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Flooding management
for underground coal mines considering regional mining networks

(Flominet)

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(Flominet)

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1 Final summary

WP 1 Development of numerical site-models for mine water rebound in large underground mine networks

The objective of this WP is to have standardised high quality numerical tools available to respond to various mine water rebound related issues. Main objective is to provide forecast methods for the impact of mine water rebound on groundwater flow, geothermal potential, degassing, water levels and water qualities in large underground coal mine fields.

Task 1.1 Continued development of the box model

The model tool and its extensions developed in this Task have been implemented in the four specific mining areas in the subsequent Tasks 1.2 – 1.5. DMT has continued the development of the boxmodel with the objective to improve the practicability and to standardise the methodology at various sites. In addition to the improvement of the already well established mine water flow models some important innovative programme codes have been developed and implemented into the model:

- Coupled gas-water flow (integrated model of gas-generation and flow in boxmodel)
- High turbulent flow routine to calculate the energy production with a turbine
- Coupling procedure of mine water and surface water models
- Implementation of heat transport model into the flow model to forecast of the temperature development during mine flooding.

Task 1.2 Enhancements of numerical model Lorraine Coal Basin

The main objective of the task was the expansion of existing model of the Lorrain coal basin for a future gas prognosis. In a first step the equations of gas flow and methane transport have been developed for a volume balance method. A proper discretisation of the gas flow in the surrounding rock massive guaranteed the use of the already existing practicable structure of the boxmodel. It has been realised via a “ring system” surrounding the drifts representing the radial-symmetric gas flow to the drifts and workings. BRGM has provided INERIS and DMT with the real measured data of gas flow and methane concentrations at the four pumping stations. By the help of these data the model has been fundamentally tested and calibrated. Finally with the calibrated model forecasts were made. Herewith the rising water table with blocking of the gas source term was considered.

Task 1.3 Design of numerical model Asturias

Implementation of a turbulent flow procedure and setup of a complete new model of the Asturias coal deposit were objectives of this task. The turbulent flow procedure has been implemented by the help of practical “Strickler Theory” using a nonlinear dependency of flow from hydraulic head. The method has been tested at the foreseen turbine system at San Fernando. The detailed boxmodel designed is considering different storage volumes at different levels of the mine and connections to other neighbouring mines. In example-calculations the influence of the wet winter and the dry summer seasons on the relationship of flow and pressure has been calculated. It was the basis for HUNOSA to select a tailored turbine for these conditions.

The developed heat-transport model has been tested and calibrated at the new Boxmodel of Asturias for prognosis of future temperature development. Further an Iron and sulphate prognosis was made.

It could be shown that the temperature calculation is working accurate and robust. The main difference of heat transport in Asturias to the parallel modelled site in the Ruhr coal area is, that the Asturias site provides nearly constant temperature of the mine water discharge in the next decades because of a huge catchment area with diffuse infiltration. This allows for long term strategies of geothermal heat use. The heat prognosis tool will be the standard procedure for temperature prognosis in future flooding projects in Germany.

Task 1.4 Design of numerical model USCB

The first objective was the expansion of the existing box model to the whole Upper Silesian Coal Basin. It has been realised by a very close cooperation with the polish colleagues of GIG. In a next step a model of 3 hanging groundwater layers has been set up. The creative step of WP1 for this task has been the finding of an adequate coupling system for both model types: 300000 model cells at the top for groundwater layers and some 1000 cells for the mines. The parallel consideration of sinking rates of groundwater to the mine firstly observed/identified by the miners (worm eyes view) and secondly sinking rates observed by the depression cone in the groundwater layers (view of the hydrologists) is a completely new approach. The model has been tested and calibrated by the help of the existing observation wells (control of head), inflow rates to the mines and pumping rates of mine water out of the mine. This coupling procedure is the basis for the future flooding models of the Ruhr Coal area. For a more realistic model use a special type of pumps, the submersible/diving pumps were implemented with their “characteristic curve”, the dependency of the flow rate of the required pressure and additional pressure losses in pipes. This is a useful method for all existing box models.

Task 1.5 Enhancements of numerical model Ruhr area

For the Ruhr Coal area three important tasks had to be fulfilled: 1. Implementation of a coupled groundwater-mine water system for a part of the Ruhr coal area, 2. Implementation of a complete heat extraction system in a mining area and installing and 3. Use of the optimisation tool developed by GIG.

