use them in land use planning, for chemical and nuclear industries (Bowden et al 2000). ANCOLD determined that if a nuclear facility was socially acceptable, then other man-made structures should be ideally constructed as safe. It based the definition of the tolerable area on the data on nuclear power plants as outlined in Figure 2 and was the first institution worldwide to make this determination. The idea was also to demonstrate that dams designed to that level are much safer than the risk people tolerate from other areas of their lives.

The limits of tolerability adopted by ANCOLD are essentially international; and are strongly influenced by those of the UK's Health and Safety Executive (HSE), which are endorsed by the UK Treasury. Fundamentally, the limits of tolerability set by ANCOLD and HSE are absolute and have no regard for the costs or benefits of the investment in safety needed to reach them. The ANCOLD Guidelines propose limits of tolerability for both individuals and for societal risks. In contrast, HSE relies primarily on limits of tolerability for individual risk. HSE is very circumspect about societal risk criteria: HSE has not published any FN criteria and appears to accept the advice of Ball and Floyd (1998) that tolerability limits for societal risk are controversial and that *"…societal risk criteria should not be used in a 'prescriptive mode' …[but] …should be regarded as no more than indicators or guidelines (Marsdon & Jacob 2007).*

Appendix 6-2. Summary of Guidelines

A selection of guidelines and other relevant studies related to assessing risks are presented in Table 15.

Table 15: Risk assessment guidance documents and relevant studies.

Country	Field	Measurement	Limits provided?
Switzerland	Ordinance on Major Accidents - Seveso (OMA, BAFU)	Number of fatalities, ALARP Soil and groundwater impacts Property Damage	Yes Yes Yes
Switzerland	Katarisk Study on Population Protection (BABS)	Number of fatalities Number of evacuees People needing subsistence Destruction of environmental resources Property damage, FD curves	No No No No No
Switzerland	Nuclear, and Energy Projects Study (PSI)	Number of Fatalities, FN curves	No

Country	Field	Measurement	Limits provided?
Germany	Railway safety Flood Damage (CEDIM study),	Probability of death to an individual, fatalities Economic damage	Yes BCA (economic optimisation)
Germany	Seveso Directive SFK/TAA-GS-1)	Probability of death to an individual, fatalities	No
France	Seveso Directive law 2003-699 for land use planning	Probability of death to an individual, fatalities, semi-quantitative only	No, Risk Matrix
Australia	Dam safety guideline (ANCOLD) Air Traffic Safety Authority guideline NSW land use planning Department guideline	Number of fatalities, FN curves, ALARP Number of fatalities, FN curves, ALARP Number of fatalities, FN curves, ALARP	Yes Yes Yes
United Kingdom	land use planning guideline (RRPP, HSE)	Individual risk	Yes
The Netherlands	Flood Damage Study (TAW, VROM)	Probability of death to an individual Economic damage	Yes No, BCA
The Netherlands	Seveso Directive - QRA guideline (TAW, VROM) Purple Book, Yellow Book	Probability of death to an individual	Yes
OECD	Tunnel Safety Study	Number of fatalities	No
United States	Dam safety Bureau of Reclamation	Number of fatalities Economic damage	Yes Yes (economic optimisation)
Canada	Dam safety Study (BC Hydro)	Number of fatalities	Yes
Norway	Oil Platforms Study	Recovery time due to ecological damage	Yes

BCA = Benefit Cost Analyses, RRPP= reducing risks protecting people guideline (UK)

For risk calculation details, also refer to Jonkman et al. (2003), and Hess 2008.

