D.7.3.1 Summary report on the elaborated geological risk mitigation schemes for the 3 pilot areas

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Contents

1. Introduction

The main aim of the DARLINGe project is to support the enhanced and efficient use of geothermal energy in Europe. One of the objectives of the project is to establish a market-replicable toolbox for sustainable geothermal reservoir management. One module of the toolbox is the Geological Risk Mitigation Scheme tailored to the needs and to geological as well as socio-economic conditions of the Danube Region. The scheme is focussing on how to mitigate the entire spectrum of geological risk during exploration and operational phase of a geothermal development. The report describing the methodology of the scheme was published within D.6.3.1. Manual on the use of the transnational toolbox.

During the implementation of pilot actions, the scheme was tested on several hypothetical sites within the 3 cross-border pilot areas using site specific data to improve the reliability of the scheme. Based on the gained experiences the scheme was updated accordingly and the improved version was the base for programming the risk mitigation toolbox of the DRGIP (Danube Region Geothermal Information Platform) website.

This report describes the method of testing, the results of testing made at pilot areas, the evaluation of common characteristics of suggested risk mitigation measures of testing, the improvements made at the scheme and the toolbox of the DRGIP website.

2. Testing of risk mitigation scheme

The main aim of the testing was to evaluate and to improve the geological risk mitigation scheme. The secondary aim was to identify suggested risk mitigation measures of a given project of an area to provide indication what kind of measures and at what time could be made to avoid, or decrease the likelihood of having foreseen damages. The emphasis is on providing indication, because the relevance of a given measure should be evaluated by site-specific data including additional technical and financial consequences. As it was described in the previous D.6.3.1 report, all risk mitigation measures are costly and call for time and special attention. Basically, all measure should be treated as an early sacrifice to avoid undesired possible damages appearing later, and thus increasing the predictability of project management.

During the implementation of WP6, the scheme was created based on gained experiences of project partners connected to previous geothermal developments. The scheme covers all phases of a geothermal project development from reconnaissance study until the operational phase, but the focus of collected experiences was rather on the early or initial development phases, when the consequences of so-called short-term risks could appear with high likelihood causing possibly a painful show stopper event, like immediate defeat of a geothermal project. The test of the scheme was based on data of different theoretical projects to be implemented in a known, but various geological environment of DARLINGe project area. For the sake of successful testing well explored and poorly explored areas, and porous and fractured aquifers were selected separately. On well explored areas hydrogeological modelling was performed to evaluate the impact on the receptors (operating wells or thermal springs) nearby. By the help of modelling the expected pressure or temperature change of long-term use could be calculated at given spatial position within the reservoir around the wells of the theoretical project.

The scheme is handling numerous uncertainties connected to reservoir properties (e.g. size, temperature, permeability, pressure conditions, fluid chemistry) and drilling considerations (e.g. drilling problems, drilling targets). Several types of geological hazards, like impact on other aquifer, or on a spring, and long-term risks, like pressure decline or early cooling in the reservoir are also included in the scheme. As the scope of DARLINGe is the heat production from geothermal resources, the risks associated with engineered geothermal systems (EGS), like induced seismicity is not part of the scheme.

The direct outcome of testing is the list of risk mitigation measures for each theoretical project. The risk mitigation measures are classified into 4 categories listed below:

- highly recommended, when the probability of connected risk event is high,
- recommended, when the probability of connected risk event is medium,
- worth to consider, when the probability of connected risk event is low,
- not relevant, when the conditions are such that the connected risk event is unlikely, or the measure could not be used.

The category of the given measure is defined by the level (high, medium or low) of likelihood of the risk event, which should be mitigated by the measure. For example when the first drilling of a project is planned on an inadequately explored area, and there is a high likelihood of having misinterpretation of temperature data because of inaccurate evaluation of subsurface data, the measure of "*Accurate collection and interpretation of temperature data measured in existing wells for securing information for temperature forecast*" is "*highly recommended*". Or a given measure could be "*not relevant*", if the connected risk event is not realistic to happen, because the given circumstances simply exclude it.

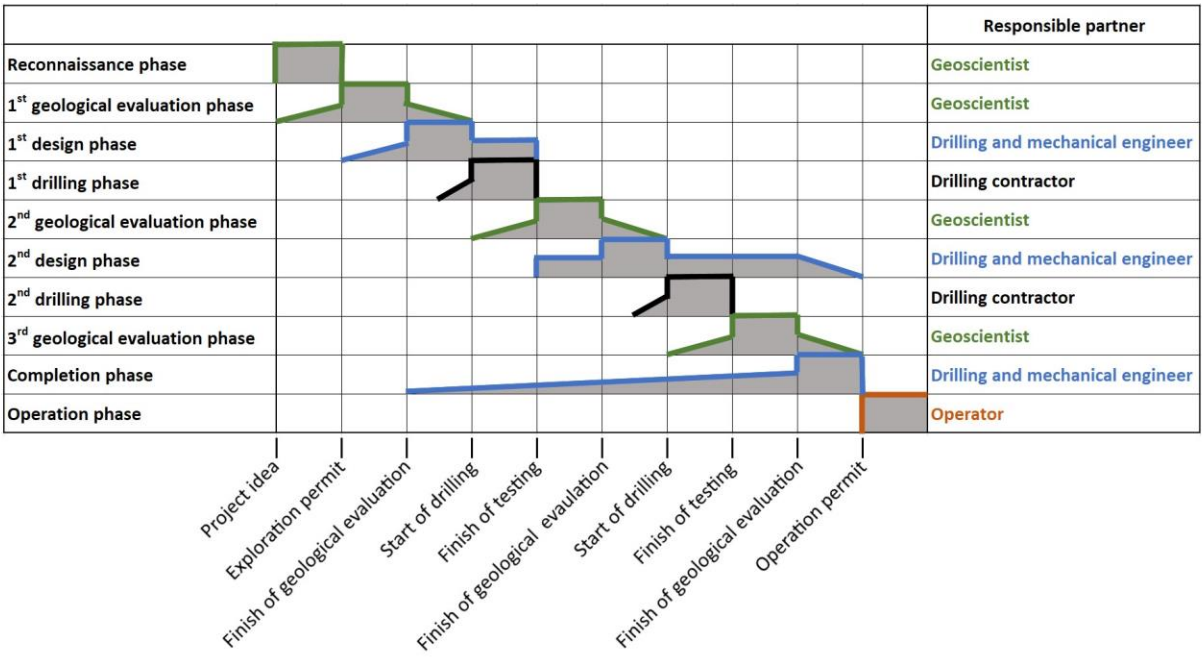

Figure 1. Phases of an idealised geothermal project development.

During the testing available data were collected, and a theoretical project was defined at a given location. Based on the evaluation of subsurface properties, the necessity of all risk mitigation measures of all project phases (see Figure 1) were defined and sorted according the level of recommendation. The description of recommended measures at each pilot project is only a short characterization trying to keep the present report in a readable manner. The whole list of evaluated measures by projects is presented in Appendix A.

The possible receptors, which might experience some impacts because of the operation of the theoretical project were defined as well. The possibly occurring impacts on these objects trigger some mitigation measures, mostly connected to hydrogeological modelling, testing and monitoring operations. Where modelling was performed, the main outcome of modelling results were indicated as well. A summary is given about the evaluation of relationship between input data and type of recommended measures defined on pilot areas in Chapter 6.

The testing induced the need of reconsideration of several aspects and suggestions of the first version of the scheme. The modifications of the scheme were recorded, and a new version of the scheme is issued, which is available at Appendix B.

3. Application of the scheme on the HU-RO-SRB pilot area

The geological risk mitigation scheme was tested by using data of three theoretical projects. The locations of projects (see Figure 2) are Palič (Serbia), Szeged (Hungary) and Sannicolau Mare (Romania).

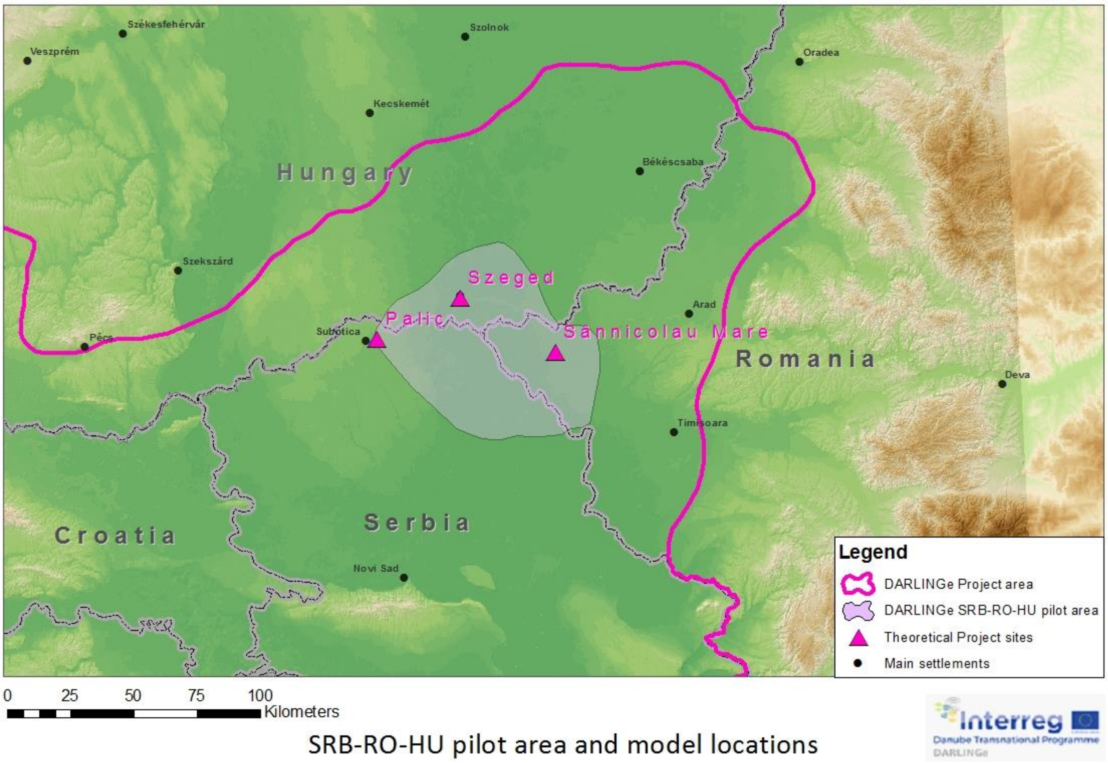

Figure 2. Location of project sites within the SRB-RO-HU pilot area

3.1. Reservoir

The reservoir is a well-explored basin fill, porous reservoir of late Pannonian age having of transboundary character extending to all 3 countries. In the case of Szeged - due to the dense network of wells and operating geothermal systems - the characteristics of the subsurface is known with higher confidence compared to the other two countries. The reservoir consists of siliciclastic sediments, alternation of permeable and impermeable formations. At the upper part of the reservoir is composed of mostly unconsolidated sediments like clay, sand, and gravel, which turn into more solid formations, like claymarl and sandstone at greater depths. The targeted sandstone layers (geothermal aquifers) are located at the bottom part of the upper Pannoniansedimentary succession. The pores within the sandstone are sensitive for clogging by particles or bacteria. The detailed description of this kind of reservoir is discussed in details in D.5.1.1. report "Identification, ranking and characterization of potential geothermal reservoirs" (Rotár-Szalkai et al., 2018).

3.2. Project idea

All theoretical projcts in the 3 countries intend to utilize the reservoir for heating purposes by triplets, which consist of one production and two injection wells. In case of Szeged the project is aiming the use of 2 triplets, while at Palič and Sannicolau Mare 1-1 triplet is envisaged.

Each triplet has 2 MW heat power output respectively. The expected outflow temperature is 85°C in Hungary and Romania, while in Serbia it is only 65°C due to the shallower position of the reservoir. The temperature difference of utilization (called as delta T) is 45°C, while the yield of production well during heating season is 20 l/s. The location of wells and the distance between the members of the triplet was defined by expert judgement taking into consideration the thermal break-through and the distance to operating wells.

The theoretical projects start from early geological evaluation and last until the operation of the triplets, so the scheme was tested at each phase of each pilot project.

3.3. Characterization of possible receptors

The existing user of the geothermal aquifer enjoys a kind of privilege, and the newcomer installations must take them into consideration regarding induced pressure and temperature change. At the very beginning, during the planning phase of the new development, a forecast is needed to be performed by the help of hydrogeological modelling. Later when the new wells completed, and the new facility starts to operate, the upgrade and verification of modelling and the monitoring of pressure and temperature values at new and old wells must be used to improve the accuracy of forecasted impacts. The main aim of this method (modelling, verification, monitoring) is to predict unfavourable impacts in due time before irreversible, or hardly reversible conditions starts to develop in the reservoir. In such an area, where existing wells are missing in the near vicinity (within 10 km) of new development, the forecast has less importance. Besides existing wells, receptors could be administrative locations, like state border, or border of protected units, like drinking water resource, or other mineral resources (e.g. hydrocarbon, geothermal fluid) protected by concession right. These features could be evaluated in the form of a compliance point, which has an arbitrary chosen location within the reservoir, and the model could calculate the expected pressure and temperature change at this point.

Looking at the map of existing wells on the pilot area, there are numerous possible receptors in the close vicinity (<3 km) of the triplets, which is due to the increased population and the popular use of the Upper Pannonian geothermal aquifer for various purposes. The locations of possible receptors around the hypothetical triplets are presented on Figure 3, Figure 4 and Figure 5 for each country.

By the help of a hydrogeological modelling, the expected impacts in the form of induced temperature and pressure change is quantifiable at each receptor. The result of the hydrogeological modelling showed that the new triplets will induce pressure and temperature changes at the majority of the nearby operating wells ("receptors"). However, the size of the expected impact is within a reasonable and acceptable range, based on industrial practices. The calculated pressure change does not exceed a couple of metres (due to reinjections) and the calculated temperature change does not exceed 1-2 °C at any existing receptor (Table 1). This is an encouraging indication for the realization of these projects. However, it has to be emphasized again that the predictions a model can provide before drilling (e.g. the current model) are hardly identical with the response of nature after the long-term operation of existing wells.

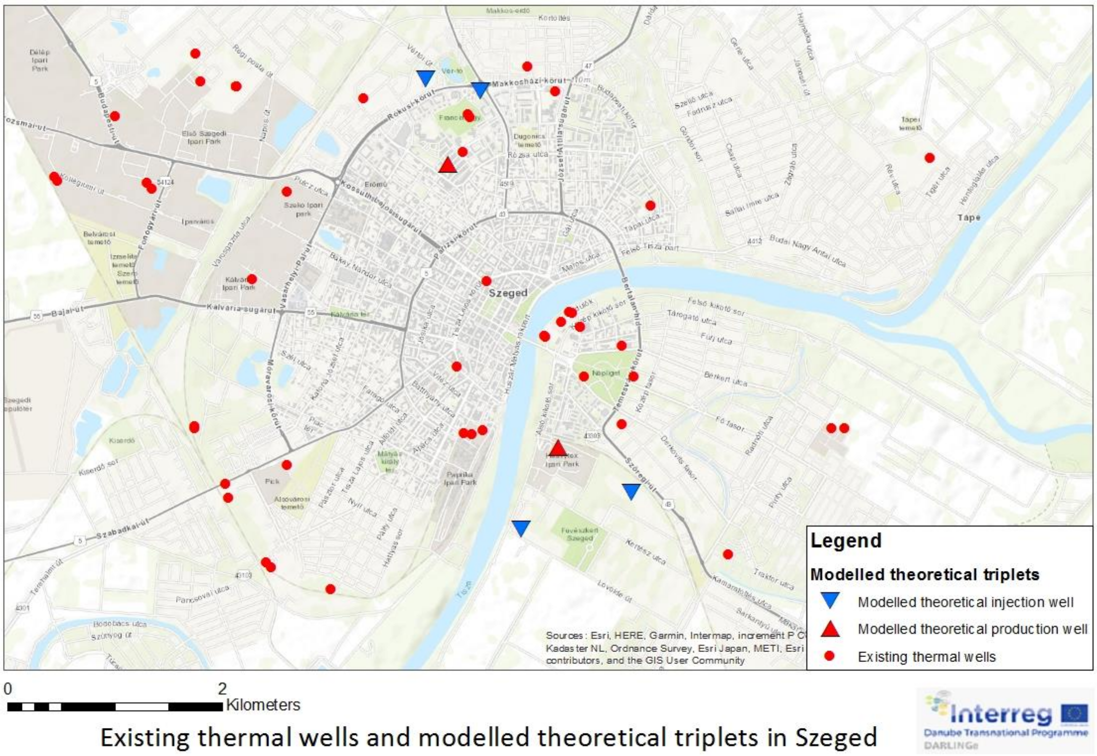

Figure 3. Location of existing wells around the planned theoretical triplets in town of Szeged (Hungary)

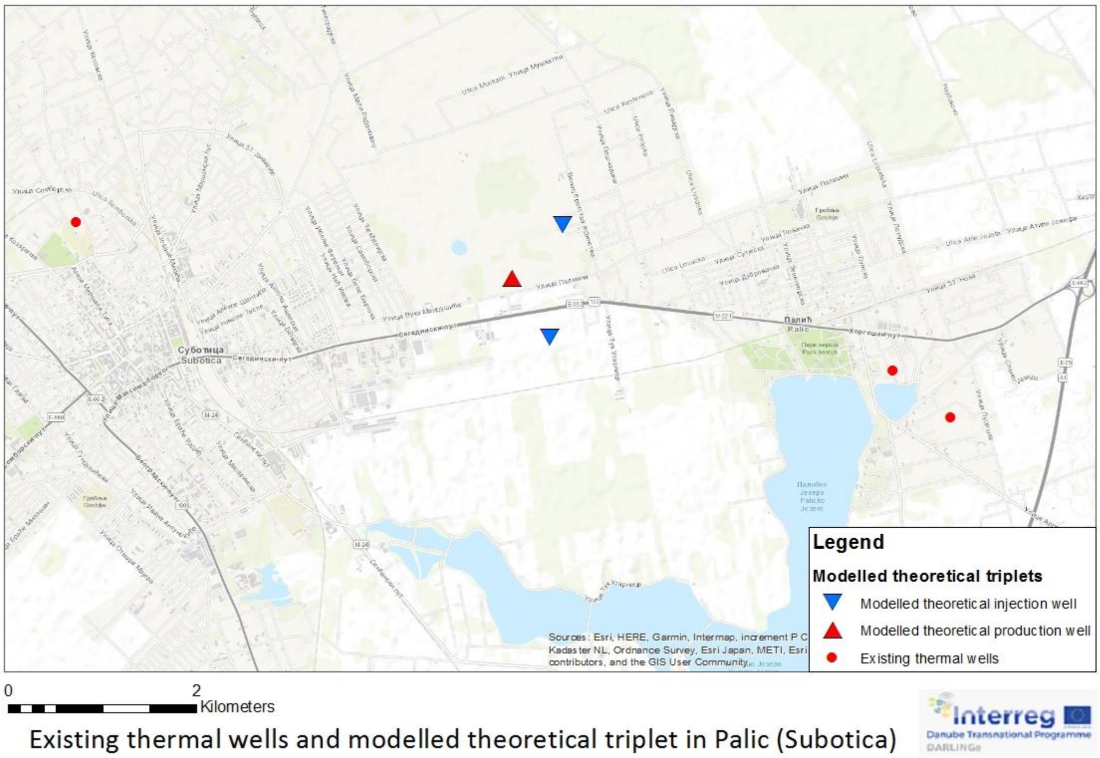

Figure 4. Location of existing wells around the planned theoretical triplet in town of Palic (Serbia)

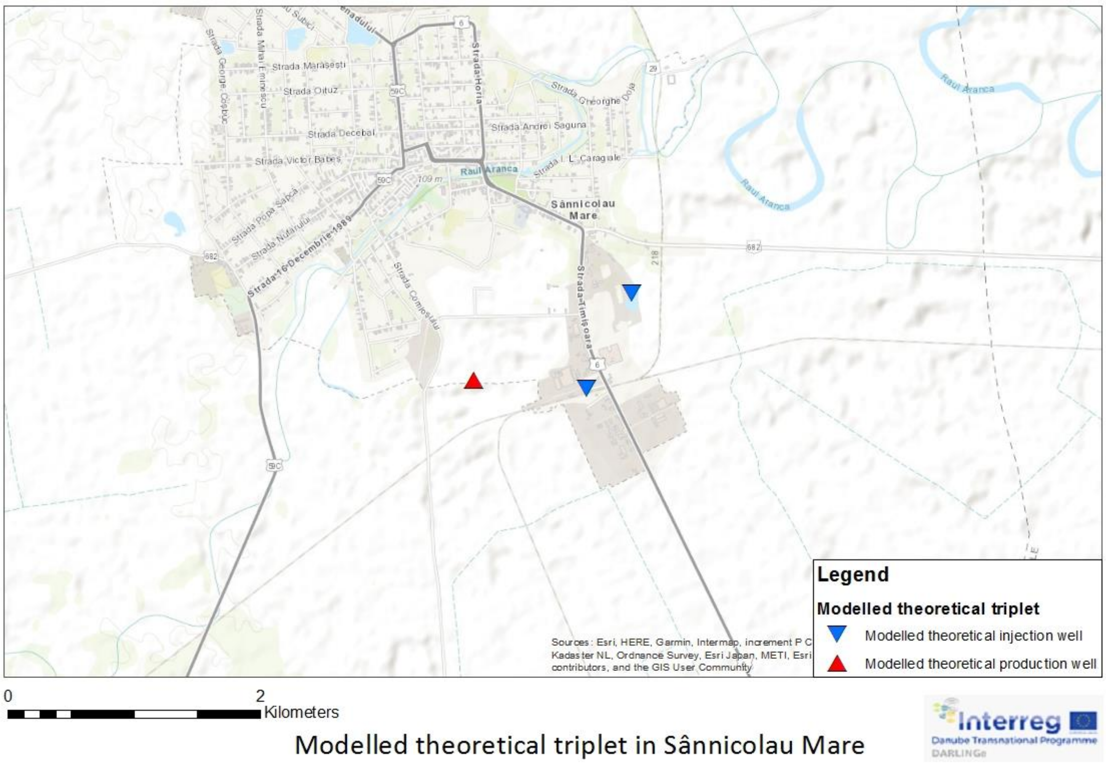

Figure 5. Location of existing wells around the planned theoretical triplet in Sannicolau Mare (Romania)

Table 1. Forecasted induced pressure and temperature changes at real and virtual receptors around the triplets to be operated based on hydrogeological modelling, the ID of virtual w ells include "v".