The sub-tasks 1 and 2 have been realised for the mine Königsborn. This mine is recent in flooding and the use of heat is a realistic and recently discussed option. We implemented a circulation system: pump out of warm water and re-injection of cooled water. In numerous test calculations we have shown, that the efficiency of the system is decreasing drastically in case of break through of the cooled out front through the open drift system. The limits of such a geothermal system have been demonstrated. By the help of the expert-system (developed by AITEMIN/HUNOSA in the frame of this project) for calculation of heat system efficiencies and costs, the break even point and practical heat-using parameters have been calculated. Furthermore the inflow of mine water from the hanging groundwater layer has been calibrated for this mine. Finally the discharge of mine water into the groundwater complex has been predicted for the completely flooded mine including the potential groundwater contamination. For the mine BW East (Sub-Task 3) the optimisation tool (developed by GIG) has been implemented. The pumping costs have been compared and evaluated for several scenarios.

WP 2 Optimising of water management in areas of interconnected systems of underground coal mines

The main objective of this Work Package is to develop a coherent innovative approach for optimised water management in the areas of interconnected systems of underground coal mines. The management of mine water, groundwater and surface water in such areas is extremely difficult both for mining industry and regional water management bodies. Today, there is no integrated approach available which allows quantification of consequences in all ramifications of the water system in case changes are introduced to one part. Therefore, the available expert knowledge cannot be easily used by decision-makers on regional level (e.g. regional water managers). The innovative approach to this problem will be to develop and implement the software interface for water management in the areas of interconnected systems of underground coal mining.

Główny Instytut Górnictwa (GIG) is the WP leader. The tasks of this WP are performed in cooperation with DMT GmbH & Co. KG (DMT) and Hulleras del Norte, S.A.

Task 2.1 Site characterisation and development of a suitable data base

The activities of this task were performed on the Polish test site of FLOMINET project. The test site includes the northern part of the Upper Silesian Coal Basin (USCB) in Poland. A total of 29 mines out of 63 mines operating in whole USCB in 1990 have been shut down and most of the closed down mines are located in the northern part of the Basin. There are 54 mines out of which 27 are already closed. This part of the USCB is characterized by very high mine water inflow rates and corresponding high discharge rates from abandoned and active coal mines. Even the closed mines have to be continuously pumped in order to prevent the water from flooding adjacent active mines. Currently there are several pumping stations in partially flooded mines in this area and there is a plan to reduce their number as well as pumping rates and depths in future.

The suitable database of the test site has been created including all relevant information important for the assessment of process of interconnected mine system flooding.

The database contains following information layers; Map of land use zones, Relief of the top surface of the Carboniferous, Digital terrain model for top of Carboniferous, Geology maps with and without Quaternary, Rivers and water bodies, Map of fresh groundwater Dynamics in the Upper Silesian Coal Basin and its margin, Occurrence of deposits overlying the top surface of the Carboniferous, Digital terrain model (DTM) for area of interest, Map of mine area, Rivers, Topographic maps. Information from these layers was gathered from regional study about Upper Silesian Coal Basin.

All existing GIS layers have been converted to MODFLOW model format and then integrated into BoxModel.

Task 2.2 Development of optimisation software tool and application for Upper Silesian Coal Basin, Poland

Software package OptTool for optimization of de-watering of abandoned coal mines was created. Software uses internally BoxModel modelling software originally developed by Dr Michael Eckart from DMT. Four variants of pumping or flooding USCB coal mines scenarios were worked out and implemented as BoxModel models and imported as templates into OptTool.

Thanks to functions accessible in OptTool as quick BoxModel results previewing in form of tables and charts can support decision makers in assessment of water hazard of coal mines. Implementation of various optimization automatically enables various users to access more sophisticated data analyses. Data in criteria are displayed in form of tables and charts with aggregated data to coal mine level. These criteria allows for pumping and environmental cost comparison and optimization.

OptTool adds to BoxModel comfortable way for creation of different variants of pumping or flooding for person not familiar with modelling. All results of BoxModel calculations, which usually takes hours, are stored by OptTool and ready for quick comparison.

During the software development process, all stakeholders: GIG, CZOK and programmer were involved in modelling and software development. It resulted in good understanding of user requirements and user acceptance.

Task 2.3 Application of the optimisation software tool for further test sites

Optimization software was applied to sites that represent three different water inflows to coal mines system. USCB (Poland) represent high water inflows, RUHR (Germany) is situated in area with moderate inflows and HUNOSA (Spain) represent low inflow. Application of French site was cancelled because it was focused on specific issue of gas hazard) from abandoned coal mines shafts.

OptTool can be easily extended with new BoxModel projects, and this way applied to new sites. It is as easy as copying BoxModel project into appropriate OptTool folder for templates or projects. Criteria parameters can be adjusted by editing criteria from Menu\Criteria.

Variety of case applications ensure OptTool to be general use tool, independent from site specific conditions of river basin.

WP 3 Application for recovery of energy from mine water rebound

The main objective of this Work Package was to produce technically and economically feasible plans to recover renewable energy during and after mine water rebound mainly through optimisation of mine water management and taking advantage of potential energy (height difference) and temperature contained within the mine water flow system.