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Appendix 8: Definitions

Definition	
Equity violation (Inequity)	unfair distribution of benefits and risks.
Exposure	contact of a hazardous agent with the facility, people, ecosystem or structure.
Hazard	a threat to a system. In the case of DHM, chiefly the hydraulic pressure on the rock system causing it to fail and thereby generating earthquakes.
Induced Earthquakes:	earthquakes set-off by the geothermal activity.
Impact	extent of damage or harm in specific units (fatalities, costs).
Intensity	a measure of the damage incurred by an earthquake. Several scales exist worldwide- in the study the EMS-98 scale is used
Lifeline	critical infrastructure - a lifeline utility is required to function 'to the fullest possible extent' (even at a diminished level) during and after an emergency, and participate in emergency management planning.
MonteCarlo simulation	mathematical tool to sample uncertainties. Defining a probability density function of costs or likelihoods is a prerequisite before any modelling can be done. Used in chance method cost modelling.
Probability of Occurrence	an estimate of a relative frequency of a hazard or risk event occurring.
Risk Appraisal	the scientific assessment of the risks to human health and the environment (in this case done by AP 5000) and the scientific assessment of related concerns as well as social and economic implications.
Risk identification	the development of a risk register where all credible risk events (also often referred to hazards) are collated. This process is usually done by a panel of experts. Cause - effect links are identified and their impact on the structure, facility or the ecosystem is estimated. This is largely dependent on the type of exposure (e.g. time) and the vulnerability.
Upstream, Midstream, Downstream:	The upstream sector is a term commonly used to refer to the searching for and the recovery and production of crude oil and natural gas including exploration wells and pipelines from the source to the processing units. The midstream industry processes, stores, markets and transports commodities such as crude oil, natural gas, and natural gas liquids. The downstream sector is a term commonly used to refer to the refining of crude oil, and the selling and distribution of natural gas and products derived from crude oil. The downstream sector includes oil refineries, petrochemical plants, petroleum product distribution, retail outlets and natural gas distribution companies.
Vulnerability	various degrees of the structure, facility or ecosystem to experience harm or a detrimental effect.

Appendix 9: Abbreviations

Abbreviations	
ALARA	as low as reasonable achievable (without consideration of economics)
ALARP	as low as reasonable practicable (with consideration of economics)
ANCOLD	Australian National Committee on Large Dams
AP	work package (Arbeitspaket)
ASTRA	Swiss traffic authority (Bundeamt für Straßen)
BABS	Swiss Federal Department for Civil Protection (Bundesamt für Bevölkerungsschutz)
BAFU	Swiss Department for the Environment (Bundesamt für Umwelt)
BaZ	Basler Newspaper (Basler Zeitung)
BCR	Benefit/cost ratio
BFE	Swiss Federal Department for Energy (Bundesamt für Energie)
CH	Country code for Switzerland
CHF	Swiss franc
CSSL	Cost of saving a statistical life
DHM	Deep Heat Mining
DINAR	research project by the German Government
EEG-EEG	a citizens initiative (Interessensgemeinschaft der Erd- Erschütterungs- Geschädigte und Erd- Erschütterungs- Gerüttelten)
EGS	Enhanced Geothermal Systems
ENSAD	Energy related severe accident database
ERKAS	Swiss Register on the Ordinance on Major Incidents (Eidgenössischen Risikokataster gemäss Störfallverordnung)
ETH	Swiss Federal Institute for Technology (Eidegenössisch technische Hochschule)
EUK	Energy and Environment Commission of the Chamber of Commerce in both Basel Cantons
FD curves	Frequency / Cost of Damage curves
FN curves	Frequency / Number of Fatalities curves
GaBE	Comprehensive Evaluation of Energy Systems (Ganzheitliche Betrachtung von Energiesystemen
GDP	Gross domestic product
GWh	Giga watt hours (=10^9Wh)

HDR	Hot Dry Rock
HFR	Hot Fractured Rock (synonymous to HDR)
HSE	Health and Safety Executive (HSE), a non-departmental public body in the United Kingdom
IRGC	International Risk Governance Council
KWh	Kilo watt hour (=10^3Wh)
MLC	most likely case (representing the case with the highest likelihood of occurrence, the mode)
M_w	Magnitude work accomplished, referring to the seismologic moment magnitude scale
MW_e	Megawatt electrical, referring to electric power (=10^9W_e)
MW_{th}	Megawatt thermal, referring to thermal power(=10^9W_{th})
NPP	Nuclear power plant
NSW	New South Wales – an Australian State
ORC	Organic rankine cycle
p.a.	per annum
PDF	Probability density function
pgv	Peak ground velocity
PRA	Probabilistic risk assessment
PSI	Paul-Scherrer-Institute
PV	Photovoltaik
QLD	Queensland – an Australian State
RISQUE	Risk Identification and Strategie Using Quantitative Evaluation
RWC	Reasonable worst case (representing a 5% chance to occur)
SED	Swiss Earthquake Service (Schweizer Erdbebendienst)
SN	Swiss norm
OMA	Swiss Ordinance on Major Accidents (Störfallverordnung)
TAW	Dutch Technical Advisory Committee on Water Defences
TWh	Tera watt hours (=10^{12}Wh)
USG	Swiss Act on Environmental Protection (Umweltschutzgesetz)
VSL	Value of Statistical Life
WBGU	German Advisory Council on Global Change (Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen)
WTP	Willingness to pay