Receptors	Head	Temperature
5-181	no change	temperature drop
5-188	no change	temperature drop
5-189	no change	no change
5-172	no change	temperature drop
5-177	no change	temperature drop
5-194	pressure increase	temperature drop
5-187	no change	no change
5-185	pressure increase	temperature drop
5-180	no change	no change
5-49	no change	temperature drop
5-176	no change	no change
5-270	pressure increase	no change
5-272	no change	no change
5-89	no change	no change
5-98	no change	no change
5-90	pressure increase	no change
5-93	no change	no change
5-91	no change	no change
Virt-2	pressure increase	temperature drop
Virt-6	pressure increase	no change
4645	pressure increase	temperature drop
4631	pressure drop	temperature increase
1524	pressure increase	no change
1521	pressure increase	no change
1522	pressure increase	no change
Pj-1/H	pressure increase	no change
5-16	pressure increase	no change
5-29	pressure increase	no change
Virt-1	no change	temperature increase
Virt-4	pressure increase	no change
Virt-5	no change	temperature increase
S-1	pressure increase	no change
Ds-2/H	pressure increase	no change
Pj-2/H	pressure increase	no change
Virt-Srb-1	pressure increase	temperature increase
Virt-3	no change	temperature drop

Legend		
	pressure increase	temperature increase
	no change	no change
	pressure drop	temperature drop

3.4 Suggested risk mitigation measures

The measures were selected from the scheme by empirical way using the available data. The list of selected measures is summarised in Appendix A.

Comparing the got measures, one can observe that the type of reservoir and the increased exploration level define the type of risk mitigation measures, and thus the emphasis is rather on adequate modelling and proper well completion. As the properties of the aquifer is very similar in all three countries, the identified measures of the scheme are described together below, but several differences are highlighted.

There are several risk mitigating measures, which should be considered in the initial geological evaluation phase. The collection of temperature, production and fluid chemistry data and collection and interpretation of geological layers and features for securing information about identification of target formation and for securing information about forecasted drilling difficulties are recommended activities to increase the knowledge about the subsurface properties. The accurate hydrogeological modelling including data collection and interpretation is a suggested measure to locate adequately the site of members of triplets for decreasing the likelihood of early cooling of production wells, and of having adverse impact on receptors nearby. The calibration of model by interference and tracer tests using the existing wells is suggested too, because this could improve the reliability of the hydrogeological model. In case of Szeged the modelling and its calibration by data of new tests has high importance due to closeness of various receptors.

During the design and drilling phase there are several highly recommended measures, like designing of the production section of the well with 8 1/2" borehole diameter and use of under-reaming (enlarging the diameter) and gravel pack (or gravel filter) in the production section. Several measures are recommended, like (1) use of clay minerals-free drilling mud, which is properly treated in the mud system by removal of cutting particles, which improves the permeability of the well, or (2) the use of professional service provider and supervised cementing activities for appropriate isolation in the well, or (3) doing hydrogeological model, or (4) performing adequate chemical sampling and analysis of produced fluid for evaluating the scaling and corrosion potential, or (5) avoidance of use of LCM (lost-circulation material) during drilling of production section.

During the interim geological evaluation phase between the first two drilling activities, the emphasis is on the interpretation of collected data at the first new well to provide improved characterization of the target formation, expected drilling difficulties, scaling and corrosion potential. The update of hydrogeological modelling is also suggested using new data.

During the design and drilling of the reinjection wells the following measures are highly recommended: (1) Use of clay minerals-free drilling mud, which is properly treated in the mud system by removal of cutting particles, (2) The production section of injection well should not contain fine grained sediments; only pure sandstone members are recommended, (3) Use of under-reaming and gravel pack in the production section, (4) Adequate filtering of re-injected water, (5) Treatment of fluid to prevent the reproduction of bacteria in productive layers of injection well. The next measures are recommended: (1) Performing adequate interference or tracer test for securing information for verification of hydrogeological model, (2) Use of professional service provider and supervised cementing activities for appropriate isolation, (3) Avoidance of use of LCM during drilling of production section. In case of Szeged the adequate interference and tracer test is highly recommended. Same refers on professional cement job by which the undesired impact on shallow groundwater bodies could be avoided.

During the final geological evaluation phase, after the result of interference and tracer tests are available, the performance of accurate hydrogeological modelling is highly recommended to verify the model, and to evaluate the duration of cooling free period of operation, and the forecasted impact of long-term utilization on operating wells nearby.

Considering the design, completion and operation of surface system, the adequate filtering of reinjected water and treatment of fluid to prevent the reproduction of bacteria in productive layers of injection well are highly recommended to avoid the clogging, which decreases the permeability of formation on such a way, which is difficult to amend. During the operation, monitoring of particle content and scaling potential of produced fluid together with regular logging, evaluation and maintenance of the well are recommended risk mitigation measures for observing changes, which might have adverse effect without intervention in due time. The observation of temperature and pressure values at surrounding exiting wells is also recommended.

Evaluating the results of the hydrogeological modelling, it is expected that the new triplets will induce some pressure and temperature changes at nearby operating wells. The size of expected impact is within a reasonable and acceptable range based on industrial practices, which is an encouraging indication for realization of these projects. But what a model could provide before drillings is hardly identical with the response of nature after long-term operation. So, the continuous update of hydrogeological modelling, and integration of data of drillings and of subsequent interference and tracer test will improve the reliability of model by degrees. The regular comparison of result of updated model with monitoring data, namely observed temperature and pressure change at surrounding wells, will improve the early recognition of undesired processes, and measures could be taken in due time to avoid the hardly reversible unfavourable impacts within the reservoir.

4. Application of the scheme on the SLO-HU-HR pilot area

The geological risk mitigation scheme was tested on two theoretical projects located in the pilot area (see Figure 66). The first focused on investigation of potential depletion of the transboundary Upper Pannonian porous reservoir and locating new reinjection wells in Moravske Toplice, Slovenia, while the other investigated geothermal potential of the carbonate reservoir for further expansion in Krapinske Toplice, Croatia by planning a new production geothermal well for heat supply. As the aquifers are different, the pilot projects are described separately. Hydrogeological model was used for the porous geothermal aquifer of Moravske Toplice, but it was not applied for the fractured geothermal aquifer due to poorly explored complex geology. The measures were selected from the scheme by empirical way using the available data. The list of selected measures is in Appendix A.

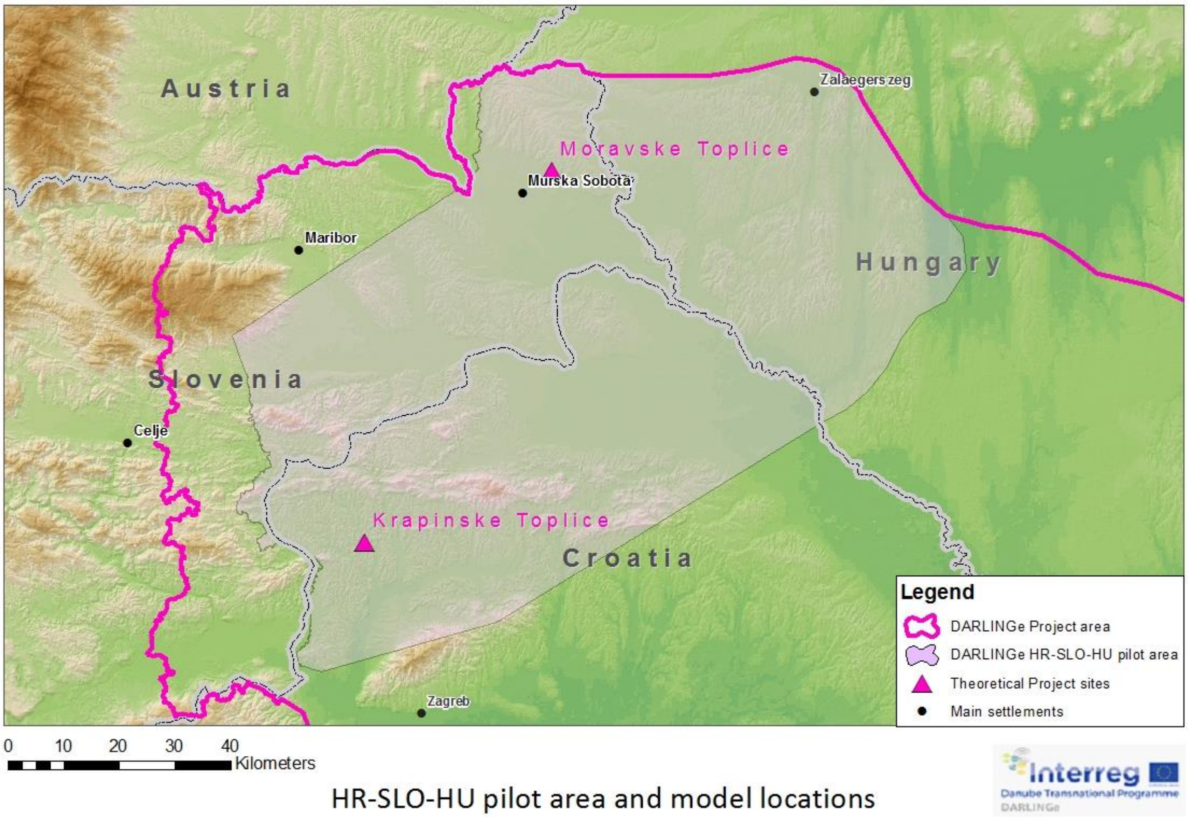

Figure 6. Location of project sites within the HR-SLO-HU pilot area

4.1. Moravske Toplice, Slovenia

4.1.1. Reservoir

The utilized reservoir is identical with the basin fill, Upper Pannonian reservoir discussed at the previous SRB-RO-HU pilot area.

4.1.2. Project idea

The project idea is to locate a reinjection well at the vicinity of spa complex to maintain the reservoir pressure, while the increasing production of geothermal water could deliver more heat to the facility. For the adequate identification of location of new reinjection well hydrogeological model was developed by GEOZS based on collected data from three countries.

4.1.3. Characterization of possible receptors

The closest wells in Moravske Toplice are the ones possibly most impacted. Furthermore, there are several wells treated as receptors, like observation well Mot-1 at Motvarjevci in Slovenia and wells across the borders, e.g. planned new production and reinjection wells at Lenti in

Hungary and two observation wells at Mursko Središče in Croatia. The model was applied for running four exploitation scenarios, the results are described below.

4.1.3.1 Production in SI and HU remains as current, none is existing in HR

Results on receptors and selected observation wells in Slovenia show, that the drawdown will continue and should reach quasi-stabilisation after around 20 years of operation. However, drawdown will be the fastest in the next decade, for about 18 m in the central part of the basin in Slovenia, and about 10 m near the HU-SI border, and will continue further for additional 5 m decrease in the following decades. Receptors in Hungary show constant drop of groundwater level in the sum of 8 m in the next 30 years, while receptors in Croatia a constant head decrease of about 3 m is foreseen in the same period. As the cumulative historical regional drawdown due to thermal water production has been evaluated to above 16 m in 2016, this scenario would imply irreversible depletion of the reservoir.

4.1.3.2 Production is extended to rates granted in water and mining permits

The summed granted annual production in water and mining rights is 4.332.376 m^3/year, which is 9.3% more than production rate in 2016. Results in all three countries show very similar situation as in the first case – constant decrease in groundwater heads in this transboundary aquifer, and its quantity depletion. Drawdowns - when applying the granted rates - are a bit stepper than in the first case, however, no significant difference is observed.

4.1.3.3 Application of a reinjection well at current production site

Potential location of a new reinjection well was applied in the numerical model 850 m away from Mt-7. It was simulated that 100% of produced thermal water from production well Mt-7 was injected back. Observation point was in the middle of the distance between the pumping and reinjection wells. Reinjection was applied in the 9th year of simulation, as it would start in 2017. The results were evaluated locally for this site, as we assume that they are transferrable over the whole transboundary reservoir. They show that the increase in groundwater heads would be about 4 m in comparison to the non-injection scenario in the observation point. Additional benefit of injection is also decreased head amplitude in the pumping well, which is especially beneficial as the reservoir is very sensitive to particle migration due to change in pressures. Hydraulic effect of the doublet is estimated around 2 km downstream, 1 km upstream and 800 m lateral from the pumping well.

4.1.3.4 Application of new geothermal doublets

Existing strategies and water management plans foresee that geothermal development will be supported by new doublets in the region. One planned is a new doublet in Lenti, Hungary, which was simulated with extraction and reinjection capacity of 1920 m^3/day (~22 l/s) all year round. Simulation results on receptors show no regional effects of such systems on the water balance of the reservoir, if 100% reinjection is applied. This enables multiple new users in the region and retaining of good aquifer's state for the future.

In Slovenia, such example is foreseen in the Municipality of Dobrovnik, who wants to activate a geothermal well Do-1/67 for the town's district heating system. After the 8th Act of the Decree on the River Basin Management Plan for the Danube Basin and the Adriatic Sea Basin, which strongly restricts issuing new thermal water permits in the Mura-Zala and Krško-Brežice basins, the Municipality may assess establishing a geothermal doublet and application for a mining concession. Here, an active pumping well Do-3g/05 already provides heating for the Ocean Orchid's greenhouse in vicinity. Since it taps the same reservoir, the optimum location of the new reinjection wells is advised towards Hungary, east of both existing wells.

4.1.4 Suggested risk mitigation measures

There are several risk mitigating measures, which should be considered in the geological evaluation phase when setting a new reinjection well. The accurate hydrogeological modelling, similarly, to the one presented above, is highly recommended to adequately locate new reinjection wells to decrease the likelihood of early cooling of production wells. The calibration of the model by interference and tracer tests using the existing wells could improve its reliability. Detailed interpretation of properties of geological layers and features for identification of the target aquifer are recommended, and will forecast potential drilling difficulties in due time.

During the design and drilling phase of a new reinjection well, there are several highly recommended measures like: (1) the use of under-reaming and gravel pack in the production section, (2) the production section of a reinjection well should contain only pure sandstone without silt, (3) the use of clay-minerals-free drilling mud, which is properly treated in the mud system by removal of cutting particles, which improves the permeability, or injectivity of the well. The use of professional service provider and supervised cementing activities for appropriate isolation in the well and performing adequate interference or tracer test are also highly recommended. When the result of interference and tracer tests are available, accurate hydrogeological modelling is highly recommended to verify the original model and evaluate the duration of cooling-free period of operation without thermal breakthrough.

Considering the design, completion and operation of surface system, the adequate treatment and filtering of injected water are highly recommended to prevent bacteria growth and clogging in the formation, which decreases the permeability. During the operation, continuous monitoring of quantities, temperature and pressure (groundwater level) data are recommended. Besides, chemical composition of water and gases with its particle content and scaling potential should be monitored, while regular logging, evaluation and maintenance of the well should identify early changes in production, and planning mitigation measures in time, if needed.

4.2 Krapinske Toplice, Croatia

4.2.1 Reservoir

The primary geothermal aquifer is fractured carbonate basement rock of Triassic age. Unfortunately, the representative deep wells intersecting the aquifer are quite rare, that's why this area could be labelled as poorly explored.

Below the Quaternary alluvial-diluvium deposits, Sarmatian marly limestone/limestone marl occur, and their thicknesses ranges from 3.9 to 7.8 m. Due to the tectonic activity, secondary porosity is developed in these rocks, and they are very permeable. Beneath them (below 60 m) Badenian Lithothamnium limestones and Triassic dolomite occur (Figure 7). Triassic carbonate rocks represent the primary thermal aquifers in these parts. Fractured carbonate rocks of Badenian age - which are often transgressive on the Triassic deposits - represent the secondary aquifer, but also the source of cold water, which is feeding the geothermal aquifer. Quaternary alluvial sediemnts (sandy clay with conglomerates) are low-permeable deposits, but they still allow the flow of ''cold'' groundwater from the hinterland, and the mixing with thermal water occurs (Larva et al., 2018).

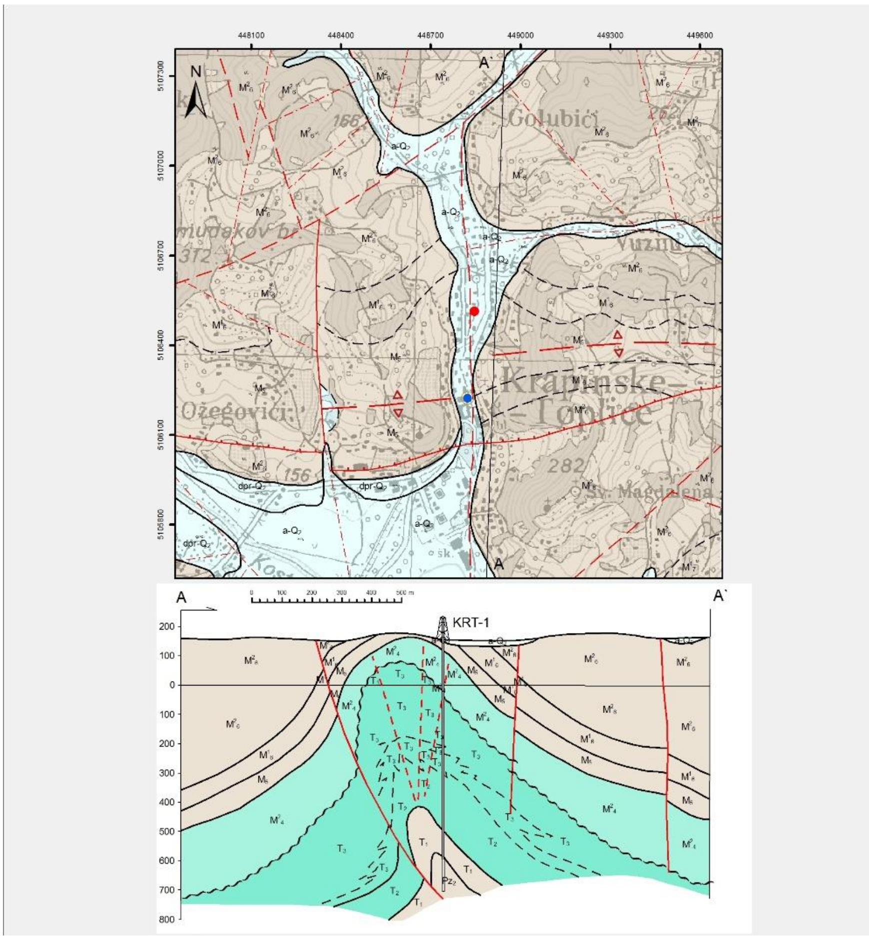

Figure 7. Schematic hydrogeological map of the spring area (modified according Šimunić, 2008)

The occurrence of thermal water is connected to the Orliska anticline structure, which is part of Sava folds. The structure has a slightly bending shape, and its orientation varies between WSW-ENE (west side of Krapinske Toplice) and W-E (on east side). As it interpreted on Figure 7, this is an asymmetric anticline due to the overthrust moved towards the south. The main fractures are subvertical and parallel with the anticline, so the thermal water presumably rather flows along W-E direction than N-S. The modelled present stress field by Bada et al. (2007) indicates that the maximum horizontal stress is close to N-S direction, which might close fractures of W-E direction. But this hardly refers to the upper few thousand meters, where the dolomite of Triassic age is located along the Orliska anticline, so the W-E fractures are likely to be ope, and thus permeable.

The main thermal springs are Pučka and Jakobova kupelj. In 1879 Vukasović stated that the total yield of springs is 46 l/s. Bać & Herak (1962) estimated the total yield around 81 l/s. In

1986 deep well KRT-1 (862.5 m) was drilled about 250 m north from the thermal springs. This borehole intersected the top of dolomite layer at 240 m depth measured from surface. During the testing by air-lifting, thermal water was produced with 30 l/s yield and 45°C outflow temperature. Interference between the borehole and thermal springs was observed, which verifies the hydraulic connection between the two objects.

The most recent measurements (Larva et al., 2018) have determined the yield amounts:

- Pučka kupelj – 38 l/s (natural outflowing)
- Jakobova kupelj – 10.4 l/s (natural outflowing)

The outflow temperature of the spring is around 40 °C, which has a slight seasonal fluctuation because of the above-described mixing of cold and thermal water.

During the drilling of KRT-1 well mud loss was observed, so it is expected that both in Miocene Lithotamnium limestone and in the Triassic dolomite layer mud loss will occur.

4.2.2 Project idea

The theoretical project is about drilling a new production well to provide heat for new customers. The required water outflow temperature is 45 °C, the expected production rate is 20 l/s, and the forecasted heat power is 2,46 MWt. Krapinske Toplice is well known on the occurrence of natural thermal springs since centuries. The springs provide thermal water with outflow temperature of 40°C and decent yield (approximately 50 l/s).

4.2.3 Characterization of possible receptors

The most precious receptor is the natural thermal springs, which provides water and heat for the next consumers:

- the Special hospital for medical rehabilitation Krapinske Toplice which uses thermal water in therapeutic treatments, swimming pools and for space heating of hospital using the heat pumps,
- Clinic Magdalena next to the Special hospital uses geothermal water for space heating,
- Waterpark Aquae vivae that extend to 18.000 m^2 of closed space used water for swimming pools and for heating entire complex,
- water supply of 271 households in Krapinske Toplice.

Anther less sensitive receptor is located 5 km away from the springs at Jurjevac village, where Company Samek Ltd. uses thermal water for heating of greenhouses for tomato production (water temperature at the well head is around 33°C). The company drilled the new well and the yield is 8 l/s.