The partners seeking economic opportunities to generate electricity and geothermal energy out of the mine water rebound process are AITEMIN, HUNOSA and DMT. The mine operator HUNOSA is seriously interested in the realisation of such projects. AITEMIN has been the WP leader but the different activities have been performed in cooperation with DMT and HUNOSA.

Task 3.1 Selection of sites potentially suitable for energy generation

First, a detailed review of the main mining structures in Caudal Coal Basin (Asturias, Spain) have been carried out in order to select the most adequate sites where to develop both the hydroelectric and geothermal uses.

Data of abandoned coal mining structures were analyzed, such as output flows, mine water quality, drainages, water temperature profiles or accessible structures. Based on these data two sites were selected for a more detailed study, one intended at hydroelectric exploitation (Sar Fernando and Urbiés mountain mining structure) and the other one for geothermal use (Barredo shaft).

Task 3.2 Hydraulic characterisation of the site selected for hydroelectric production and model development

Hydraulic characterization works were carried out both at San Fernando mine and Urbiés mountain mine. These mining structures are located in contiguous valleys but each one has particular characteristics (mining floors, internal connection, discharge flow, etc). Nevertheless, the structural whole of both could be the best possibility to develop a hydroelectric exploitation use because both mines together constitute a big underground storage of water which is infiltrated annually through the surface. Also, the model developed by DMT in WP1 helped to characterize the mines and allowed to estimate the recharge and flow rates.

These works showed that a 170 m of hydraulic net head and 80 l/s of average discharge flow could be available, which means a potential electric power output of some 82 KW could be obtained by means of a micro-turbine located in the lowest discharge point (Socavón adit).

Task 3.3 Technical feasibility of hydroelectric energy production

In this task, a complete study of the available technology to the hydroelectric energy production (turbines, generators, electrical installations, auxiliary equipments, etc) was carried out in order to design a hydroelectric plant with a power less than 100 KW (known as Micro-hydroelectric plants). Likewise, a preliminary design of the plug needed to adequate the main discharge adit and the subsequent civil works required in the mine was done.

According to the results obtained, a feasibility study for a micro-hydroelectric generation system was carried out. Furthermore, the main feature of the micro-hydroelectric generation system was drafted, namely, the projected concrete plug to be placed into the lower discharge gallery (Socavón adit in San Fernando mine).

Task 3.4 Economic viability of hydroelectric energy production

An analysis of investment and exploitation cost of a Micro-plant installation was carried out. The study of the energy selling price was done too taking into account the current Spanish regulations and the special discounts (bonus) that could be obtained. Likewise, a business plan for a standard pilot project, replicable in general mountain mine conditions, was also carried out including the main financial parameters: Net Present Value (NPV) and Internal Rate of Return (IRR).

According to the data reviewed and as a first conclusion, the development of a hydroelectric plant of lees than 100 KW would be economically feasible in these special cases. In addition, this exploitation system could be extrapolated to other sites with similar hydrogeological characteristics and special conditions of demand.

Task 3.5 Characterisation of the sites selected for geothermal production

Barredo is an abandoned and flooded mine located at Mieres (Asturias, Spain). This shaft has five floors, with a total depth around 362 m, and its galleries are interconnected with other important shafts of this coal basin. Barredo shaft is the lower discharge point of the area and receives an important underground mine water flow each year.

The mine water at this shaft has been characterized by conducting several temperature profiles and chemical analysis in order to establish its geothermal potential. The results show a difference of temperature of up to 5 ºC between the higher level (with 20 ºC) and the lower layer (with 25 ºC) within the shaft. This temperature gap could allow for further geothermal exploitation.

Task 3.6 Design of a geothermal pilot project

In this task several items have been addressed such as the pumping system, the infrastructure needed for both the heating and cooling distribution and generation systems. The excellent results of the characterization of geothermal reservoir obtained in the previous task drove to the implementation of a real scale project for this task even though only a desk study was planned.

This newly achieved expertise was applied to a real scale project which emerged following the development of this research project in the form of a project for geothermal energy supply by means of water from the mine to two new buildings of Barredo Campus very close to Barredo Shaft and owned by the University of Oviedo.

Task 3.7 Feasibility of geothermal energy production

Finally, this task saw a detailed study on the thermal production comparing conventional systems (natural gas or diesel oil boilers) to geothermal heating/cooling system using mine water. Necessary investment for this kind of projects was analyzed and an estimation of the operating costs considering the system particularities was also performed.

This study showed that a geothermal system with commercial heat pumps using mine water as the hot pole (provided that the heat pump is working on heating mode) has a temperature of 20-23 ºC and that the seasonal variation of the efficiency is much higher than those of the conventional equipment. This is also the case when the heat pump is working in cooling mode.