4.2.4 Suggested risk mitigation measures

During testing of this scheme, it was concluded that the hardly predictable nature of aquifer rock, the complex tectonic structure of the area, the lack of deep drilling data and the presence of valuable receptors (thermal springs of the village) define the type of recommended risk mitigation measures.

Most of the recommended measures of initial geological evaluation phase are connected to collection of accurate data and their interpretation. The evaluation should focus on expected temperature, yield, drilling difficulties and characterization of target formation, trying to identify more than one target zone. The fluid properties, like gas content, scaling and corrosion potential should be evaluated too. New surface geophysical measurements are also recommended to identify and locate target zone(s) with higher accuracy. The performance of hydrogeological modelling is a useful opportunity to evaluate in which direction and distance the new production well might have the least impact on thermal springs at Krapinske Toplice. This is a crucial aspect of the project, because the induced pressure drop by a new production well might result in decreased inflow of thermal water, and intrusion of cold water which would eventually cause cooling of thermal springs.

Amongst the mitigation measures of the design and drilling phase, several measures are highly recommended: (1) designing of the production section of the well with 8 1/2" diameter, (2) drilling long enough production section for securing the expected yield, (3) using an external casing packer between the loose formation and productive layer, (4) using clay minerals-free drilling mud in the production section which is properly treated in the mud system by removal of cutting particles, (5) avoiding cementing of previous casing string in the production section and using LCM during drilling of production section, (6) using a professional service provider and supervised cementing activities for appropriate isolation, (7) performing adequate chemical sampling and analysis of produced fluid, and last but not least, (8) performing hydrogeological modelling prior and after the drilling to determine the distance from the springs.

After the completion of a new production well, the performance of adequate interference and tracer tests and accurate hydrogeological modelling are highly recommended to evaluate the long-term impact of production on thermal springs.

During the operation, the performance of regular logging, evaluation and maintenance of the well is a recommended measure. By continuous monitoring of production rate, pressure and temperature of water at thermal springs and wells, the adverse changes within the aquifer could be verified and mitigation measures planned in time, if needed.

5. Application of the scheme on the BH-SRB pilot area

The geological risk mitigation scheme of DARLINGe project was tested on the BH-SRB pilot area too, by using of data of two theoretical projects. The locations of projects (Figure 88) are Slobomir (Bosnia and Herzegovina) and Bogatič (Serbia).

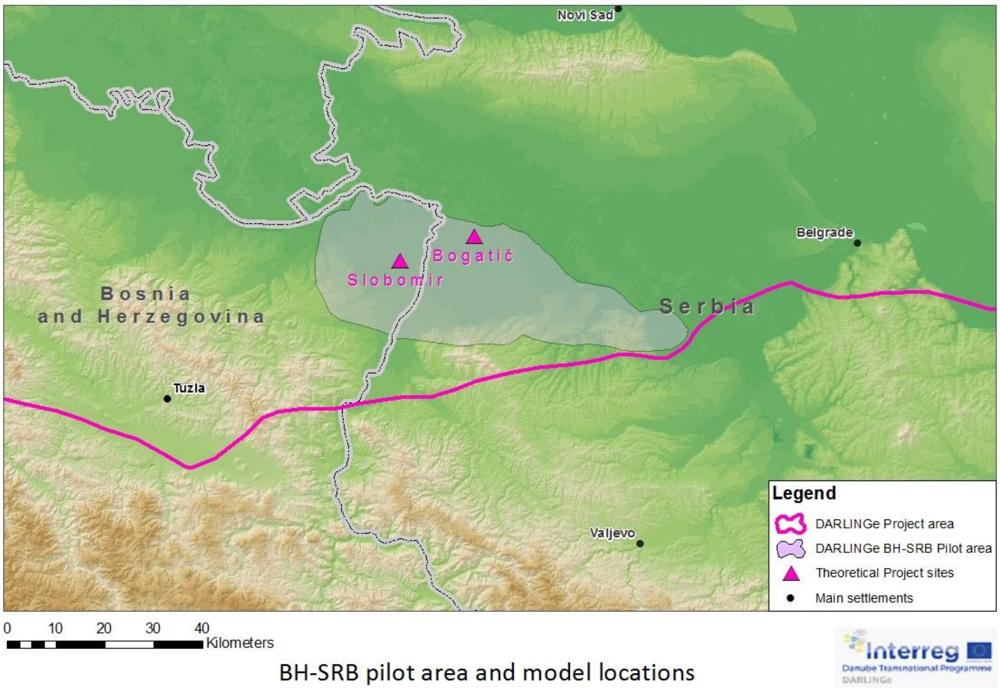

Figure 8. Location of project sites within the BH-SRB pilot area

5.1 Reservoir

The aquifer rock is 500-1000 m thick karstified and fractured carbonate (limestone and dolomite) of middle Triassic age. The geology and tectonic structure of the area is quite complex and the available drilling data could not provide enough information for satisfying evaluation of subsurface properties. The geological cross section of the area is depicted on Figure 9.

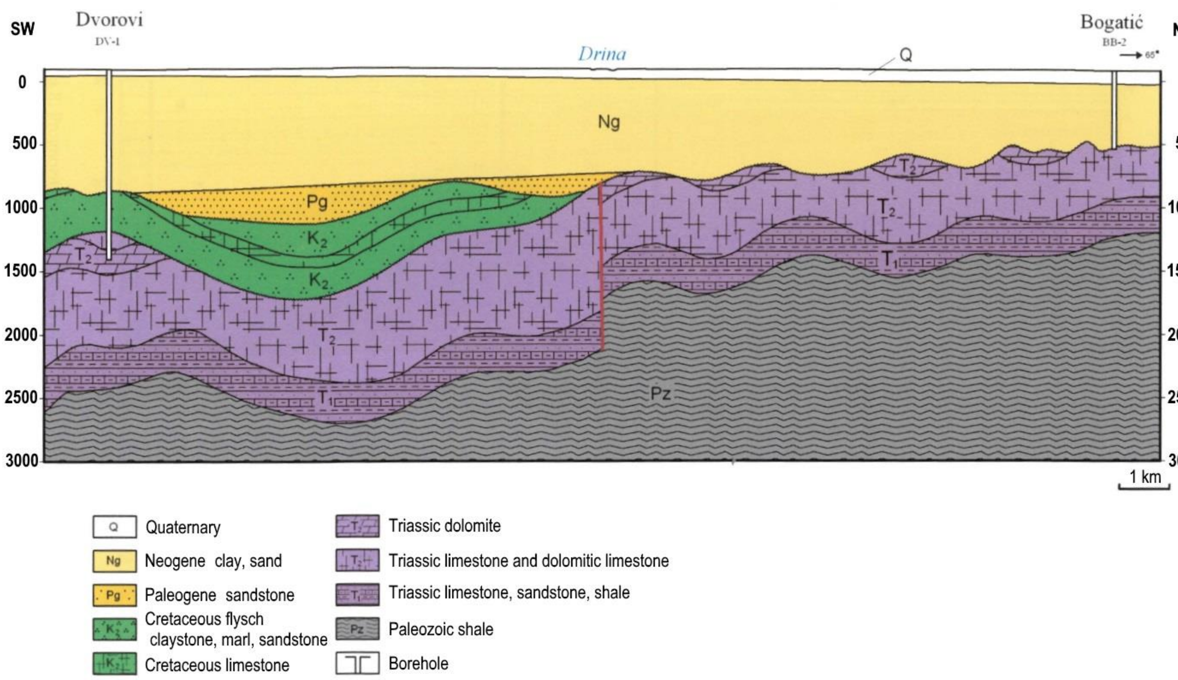

Figure 9. Geological cross section between Dvorovi (Bosnia and Herzegovina) and Bogatic (Serbia)

The top of aquifer is at 500-1000 m depth on the Serbian side and covered by sediments of Neogene age. This is confirmed by the deep wells around town of Bogatic. On the Bosnian side the aquifer is deeper and covered by Cretaceous flysch sediments. On the eastern (Serbian) side the karstification happened during much longer time, compared to west (Bosnia), so the top part is very permeable on the Serbian side. The impermeable bottom of the Triassic geothermal aquifer is made up of Paleozoic shale. On the Bosnian side six wells were drilled deeper than 1300 m, and 5 of them confirmed the presence of Triassic carbonates (e.g. Bij-1 well at Bijeljina at 2410m depth), but only two wells are producing water from the aquifer: GD-2 at Slobomir, and S-1 at Dvorovi. The latter one did not reach the Triassic layers, only Cretaceous limestone, which is very likely hydraulically connected to the main Triassic aquifer.

In case of fractured aquifers, the distribution and orientation of faults and other structural elements are very important features, but unfortunately this kind of information is not available. Only interpretations could be made that the strike of main faults follows the W-E direction, as it is anticipated from large-scale tectonic movements of the past.

5.2 Project idea

Both projects intend to utilize the cross-border fractured basement reservoir for heat production. The production wells are existing wells, the main aim of the theoretical project is to locate and complete a reinjection pair on both areas for avoiding pressure decline, which makes possible the sustainable and problem-free, long-term use of the aquifer.

5.3 Characterization of possible receptors

The operating wells are the primary receptors around the planned injection wells. There are two operating wells in Bosnia (GD-2 at Slobomir, S-1 at Dvorovi) and two wells in Serbia, at Bogatic. The distance between the members of the doublet should exceed 1,5 km as rule of thumb to avoid thermal break-through. The state border is considered as a receptor as well, along with this the pressure or temperature change should be avoided. By the use of verified hydrogeological modelling, the direction of groundwater flow could be determined, and one can define the most optimal location of injection wells to avoid the impact of pressure or temperature change.

5.4 Suggested risk mitigation measures

The type of reservoir and the level of exploration define the type of risk mitigation measures, and thus the emphasis is rather on data gathering, interpretation and completing new measurements. As the task and properties of the aquifer is very similar on both areas, the identified measures of the scheme are described together below.

Most of the recommended measures of initial geological evaluation phase are connected to accurate data collection and interpretation. The evaluation should focus on expected temperature, yield, drilling difficulties and characterization of target formation and target features, trying to identify more than one target zone. The fluid properties, like gas content, scaling and corrosion potential should be evaluated too. New surface geophysical measurements are also recommended to identify and locate target zone(s) with higher accuracy. The more accurate location of target zone will presumably increase the reliability of drilling plan, and thus the cost of drilling will be more predictable. The identification of more than one target zone will increase the likelihood of successful drilling. The performance of accurate hydrogeological modelling including data collection and interpretation is a useful opportunity to evaluate in which direction and distance of new injection well might have the least cooling effect on the production well.

Amongst the mitigation measures of design and drilling phase, designing of the production section of the well with 8 1/2" diameter, and avoidance of cementing of previous casing string in the production section, as well as trying to drill long enough production section for securing the expected yield are highly recommended. These measures will ensure the increased probability of a highly productive well. The next measures are recommended: (1) Performing hydrogeological modelling, (2) Using of external casing packer between the loose formation and productive layer, (3) Using of clay minerals-free drilling mud in the production section, which is properly treated in the mud system by removal of cutting particles, (4) Performing adequate chemical sampling and analysis of produced fluid, (5) Using of professional service provider and supervised cementing activities for appropriate isolation, (6) Avoidance of use of LCM during drilling of production section.

After the completion of reinjection well, the performance of adequate interference and tracer tests and accurate hydrogeological modelling are highly recommended to evaluate the long-term impact of the operation of the doublet including cross border effects.

During the operation the adequate filtering of reinjected water, monitoring of scaling potential of produced fluid and the performance of regular logging, evaluation and maintenance of the well are recommended measures to ensure the long-term problem-free operation.

6. Evaluation of suggested risk mitigation measures on pilot areas

Based on the performed testing on the pilot areas, one can conclude that the amount of available data has the strongest effect on the selection of mitigation measures. When the amount of available data is low and/or poor quality, the recommended mitigation measures are rather connected to data collection, interpretation and procurement of new data to increase the predictability of circumstances of subsurface. When the amount of data is significant, and the parameters of the subsurface is known with high likelihood, the mitigation measures are rather connected to the proper use of hydrogeological modelling to avoid the conflict with existing thermal water use. The flow of a development is also recognisable amongst the identified measures, because in early phase the data collection, analysis and procurement are dominating, during drilling mostly technical measures could be made, while in the phase of operation the monitoring measures are characteristic.

7. Modifications made in the Risk Mitigation Scheme

The experiences gained during the testing initiated the following changes of the scheme compared to its previous version published in D.6.3.1. Manual on the use of the transnational toolbox.

1. A new mitigation measure was inserted: "Drilling a slim/test hole for new temperature measurements for securing information for temperature forecast". This measure could reduce the likelihood of having lower amount of energy, than it was expected before. This damage could appear at testing, when the temperature is measured. The new measure should be performed at 1st geological evaluation phase. In areas where deep drilling is totally missing, this measure could provide an alternative of full-scale geothermal drilling for verifying the presence of needed temperature.
2. The mitigation measure "Accurate collection and interpretation of productivity data of wells for securing information for the expected yield of the well." was at design phase previously, which was not the appropriate timing of the measure. This measure was moved to 1st geological evaluation phase.
3. The mitigation measure "Doing new measurements in existing wells for securing information for the expected yield of the well." was at design phase previously, which was not the appropriate timing of the measure. This measure was moved to 1st geological evaluation phase.
4. The name of measure "Doing new surface geophysical measurements for better understanding of geological layers for securing information about identification of target reservoir" was modified to "Doing new surface geophysical measurements for better understanding of geological layers for securing information about identification of target formation."
5. The name of measure "Accurate hydrogeological modelling" was modified to "Accurate hydrogeological modelling including data collection and interpretation" in case when

the risk event is "If the position of the well was designed too close to receptors, then the induced pressure change will be higher than it was expected".

6. The risk event, follow on event and root activity was modified in case of measure "Use of external casing packer between the loose formation and productive layer", when it is used at 1st drilling phase to avoid damage "Cost increase in operation" caused by continuous pressure increase observed at the screens/injection well.
7. The name of measure "Use of chemicals to prevent the reproduction of bacterias in productive layers of injection well" was modified to "Treatment of fluid to prevent the reproduction of bacteria in productive layers of injection well".
8. The name of measure "Adequate filtering of produced water before the heat-exchanger" was modified to "Adequate filtering of reinjected water" at damage "Cost increase in operation", when the code of proof is PD.O.8.HeE.
9. A redundant mitigation measure was observed at operation phase "Adequate filtering of re-injected water" and one of them was deleted. The risk event ("If bacterias are invading the surface of formation, then the injectivity will decrease") of deleted measure was identical with another measure of operational phase "Use of chemicals to prevent the reproduction of bacterias in productive layers of injection well".
10. The name of proof "Pressure increase. Continuous pressure increase is observed at the injection well" (code is PD.O.3.PrI) was modified to "Pressure increase. Continuous pressure increase is observed at the screens/injection well".
11. The name of measure "Use of clay minerals-free drilling mud, which is properly treated in the mud system by removal of cutting particles" was modified to "Use of clay minerals-free drilling mud in the production section, which is properly treated in the mud system by removal of cutting particles".
12. At 2nd geological evaluation phase a new measure was inserted: "Accurate collection and interpretation of geological layers and features for securing information about identification of target formation".
13. The measure "Accurate collection and interpretation of geological layers and features for securing information about forecasted drilling difficulties" is relevant at 2nd geological evaluation phase too.
14. An identifying code was given to each mitigation measure for programming.

The above listed changes are included in the final version of Scheme (see Appendix B).

8. Risk Mitigation Tool on the DRGIP website

The improved, or final version of Geological Risk Mitigation Scheme was the base of the creation of toolpublished on the DRGIP website. The main aim of the tool was to educate the users, what kind of measures could be taken at given phase of geothermal project to avoid known negative consequences. The idea of the tool is to collect information about an idealised or real project, and after analysing of data, providing the list of measures to be taken into consideration according to their importance.

8.1 Collecting information on project

The form of collecting of information is a questionnaire, the user needs to provide answers on predefined questions choosing the most appropriate predefined answer. The questions are covering four topics:

1. project: general information about the geothermal project,
2. exploration: characterization of available exploratory data,
3. reservoir: characterization of reservoir and geological layers,
4. fluid: characterization of expected fluid and gas content.

After answering the technical questions, the user needs to define the relevant phase of the project. The questions and answers of each topic presented below.

8.1.1 Project questions

Code	Description
Q1	What is the aim of the project?
A1.1	Heat production.
A1.2	Electricity production.
A1.3	Electricity and heat production.
Q2	What is the planned annual production amount (m^3)?
A2.1	<100.000
A2.2	100.000-500.000
A2.3	500.000-2.000.000
A2.4	2.000.000<
Q3	What is the planned depth interval for production (m)?
A3.1	<500
A3.2	500-1.000
A3.3	1.000-2.000
A3.4	2.000<
Q4	What is the expected outflow temperature (°C)?
A4.1	30-50
A4.2	50-80
A4.3	80-120
A4.4	120<
Q5	What is the expected distance between the production and injection well (km)?
A5.1	<1
A5.2	1-2
A5.3	2<

8.1.2 Exploration questions

Code	Description
Q1	What is the number of deep wells penetrated the resource
Q1.1	within 10 km?
Q1.2	within 4 km?*
Q1.3	within 1 km?*
A1.1	0
A1.2	1-3
A1.3	4-9
A1.4	10<

Code	Description
Q2	Is there 3D seismic measurement?
A2.1	yes
A2.2	no
A2.3	partly
Q3	Are 2D seismic measurements crossing the area within 10 km?
A3.1	yes
A3.2	no
	in case of "yes" answer at Question3
Q4	How many 2D seismic measurements are
Q4.1	within 10 km?
Q4.2	within 3 km?*
A4.1	0
A4.2	1-3
A4.3	4-9
A4.4	10<
Q5	How many temperature data (bottom hole or outflow) of the aquifer from the planned depth interval for production are available within 20 km?
A5.1	0
A5.2	1-3
A5.3	4-9
A5.4	10<
Q6	How many temperature data (bottom hole or outflow) of the aquifer from the planned depth interval for production are available within 5 km?*
A6.1	0
A6.2	1-3
A6.3	4-9
A6.4	10<
Q7	How many water sample analyses are available from the aquifer within 10 km?
A7.1	0
A7.2	1-3
A7.3	4-9
A7.4	10<
Q8	How many operating wells use the same aquifer
Q8.1	for balneological use within 10 km?
Q8.2	for only heating purpose within 10 km?
Q8.3	for balneological use within 4 km?*
Q8.4	for only heating purpose within 4 km?*
Q8.5	for balneological use within 1 km?*
Q8.6	for only heating purpose within 1 km?*
A8.1	0
A8.2	1-3
A8.3	4-9
A8.4	10<

*no need to ask, if the previous answer was 0, e.g. if there is no well within 10 km, there is no need to ask how many is within 4 km?

8.3. Reservoir questions

Code	Description
Q1	What is the type of the reservoir?
A1.1	porous aquifer
A1.2	fractured, karstified carbonate rock
A1.3	fractured, crystalline rock
Q2	What is the expected distance between the project site and recharge area of the reservoir (in km)?
A2.1	0-3
A2.2	3-10
A2.3	10<
Q3	Is loose formation expected above the target formation, but within the production interval of the well?
A3.1	yes
A3.2	no
Q4	Is a produced aquifer located above the target formation?
A4.1	yes
A4.2	no

8.4. Fluid questions

Code	Description
Q1	What is the expected gas content?
A1.1	low (<100l/m³)
A1.2	medium (100-1.000 l/m³)
A1.3	high (1.000 l/m³<)
Q2	What is the expected share of flammable gas?
A2.1	low (<10%)
A2.2	medium (10-30%)
A2.3	high (30-60%)
A2.4	very high (60%<)
Q3	What is the expected TDS of the fluid?
A3.1	low (<1g/l)
A3.2	medium (1-5 g/l)
A3.3	high (5-10 g/l)
A3.4	very high (10 g/l<)

8.5. Definition of project's phase

Code	Description	Explanation
Q1	What is the phase of the project?	The definition of phase of project is needed to narrow down the relevant risk mitigation measures.
A1.1	Reconnaissance phase	Reconnaissance phase starts from the project idea and lasts until the decision to obtain an exploration permit or not.
A1.2	1st geological evaluation phase	This phase theoretically starts in the reconnaissance phase and last until the drilling, but the main activity is made between the approved exploration permit and the start of the design phase.
A1.3	1st design phase	The main activity of this phase is between the

Code	Description	Explanation
		geological evaluation and drilling.
A1.4	1st drilling phase	The drilling phase starts from the mobilization of the rig and lasts until the finish of operation of end of drilling (OED), which period (OED) covers the testing activities in general.
A1.5	2nd geological evaluation phase	This phase theoretically starts together with the 1st drilling phase and last until the 2nd drilling, but the main activity is made between the finish of testing and the start of the 2nd design phase.
A1.6	2nd design phase	The main activity of this phase is between the geological evaluation and drilling.
A1.7	2nd drilling phase	The drilling phase starts from the mobilization of the rig and lasts until the finish of operation of end of drilling (OED), which period (OED) covers the testing activities in general.
A1.8	3rd geological evaluation phase	The 3rd geological evaluation is based on the data collected during the completion of second drilling.
A1.9	Completion phase	The completion phase covers the activities of surface works excluding drilling activities.
A1.10	Operation phase	The operation phase is when the construction is finished, and the plant is working continuously according to the approved operational permit.

8.2 Presentation of results

After the selection of phase, the tool calculates and presents the relevant risk mitigation measures. The user could easily modify the phase and calculate again the relevant measures for the same project, but for a different phase. The measures will be listed according to the importance (see the description at chapter 2), the highly recommended measures are the first ones. The tool presents the connected damage also, which could be avoided by the application of given measure.

9. Conclusion

The first version of geological risk mitigation scheme was published within D.6.3.1. "Manual on the use of the transnational toolbox". The upgrade of geological risk mitigation scheme was made after the testing of the method on theoretical projects on all three cross-border pilot areas at each participating country. The upgrade includes introduction of new risk mitigation measures, refinement of measures, and definition of code of measures. The improved version of the schema was the base for designing the risk mitigation tool on the project website. The tool is providing a list of recommended risk mitigation measures by project phases, based on the evaluation of input data of a theoretical project. The draft version of the tool was tested by project partners and the final version of the tool was updated accordingly. The results of testing on pilot areas, the improved version of the scheme, and the pages of risk mitigation tool are attached to this report as an appendix.