WP 4 Application for management of gas emissions related to flooding process

The main objective of this Work Package was to increase the understanding of mechanisms and the possibility of gas migration and emission during and after mine flooding process. Three different paths of investigation have been developed.

- On the one hand, in situ monitoring of gas fluxes during Lorrain coal mine (La Houve basin) flooding. This monitoring allowed us to test the influence of flooding at short time scale.
- On the second hand, the experimental device CASPER (CApacité de Sorption à hautes Pressions lors de l’Ennoyage des Roches / sorption capacity at high pressures during rock flooding) was developed by INERIS. The aim of these experimental developments and of the correspond-

ing laboratories experiments were to determine the rate of gas release at elevated pressure from flooded coal sample.

- And finally, on the third hand a modelling approach calibrated with experimental data obtained in the preceding stage. The target of this task was, after having tested the degassing properties, to simulate the methane migration capacity under dissolved phase, at long time scale after the flooding. For this we used the reactive transport model HYTEC, developed by the Reactive Hydrodynamic group of the Department of Geosciences of Mines ParisTech.

Results of WP4 will be compared to results of WP1 to highlight the difference of gas fluxes depending of gas migration processes controlled by flooding state of mine voids. These results will be useful for considering future flooding of coal mine.

Task 4.1 Monitoring of gases flux during coal mine flooding

To understand a number of the mechanisms and parameters involved in mine gas emissions and migration, the old shaft called PUITS BARROIS and SDEC OUEST 1 decompression borehole have been instrumented. The measurement results were used and analysed so as to learn from them, what mechanisms control underground gaseous movements during mines flooding.

We have highlighted that the variations in the barometric pressure drive the release of gasses from the mining voids to the surface, so long as the mining voids are significant enough and that the coal is not drowned up to a given water level. Indeed, barometric pressure which may trigger variations in differential pressure of many thousands of Pascal while the temperature only induces far smaller variations.

The flooding of the old workings in the Lorraine coal basin was able to stop carbone dioxide, radon and methane emission in the short term as the same time as it caused the filling of mining voids with water.

Task 4.2 Laboratory experiments

FLOMINET project gives us the opportunity to develop an original experimental device. It aims to determine the exact influence of hydrostatic pressure on the capacity of coal to release CH_4. The knowledge of this parameter is essential to estimate the possibility of gas migration from old coal mines toward the surface after the flooding process, at large time scales. During the last two years, the device was tested in order to identify the different points to develop and improve, then several apparatus were added to the initial device and a rigorous experimental protocol was defined.

Now the experimental device is running and the gas chromatograph analysis coupled to CASPER insures to determine precisely the point of equilibrium of dissolved CH_4 in water at a given pressure. We have tested the CH_4 take in solution at the following pressures: 10 bars, 20 bars, 30 bars and 40 bars.

This device allows a monitoring of $CH_{4(aq)}$ content in the cell, thus it is possible to characterize the kinetics of CH_4 desorption for these different pressure conditions. Moreover, the device makes possible the measurement of $CH_{4(aq)}$ content for different pressures with a single run. The knowledge of the content evolution guarantees the determination of precise equilibrium time and kinetics of desorption.

Task 4.3 Modelling effect of water flooding on gas emissions

The main target of this task was to realize a first model of methane migration under dissolved phase, in a flooded post-mining context.

After a first period of tests, to approach the different possibilities for using the reactive transport code HYTEC (HYdrological Transport coupled with Equilibrium Chemistry), we realized different scenarios of $CH_{4(aq)}$ migration modeling through flooded mines. Taking the results of the preceding tests into account we define our definitive approach for modelling. Our scenarios tend to approach real cases of the coal basin of Lorraine.

In the simulations, the $CH_{4(aq)}$ emissions from coal corresponds to desorption values we measure in the CASPER cell (Task 4.2). The constant of this reaction is determined for every conditions of pressure thanks to the experimental results and the geochemical module CHESS.

We consider two types of migration of the CH_4 after it comes in aqueous phase: diffusion and advection, taking account of the gradient of permeability, diffusion and porosity of the medium, between fresh rock, damaged rock and exploited zones. The chosen values of the hydrodynamic parameters have been taken or defined from bibliographic data.

WP 5 Reporting and Coordination

The coordination concept of this project based on workshops organized by DMT either bilateral during specific meetings or within the frame of the regular coordination meetings. In doing so partners have been instructed in the model handling and the different site models have been designed by interaction of DMT and the partners. It has facilitated identification of gaps in the work realised and adjustment with the work program given in the Technical Annex.

The partners have been regularly pointed to weak spots in their results. A detailed check of the work program with the results achieved so far and the comparison of actual situation with initial planning has been discussed during all routine coordination meetings. The additional often bilateral meetings proved as essential for the project progress and can be considered as main reason for the results achieved.