10. References

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11. APPENDICIES

A. Recommended measures by theoretical projects of pilot areas
B. Improved version of Geological Risk Mitigation Tool
C. Pages of Risk Mitigation toolbox published on DRGIP (Danube Region Geothermal Information Platform) website (www.darlinge.eu)

Appendix A: Recommended measures by theoretical projects of pilot areas

List of measures by type including codes:

Measures connected to data collection, evaluation and interpretation	
Code of measure	Risk mitigation measure
CO.01_dr	Accurate collection and interpretation of geological layers and features for securing information about forecasted drilling difficulties.
CO.02_tafe	Accurate collection and interpretation of geological layers and features for securing information about identification of target feature (fault, karstified surface).
CO.03_tafo	Accurate collection and interpretation of geological layers and features for securing information about identification of target formation.
CO.04_ovpr	Accurate collection and interpretation of pressure data measured in existing wells for securing information about hazard of overpressure.
CO.05_mota	Try to identify and aim more than one target for the drilling.
CO.06_te	Accurate collection and interpretation of temperature data measured in existing wells for securing information for temperature forecast.
CO.07_yi	Accurate collection and interpretation of productivity data of wells for securing information for the expected yield of the well.
CO.08_chco	Accurate collection and interpretation of chemical data for securing information about the forecasted corrosion potential of the produced fluid.
CO.09_chga	Accurate collection and interpretation of chemical data for securing information about the forecasted gas content of the produced fluid.
CO.10_chsc	Accurate collection and interpretation of chemical data for securing information about the forecasted scaling potential of the produced fluid.
CO.11_strev	Accurate data collection and interpretation for securing information for realistic structural evaluation.
CO.12_evco	Performing adequate evaluation of corrosion potential.
CO.13_evsc	Performing adequate evaluation of scaling potential.
Measures connected to new measurements	
Code of measure	Risk mitigation measure
ME.01_pr	Doing new pressure measurements at old wells for securing information about hazard of overpressure.
ME.02_gphdr	Doing new surface geophysical measurements for better understanding of geological layers and for securing information about forecasted drilling difficulties.
ME.03_gphtafe	Doing new surface geophysical measurements for better understanding of geological layers for securing information about identification of target feature (fault, karstified surface).
ME.04_gphtafo	Doing new surface geophysical measurements for better understanding of geological layers for securing information about identification of target reservoir.
ME.05_te	Doing new temperature measurements in existing wells for securing information for temperature forecast.
ME.06_slim	Drilling a slim/test hole for new temperature measurements for securing information for temperature forecast.
ME.07_yi	Doing new measurements in existing wells for securing information for the expected yield of the well.
ME.08_hymo	Doing new measurements in existing wells for securing information for hydrogeological modelling.
ME.09_chco	Doing new chemical sampling and analysis at existing wells for securing information about the forecasted corrosion potential of the produced fluid.
ME.10_chga	Doing new chemical sampling and analysis at existing wells for securing information about the forecasted gas content of the produced fluid.
ME.11_chsc	Doing new chemical sampling and analysis at existing wells for securing information about the forecasted scaling potential of the produced fluid.
ME.12_chsa	Performing adequate chemical sampling and analysis of produced fluid.

ME.13_strev	Doing new measurements in existing wells for securing information for realistic structural evaluation.
ME.14_trte	Performing adequate interference or tracer test for securing information for verification of hydrogeological model.
Technical measures	
Code of measure	Risk mitigation measure
TE.01_oh8	Designing of the production section of the well with 8 1/2" diameter.
TE.02_ecp	Use of external casing packer between the loose formation and productive layer.
TE.03_grpa	In case of porous aquifer use of underreaming and gravel pack in the production section.
TE.04_cemj	Use of professional service provider and supervised cementing activites for appropriate isolation.
TE.05_droh	Trying to drill long enough production section for securing the expected yield.
TE.06_cemins	Use of cement with increased heat insulation properties for cementing of casings of production well.
TE.07_drmud	Use of clay minerals-free drilling mud in the production section, which is properly treated in the mud system by removal of cutting particles.
TE.08_avcem	Avoid the cementing of previous casing string in the production section. (no need for preparation)
TE.09_avLCM	Avoid the use of LCM during drilling of production section. (no need for preparation)
TE.10_sand	In case of porous aquifer the production section of injection well should not contain fine grained sediments, only pure sandstone members are recommended.
TE.11_filt	Adequate filtering of re-injected water.
TE.12_trfl	Treatment of fluid to prevent the reproduction of bacterias in productive layers of injection well.
TE.13_log	Doing regular logging, evaluation and maintenance of the well.
Measure connected to hydrogeological modelling	
Code of measure	Risk mitigation measure
MO.01	Accurate hydrogeological modelling including data collection and interpretation.
Measures connected to monitoring	
Code of measure	Risk mitigation measure
MN.01_part	Monitoring of change of produced fluid's particle content.
MN.02_corp	Monitoring of corrosion potential of produced fluid.
MN.03_scap	Monitoring of scaling potential of produced fluid

List of recommended measures by pilot areas:

SRB-RO-HU

Code of measure	Szeged (HU)	Sannicolau Mare (RO)	Palic (SRB)
1st geological evaluation phase			
Perform a mitigation measure			
CO.01_dr	Recommended	Recommended	Recommended
CO.02_tafe	Not relevant	Not relevant	Not relevant
CO.03_tafo	Recommended	Recommended	Recommended
CO.04_ovpr	Not relevant	Not relevant	Not relevant
ME.01_pr	Not relevant	Not relevant	Not relevant
ME.02_gphdr	Not relevant	Not relevant	Not relevant
ME.03_gphtafe	Not relevant	Not relevant	Not relevant
ME.04_gphtafo	Not relevant	Not relevant	Not relevant
CO.05_mota	Not relevant	Not relevant	Not relevant
CO.06_te	Recommended	Recommended	Recommended
MO.01	Highly recommended	Recommended	Recommended
ME.05_te	Not relevant	Recommended	Recommended
ME.06_slim	Not relevant	Not relevant	Not relevant

Code of measure	Szeged (HU)	Sannicolau Mare (RO)	Palic (SRB)
CO.07_yi	Recommended	Recommended	Recommended
ME.07_yi	Not relevant	Worth to consider	Worth to consider
MO.01	repetition	repetition	repetition
ME.08_hymo	Highly recommended	Recommended	Recommended
CO.08_chco	Recommended	Recommended	Recommended
CO.09_chga	Recommended	Recommended	Recommended
CO.10_chsc	Recommended	Recommended	Recommended
ME.09_chco	Not relevant	Worth to consider	Worth to consider
ME.10_chga	Not relevant	Recommended	Recommended
ME.11_chsc	Not relevant	Recommended	Recommended

1st design phase

Perform a mitigation measure

TE.01_oh8	Highly recommended	Highly recommended	Highly recommended
MO.01	Highly recommended	Recommended	Recommended

1st design phase

Prepare a mitigation measure

TE.02_ecp	Worth to consider	Worth to consider	Worth to consider
TE.03_grpa	Highly recommended	Highly recommended	Highly recommended
TE.04_cemj	Highly recommended	Recommended	Recommended
TE.05_droh	Worth to consider	Worth to consider	Worth to consider
TE.06_cemins	Worth to consider	Worth to consider	Worth to consider
TE.07_drmud	Recommended	Recommended	Recommended
TE.04_cemj	repetition	repetition	repetition
TE.04_cemj	repetition	repetition	repetition
TE.02_ecp	repetition	repetition	repetition
TE.03_grpa	repetition	repetition	repetition
TE.03_grpa	repetition	repetition	repetition
ME.12_chsa	Recommended	Recommended	Recommended
ME.12_chsa	repetition	repetition	repetition

1st drilling phase

Perform a mitigation measure

TE.02_ecp	Worth to consider	Worth to consider	Worth to consider
TE.03_grpa	Highly recommended	Highly recommended	Highly recommended
TE.08_avcem	Worth to consider	Worth to consider	Worth to consider
TE.09_avLCM	Recommended	Recommended	Recommended
TE.04_cemj	Highly recommended	Recommended	Recommended
TE.05_droh	Worth to consider	Worth to consider	Worth to consider
TE.06_cemins	Worth to consider	Worth to consider	Worth to consider
TE.07_drmud	Recommended	Recommended	Recommended
TE.04_cemj	repetition	repetition	repetition
TE.04_cemj	repetition	repetition	repetition
TE.02_ecp	repetition	repetition	repetition
TE.03_grpa	repetition	repetition	repetition
TE.03_grpa	repetition	repetition	repetition
ME.12_chsa	Recommended	Recommended	Recommended
ME.12_chsa	repetition	repetition	repetition

2nd geological evaluation phase

Perform a mitigation measure

Code of measure	Szeged (HU)	Sannicolau Mare (RO)	Palic (SRB)
CO.02_tafe	Not relevant	Not relevant	Not relevant
ME.03_gphtafe	Not relevant	Not relevant	Not relevant
CO.03_tafo	Recommended	Recommended	Recommended
CO.05_mota	Not relevant	Not relevant	Not relevant
CO.11_strev	Not relevant	Not relevant	Not relevant
MO.01	Highly recommended	Recommended	Recommended
ME.13_strev	Not relevant	Not relevant	Not relevant
MO.01	repetition	repetition	repetition
MO.01	repetition	repetition	repetition
CO.12_evco	Recommended	Recommended	Recommended
CO.13_evsc	Recommended	Recommended	Recommended
CO.01_dr	Recommended	Recommended	Recommended

2nd design phase

Perform a mitigation measure

no measure

2nd design phase

Prepare a mitigation measure

TE.02_ecp	Worth to consider	Worth to consider	Worth to consider
TE.03_grpa	Highly recommended	Highly recommended	Highly recommended
TE.10_sand	Highly recommended	Highly recommended	Highly recommended
ME.14_trte	Highly recommended	Recommended	Recommended
TE.04_cemj	Highly recommended	Recommended	Recommended
TE.05_droh	Worth to consider	Worth to consider	Worth to consider
TE.07_drmud	Highly recommended	Highly recommended	Highly recommended
ME.14_trte	repetition	repetition	repetition
ME.14_trte	repetition	repetition	repetition
TE.04_cemj	repetition	repetition	repetition
TE.04_cemj	repetition	repetition	repetition
TE.11_filt	Highly recommended	Highly recommended	Highly recommended
TE.11_filt	repetition	repetition	repetition
TE.02_ecp	repetition	repetition	repetition
TE.03_grpa	repetition	repetition	repetition
TE.03_grpa	repetition	repetition	repetition
TE.12_trfl	Highly recommended	Highly recommended	Highly recommended
TE.10_sand	repetition	repetition	repetition
TE.11_filt	repetition	repetition	repetition
ME.14_trte	repetition	repetition	repetition
ME.14_trte	repetition	repetition	repetition

2nd drilling phase

Perform a mitigation measure

TE.02_ecp	Worth to consider	Worth to consider	Worth to consider
TE.03_grpa	Highly recommended	Highly recommended	Highly recommended
TE.10_sand	Highly recommended	Highly recommended	Highly recommended
TE.08_avcem	Worth to consider	Worth to consider	Worth to consider
TE.09_avLCM	Recommended	Recommended	Recommended
ME.14_trte	Highly recommended	Recommended	Recommended

Code of measure	Szeged (HU)	Sannicolau Mare (RO)	Palic (SRB)
TE.04_cemj	Highly recommended	Recommended	Recommended
TE.05_droh	Worth to consider	Worth to consider	Worth to consider
TE.07_drmud	Highly recommended	Highly recommended	Highly recommended
ME.14_trte	repetition	repetition	repetition
ME.14_trte	repetition	repetition	repetition
TE.04_cemj	repetition	repetition	repetition
TE.04_cemj	repetition	repetition	repetition
TE.02_ecp	repetition	repetition	repetition
TE.03_grpa	repetition	repetition	repetition
TE.03_grpa	repetition	repetition	repetition
TE.10_sand	repetition	repetition	repetition
ME.14_trte	repetition	repetition	repetition
ME.14_trte	repetition	repetition	repetition

3rd geological evaluation phase

Perform a mitigation measure

MO.01	Highly recommended	Recommended	Recommended
MO.01	repetition	repetition	repetition

Completion phase

Perform a mitigation measure

TE.11_filt	Highly recommended	Highly recommended	Highly recommended
TE.11_filt	repetition	repetition	repetition
TE.12_trfl	Highly recommended	Highly recommended	Highly recommended
TE.11_filt	repetition	repetition	repetition

Operation phase

Perform a mitigation measure

TE.11_filt	Highly recommended	Highly recommended	Highly recommended
TE.11_filt	repetition	repetition	repetition
TE.12_trfl	Highly recommended	Highly recommended	Highly recommended
TE.13_log	Recommended	Recommended	Recommended
TE.13_log	repetition	repetition	repetition
MN.01_part	Recommended	Recommended	Recommended
TE.11_filt	repetition	repetition	repetition
MN.02_corp	Worth to consider	Worth to consider	Worth to consider
MN.03_scap	Recommended	Recommended	Recommended

HR-SLO-HU and BH-SRB

Code of measure	Moravske Toplice (SLO)	Krapinske Toplice (Hr)	Bogatic (SRB)	Slobomir (BH)
1st geological evaluation phase				
Perform a mitigation measure				
CO.01_dr	Recommended	Recommended	Recommended	Recommended
CO.02_tafe	Not relevant	Recommended	Recommended	Recommended
CO.03_tafo	Recommended	Recommended	Recommended	Recommended
CO.04_ovpr	Not relevant	Not relevant	Not relevant	Not relevant
ME.01_pr	Not relevant	Not relevant	Not relevant	Not relevant
ME.02_gphdr	Not relevant	Recommended	Recommended	Recommended
ME.03_gphtafe	Not relevant	Recommended	Recommended	Recommended
ME.04_gphtafo	Not relevant	Recommended	Recommended	Recommended

Code of measure	Moravske Toplice (SLO)	Krapinske Toplice (Hr)	Bogatic (SRB)	Slobomir (BH)
CO.05_mota	Not relevant	Recommended	Recommended	Recommended
CO.06_te	Recommended	Recommended	Recommended	Recommended
MO.01	Highly recommended	Recommended	Recommended	Recommended
ME.05_te	Worth to consider	Worth to consider	Worth to consider	Worth to consider
ME.06_slim	Not relevant	Worth to consider	Worth to consider	Worth to consider
CO.07_yi	Worth to consider	Recommended	Recommended	Recommended
ME.07_yi	Not relevant	Recommended	Worth to consider	Worth to consider
MO.01	repetition	repetition	repetition	repetition
ME.08_hymo	Highly recommended	Worth to consider	Worth to consider	Worth to consider
CO.08_chco	Recommended	Recommended	Recommended	Recommended
CO.09_chga	Recommended	Recommended	Recommended	Recommended
CO.10_chsc	Recommended	Recommended	Recommended	Recommended
ME.09_chco	Worth to consider	Worth to consider	Worth to consider	Worth to consider
ME.10_chga	Worth to consider	Worth to consider	Worth to consider	Worth to consider
ME.11_chsc	Worth to consider	Worth to consider	Worth to consider	Worth to consider

1st design phase

Perform a mitigation measure

TE.01_oh8	Highly recommended	Highly recommended	Highly recommended	Highly recommended
MO.01	Highly recommended	Recommended	Recommended	Recommended

1st design phase

Prepare a mitigation measure

TE.02_ecp	Worth to consider	Recommended	Recommended	Recommended
TE.03_grpa	Highly recommended	Not relevant	Not relevant	Not relevant
TE.04_cemj	Highly recommended	Highly recommended	Recommended	Recommended
TE.05_droh	Worth to consider	Highly recommended	Highly recommended	Highly recommended
TE.06_cemins	Worth to consider	Worth to consider	Worth to consider	Worth to consider
TE.07_drmud	Recommended	Recommended	Recommended	Recommended
TE.04_cemj	repetition	repetition	repetition	repetition
TE.04_cemj	repetition	repetition	repetition	repetition
TE.02_ecp	repetition	repetition	repetition	repetition
TE.03_grpa	repetition	repetition	repetition	repetition
TE.03_grpa	repetition	repetition	repetition	repetition
ME.12_chsa	Recommended	Recommended	Recommended	Recommended
ME.12_chsa	repetition	repetition	repetition	repetition

1st drilling phase

Perform a mitigation measure

TE.02_ecp	Worth to consider	Recommended	Recommended	Recommended
TE.03_grpa	Highly recommended	Not relevant	Not relevant	Not relevant
TE.08_avcem	Worth to consider	Recommended	Highly recommended	Highly recommended
TE.09_avLCM	Recommended	Recommended	Recommended	Recommended
TE.04_cemj	Highly recommended	Highly recommended	Recommended	Recommended
TE.05_droh	Worth to consider	Highly recommended	Highly recommended	Highly recommended
TE.06_cemins	Worth to consider	Worth to consider	Worth to consider	Worth to consider
TE.07_drmud	Recommended	Recommended	Recommended	Recommended
TE.04_cemj	repetition	repetition	repetition	repetition
TE.04_cemj	repetition	repetition	repetition	repetition
TE.02_ecp	repetition	repetition	repetition	repetition
TE.03_grpa	repetition	repetition	repetition	repetition
TE.03_grpa	repetition	repetition	repetition	repetition

Code of measure	Moravske Toplice (SLO)	Krapinske Toplice (Hr)	Bogatic (SRB)	Slobomir (BH)
ME.12_chsa	Recommended	Recommended	Recommended	Recommended
ME.12_chsa	repetition	repetition	repetition	repetition

2nd geological evaluation phase

Perform a mitigation measure

CO.02_tafe	Not relevant	Recommended	Recommended	Recommended
ME.03_gphtafe	Not relevant	Recommended	Recommended	Recommended
CO.03_tafo	Recommended	Recommended	Recommended	Recommended
CO.05_mota	Not relevant	Recommended	Recommended	Recommended
CO.11_strev	Not relevant	Recommended	Recommended	Recommended
MO.01	Highly recommended	Recommended	Recommended	Recommended
ME.13_strev	Not relevant	Recommended	Worth to consider	Worth to consider
MO.01	repetition	repetition	repetition	repetition
MO.01	repetition	repetition	repetition	repetition
CO.12_evco	Worth to consider	Worth to consider	Recommended	Recommended
CO.13_evsc	Recommended	Recommended	Recommended	Recommended
CO.01_dr	Recommended	Recommended	Recommended	Recommended

2nd design phase

Perform a mitigation measure

no measure

2nd design phase

Prepare a mitigation measure

TE.02_ecp	Worth to consider	Recommended	Recommended	Recommended
TE.03_grpa	Highly recommended	Not relevant	Not relevant	Not relevant
TE.10_sand	Highly recommended	Not relevant	Not relevant	Not relevant
ME.14_trte	Highly recommended	Highly recommended	Highly recommended	Highly recommended
TE.04_cemj	Highly recommended	Highly recommended	Recommended	Recommended
TE.05_droh	Worth to consider	Highly recommended	Highly recommended	Highly recommended
TE.07_drmud	Highly recommended	Recommended	Recommended	Recommended
ME.14_trte	repetition	repetition	repetition	repetition
ME.14_trte	repetition	repetition	repetition	repetition
TE.04_cemj	repetition	repetition	repetition	repetition
TE.04_cemj	repetition	repetition	repetition	repetition
TE.11_filt	Highly recommended	Recommended	Recommended	Recommended
TE.11_filt	repetition	repetition	repetition	repetition
TE.02_ecp	repetition	repetition	repetition	repetition
TE.03_grpa	repetition	repetition	repetition	repetition
TE.03_grpa	repetition	repetition	repetition	repetition
TE.12_trfl	Highly recommended	Worth to consider	Worth to consider	Worth to consider
TE.10_sand	repetition	repetition	repetition	repetition
TE.11_filt	repetition	repetition	repetition	repetition
ME.14_trte	repetition	repetition	repetition	repetition
ME.14_trte	repetition	repetition	repetition	repetition

2nd drilling phase

Perform a mitigation measure

TE.02_ecp	Worth to consider	Recommended	Recommended	Recommended

Code of measure	Moravske Toplice (SLO)	Krapinske Toplice (Hr)	Bogatic (SRB)	Slobomir (BH)
TE.03_grpa	Highly recommended	Not relevant	Not relevant	Not relevant
TE.10_sand	Highly recommended	Not relevant	Not relevant	Not relevant
TE.08_avcem	Worth to consider	Recommended	Highly recommended	Highly recommended
TE.09_avLCM	Recommended	Recommended	Recommended	Recommended
ME.14_trte	Highly recommended	Highly recommended	Highly recommended	Highly recommended
TE.04_cemj	Highly recommended	Highly recommended	Recommended	Recommended
TE.05_droh	Worth to consider	Highly recommended	Highly recommended	Highly recommended
TE.07_drmud	Highly recommended	Recommended	Recommended	Recommended
ME.14_trte	repetition	repetition	repetition	repetition
ME.14_trte	repetition	repetition	repetition	repetition
TE.04_cemj	repetition	repetition	repetition	repetition
TE.04_cemj	repetition	repetition	repetition	repetition
TE.02_ecp	repetition	repetition	repetition	repetition
TE.03_grpa	repetition	repetition	repetition	repetition
TE.03_grpa	repetition	repetition	repetition	repetition
TE.10_sand	repetition	repetition	repetition	repetition
ME.14_trte	repetition	repetition	repetition	repetition
ME.14_trte	repetition	repetition	repetition	repetition

3rd geological evaluation phase

Perform a mitigation measure

MO.01	Highly recommended	Highly recommended	Highly recommended	Highly recommended
MO.01	repetition	repetition	repetition	repetition

Completion phase

Perform a mitigation measure

TE.11_filt	Highly recommended	Recommended	Recommended	Recommended
TE.11_filt	repetition	repetition	repetition	repetition
TE.12_trfl	Highly recommended	Worth to consider	Worth to consider	Worth to consider
TE.11_filt	repetition	repetition	repetition	repetition