The results of the project are published in two articles of the peer reviewed International Journal of Coal Geology. One discusses the entire project with the different facets of post mining water management and the focuses on the laboratory results of gas – coal interaction. Beside this results have been presented at three congresses in Freiberg (Germany), Nova Scotia (Canada) and Darmstadt (Germany). Furthermore results have been integrated into the regular work of the partners and are a contribution to knowledge transfer and standardisation of methods used for mine water related prognosis work.

2 Scientific and technical description of the results

2.1 Objectives of the project

The project results are a contribution to efficient protection of the environment, protection of water tables, the purification of mine drainage water and the reduction of greenhouse gas emissions. For these purposes necessary tools allowing suitable water management decisions considering the complex mine and surface water interactions and taking regional water management aspects into account have been developed and applied.

The same numerical tools allows better assessment of risks of uncontrolled gas emissions inherent to large scale mine water rebound thus improving the protection of the environment and supporting plans to use methane originating from coal.

Coal industry has also recognised some chances to recover renewable energy based on water flow and heat content of mine water. The numerical tool includes the forecast on temperature development. These effects can appear when re-injecting the cooled mine water or implementing closed geothermal probes deep in the flooded mine workings.

As a final result the project provides a comprehensive tool which integrates all aspects (levels, quantities, qualities, density flow, gas flow) of environmental and economic importance and which is found acceptable at major European coal mine water rebound areas. This joint European approach has a great potential for application in the large international mining and environment markets.

The variety of model applications demonstrates the capability of the proposed methodology for regional mine water rebound in interconnected underground hard coal mines.

WP 1 Development of numerical site-models for mine water rebound in large underground mine networks

The objective of WP 1 was to provide standardised high quality numerical tools to respond to various mine water rebound related issues. Following the development of a basic high level programme code various site specific models haven been designed. The new functionalities have been tested at least at one important European hard coal mining area. Sites selected and specific study cases are:

- Enhancement of the boxmodel as a versatile prognostic tool for issues related to mine water rebound at underground hard coal mines
- Realisation of a standard methodology to control and utilize mine water rebound, acceptable to major European stakeholders in the hard coal mining industry
- Numerical model Lorraine Coal Basin — coupled gas-water flow
- Numerical model Asturias — energy production, high turbulent flow, storage
- Numerical model Upper Silesian Coal Basin — coupling of mine water and surface water models
- Numerical model Ruhr area — heat transport

Main objective was to provide trustworthy forecast methods for the impact of mine water rebound on groundwater flow, geothermal potential, degassing, water levels and water qualities in large underground coal mine fields.

WP 2 Optimising of water management in areas of interconnected systems of underground coal mines

The main objective of WP 2 was to develop a coherent innovative approach for optimised water management in the areas of interconnected systems of underground coal mines. The management of mine water, groundwater and surface water in such areas is extremely difficult both for mining industry and regional water management bodies. Before FLOMINET, there was no integrated approach available which would allow to see consequences in all ramifications of the water system in case changes are introduced to one part. Therefore, the available expert knowledge could not be easily used by decision-makers on regional level (e.g. regional water managers). The innovative approach to this problem applied within FLOMINET was to develop and implement the software interface for water management in the areas of interconnected systems of underground coal mining. This software is tailored according to the needs of mining industry and the water managers. The software is able to help the decision-makers to:

- calculate mine water balance taking into consideration the recharge from precipitation, mine water-groundwater interactions, density flow effects.
- estimate mine water quality in the areas it can influence groundwater and surface water chemical status.
- calculate and evaluate various scenarios for impact of mine water rebound on the regional groundwater levels.
- forecast the long term consequences on groundwater at a river basin scale,
- calculation of loads of contaminants discharged to surface and groundwater.
- estimate the operational costs for running the pumping station used for mines dewatering
- estimate possible income from the use of good quality mine water
- consider the possibility of use of the geothermal energy from mine water
- develop a site-specific strategy for cost and environmental optimisation for discharging mine water out of a system of interconnected underground mines.

The main feature of the software is to group all above-mentioned aspects of mine water man-agement under one umbrella of user-friendly software interface. This will allow for effective transfer of innovative expert knowledge towards decision-makers. As a consequence, this will assure that the decisions of regional impact are made with proper consideration of up-to-date knowledge.

WP 3 Application for recovery of energy from mine water rebound

The aim of WP 3 was to investigate the possibilities of taking advantage of mine drainage, in order to produce electric power and geothermal energy. The objectives have been:

- Establishment of a methodology for the estimation of the hydroelectric potential of the mines.
- Design of a suitable system to generate hydroelectric energy.
- Development of an operation test of hydroelectric production.
- Evaluation of the geothermal potential on pumping stations of coalmines and isolated mines
- Establishment of an operation test of geothermal production.
- Analysis of different factors that control the technical and economical viability of the hydroelectric and geothermal productions.