Operation phase

Perform a mitigation measure

TE.11_filt	Highly recommended	Recommended	Recommended	Recommended
TE.11_filt	repetition	repetition	repetition	repetition
TE.12_trfl	Highly recommended	Worth to consider	Worth to consider	Worth to consider
TE.13_log	Recommended	Recommended	Recommended	Recommended
TE.13_log	repetition	repetition	repetition	repetition
MN.01_part	Recommended	Worth to consider	Worth to consider	Worth to consider
TE.11_filt	repetition	repetition	repetition	repetition
MN.02_corp	Worth to consider	Worth to consider	Worth to consider	Worth to consider
MN.03_scap	Recommended	Recommended	Recommended	Recommended

Appendix B: Improved version of Geological Risk Mitigation

Code of mitigation	Timing of mitigation	Mitigation	Condition of mitigation	Monitoring activity of mitigation	Definition of damage	Proof of damage	Root activity	Risk event - IF member	Risk event - THEN member	Follow on event 1.	Follow on event 2.	Follow on event 3.	Follow on event 4.	Code of proof	Amending activity	Conditions of amending activity
	1st geological evaluation phase	**PERFORM A MITIGATION MEASURE**														
CO.01_dr	1st geological evaluation phase	Accurate collection and interpretation of geological layers and features for securing information about forecasted drilling difficulties.		Reporting	The loss of well.	Technical failure. An irreversible technical failure occurs at the drilling.	Drilling into inadequately explored area	If the evaluation of subsurface data is inaccurate,	then the forecast of drilling difficulties will be inaccurate.	Drilling difficulties	Unsuccessful handling of drilling difficulties	The production section of the well can not be completed.		PD.D.1.TeF		
CO.02_tafe	1st geological evaluation phase	Accurate collection and interpretation of geological layers and features for securing information about identification of target feature (fault, karstified surface).		Reporting	The loss of well.	No production/injection. The well is not able to produce/inject any fluid.	Drilling into inadequately explored area	If the evaluation of subsurface data is inaccurate,	then the geological features and layers will be misinterpreted.	The target is missing in the drilling.	The well is not productive.			PD.T.1.NoP	Drilling on deeper.	The design of the well and the used rig should be suitable for the activity.
CO.03_tafo	1st geological evaluation phase	Accurate collection and interpretation of geological layers and features for securing information about identification of target formation.		Reporting	The loss of well.	Missing formation. The targeted reservoir formation is missing in the well.	Drilling into inadequately explored area	If the evaluation of subsurface data is inaccurate,	then the geological features and layers will be misinterpreted.	There is a significant difference between the interpretation and the reality.	The target is missing in the drilling.			PD.D.2.MiF	Finding suitable water bearing formation in the already drilled section.	Proper logging data for identification of auxiliary targets.
CO.04_ovpr	1st geological evaluation phase	Accurate collection and interpretation of pressure data measured in existing wells for securing information about hazard of overpressure.		Reporting	The loss of well.	Overpressure. The formation pressure is much higher as it was originally expected.	Drilling into inadequately explored area	If the evaluation of subsurface data is inaccurate,	then pressure data will be misinterpreted.	The pressure forecast was inaccurate.	Appearance of high ovepressure.			PD.D.3.OvP		
ME.01_pr	1st geological evaluation phase	Doing new pressure measurements at old wells for securing information about hazard of overpressure.		Reporting	The loss of well.	Overpressure. The formation pressure is much higher as it was originally expected.	Drilling into inadequately explored area	If previous exploratory data are poor and rare,	then a very simlified interpretation of pressure data will be made.	There is a significant difference between the interpretation and the reality.	The pressure forecast was inaccurate.	Appearance of high ovepressure.		PD.D.3.OvP		
ME.02_gphdr	1st geological evaluation phase	Doing new surface geophysical measurements for better understanding of geological layers and for securing information about forecasted drilling difficulties.		Reporting	The loss of well.	Technical failure. An irreversible technical failure occurs at the drilling.	Drilling into inadequately explored area	If previous exploratory data are poor and rare,	then the forecast of drilling difficulties will be inaccurate.	Drilling difficulties	Unsuccessful handling of drilling difficulties	The production section of the well can not be completed.		PD.D.1.TeF		
ME.03_gphtafe	1st geological evaluation phase	Doing new surface geophysical measurements for better understanding of geological layers for securing information about identification of target feature (fault, karstified surface).		Reporting	The loss of well.	No production/injection. The well is not able to produce/inject any fluid.	Drilling into inadequately explored area	If previous exploratory data are poor and rare,	then a very simlified interpretation of geological features and layers will be made.	There is a significant difference between the interpretation and the reality.	The target is missing in the drilling.	The well is not productive.		PD.T.1.NoP	Finding suitable water bearing formation in the already drilled section.	Proper logging data for identification of auxiliary targets.
ME.04_gphtafo	1st geological evaluation phase	Doing new surface geophysical measurements for better understanding of geological layers for securing information about identification of target formation.		Reporting	The loss of well.	Missing formation. The targeted reservoir formation is missing in the well.	Drilling into inadequately explored area	If previous exploratory data are poor and rare,	then a very simlified interpretation of geological features and layers will be made.	There is a significant difference between the interpretation and the reality.	The target is missing in the drilling.			PD.D.2.MiF	Drilling on deeper.	The design of the well and the used rig should be suitable for the activity.
CO.05_mota	1st geological evaluation phase	Try to identify and aim more than one target for the drilling.		Reporting	The loss of well.	No production/injection. The well is not able to produce/inject any fluid.	Selection of only one target zone	If the drilled target is not permeable,	then the well is not productive.					PD.T.1.NoP		
CO.06_te	1st geological evaluation phase	Accurate collection and interpretation of temperature data measured in existing wells for securing		Reporting	The amount of energy is lower than	Low temperature. The temperature is lower, what was expected.	Drilling into inadequately explored area	If the evaluation of subsurface data is	then temperature data will be misinterpreted.	The temperature forecast is inaccurate.	The temperature of fluid is low.			PD.T.2.LoT	Drilling on deeper.	The design of the well and the used rig should be

Code of mitigation	Timing of mitigation	Mitigation	Condition of mitigation	Monitoring activity of mitigation	Definition of damage	Proof of damage	Root activity	Risk event - IF member	Risk event - THEN member	Follow on event 1.	Follow on event 2.	Follow on event 3.	Follow on event 4.	Code of proof	Amending activity	Conditions of amending activity
		information for temperature forecast.			it was expected.			inaccurate,								suitable for the activity.
MO.01	1st geological evaluation phase	Accurate hydrogeological modelling including data collection and interpretation.		Reporting	The amount of energy is lower than it was expected.	Low temperature. The temperature is lower, what was expected.	Modelling of subsurface environment	If significant recharge of groundwater takes place around the well,	then the production zone is colder what was expected.	Cold groundwater appears at the production section.	The cold groundwater cools down the produced water.	The temperature of fluid is low.		PD.T.2.LoT		
ME.05_te	1st geological evaluation phase	Doing new temperature measurements in existing wells for securing information for temperature forecast.		Reporting	The amount of energy is lower than it was expected.	Low temperature. The temperature is lower, what was expected.	Drilling into inadequately explored area	If previous exploratory data are poor and rare,	then a very simlified interpretation of temperature data will be made.	There is a significant difference between the interpretation and the reality.	The temperature forecast is inaccurate.	The temperature of fluid is low.		PD.T.2.LoT		
ME.06_slim	1st geological evaluation phase	Drilling a slim/test hole for new temperature measurements for securing information for temperature forecast.		Reporting	The amount of energy is lower than it was expected.	Low temperature. The temperature is lower, what was expected.	Drilling into inadequately explored area	If previous exploratory data are poor and rare,	then a very simlified interpretation of temperature data will be made.	There is a significant difference between the interpretation and the reality.	The temperature forecast is inaccurate.	The temperature of fluid is low.		PD.T.2.LoT		
CO.07_yi	1st geological evaluation phase	Accurate collection and interpretation of productivity data of wells for securing information for the expected yield of the well.		Reporting	The amount of energy is lower than it was expected.	Low yield. The yield (production or injection) is lower, what was expected.	Drilling into inadequately explored area	If the evaluation of subsurface data is inaccurate,	then the geological features and layers will be misinterpreted.	The yield forecast was inaccurate.	The yield of the well is low.			PD.T.3.LoY	Stimulation (thermal, chemical or hydraulic).	The design of the well should be suitable for the activity.
ME.07_yi	1st geological evaluation phase	Doing new measurements in existing wells for securing information for the expected yield of the well.		Reporting	The amount of energy is lower than it was expected.	Low yield. The yield (production or injection) is lower, what was expected.	Drilling into inadequately explored area	If previous exploratory data are poor and rare,	then a very simlified interpretation of geological features and layers will be made.	Very simlified geological interpretation of layers.	There is a significant difference between the interpretation and the reality.	The yield forecast was inaccurate.	The yield of the well is low.	PD.T.3.LoY		
MO.01	1st geological evaluation phase	Accurate hydrogeological modelling including data collection and interpretation.		Reporting	Pending of operation.	Induced pressure change. Significant induced pressure change is observed at existing production facility (water well or spring, hydrocarbon well) nearby.	Drilling into inadequately explored area	If the evaluation of subsurface data is inaccurate,	then the geological features and layers will be misinterpreted.	Inadeqaute modelling of subsurface environment.	The induced pressure change could affect protected receptor(s) more than it was expected previously.	The authority/receptor does not approve the operation of drilled well.		PD.T.4.InP		
ME.08_hymo	1st geological evaluation phase	Doing new measurements in existing wells for securing information for hydrogeological modelling.		Reporting	Pending of operation.	Induced pressure change. Significant induced pressure change is observed at existing production facility (water well or spring, hydrocarbon well) nearby.	Drilling into inadequately explored area	If previous exploratory data are poor and rare,	then a very simlified interpretation of geological features and layers will be made.	Inadeqaute modelling of subsurface environment.	The induced pressure change could affect protected receptor(s) more than it was expected previously.	The authority/receptor does not approve the operation of drilled well.		PD.T.4.InP		
CO.08_chco	1st geological evaluation phase	Accurate collection and interpretation of chemical data for securing information about the forecasted corrosion potential of the produced fluid.		Reporting	Cost increase in investment and operation.	Increased corrosion. The observed corrosion activity of produced fluid is higher as it was anticipated originally.	Drilling into inadequately explored area	If the evaluation of subsurface data is inaccurate,	then the geological features and layers will be misinterpreted.	The forecast of corrosion potential was inaccurate.	The corrosion potential is higher than forecasted value.	The corrosion creates problems in surface infrastructure.		PD.T.8.InC	Use of inhibitors.	The design of the well should be suitable for the activity.
CO.09_chga	1st geological evaluation phase	Accurate collection and interpretation of chemical data for securing information about the forecasted gas content of the produced fluid.		Reporting	Cost increase in investment and operation.	High gas content. Th amount of gas observed in the produced fluid is much higher as it was anticipated originally.	Drilling into inadequately explored area	If the evaluation of subsurface data is inaccurate,	then the geological features and layers will be misinterpreted.	The gas content forecast was inaccurate.	The gas content of the fluid is higher than forecasted value.			PD.T.6.HiG	Re-design of depth of pump and pressure of surface system according to measured values.	The bottom of pump chamber should be designed and completed deep enough.

Code of mitigation	Timing of mitigation	Mitigation	Condition of mitigation	Monitoring activity of mitigation	Definition of damage	Proof of damage	Root activity	Risk event - IF member	Risk event - THEN member	Follow on event 1.	Follow on event 2.	Follow on event 3.	Follow on event 4.	Code of proof	Amending activity	Conditions of amending activity
CO.10_chsc	1st geological evaluation phase	Accurate collection and interpretation of chemical data for securing information about the forecasted scaling potential of the produced fluid.		Reporting	Cost increase in investment and operation.	Increased scaling. The observed scaling activity of produced fluid is higher as it was anticipated originally.	Drilling into inadequately explored area	If the evaluation of subsurface data is inaccurate,	then the geological features and layers will be misinterpreted.	The forecast of scaling potential was inaccurate.	The scaling potential is higher than forecasted value.	Scaling appears in well and surface infrastructure.		PD.T.7.InS	Use of chemicals via coil tubing.	During the design of the well the use of coil tubing should be taken into consideration.
ME.09_chco	1st geological evaluation phase	Doing new chemical sampling and analysis at existing wells for securing information about the forecasted corrosion potential of the produced fluid.		Reporting	Cost increase in investment and operation.	Increased corrosion. The observed corrosion activity of produced fluid is higher as it was anticipated originally.	Drilling into inadequately explored area	If previous exploratory data are poor and rare,	then a very simlified interpretation of geological features and layers will be made.	There is a significant difference between the interpretation and the reality.	The forecast of corrosion potential was inaccurate.	The corrosion potential is higher than forecasted value.	The corrosion creates problems in surface infrastructure.	PD.T.8.InC	Use of corrosive resistant inner casing.	The design of the well should be suitable for the activity.
ME.10_chga	1st geological evaluation phase	Doing new chemical sampling and analysis at existing wells for securing information about the forecasted gas content of the produced fluid.		Reporting	Cost increase in investment and operation.	High gas content. Th amount of gas observed in the produced fluid is much higher as it was anticipated originally.	Drilling into inadequately explored area	If previous exploratory data are poor and rare,	then a very simlified interpretation of geological features and layers will be made.	There is a significant difference between the interpretation and the reality.	The gas content forecast was inaccurate.	The gas content of the fluid is higher than forecasted value.		PD.T.6.HiG		
ME.11_chsc	1st geological evaluation phase	Doing new chemical sampling and analysis at existing wells for securing information about the forecasted scaling potential of the produced fluid.		Reporting	Cost increase in investment and operation.	Increased scaling. The observed scaling activity of produced fluid is higher as it was anticipated originally.	Drilling into inadequately explored area	If previous exploratory data are poor and rare,	then a very simlified interpretation of geological features and layers will be made.	There is a significant difference between the interpretation and the reality.	The forecast of scaling potential was inaccurate.	The scaling potential is higher than forecasted value.	Scaling appears in well and surface infrastructure.	PD.T.7.InS		
	1st design phase	**PERFORM A MITIGATION MEASURE**														
TE.01_oh8	1st design phase	Designing the production section of the well with 8 1/2" diameter.		Reporting	The amount of energy is lower than it was expected.	Low yield. The yield (production or injection) is lower, what was expected.	Drilling of production section	If the diameter of production section is too narrow,	then the openhole section will have limited capacity.	The narrow openhole section has limited capacity.	The yield of the well is low.			PD.T.3.LoY	Stimulation (thermal, chemical or hydraulic).	The design of the well should be suitable for the activity.
MO.01	1st design phase	Accurate hydrogeological modelling including data collection and interpretation.		Reporting	Pending of operation.	Induced pressure change. Significant induced pressure change is observed at existing production facility (water well or spring, hydrocarbon well) nearby.	Modelling of subsurface environment	If the position of the well was designed too close to receptors,	then the induced pressure change will be higher than it was expected.	The receptor does not approve the operation of drilled well.				PD.T.4.InP	Decrease of production rate (temporary solution).	
	1st design phase	**PREPARE A MITIGATION MEASURE**														
TE.02_ecp	1st design phase	Use of external casing packer between the loose formation and productive layer.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The amount of energy is lower than it was expected.	Low yield. The yield (production or injection) is lower, what was expected.	Drilling of production section	If the drilled production section contains less consolidated fine grained sediments,	then the loose, clayey sediments will contaminate the production zone.	The production zone has decreased permeability.	The yield of the well is low.			PD.T.3.LoY		
TE.03_grpa	1st design phase	In case of porous aquifer use of underreaming and gravel pack in the production section.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The amount of energy is lower than it was expected.	Low yield. The yield (production or injection) is lower, what was expected.	Drilling of production section	If the drilled production section contains less consolidated fine grained sediments,	then the loose, clayey sediments will contaminate the production zone.					PD.T.3.LoY		
TE.04_cemj	1st design phase	Professional service provider and supervised cementing activites for appropriate isolation.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The amount of energy is lower than it was expected.	Low temperature. The temperature is lower, what was expected.	Completion of geothermal well	If the cement behind the casing is (partially) missing and there are water bearing layers above	then the cold groundwater could be produced.	Cold groundwater appears at the production section.	The cold groundwater cools down the produced water.	The temperature of fluid is low.		PD.T.2.LoT		

Code of mitigation	Timing of mitigation	Mitigation	Condition of mitigation	Monitoring activity of mitigation	Definition of damage	Proof of damage	Root activity	Risk event - IF member	Risk event - THEN member	Follow on event 1.	Follow on event 2.	Follow on event 3.	Follow on event 4.	Code of proof	Amending activity	Conditions of amending activity
								the production zone,								
TE.05_droh	1st design phase	Try to drill long enough production section for securing the expected yield.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The amount of energy is lower than it was expected.	Low yield. The yield (production or injection) is lower, what was expected.	Drilling of production section	If the production section is short,	then the production section will have limited capacity.	The yield of the well is low.				PD.T.3.LoY	Drilling on deeper.	The design of the well and the used rig should be suitable for the activity.
TE.06_cemins	1st design phase	Use of cement with increased heat insulation properties for cementing of casings of production well.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The amount of energy is lower than it was expected.	Low temperature. The temperature is lower, what was expected.	The planned production is low	If the flow in the well is very slow,	then the produced fluid will be cooled.	The temperature of fluid is low.				PD.T.2.LoT	Increase of yield, when the cooling up to surface is high.	The design of well should allow the lowering of pump for securing higher yield.
TE.07_drmud	1st design phase	Use of clay minerals-free drilling mud, which is properly treated in the mud system by removal of cutting particles.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The amount of energy is lower than it was expected.	Low yield. The yield (production or injection) is lower, what was expected.	Drilling of production section	If clayey drilling mud is used during the drilling of production section,	then drilling mud will clog the pores.	The solid particles of the mud decrease the permeability of the layer.	The yield of the well is low.			PD.T.3.LoY	Cleaning by airlifting and/or acidizing.	
TE.04_cemj	1st design phase	Professional service provider and supervised cementing activites for appropriate isolation.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Pending of operation.	Induced pressure change. Significant induced pressure change is observed at existing production facility (water well or spring, hydrocarbon well) nearby.	Completion of geothermal well	If the cement behind the casing is (partially) missing and there are water bearing layers above the production zone,	then the induced pressure change could affect another aquifer(s).	The authority does not approve the operation of drilled well.				PD.T.4.InP	Compensation of affected receptor(s).	
TE.04_cemj	1st design phase	Professional service provider and supervised cementing activites for appropriate isolation.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Pending of operation.	Induced pressure change. Significant induced pressure change is observed at existing production facility (water well or spring, hydrocarbon well) nearby.	Completion of geothermal well	If the cement behind the casing is (partially) missing and there are water bearing layers above the production zone,	then the induced pressure change could affect another aquifer(s).	The induced pressure change at receptor is higher than it was expected.	The authority/receptor disapprove the operation of development.			PD.O.5.InP		
TE.02_ecp	1st design phase	Use of external casing packer between the loose formation and productive layer.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Cost increase in operation.	Pressure increase. Continuous pressure increase is observed at the injection well.	Completion of geothermal well	If the drilled production section contains less consolidated fine grained sediments,	then the loose, clayey sediments will be in the produced brine.	The produced particles will decrease the efficiency of screening system at surface.				PD.O.3.PrI		
TE.03_grpa	1st design phase	In case of porous aquifer use of underreaming and gravel pack in the production section.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Cost increase in operation.	Pressure increase. Continuous pressure increase is observed at the injection well.	Treatment of produced fluid	If the injected water contain particles,	then the pores will be clogged.					PD.O.3.PrI		
TE.03_grpa	1st design phase	In case of porous aquifer use of underreaming and gravel pack in the production section.	The service should be designed and	Drilling supervisor, daily reports of activity	Cost increase in operation.	Pressure increase. Continuous pressure increase is observed at the injection well.	Completion of injection well	If the drilled production section contains less consolidated	then the loose, clayey sediments will clog the production					PD.O.3.PrI		