The hydroelectric generation and the use of geothermal energy have a high industrial interest. The works aim at solving energy shortage and diminishing CO_2 emissions taking advantage of what it used to be a problem: mine water rebound and drainage. Its extension to other mining zones in Europe will improve the profitability and the environmental benefits in all of them.

In general, the use of these two types of energy can not be considered to be innovative in itself; nevertheless taking advantage of the challenges that the mine drainage supposes it is an innovation of great interest for the mining companies.

WP 4 Application for management of gas emissions related to flooding process

The main objective of WP4 was to increase the understanding of mechanisms and the possibility of gas migration and emission during and after mine flooding process. Three different paths of investigation have been developed.

- On the one hand, in situ monitoring of gas fluxes during Lorrain coal mine (La Houve basin) flooding. This monitoring allowed us to test the influence of flooding at short time scale.

- On the second hand, the experimental device CASPER (CApacité de Sorption à hautes Pressions lors de l'Ennoyage des Roches / sorption capacity at high pressures during rock flooding) was developed by INERIS. The aim of these experimental developments and of the corresponding laboratories experiments were to determine the rate of gas release at elevated pressure from flooded coal sample.
- And finally, on the third hand a modelling approach calibrated with experimental data obtained in the preceding stage. The target of this task was, after having tested the degassing properties, to simulate the methane migration capacity under dissolved phase, at long time scale after the flooding. For this we used the reactive transport model HYTEC, developed by the Reactive Hydrodynamic group of the Department of Geosciences of Mines ParisTech.

WP 5 Reporting and Coordination

The main focus has been the coordination of DMT model developments for the different site models and the interaction of all Partners. Besides standard technical and financial reporting the objectives within this WP comprised:

- Installation of a project platform for data exchange
- Distribution of references and guidelines for data collection for the particular model types
- Data transfer and exchange between the partners
- Assignment of tasks and controlling of timely completion
- Trips to the partners running the local models to implement and assist with the models
- Presentation of the interim and final outcomes of the Project to TGC1
- Dissemination of key results to the industry and public

2.2 Comparison of initially planned activities and work accomplished

WP 1 Development of numerical site-models for mine water rebound in large underground mine networks

Task 1.1 Continued development of the box model

All partners have been provided with the newest software application. During the detailed processing of the site models (4 mining areas) recommendations of the particular users have been incorporated for a more practical application beside the primary scientific software developments, which are pointed out in the tasks 1.2 - 1.5. One of these developments, which has not explicitly been planned in the FLOMINET proposal, is the implementation of submersible pumps with time depended flow rates and characteristic performance curves.

The key developments of the models are:

- Implementation of gas-transport into the boxmodel and combination of the gas prognosis with the rising water table (suppression of the gas source term during flooding)
- Implementation of heat transport into the boxmodel code and implementation of density effects
- Implementation of turbulent flow (via drifts and drill holes)
- Coupling procedure between groundwater layers (regular grids) and mine-water boxes (variable boxes)

All these scientific objectives of the proposal have been realised, implemented in the site models and tested in some scenarios. Into models already existing before the FLOMINET project more enhancements have been implemented. Those sites had more demands for practical model applications due to the experience of the user.

Task 1.2 Enhancements of numerical model Lorraine Coal Basin

The objective (on the basis of an existing flooding model) was the implementation of gas flow. Several possibilities for realisation have been discussed during the project. The recommendation consists on following steps:

- Transfer of the complete model structure of the existing boxmodel
- Implementation of the developed equations for gas flow in an own program code. These equations include (1) the flow of gas by pressure differences and (2) the transport of two components: Methane and “Sum of non Methane” on the basis of gas-velocities, calculated in step (1). The deviation from the original plan was the now decoupled procedure with the basic assumption, that the gas flow in the open mine system will not influence the rising water level.
- The coupling routine between the flooding level (calculated in the flooding model) and the source-term of gas generation bases on the assumption that the main flow of gas in the open drift system stops with the complete flooding of this box. This assumption is the interface to WP4 of INERIS. In opposite to this assumption a diffuse gas flow in the water through the covering groundwater layers after flooding is possible and a residual source term exists. The prognosis calculations of WP 4 are starting after flooding of the mine with a finer model resolution.
- Calibration of the gas transport model / logic test of the developed model by means of real gas extraction data delivered by BRGM (pressure, flow rate and methane concentration on each of 4 gas pumping stations).

Task 1.3 Design of numerical model Asturias

The boxmodel for the whole mining area of Asturias was designed, installed and calibrated by help of real measured flooding curves. The first scientific objective of this task consisted in the implementation of turbulent flow to give a prognosis of energy production via a turbine. The second objective was the implementation of heat transport to provide the user of a heat pump at the Barredo shaft with a prognosis for temperature-development. Beside this fulfilled main goals a boxmodel prognosis for iron- and sulphate concentration development in the mine water has been generated. Some differences between calculated flooding curves and the measurements could not be explained by the help of existing void space data. Manual correction hat do be made.