Code of mitigation	Timing of mitigation	Mitigation	Condition of mitigation	Monitoring activity of mitigation	Definition of damage	Proof of damage	Root activity	Risk event - IF member	Risk event - THEN member	Follow on event 1.	Follow on event 2.	Follow on event 3.	Follow on event 4.	Code of proof	Amending activity	Conditions of amending activity
			procured in advance.					fine grained sediments,	zone.							
ME.12_chsa	1st design phase	Performing adequate chemical sampling and analysis of produced fluid.	The service should be designed and procured in advance.	Reporting	Cost increase in operation.	Increased scaling. Increased scaling activity of produced fluid is observed.	Measurement of chemistry of produced fluid	If the chemical analysis is inaccurate,	then the evaluation of scaling potential is inaccurate.	The scaling activity is higher than it was expected.	Scaling appears in well and surface infrastructure.			PD.O.6.InS	Decrease of production rate (temporary solution).	
ME.12_chsa	1st design phase	Performing adequate chemical sampling and analysis of produced fluid.	The service should be designed and procured in advance.	Reporting	Cost increase in operation.	Increased corrosion. Increased corrosion activity of produced fluid is observed.	Measurement of chemistry of produced fluid	If the chemical analysis is inaccurate,	then the evaluation of corrosion potential is inaccurate.	The corrosion activity is higher than it was expected.	The corrosion creates problems in surface infrastructure.			PD.O.7.InC	Decrease of production rate (temporary solution).	
	1st drilling phase	**PERFORM A MITIGATION MEASURE**														
TE.02_ecp	1st drilling phase	Use of external casing packer between the loose formation and productive layer.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The amount of energy is lower than it was expected.	Low yield. The yield (production or injection) is lower, what was expected.	Drilling of production section	If the drilled production section contains less consolidated fine grained sediments,	then the loose, clayey sediments will contaminate the production zone.	The production zone has decreased permeability.	The yield of the well is low.			PD.T.3.LoY		
TE.03_grpa	1st drilling phase	In case of porous aquifer use of underreaming and gravel pack in the production section.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The amount of energy is lower than it was expected.	Low yield. The yield (production or injection) is lower, what was expected.	Drilling of production section	If the drilled production section contains less consolidated fine grained sediments,	then the loose, clayey sediments will contaminate the production zone.					PD.T.3.LoY		
TE.08_avcem	1st drilling phase	Avoid the cementing of previous casing string in the production section.	The forecasted production section cannot be intersected by the previous section.	Drilling supervisor, daily reports of activity	The amount of energy is lower than it was expected.	Low yield. The yield (production or injection) is lower, what was expected.	Drilling of production section	If the previous casing section is cemented and intersects the production section,	then the cement will contaminate the pores.	The cement decreases the permeability of the layer	The yield of the well is low.			PD.T.3.LoY	Acidizing.	
TE.09_avLCM	1st drilling phase	Avoid the use of LCM during drilling of production section.		Drilling supervisor, daily reports of activity	The amount of energy is lower than it was expected.	Low yield. The yield (production or injection) is lower, what was expected.	Drilling of production section	If LCM (loss control material) is used during the drilling of production section,	then LCM will contaminate the pores.	The LCM decreases the permeability of the layer.	The yield of the well is low.			PD.T.3.LoY	Cleaning by airlifting and/or acidizing.	
TE.04_cemj	1st drilling phase	Professional service provider and supervised cementing activites for appropriate isolation.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The amount of energy is lower than it was expected.	Low temperature. The temperature is lower, what was expected.	Completion of geothermal well	If the cement behind the casing is (partially) missing and there are water bearing layers above the production zone,	then the cold groundwater could be produced.	Cold groundwater appears at the production section.	The cold groundwater cools down the produced water.	The temperature of fluid is low.		PD.T.2.LoT		
TE.05_droh	1st drilling phase	Try to drill long enough production section for securing the expected yield.	The service should be designed and	Drilling supervisor, daily reports of activity	The amount of energy is lower than it was	Low yield. The yield (production or injection) is lower, what was expected.	Drilling of production section	If the production section is short,	then the production section will have limited capacity.	The yield of the well is low.				PD.T.3.LoY	Drilling on deeper.	The design of the well and the used rig should be suitable for

Code of mitigation	Timing of mitigation	Mitigation	Condition of mitigation	Monitoring activity of mitigation	Definition of damage	Proof of damage	Root activity	Risk event - IF member	Risk event - THEN member	Follow on event 1.	Follow on event 2.	Follow on event 3.	Follow on event 4.	Code of proof	Amending activity	Conditions of amending activity
			procured in advance.		expected.											the activity.
TE.06_cemins	1st drilling phase	Use of cement with increased heat insulation properties for cementing of casings of production well.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The amount of energy is lower than it was expected.	Low temperature. The temperature is lower, what was expected.	The planned production is low	If the flow in the well is very slow,	then the produced fluid will be cooled.	The temperature of fluid is low.				PD.T.2.LoT	Increase of yield, when the cooling up to surface is high.	The design of well should allow the lowering of pump for securing higher yield.
TE.07_drmud	1st drilling phase	Use of clay minerals-free drilling mud, which is properly treated in the mud system by removal of cutting particles.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The amount of energy is lower than it was expected.	Low yield. The yield (production or injection) is lower, what was expected.	Drilling of production section	If clayey drilling mud is used during the drilling of production section,	then drilling mud will clog the pores.	The solid particles of the mud decrease the permeability of the layer.	The yield of the well is low.			PD.T.3.LoY	Cleaning by airlifting and/or acidizing.	
TE.04_cemj	1st drilling phase	Professional service provider and supervised cementing activites for appropriate isolation.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Pending of operation.	Induced pressure change. Significant induced pressure change is observed at existing production facility (water well or spring, hydrocarbon well) nearby.	Completion of geothermal well	If the cement behind the casing is (partially) missing and there are water bearing layers above the production zone,	then the induced pressure change could affect another aquifer(s).	The authority does not approve the operation of drilled well.				PD.T.4.InP	Compensation of affected receptor(s).	
TE.04_cemj	1st drilling phase	Professional service provider and supervised cementing activites for appropriate isolation.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Pending of operation.	Induced pressure change. Significant induced pressure change is observed at existing production facility (water well or spring, hydrocarbon well) nearby.	Completion of geothermal well	If the cement behind the casing is (partially) missing and there are water bearing layers above the production zone,	then the induced pressure change could affect another aquifer(s).	The induced pressure change at receptor is higher than it was expected.	The authority/receptor disapprove the operation of development.			PD.O.5.InP		
TE.02_ecp	1st drilling phase	Use of external casing packer between the loose formation and productive layer.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Cost increase in operation.	Pressure increase. Continuous pressure increase is observed at the injection well.	Completion of geothermal well	If the drilled production section contains less consolidated fine grained sediments,	then the loose, clayey sediments will be in the produced brine.	The produced particles will decrease the efficiency of screening system at surface.				PD.O.3.PrI		
TE.03_grpa	1st drilling phase	In case of porous aquifer use of underreaming and gravel pack in the production section.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Cost increase in operation.	Pressure increase. Continuous pressure increase is observed at the injection well.	Treatment of produced fluid	If the injected water contain particles,	then the pores will be clogged.					PD.O.3.PrI		
TE.03_grpa	1st drilling phase	In case of porous aquifer use of underreaming and gravel pack in the production section.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Cost increase in operation.	Pressure increase. Continuous pressure increase is observed at the injection well.	Completion of injection well	If the drilled production section contains less consolidated fine grained sediments,	then the loose, clayey sediments will clog the production zone.					PD.O.3.PrI		
ME.12_chsa	1st drilling phase	Performing adequate chemical sampling and analysis of produced fluid.	The service should be designed and procured in advance.	Reporting	Cost increase in operation.	Increased scaling. Increased scaling activity of produced fluid is observed.	Measurement of chemistry of produced fluid	If the chemical analysis is inaccurate,	then the evaluation of scaling potential is inaccurate.	The scaling activity is higher than it was expected.	Scaling appears in well and surface infrastructure.			PD.O.6.InS	Decrease of production rate (temporary solution).	

Code of mitigation	Timing of mitigation	Mitigation	Condition of mitigation	Monitoring activity of mitigation	Definition of damage	Proof of damage	Root activity	Risk event - IF member	Risk event - THEN member	Follow on event 1.	Follow on event 2.	Follow on event 3.	Follow on event 4.	Code of proof	Amending activity	Conditions of amending activity
ME.12_chsa	1st drilling phase	Performing adequate chemical sampling and analysis of produced fluid.	The service should be designed and procured in advance.	Reporting	Cost increase in operation.	Increased corrosion. Increased corrosion activity of produced fluid is observed.	Measurement of chemistry of produced fluid	If the chemical analysis is inaccurate,	then the evaluation of corrosion potential is inaccurate.	The corrosion activity is higher than it was expected.	The corrosion creates problems in surface infrastructure.			PD.O.7.InC	Decrease of production rate (temporary solution).	
	2nd geological evaluation phase	**PERFORM A MITIGATION MEASURE**														
CO.01_dr	2nd geological evaluation phase	Accurate collection and interpretation of geological layers and features for securing information about forecasted drilling difficulties.														
CO.02_tafe	2nd geological evaluation phase	Accurate collection and interpretation of geological layers and features for securing information about identification of target feature (fault, karstified surface).		Reporting	The loss of well.	No production/injection. The well is not able to produce/inject any fluid.	Drilling into inadequately explored area	If the evaluation of subsurface data is inaccurate,	then the geological features and layers will be misinterpreted.	The target is missing in the drilling.	The well is not productive.			PD.T.1.NoP	Drilling on deeper.	The design of the well and the used rig should be suitable for the activity.
ME.03_gphtafe	2nd geological evaluation phase	Doing new surface geophysical measurements for better understanding of geological layers for securing information about identification of target feature (fault, karstified surface).		Reporting	The loss of well.	No production/injection. The well is not able to produce/inject any fluid.	Drilling into inadequately explored area	If previous exploratory data are poor and rare,	then a very simlified interpretation of geological features and layers will be made.	There is a significant difference between the interpretation and the reality.	The target is missing in the drilling.	The well is not productive.		PD.T.1.NoP	Finding suitable water bearing formation in the already drilled section.	Proper logging data for identification of auxiliary targets.
CO.03_tafo	1st geological evaluation phase	Accurate collection and interpretation of geological layers and features for securing information about identification of target formation.		Reporting	The loss of well.	Missing formation. The targeted reservoir formation is missing in the well.	Drilling into inadequately explored area	If the evaluation of subsurface data is inaccurate,	then the geological features and layers will be misinterpreted.	There is a significant difference between the interpretation and the reality.	The target is missing in the drilling.			PD.D.2.MiF	Finding suitable water bearing formation in the already drilled section.	Proper logging data for identification of auxiliary targets.
CO.05_mota	2nd geological evaluation phase	Try to identify and aim more than one target for the drilling.		Reporting	The loss of well.	No production/injection. The well is not able to produce/inject any fluid.	Selection of only one target zone	If the drilled target is not permeable,	then the well is not productive.					PD.T.1.NoP		
CO.11_strev	2nd geological evaluation phase	Accurate data collection and interpretation for securing information for realistic structural evaluation.		Reporting	The amount of energy is lower than it was expected.	No connection. There is no hydraulic connection between the members of the doublet.	Drilling into inadequately explored area	If the evaluation of subsurface data is inaccurate,	then the geological features and layers will be misinterpreted.	The design of location of wells of doublet is inadequate.	Lack of connection between the members of the doublet.			PD.T.5.NoC	Drill another well to be located in the same hydrogeoloigcal unit as the pair of well.	
MO.01	2nd geological evaluation phase	Accurate hydrogeological modelling including data collection and interpretation.		Reporting	The amount of energy is lower than it was expected.	Cooling of production well. Unusual cooling of produced fluid is observed at the production well.	Modelling of subsurface environment	If the modelled effect of the development is inaccurate,	then the location of wells of doublet will be improper.	Premature cold break through between production and injection well.	Early cooling of production well.			PD.O.1.CoP	Drill a new production well at more appropriate direction and distance from injection well.	
ME.13_strev	2nd geological evaluation phase	Doing new measurements in existing wells for securing information for realistic structural evaluation.		Reporting	The amount of energy is lower than it was expected.	No connection. There is no hydraulic connection between the members of the doublet.	Drilling into inadequately explored area	If previous exploratory data are poor and rare,	then a very simlified interpretation of geological features and layers will be made.	The design of location of wells of doublet is inadequate.	Lack of connection between the members of the doublet.			PD.T.5.NoC	Decrease of production rate (temporary solution).	

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MO.01	2nd geological evaluation phase	Accurate hydrogeological modelling including data collection and interpretation.		Reporting	Cost increase in operation.	Pressure drop. Continuous pressure drop is observed at the production well.	Modelling of subsurface environment	If the modelled effect of the development is inaccurate,	then the location of wells of doublet will be improper.	The produced aquifer suffers from lack of water, the injected water is not reaching the production well.	The reservoir pressure is decreasing at production well.			PD.O.2.PrD	Drill a new well, which is presumably not affected by the pressure change.	
MO.01	2nd geological evaluation phase	Accurate hydrogeological modelling including data collection and interpretation.		Reporting	Cost increase in operation.	Pressure increase. Continuous pressure increase is observed at the injection well.	Modelling of subsurface environment	If the modelled effect of the development is inaccurate,	then the location of wells of doublet will be improper.	The produced aquifer suffers from surplus of water, the injected water is not reaching the production well.	The reservoir pressure is increasing at injection well.			PD.O.3.PrI	Drill a new well, which is presumably not affected by the pressure change.	
CO.12_evco	2nd geological evaluation phase	Performing adequate evaluation of corrosion potential.		Reporting	Cost increase in operation.	Increased corrosion. Increased corrosion activity of produced fluid is observed.	Chemical evaluation of produced fluid	If the evaluation of corrosion potential is inaccurate,	then the corrosion activity is higher than it was expected.	The corrosion creates problems in surface infrastructure.				PD.O.7.InC	Use of inhibitors.	The design of the well should be suitable for the activity.
CO.13_evsc	2nd geological evaluation phase	Performing adequate evaluation of scaling potential.		Reporting	Cost increase in operation.	Increased scaling. Increased scaling activity of produced fluid is observed.	Chemical evaluation of produced fluid	If the evaluation of scaling potential is inaccurate,	then the scaling activity is higher than it was expected.	Scaling appears in well and surface infrastructure.				PD.O.6.InS	Use of chemicals via coil tubing.	During the design of the well the use of coil tubing should be taken into consideration.
	2nd design phase	**PREPARE A MITIGATION MEASURE**														
TE.02_ecp	2nd design phase	Use of external casing packer between the loose formation and productive layer.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The amount of energy is lower than it was expected.	Low yield. The yield (production or injection) is lower, what was expected.	Drilling of production section	If the drilled production section contains less consolidated fine grained sediments,	then the loose, clayey sediments will contaminate the production zone.	The production zone has decreased permeability.	The yield of the well is low.			PD.T.3.LoY		
TE.03_grpa	2nd design phase	In case of porous aquifer use of underreaming and gravel pack in the production section.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The amount of energy is lower than it was expected.	Low yield. The yield (production or injection) is lower, what was expected.	Drilling of production section	If the drilled production section contains less consolidated fine grained sediments,	then the loose, clayey sediments will contaminate the production zone.					PD.T.3.LoY		
TE.10_sand	2nd design phase	In case of porous aquifer the production section of injection well should not contain fine grained sediments, only pure sandstone members are recommended.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The amount of energy is lower than it was expected.	Low yield. The yield (production or injection) is lower, what was expected.	Drilling of production section	If the drilled production section contains less consolidated fine grained sediments,	then the loose, clayey sediments will contaminate the production zone.					PD.T.3.LoY		
ME.14_trte	2nd design phase	Performing adequate interference or tracer test for securing information for verification of hydrogeological model.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The amount of energy is lower than it was expected.	Cooling of production well. Unusual cooling of produced fluid is observed at the production well.	Testing operation	If the verification of reservoir model is inaccurate,	then the location of wells of doublet will be improper.	Premature cold break through between production and injection well.	Early cooling of production well.			PD.O.1.CoP	Decrease of production rate (temporary solution).	
TE.04_cemj	2nd design phase	Professional service provider and supervised cementing activites for appropriate isolation.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The amount of energy is lower than it was expected.	Low temperature. The temperature is lower, what was expected.	Completion of geothermal well	If the cement behind the casing is (partially) missing and there are water bearing layers above the	then the cold groundwater could be produced.	Cold groundwater appears at the production section.	The cold groundwater cools down the produced water.	The temperature of fluid is low.		PD.T.2.LoT		

Code of mitigation	Timing of mitigation	Mitigation	Condition of mitigation	Monitoring activity of mitigation	Definition of damage	Proof of damage	Root activity	Risk event - IF member	Risk event - THEN member	Follow on event 1.	Follow on event 2.	Follow on event 3.	Follow on event 4.	Code of proof	Amending activity	Conditions of amending activity
								production zone,								
TE.05_droh	2nd design phase	Try to drill long enough production section for securing the expected yield.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The amount of energy is lower than it was expected.	Low yield. The yield (production or injection) is lower, what was expected.	Drilling of production section	If the production section is short,	then the production section will have limited capacity.	The yield of the well is low.				PD.T.3.LoY	Drilling on deeper.	The design of the well and the used rig should be suitable for the activity.
TE.07_drmud	2nd design phase	Use of clay minerals-free drilling mud, which is properly treated in the mud system by removal of cutting particles.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The amount of energy is lower than it was expected.	Low yield. The yield (production or injection) is lower, what was expected.	Drilling of production section	If clayey drilling mud is used during the drilling of production section,	then drilling mud will clog the pores.	The solid particles of the mud decrease the permeability of the layer.	The yield of the well is low.			PD.T.3.LoY	Cleaning by airlifting and/or acidizing.	
ME.14_trte	2nd design phase	Performing adequate interference or tracer test for securing information for verification of hydrogeological model.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Pending of operation.	Induced temperature change. Significant induced temperature change is observed at existing production facility (water well or spring, hydrocarbon well) nearby.	Testing operation	If the verification of reservoir model is inaccurate,	then the location of wells of doublet will be improper.	The induced temperature change at receptor is higher than it was expected.	The authority/receptor disapprove the operation of development.			PD.O.4.InT	Decrease of production rate (temporary solution).	
ME.14_trte	2nd design phase	Performing adequate interference or tracer test for securing information for verification of hydrogeological model.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Pending of operation.	Induced pressure change. Significant induced pressure change is observed at existing production facility (water well or spring, hydrocarbon well) nearby.	Testing operation	If the verification of reservoir model is inaccurate,	then the location of wells of doublet will be improper.	The induced pressure change at receptor is higher than it was expected.	The authority/receptor disapprove the operation of development.			PD.O.5.InP	Decrease of production rate (temporary solution).	
TE.04_cemj	2nd design phase	Professional service provider and supervised cementing activites for appropriate isolation.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Pending of operation.	Induced pressure change. Significant induced pressure change is observed at existing production facility (water well or spring, hydrocarbon well) nearby.	Completion of geothermal well	If the cement behind the casing is (partially) missing and there are water bearing layers above the production zone,	then the induced pressure change could affect another aquifer(s).	The authority does not approve the operation of drilled well.				PD.T.4.InP	Compensation of affected receptor(s).	
TE.04_cemj	2nd design phase	Professional service provider and supervised cementing activites for appropriate isolation.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Pending of operation.	Induced pressure change. Significant induced pressure change is observed at existing production facility (water well or spring, hydrocarbon well) nearby.	Completion of geothermal well	If the cement behind the casing is (partially) missing and there are water bearing layers above the production zone,	then the induced pressure change could affect another aquifer(s).	The induced pressure change at receptor is higher than it was expected.	The authority/receptor disapprove the operation of development.			PD.O.5.InP		
TE.11_filt	2nd design phase	Adequate filtering of re-injected water.	The service should be designed and procured in advance.	Monitoring of parameters of groundwater	Cost increase in operation.	Pressure increase. Continuous pressure increase is observed at the injection well.	Treatment of produced fluid	If the injected water contain particles,	then the pores will be clogged.	The reservoir pressure is increasing at injection well.				PD.O.3.PrI	Stimulation (thermal, chemical or hydraulic).	The design of the well should be suitable for the activity.

Code of mitigation	Timing of mitigation	Mitigation	Condition of mitigation	Monitoring activity of mitigation	Definition of damage	Proof of damage	Root activity	Risk event - IF member	Risk event - THEN member	Follow on event 1.	Follow on event 2.	Follow on event 3.	Follow on event 4.	Code of proof	Amending activity	Conditions of amending activity
TE.11_filt	2nd design phase	Adequate filtering of re-injected water.	The service should be designed and procured in advance.	Monitoring of parameters of groundwater	Cost increase in operation.	Pressure increase. Continuous pressure increase is observed at the injection well.	Treatment of produced fluid	If bacterias are invading the surface of formation,	then the injectivity will decrease.	The reservoir pressure is increasing at injection well.				PD.O.3.PrI		
TE.02_ecp	2nd design phase	Use of external casing packer between the loose formation and productive layer.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Cost increase in operation.	Pressure increase. Continuous pressure increase is observed at the injection well.	Completion of injection well	If the drilled production section contains less consolidated fine grained sediments,	then the loose, clayey sediments will clog the production zone.	The reservoir pressure is increasing at injection well.				PD.O.3.PrI		
TE.03_grpa	2nd design phase	In case of porous aquifer use of underreaming and gravel pack in the production section.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Cost increase in operation.	Pressure increase. Continuous pressure increase is observed at the injection well.	Treatment of produced fluid	If the injected water contain particles,	then the pores will be clogged.					PD.O.3.PrI		
TE.03_grpa	2nd design phase	In case of porous aquifer use of underreaming and gravel pack in the production section.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Cost increase in operation.	Pressure increase. Continuous pressure increase is observed at the injection well.	Completion of injection well	If the drilled production section contains less consolidated fine grained sediments,	then the loose, clayey sediments will clog the production zone.					PD.O.3.PrI		
TE.12_trfl	2nd design phase	Treatment of fluid to prevent the reproduction of bacteria in productive layers of injection well.	The service should be designed and procured in advance.	Reporting	Cost increase in operation.	Pressure increase. Continuous pressure increase is observed at the injection well.	Treatment of produced fluid	If bacterias are invading the surface of formation,	then the injectivity will decrease.					PD.O.3.PrI		
TE.10_sand	2nd design phase	In case of porous aquifer the production section of injection well should not contain fine grained sediments, only pure sandstone members are recommended.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Cost increase in operation.	Pressure increase. Continuous pressure increase is observed at the injection well.	Completion of injection well	If the drilled production section contains less consolidated fine grained sediments,	then the loose, clayey sediments will clog the production zone.					PD.O.3.PrI		
TE.11_filt	2nd design phase	Adequate filtering of re-injected water.	The service should be designed and procured in advance.	Monitoring of parameters of groundwater	Cost increase in operation.	Clogged heat exchangers. Particles of produced fluid clog the heat exchanger.	Treatment of produced fluid	If the produced water contain particles,	then the pores of heat exchangers will be clogged.	The efficiency of heat exchanger is decreasing.				PD.O.8.HeE	Use of filter system at the surface.	
ME.14_trte	2nd design phase	Performing adequate interference or tracer test for securing information for verification of hydrogeological model.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Cost increase in operation.	Pressure drop. Continuous pressure drop is observed at the production well.	Testing operation	If the verification of reservoir model is inaccurate,	then the location of wells of doublet will be improper.	The produced aquifer suffers from lack of water, the injected water is not reaching the production well.	The reservoir pressure is decreasing at production well.			PD.O.2.PrD	Decrease of production rate (temporary solution).	
ME.14_trte	2nd design phase	Performing adequate interference or tracer test for securing information for verification of hydrogeological model.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Cost increase in operation.	Pressure increase. Continuous pressure increase is observed at the injection well.	Testing operation	If the verification of reservoir model is inaccurate,	then the location of wells of doublet will be improper.	The produced aquifer suffers from surplus of water, the injected water is not reaching the production well.	The reservoir pressure is increasing at injection well.			PD.O.3.PrI	Decrease of production rate (temporary solution).	
	2nd drilling phase	**PERFORM A MITIGATION MEASURE**														