Task 1.4 Design of numerical model USCB

For the Upper Silesian Coal Basin a running draft boxmodel already existed at the start of the project. This model has been upgraded now to the newest knowledge and been expanded to the whole mine area of USCB and to the hanging ground water layers. Not proposed, but realised in the project was an additional boxmodel feature for implementation of submersible pumps with time depended pumping cycle and characteristic performance curves in order to meet demands of the optimisation tool (see WP 2).

The main scientific goal of the task was the development of a coupling routine of boxmodel and hanging groundwater layers. The hanging groundwater layer is modelled via numerous small model cells in a range of 250 x 250 m. The under laying boxes of the mine have an area of 10 km^2 and more.

The developed solution for coupled modelling of both water bodies is the transfer of a separate existing MODFLOW model into the scheme of the boxmodel and a special calibration routine for the communication of hundred's of groundwater cells with 1 single box. Special demands of GIG application like implementation of sinking rates out of the groundwater layer and inflow rates into the mine in the calibration routine have been considered beyond the original concept. In spite of the work done the model has still a draft status for hanging groundwater layers, because some model refinements are required in connection with additional hydrogeological data.

Task 1.5 Enhancements of numerical model Ruhr area

The software enhancements have been implemented into the Ruhr Area model for several applications. For the mine Köngisborn the coupling routine, described in the section above, has been used to connect the hanging groundwater layers in the Quaternary and Turonian to the mine water model. Furthermore a software concept for a coupled large field model of the Ruhr Area has been developed and implemented in draft version with a cell size of 250 m x 250 m.

A heat prognosis case study has been realised for the mine Königsborn in the eastern part of the Ruhr Area. For the entire area the models are still not complete and the input data are not available. We developed a scenario of re-infiltration of mine water after extraction of heat in a heat pump (dt = 5 °C) into the mine. In opposite to the heat use in Asturias this scenario shows a relevant decrease of the discharge temperature over a time period of 10 years with loss of efficiency.

For this scenario an economic and technical evaluation of the complex heat extraction system and pipes/losses of heat has been realised by the help of the Expert System developed by HUNOSA/AITEMIN in this project. The result was, that under the given assumptions and the energy prices in Germany the breakeven point will not be reached.

WP 2 Optimising of water management in areas of interconnected systems of underground coal mines

Task 2.1 Site characterisation and development of a suitable data base

Site characterization and development of suitable database was done as planned in the form of in-depth survey of existing maps, cross-sections and profiles of shafts and boreholes. Also large amount of data about the water level and pumping rates as well as some data about chemistry all over the model area have been gathered. Therefore, drilling works, planned in case of not sufficient existing data, were not necessary. Close relationship with mining industry and water management authorities has been established and the software as well as simulation suns have been tailored according to the needs of stakeholders, just as previously planned.

Task 2.2 Development of optimisation software tool and application for Upper Silesian Coal Basin, Poland

The software interfaces have been developed by GIG as planned basing on the Boxmodel provided by DMT. The software have been applied in Upper Silesian Coal Basin as planned with several scenarios for future mine water level development.

Task 2.3 Application of the optimisation software tool for further test sites

The Optimisation software has been used with the Boxmodels for the Barredo water province (Asturias, Spain) and BW-Ost (Ruhr, Germany). The whole Barredo Boxmodel project is quite small and was therefore very practical for testing software purposes. It consists of eight pump stations with a total of 15 pumps installed. Moreover a water province in the eastern part of the Ruhr area has been evaluated with the Boxmodel. It consists of eight pump stations with 18 pumps. The link-up between Boxmodel and Optimisation tool operates at both sites successfully.

WP 3 Application for recovery of energy from mine water rebound

Task 3.1 Selection of sites potentially suitable for energy generation

The planned activities within this task comprised the search and evaluation of sites potentially suitable for developing hydroelectric and geothermal exploitation systems. Related to the geothermal use, the task was accomplished as planned, obtaining detailed information on different aspects of many shafts in the area and selecting the most interesting site. Nevertheless, some details changed related to the hydroelectric exploitation.

Although for the proposal the hydroelectric use of mine water was planned as an underground mine project taking advantage of the different rates of electricity during the day, for the situation of the Asturian mines the first studies showed that this kind of use will not be feasible. The first idea was to store the pumped water in an upper layer of the mine during the night and generate energy during the day with a Pelton or a Francis turbine, taking advantage of the large pressure head and flow. As long as electricity price during the nightly pumping drops to 70% of the peak time price during the daylight, the different electricity rates may produce cash-flow enough to finance the required investments.