Code of mitigation	Timing of mitigation	Mitigation	Condition of mitigation	Monitoring activity of mitigation	Definition of damage	Proof of damage	Root activity	Risk event - IF member	Risk event - THEN member	Follow on event 1.	Follow on event 2.	Follow on event 3.	Follow on event 4.	Code of proof	Amending activity	Conditions of amending activity
TE.02_ecp	2nd drilling phase	Use of external casing packer between the loose formation and productive layer.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The amount of energy is lower than it was expected.	Low yield. The yield (production or injection) is lower, what was expected.	Drilling of production section	If the drilled production section contains less consolidated fine grained sediments,	then the loose, clayey sediments will contaminate the production zone.	The production zone has decreased permeability.	The yield of the well is low.			PD.T.3.LoY		
TE.03_grpa	2nd drilling phase	In case of porous aquifer use of underreaming and gravel pack in the production section.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The amount of energy is lower than it was expected.	Low yield. The yield (production or injection) is lower, what was expected.	Drilling of production section	If the drilled production section contains less consolidated fine grained sediments,	then the loose, clayey sediments will contaminate the production zone.					PD.T.3.LoY		
TE.10_sand	2nd drilling phase	In case of porous aquifer the production section of injection well should not contain fine grained sediments, only pure sandstone members are recommended.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The amount of energy is lower than it was expected.	Low yield. The yield (production or injection) is lower, what was expected.	Drilling of production section	If the drilled production section contains less consolidated fine grained sediments,	then the loose, clayey sediments will contaminate the production zone.					PD.T.3.LoY		
TE.08_avcem	2nd drilling phase	Avoid the cementing of previous casing string in the production section.	The forecasted production section cannot be intersected by the previous section.	Drilling supervisor, daily reports of activity	The amount of energy is lower than it was expected.	Low yield. The yield (production or injection) is lower, what was expected.	Drilling of production section	If the previous casing section is cemented and intersects the production section,	then the cement will contaminate the pores.	The cement decreases the permeability of the layer	The yield of the well is low.			PD.T.3.LoY	Acidizing.	
TE.09_avLCM	2nd drilling phase	Avoid the use of LCM during drilling of production section.		Drilling supervisor, daily reports of activity	The amount of energy is lower than it was expected.	Low yield. The yield (production or injection) is lower, what was expected.	Drilling of production section	If LCM (loss control material) is used during the drilling of production section,	then LCM will contaminate the pores.	The LCM decreases the permeability of the layer.	The yield of the well is low.			PD.T.3.LoY	Cleaning by airlifting and/or acidizing.	
ME.14_trte	2nd drilling phase	Performing adequate interference or tracer test for securing information for verification of hydrogeological model.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The amount of energy is lower than it was expected.	Cooling of production well. Unusual cooling of produced fluid is observed at the production well.	Testing operation	If the verification of reservoir model is inaccurate,	then the location of wells of doublet will be improper.	Premature cold break through between production and injection well.	Early cooling of production well.			PD.O.1.CoP	Decrease of production rate (temporary solution).	
TE.04_cemj	2nd drilling phase	Professional service provider and supervised cementing activites for appropriate isolation.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The amount of energy is lower than it was expected.	Low temperature. The temperature is lower, what was expected.	Completion of geothermal well	If the cement behind the casing is (partially) missing and there are water bearing layers above the production zone,	then the cold groundwater could be produced.	Cold groundwater appears at the production section.	The cold groundwater cools down the produced water.	The temperature of fluid is low.		PD.T.2.LoT		
TE.05_droh	2nd drilling phase	Try to drill long enough production section for securing the expected yield.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The amount of energy is lower than it was expected.	Low yield. The yield (production or injection) is lower, what was expected.	Drilling of production section	If the production section is short,	then the production section will have limited capacity.	The yield of the well is low.				PD.T.3.LoY	Drilling on deeper.	The design of the well and the used rig should be suitable for the activity.
TE.07_drmud	2nd drilling phase	Use of clay minerals-free drilling mud, which is properly treated in the mud system by removal of cutting particles.	The service should be designed and	Drilling supervisor, daily reports of activity	The amount of energy is lower than it was	Low yield. The yield (production or injection) is lower, what was expected.	Drilling of production section	If clayey drilling mud is used during the drilling of	then drilling mud will clog the pores.	The solid particles of the mud decrease the permeability	The yield of the well is low.			PD.T.3.LoY	Cleaning by airlifting and/or acidizing.	

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			procured in advance.		expected.			production section,		of the layer.						
ME.14_trte	2nd drilling phase	Performing adequate interference or tracer test for securing information for verification of hydrogeological model.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Pending of operation.	Induced temperature change. Significant induced temperature change is observed at existing production facility (water well or spring, hydrocarbon well) nearby.	Testing operation	If the verification of reservoir model is inaccurate,	then the location of wells of doublet will be improper.	The induced temperature change at receptor is higher than it was expected.	The authority/receptor disapprove the operation of development.			PD.O.4.InT	Decrease of production rate (temporary solution).	
ME.14_trte	2nd drilling phase	Performing adequate interference or tracer test for securing information for verification of hydrogeological model.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Pending of operation.	Induced pressure change. Significant induced pressure change is observed at existing production facility (water well or spring, hydrocarbon well) nearby.	Testing operation	If the verification of reservoir model is inaccurate,	then the location of wells of doublet will be improper.	The induced pressure change at receptor is higher than it was expected.	The authority/receptor disapprove the operation of development.			PD.O.5.InP	Decrease of production rate (temporary solution).	
TE.04_cemj	2nd drilling phase	Professional service provider and supervised cementing activites for appropriate isolation.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Pending of operation.	Induced pressure change. Significant induced pressure change is observed at existing production facility (water well or spring, hydrocarbon well) nearby.	Completion of geothermal well	If the cement behind the casing is (partially) missing and there are water bearing layers above the production zone,	then the induced pressure change could affect another aquifer(s).	The authority does not approve the operation of drilled well.				PD.T.4.InP	Compensation of affected receptor(s).	
TE.04_cemj	2nd drilling phase	Professional service provider and supervised cementing activites for appropriate isolation.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Pending of operation.	Induced pressure change. Significant induced pressure change is observed at existing production facility (water well or spring, hydrocarbon well) nearby.	Completion of geothermal well	If the cement behind the casing is (partially) missing and there are water bearing layers above the production zone,	then the induced pressure change could affect another aquifer(s).	The induced pressure change at receptor is higher than it was expected.	The authority/receptor disapprove the operation of development.			PD.O.5.InP		
TE.02_ecp	2nd drilling phase	Use of external casing packer between the loose formation and productive layer.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Cost increase in operation.	Pressure increase. Continuous pressure increase is observed at the injection well.	Completion of injection well	If the drilled production section contains less consolidated fine grained sediments,	then the loose, clayey sediments will clog the production zone.	The reservoir pressure is increasing at injection well.				PD.O.3.PrI		
TE.03_grpa	2nd drilling phase	In case of porous aquifer use of underreaming and gravel pack in the production section.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Cost increase in operation.	Pressure increase. Continuous pressure increase is observed at the injection well.	Treatment of produced fluid	If the injected water contain particles,	then the pores will be clogged.					PD.O.3.PrI		
TE.03_grpa	2nd drilling phase	In case of porous aquifer use of underreaming and gravel pack in the production section.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Cost increase in operation.	Pressure increase. Continuous pressure increase is observed at the injection well.	Completion of injection well	If the drilled production section contains less consolidated fine grained sediments,	then the loose, clayey sediments will clog the production zone.					PD.O.3.PrI		

Code of mitigation	Timing of mitigation	Mitigation	Condition of mitigation	Monitoring activity of mitigation	Definition of damage	Proof of damage	Root activity	Risk event - IF member	Risk event - THEN member	Follow on event 1.	Follow on event 2.	Follow on event 3.	Follow on event 4.	Code of proof	Amending activity	Conditions of amending activity
TE.10_sand	2nd drilling phase	In case of porous aquifer the production section of injection well should not contain fine grained sediments, only pure sandstone members are recommended.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Cost increase in operation.	Pressure increase. Continuous pressure increase is observed at the injection well.	Completion of injection well	If the drilled production section contains less consolidated fine grained sediments,	then the loose, clayey sediments will clog the production zone.					PD.O.3.PrI		
ME.14_trte	2nd drilling phase	Performing adequate interference or tracer test for securing information for verification of hydrogeological model.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Cost increase in operation.	Pressure drop. Continuous pressure drop is observed at the production well.	Testing operation	If the verification of reservoir model is inaccurate,	then the location of wells of doublet will be improper.	The produced aquifer suffers from lack of water, the injected water is not reaching the production well.	The reservoir pressure is decreasing at production well.			PD.O.2.PrD	Decrease of production rate (temporary solution).	
ME.14_trte	2nd drilling phase	Performing adequate interference or tracer test for securing information for verification of hydrogeological model.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Cost increase in operation.	Pressure increase. Continuous pressure increase is observed at the injection well.	Testing operation	If the verification of reservoir model is inaccurate,	then the location of wells of doublet will be improper.	The produced aquifer suffers from surplus of water, the injected water is not reaching the production well.	The reservoir pressure is increasing at injection well.			PD.O.3.PrI	Decrease of production rate (temporary solution).	
	3rd geological evaluation phase	**PERFORM A MITIGATION MEASURE**														
MO.01	3rd geological evaluation phase	Accurate hydrogeological modelling including data collection and interpretation.		Reporting	Pending of operation.	Induced temperature change. Significant induced temperature change is observed at existing production facility (water well or spring, hydrocarbon well) nearby.	Modelling of subsurface environment	If the modelled effect of the development is inaccurate,	then the location of wells of doublet will be improper.	The induced temperature change at receptor is higher than it was expected.	The authority/receptor disapprove the operation of development.			PD.O.4.InT	Compensation of affected receptor(s).	
MO.01	3rd geological evaluation phase	Accurate hydrogeological modelling including data collection and interpretation.		Reporting	Pending of operation.	Induced pressure change. Significant induced pressure change is observed at existing production facility (water well or spring, hydrocarbon well) nearby.	Modelling of subsurface environment	If the modelled effect of the development is inaccurate,	then the location of wells of doublet will be improper.	The induced pressure change at receptor is higher than it was expected.	The authority/receptor disapprove the operation of development.			PD.O.5.InP	Compensation of affected receptor(s).	
	Completion phase	**PERFORM A MITIGATION MEASURE**														
TE.11_filt	Completion phase	Adequate filtering of re-injected water.	The service should be designed and procured in advance.	Monitoring of parameters of groundwater	Cost increase in operation.	Pressure increase. Continuous pressure increase is observed at the injection well.	Treatment of produced fluid	If the injected water contain particles,	then the pores will be clogged.	The reservoir pressure is increasing at injection well.				PD.O.3.PrI	Stimulation (thermal, chemical or hydraulic).	The design of the well should be suitable for the activity.
TE.11_filt	Completion phase	Adequate filtering of re-injected water.	The service should be designed and procured in advance.	Monitoring of parameters of groundwater	Cost increase in operation.	Pressure increase. Continuous pressure increase is observed at the injection well.	Treatment of produced fluid	If bacterias are invading the surface of formation,	then the injectivity will decrease.	The reservoir pressure is increasing at injection well.				PD.O.3.PrI		
TE.12_trfl	Completion phase	Treatment of fluid to prevent the reproduction of bacteria in productive layers of injection well.	The service should be designed and procured in advance.	Reporting	Cost increase in operation.	Pressure increase. Continuous pressure increase is observed at the injection well.	Treatment of produced fluid	If bacterias are invading the surface of formation,	then the injectivity will decrease.					PD.O.3.PrI		

Code of mitigation	Timing of mitigation	Mitigation	Condition of mitigation	Monitoring activity of mitigation	Definition of damage	Proof of damage	Root activity	Risk event - IF member	Risk event - THEN member	Follow on event 1.	Follow on event 2.	Follow on event 3.	Follow on event 4.	Code of proof	Amending activity	Conditions of amending activity
TE.11_filt	Completion phase	Adequate filtering of re-injected water.	The service should be designed and procured in advance.	Monitoring of parameters of groundwater	Cost increase in operation.	Clogged heat exchangers. Particles of produced fluid clog the heat exchanger.	Treatment of produced fluid	If the produced water contain particles,	then the pores of heat exchangers will be clogged.	The efficiency of heat exchanger is decreasing.				PD.O.8.HeE	Use of filter system at the surface.	
	Operation phase	**PERFORM A MITIGATION MEASURE**														
TE.11_filt	Operation phase	Adequate filtering of re-injected water.	The service should be designed and procured in advance.	Monitoring of parameters of groundwater	Cost increase in operation.	Pressure increase. Continuous pressure increase is observed at the injection well.	Treatment of produced fluid	If the injected water contain particles,	then the pores will be clogged.	The reservoir pressure is increasing at injection well.				PD.O.3.PrI	Stimulation (thermal, chemical or hydraulic)	The design of the well should be suitable for the activity.
TE.11_filt	Operation phase	Adequate filtering of re-injected water.	The service should be designed and procured in advance.	Monitoring of parameters of groundwater	Cost increase in operation.	Pressure increase. Continuous pressure increase is observed at the injection well.	Treatment of produced fluid	If bacterias are invading the surface of formation,	then the injectivity will decrease.	The reservoir pressure is increasing at injection well.				PD.O.3.PrI		
TE.12_trfl	Operation phase	Treatment of fluid to prevent the reproduction of bacteria in productive layers of injection well.	The service should be designed and procured in advance.	Reporting	Cost increase in operation.	Pressure increase. Continuous pressure increase is observed at the injection well.	Treatment of produced fluid	If bacterias are invading the surface of formation,	then the injectivity will decrease.					PD.O.3.PrI		
TE.13_log	Operation phase	Doing regular logging, evaluation and maintenance of the well.		Reporting	Cost increase in operation.	Pressure increase. Continuous pressure increase is observed at the injection well.	Completion of injection well	If the drilled production section contains less consolidated fine grained sediments,	then the loose, clayey sediments will clog the production zone.					PD.O.3.PrI		
TE.13_log	Operation phase	Doing regular logging, evaluation and maintenance of the well.		Reporting	Cost increase in operation.	Pressure drop. Continuous pressure drop is observed at the production well.	Drilling of production section	If the drilled production section contains less consolidated fine grained sediments,	then the loose, clayey sediments will clog the production zone.	The bottomhole pressure is decreasing in the production well.				PD.O.2.PrD		
MN.01_part	Operation phase	Monitoring of change of produced fluid's particle content.		Monitoring of parameters of groundwater	Cost increase in operation.	Clogged heat exchangers. Particles of produced fluid clog the heat exchanger.	Operation of utility	If the particle content of produced water is increasing,	then the pores of heat exchangers might be clogged.	The efficiency of heat exchanger is decreasing.				PD.O.8.HeE		
TE.11_filt	Operation phase	Adequate filtering of re-injected water.	The service should be designed and procured in advance.	Monitoring of parameters of groundwater	Cost increase in operation.	Clogged heat exchangers. Particles of produced fluid clog the heat exchanger.	Treatment of produced fluid	If the produced water contain particles,	then the pores of heat exchangers will be clogged.	The efficiency of heat exchanger is decreasing.				PD.O.8.HeE	Use of filter system at the surface.	
MN.02_corp	Operation phase	Monitoring of corrosion potential of produced fluid.		Monitoring of parameters of groundwater	Cost increase in operation.	Increased corrosion. Increased corrosion activity of produced fluid is observed.	Operation of utility	If the corrosion potential is changing during the production,	then the corrosion activity might be inreased with time.	The corrosion creates problems in surface infrastructure.				PD.O.7.InC	Use of corrosive resistant inner casing.	The design of the well should be suitable for the activity.
MN.03_scap	Operation phase	Monitoring of scaling potential of produced fluid		Monitoring of parameters of groundwater	Cost increase in operation.	Increased scaling. Increased scaling activity of produced fluid is observed.	Operation of utility	If the scaling potential is changing during the production,	then the scaling activity might be inreased with time.	Scaling appears in well and surface infrastructure.				PD.O.6.InS		
	3rd party's phases	**THE RISK OWNER CANNOT APPLY THESE MEASURES**														

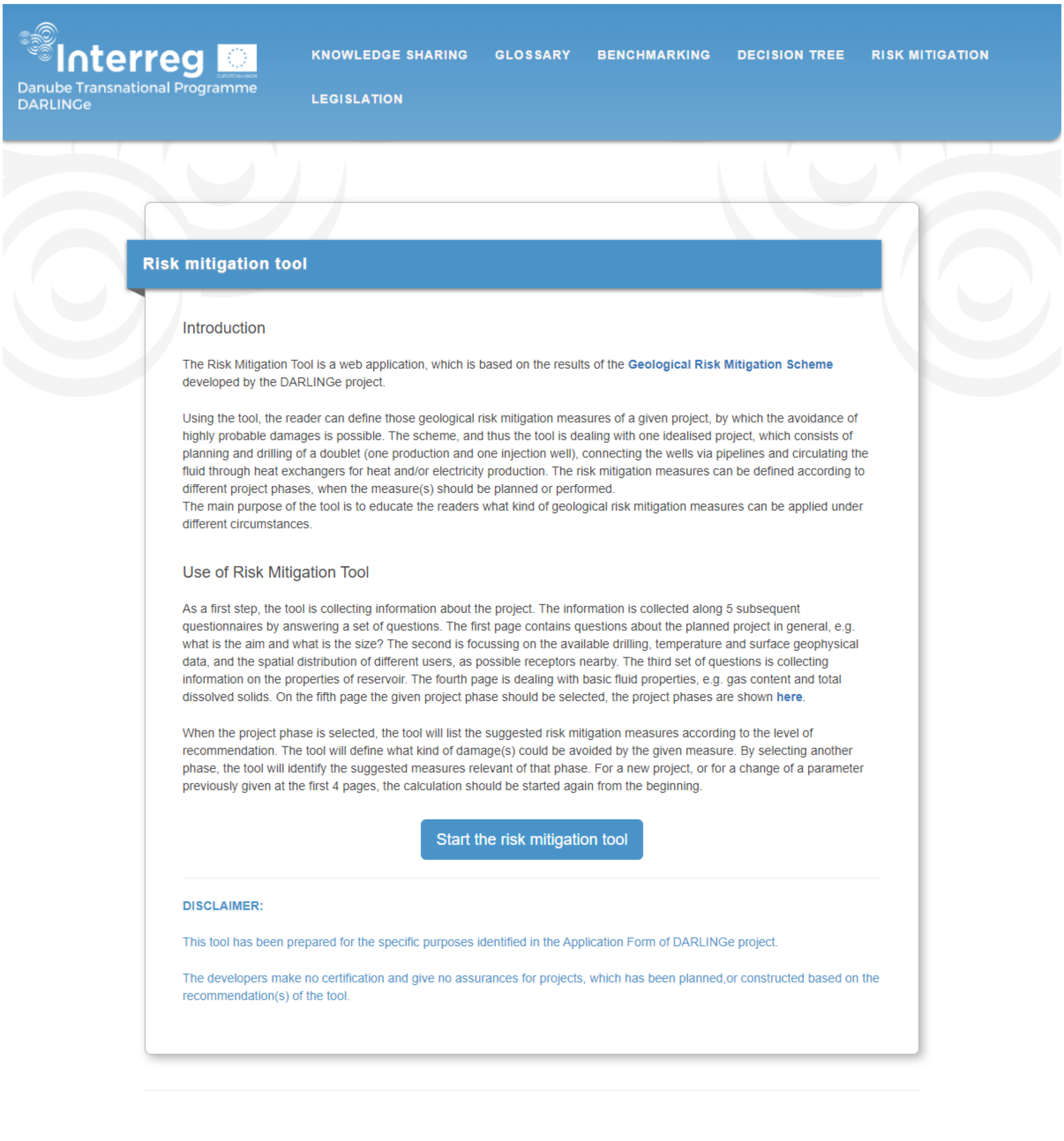
Code of mitigation	Timing of mitigation	Mitigation	Condition of mitigation	Monitoring activity of mitigation	Definition of damage	Proof of damage	Root activity	Risk event - IF member	Risk event - THEN member	Follow on event 1.	Follow on event 2.	Follow on event 3.	Follow on event 4.	Code of proof	Amending activity	Conditions of amending activity
		OR ANY MEASURES														
	3rd party's geological evaluation phase	Accurate hydrogeological modelling including data collection and interpretation.		Reporting	Cost increase in operation.	Pressure increase. Continuous pressure increase is observed at the injection well.	New development nearby	If the modelling is inadequate,	then the modelled effect of new development will be misleading.	The location of wells of new development's doublet will be improper.	The reservoir pressure is increasing at injection well.			PD.O.3.PrI		
	3rd party's geological evaluation phase	Accurate hydrogeological modelling including data collection and interpretation.		Reporting	The amount of energy is lower than it was expected.	Cooling of production well. Unusual cooling of produced fluid is observed at the production well.	New development nearby	If the modelling is inadequate,	then the modelled effect of new development will be misleading.	The location of wells of new development's doublet will be improper.	Adverse effect on the development.	Early cooling of production well.		PD.O.1.CoP		
	3rd party's geological evaluation phase	Accurate hydrogeological modelling including data collection and interpretation.		Reporting	Cost increase in operation.	Pressure drop. Continuous pressure drop is observed at the production well.	New development nearby	If the modelling is inadequate,	then the modelled effect of new development will be misleading.	The location of wells of new development's doublet will be improper.	Adverse effect on the development.	The reservoir pressure is decreasing at production well.		PD.O.2.PrD		
	3rd party's design phase	Performing adequate interference or tracer test for securing information for verification of hydrogeological model.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The amount of energy is lower than it was expected.	Cooling of production well. Unusual cooling of produced fluid is observed at the production well.	New development nearby	If the testing is inadequate,	then the verification of reservoir model is inaccurate.	The location of wells of new development's doublet will be improper.	Adverse effect on the development.	Early cooling of production well.		PD.O.1.CoP		
	3rd party's design phase	Performing adequate interference or tracer test for securing information for verification of hydrogeological model.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Cost increase in operation.	Pressure drop. Continuous pressure drop is observed at the production well.	New development nearby	If the testing is inadequate,	then the verification of reservoir model is inaccurate.	The location of wells of new development's doublet will be improper.	Adverse effect on the development.	The reservoir pressure is decreasing at production well.		PD.O.2.PrD	Stimulation (thermal, chemical or hydraulic).	The design of the well should be suitable for the activity.
	3rd party's drilling phase	Performing adequate interference or tracer test for securing information for verification of hydrogeological model.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Cost increase in operation.	Pressure increase. Continuous pressure increase is observed at the injection well.	New development nearby	If the testing is inadequate,	then the verification of reservoir model is inaccurate.	The location of wells of new development's doublet will be improper.	The reservoir pressure is increasing at injection well.			PD.O.3.PrI		
	3rd party's drilling phase	Performing adequate interference or tracer test for securing information for verification of hydrogeological model.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The amount of energy is lower than it was expected.	Cooling of production well. Unusual cooling of produced fluid is observed at the production well.	New development nearby	If the testing is inadequate,	then the verification of reservoir model is inaccurate.	The location of wells of new development's doublet will be improper.	Adverse effect on the development.	Early cooling of production well.		PD.O.1.CoP		
	3rd party's drilling phase	Performing adequate interference or tracer test for securing information for verification of hydrogeological model.	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Cost increase in operation.	Pressure drop. Continuous pressure drop is observed at the production well.	New development nearby	If the testing is inadequate,	then the verification of reservoir model is inaccurate.	The location of wells of new development's doublet will be improper.	Adverse effect on the development.	The reservoir pressure is decreasing at production well.		PD.O.2.PrD	Stimulation (thermal, chemical or hydraulic).	The design of the well should be suitable for the activity.
	(Not managable geological risk)	-			The loss of well.	Technical failure. An irreversible technical failure occurs at the drilling.	Drilling operation	If the drilling runs into unforeseen subsurface condition,	then the real situation will be fully different from interpreted conditions.	Drilling difficulties	Unsuccessful handling of drilling difficulties	The production section of the well can not be completed.		PD.D.1.TeF		
	(Not managable geological risk)	-			The loss of well.	Missing formation. The targeted reservoir formation is missing in the well.	Drilling operation	If the drilling runs into unforeseen subsurface condition,	then the real situation will be fully different from interpreted conditions.	The target is missing in the drilling.				PD.D.2.MiF		

Code of mitigation	Timing of mitigation	Mitigation	Condition of mitigation	Monitoring activity of mitigation	Definition of damage	Proof of damage	Root activity	Risk event - IF member	Risk event - THEN member	Follow on event 1.	Follow on event 2.	Follow on event 3.	Follow on event 4.	Code of proof	Amending activity	Conditions of amending activity
	(Not managable geological risk)	-			The loss of well.	Overpressure. The formation pressure is much higher as it was originally expected.	Drilling operation	If the drilling runs into unforeseen subsurface condition,	then the real situation will be fully different from interpreted conditions.	Appearance of high ovepressure.	The well can not be operated on the high level of high overpressure.			PD.D.3.OvP		
	(Not managable geological risk)	-			The loss of well.	No production/injection. The well is not able to produce/inject any fluid.	Drilling operation	If the drilling runs into unforeseen subsurface condition,	then the real situation will be fully different from interpreted conditions	The target is missing in the drilling.	There is no permeable layer in the openhole.	The well is not productive.		PD.T.1.NoP		
	(Not managable geological risk)	-			The amount of energy is lower than it was expected.	Low temperature. The temperature is lower, what was expected.	Drilling operation	If the drilling runs into unforeseen subsurface condition,	then the real situation will be fully different from interpreted conditions	The temperature of fluid is low.				PD.T.2.LoT		
	(Not managable geological risk)	-			The amount of energy is lower than it was expected.	Low yield. The yield (production or injection) is lower, what was expected.	Drilling operation	If the drilling runs into unforeseen subsurface condition,	then the real situation will be fully different from interpreted conditions	The yield of the well is low.				PD.T.3.LoY		
	(Not managable geological risk)	-			The amount of energy is lower than it was expected.	No connection. There is no hydraulic connection between the members of the doublet.	Drilling operation	If the drilling runs into unforeseen subsurface condition,	then the real situation will be fully different from interpreted conditions	Lack of connection between the members of the doublet.				PD.T.5.NoC		
	(Not managable geological risk)	-			Pending of operation.	Induced pressure change. Significant induced pressure change is observed at existing production facility (water well or spring, hydrocarbon well) nearby.	Drilling operation	If the drilling runs into unforeseen subsurface condition,	then the real situation will be fully different from interpreted conditions	The induced pressure change could affect protected receptor(s) more than it was expected previously.	The authority/receptor does not approve the operation of drilled well.			PD.T.4.InP		
	(Not managable geological risk)	-			Cost increase in investment and operation.	High gas content. Th amount of gas observed in the produced fluid is much higher as it was anticipated originally.	Drilling operation	If the drilling runs into unforeseen subsurface condition,	then the real situation will be fully different from interpreted conditions	The gas content of the fluid is higher than forecasted value.				PD.T.6.HiG		
	(Not managable geological risk)	-			Cost increase in investment and operation.	Increased scaling. The observed scaling activity of produced fluid is higher as it was anticipated originally.	Drilling operation	If the drilling runs into unforeseen subsurface condition,	then the real situation will be fully different from interpreted conditions	The scaling potential is higher than forecasted value.	Scaling appears in well and surface infrastructure.			PD.T.7.InS		
	(Not managable geological risk)	-			Cost increase in investment and operation.	Increased corrosion. The observed corrosion activity of produced fluid is higher as it was anticipated originally.	Drilling operation	If the drilling runs into unforeseen subsurface condition,	then the real situation will be fully different from interpreted conditions	The corrosion potential is higher than forecasted value.	The corrosion creates problems in surface infrastructure.			PD.T.8.InC		

Interpretation of geoscientific data
Collection of new information
Hydrogeological modelling
Technical activity
Monitoring activity

Appendix C: Pages of Risk Mitigation toolbox published on DRGIP (Danube Region Geothermal Information Platform) website

Opening page



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KNOWLEDGE SHARING GLOSSARY BENCHMARKING DECISION TREE RISK MITIGATION LEGISLATION

Risk mitigation tool

Introduction

The Risk Mitigation Tool is a web application, which is based on the results of the **Geological Risk Mitigation Scheme** developed by the DARLINGe project.

Using the tool, the reader can define those geological risk mitigation measures of a given project, by which the avoidance of highly probable damages is possible. The scheme, and thus the tool is dealing with one idealised project, which consists of planning and drilling of a doublet (one production and one injection well), connecting the wells via pipelines and circulating the fluid through heat exchangers for heat and/or electricity production. The risk mitigation measures can be defined according to different project phases, when the measure(s) should be planned or performed.
The main purpose of the tool is to educate the readers what kind of geological risk mitigation measures can be applied under different circumstances.

Use of Risk Mitigation Tool

As a first step, the tool is collecting information about the project. The information is collected along 5 subsequent questionnaires by answering a set of questions. The first page contains questions about the planned project in general, e.g. what is the aim and what is the size? The second is focussing on the available drilling, temperature and surface geophysical data, and the spatial distribution of different users, as possible receptors nearby. The third set of questions is collecting information on the properties of reservoir. The fourth page is dealing with basic fluid properties, e.g. gas content and total dissolved solids. On the fifth page the given project phase should be selected, the project phases are shown **here**.

When the project phase is selected, the tool will list the suggested risk mitigation measures according to the level of recommendation. The tool will define what kind of damage(s) could be avoided by the given measure. By selecting another phase, the tool will identify the suggested measures relevant of that phase. For a new project, or for a change of a parameter previously given at the first 4 pages, the calculation should be started again from the beginning.

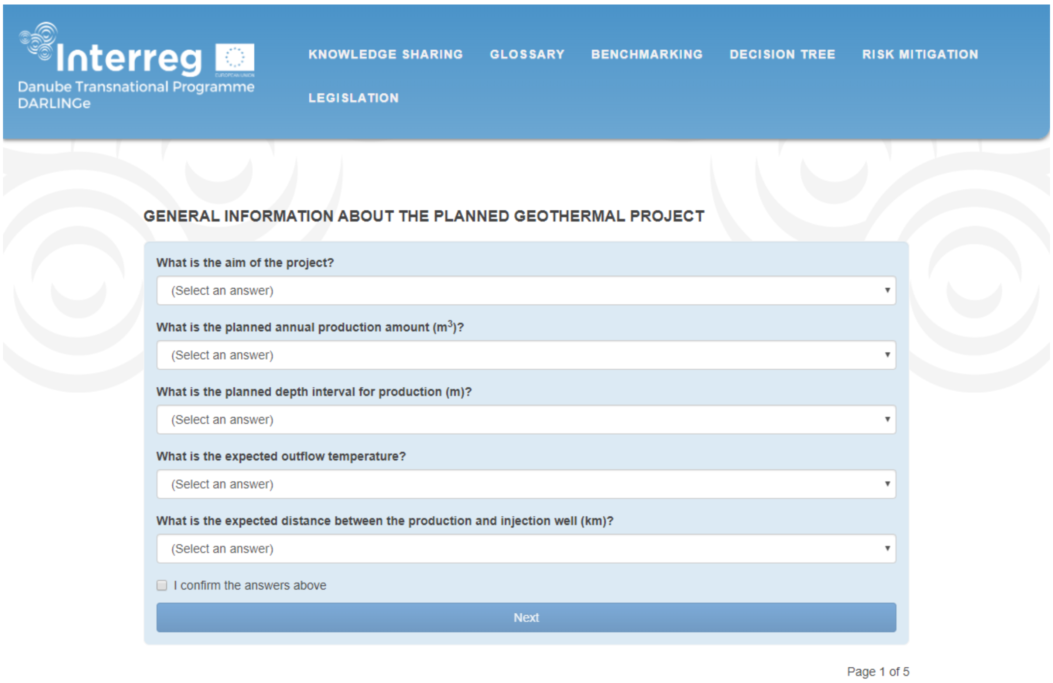
Start the risk mitigation tool

DISCLAIMER:

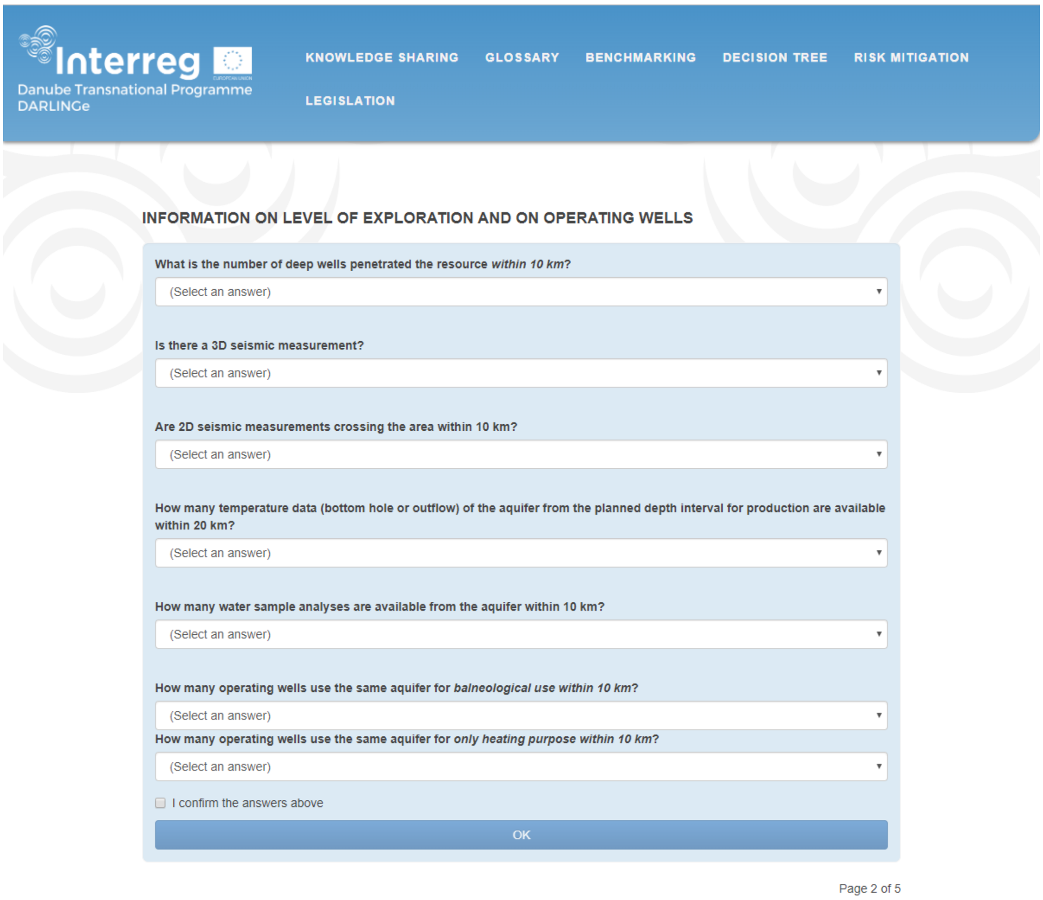
This tool has been prepared for the specific purposes identified in the Application Form of DARLINGe project.

The developers make no certification and give no assurances for projects, which has been planned,or constructed based on the recommendation(s) of the tool.

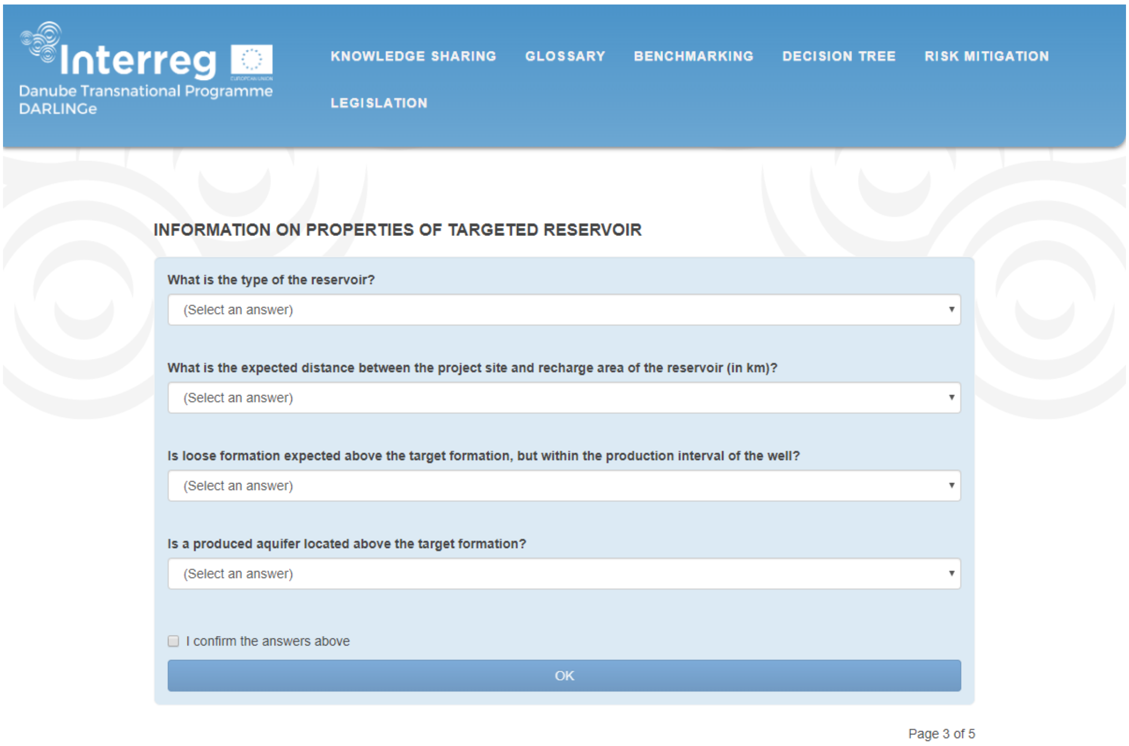
1st page of questions



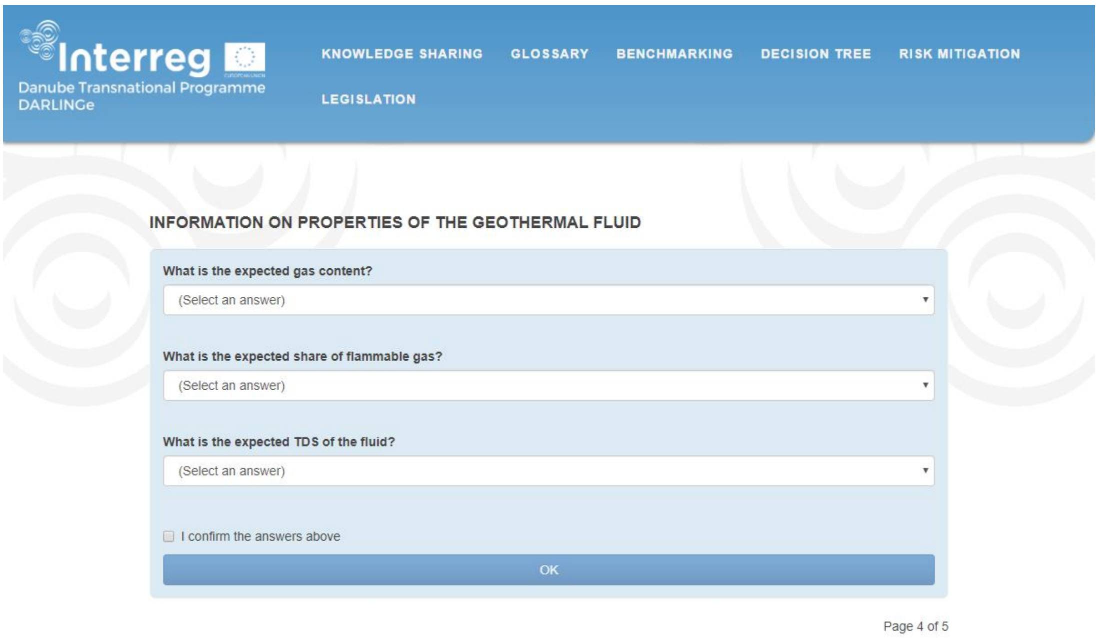
2nd page of questions



<u>3rd page of questions</u>



<u>4th page of questions</u>



5th page of questions

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LEGISLATION

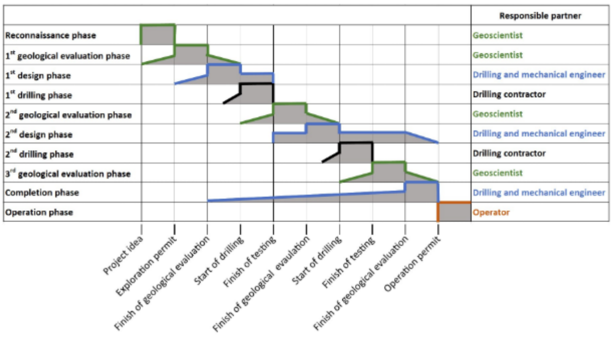
RECOMMENDED MITIGATION MEASURES

Select the phase of the planned geothermal project, when the preparation or completion of mitigation measure is actual:

(Select an answer)

Page 5 of 5

PROJECT PHASES:



EXPLANATION:

Reconnaissance phase - Reconnaissance phase starts from the project idea and lasts until the decision to obtain an exploration permit or not

1st geological evaluation phase - This phase theoretically starts in the reconnaissance phase and last until the drilling, but the main activity is made between the approved exploration permit and the start of the design phase.

1st design phase - The main activity o this phase is between the geological evaluation and drilling

1st drilling phase - The drilling phase starts from the mobilization of the rig and lasts until the finish of operation of end of drilling (OED), which period (OED) covers the testing activities in general.

2nd geological evaluation phase - This phase theoretically starts together with the 1st drilling phase and last until the 2nd drilling, but the main activity is made between the finish of testing and the start of the 2nd design phase.

2nd design phase - The main activity o this phase is between the geological evaluation and drilling

2nd drilling phase - The drilling phase starts from the mobilization of the rig and lasts until the finish of operation of end of drilling (OED), which period (OED) covers the testing activities in general.

3rd geological evaluation phase - The 3rd geological evaluation is based on the data collected during the completion of second drilling.

Completion phase - The completion phase covers the activities of surface works excluding drilling activities

Operation phase - The operation phase is when the construction is finished, and the plant is working continuously according to the approved operational permit.

Result page

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RECOMMENDED MITIGATION MEASURES

Select the phase of the planned geothermal project, when the preparation or completion of mitigation measure is actual:

1st design phase

Page 5 of 5

PERFORM A MITIGATION MEASURE:

Level of recommendation	Measure	If the measure is not applied, the following damage might occur with higher probability
Highly recommended	Designing the production section of the well with 8 1/2" diameter.	The amount of energy is low, because of low yield.

PREPARE A MITIGATION MEASURE:

Level of recommendation	Measure	By the use of the measure the next damage(s) could be avoided
Highly recommended	In case of porous aquifer use of underreaming and gravel pack in the production section.	1) The amount of energy is low, because of low yield. 2) Cost increase in operation because of pressure increase at reinjection.
Highly recommended	Use of clay minerals-free drilling mud in the production section, which is properly treated in the mud system by removal of cutting particles.	The amount of energy is low, because of low yield.
Recommended	Professional service provider and supervised cementing activites for appropriate isolation.	1) The amount of energy is low, because of low temperature. 2) Pending of operation, because significant induced pressure change is observed at a waterwork nearby.
Recommended	Use of cement with increased heat insulation properties for cementing of casings of production well.	The amount of energy is low, because of low temperature.
Worth to consider	Try to drill long enough production section for securing the expected yield.	The amount of energy is low, because of low yield.
Worth to consider	Performing adequate chemical sampling and analysis of produced fluid.	Cost increase in operation because of increased scaling activity of produced fluid.