However, the analysis of the Asturian mining works showed that the available void volume on the mines was not enough to ensure the economic feasibility of the project. Although the total void volume was huge, only the first meters of the general galleries could be used under safe conditions, because the main exploitation method, sublevel caving method, wins the coal by collapsing the roof. So the exploitation method causes extensive damage on the infrastructures near the exploitation area and numerous fractures in the host rock all along the mining galleries. Sealing works needed in order to extend the storage capacity of the different infrastructures of the shafts would have been too expensive. These costs, added to those required to keep the underground facilities operative ruled out the hydroelectric use of the mine, mainly of those shafts that allow the alternative option of being flooded on the long term.

Therefore the project focused its efforts on the use of abandoned mountain mines for electricity production. Ancient adits with enough water outflow were to be identified for subsequent installation with a micro turbine. In order to store the mine water, the mine entrance would be dammed up. The mine water level inside the infrastructure of the mine will provide enough pressure to allow the turbine to produce hydroelectric energy.

Although the electric power of each system wouldn't be as high as initially intended (that's why this technology is called Microhydraulic) the fundamental advantage of this alternative is the use of a flow that must not be pumped. So this is environmentally friendlier than the underground use of the mines with production of really green energy instead of being only a system of energy storage. Apart from better CO_2 emission balance, the low tech use of the natural outflow of the mine water will also reduce the operating cost of the system. With this approach, a review of all mine water discharge points with high flows in the area was carried out. Based on all data gathered, two different but interconnected sites, San Fernando and Urbiés mining structures, were selected for a more detailed study in order to research the possibilities to develop a hydroelectric energy production system.

Task 3.2 Hydraulic characterisation of the site selected for hydroelectric production and model development

This task was completed on time in March 2010 without any deviations respect to the initial planning. Nevertheless, in addition some activities continued until the end of the project to take accurate measures of the outflow rates in the different adits and complete a year of measures. The Parshall weirs and pressure probes installed in Urbiés and San Fernando adits have been recording data continuously since they were installed and until the end of the project, with the aim to complete at least one year of measures.

As was planned, a hydrogeological study of the selected site was carried out including calculation of annual water balance, estimation of groundwater flows and void volume to storage water and maximum height of water expected (hydraulic head). Likewise, a local study of the chemical characteristics of the water was carried out in order to evaluate the possible implications (corrosion, incrustation) to the facilities. At the same time, the numerical model developed by DMT has been applied to estimate the amount of water in storage and the flow rates possible respectively needed for energy production.

Task 3.3 Technical feasibility of hydroelectric energy production

According to the initial planning, this task was completed on time without any important deviations from schedule. These activities included an evaluation of the hydraulic available conditions of both Urbies and San Fernando mining structures, a review of the equipments needed and its availability in the current market (with special attention to the kind of turbine) and the description of the civil works required to adequate the adit and to install the exploitation system (mine gallery conditioning, plug construction, etc). Likewise, the evaluation of other activities was carried out, like the adaptation of the penstock and the water discharge channel, the powerhouse construction, the power line connection, etc.

Task 3.4 Economic viability of hydroelectric energy production

The economic viability study foreseen in this task was accomplished as planned on May 2011, taking into account concepts like the investment cost of installation, the exploitation costs, or the energy selling price in the current market. Although in task 3.2 characterization of the two test sites was carried out separately and jointly (Urbiés mountain mine structure, San Fernando mine and both together), the economic feasibility study only was carried out for Urbiés due to its better technical conditions. Likewise, a business plan for a standard pilot project (replicable in general mountain mine conditions) was carried out, including the main financial parameters: Annual Added Value and Internal Rate of Return.

Task 3.5 Characterisation of the sites selected for geothermal production

The planned activities within this task comprised basically the characterization of Barredo shaft and surrounding mining structures in order to assess the possibilities of developing a geothermal use.

The task was finished on time December 2009 and all activities were accomplished as planned. Special attention was put in the installation of continuous temperature sensors in Barredo shaft and other surrounding shafts. Nevertheless, it is worth noting that although this task was not planned to start until March 2009, a regular monitoring of the temperature of these shafts was carried out during their flooding process because these data could be interesting in order to improve the knowledge of the behaviour of convective cells along the whole flooding process.

For the characterisation of the site selected, three main parameters that define the feasibility of the geothermal use of the water were studied in detail: available water flow, temperature of the water and the total void volume important for the reservoir management. Furthermore, the chemical characteristics of the water have been studied too in order to guarantee the equipment security.

Task 3.6 Design of a geothermal pilot project

As was mentioned above, although this task was planned to begin in July 2009, with a total duration of 18 months, the activity started in May 2009 and during the first six month of the project the works were advancing ahead of schedule.

At the same time, the opportunity of having two new buildings under construction conditioned very close to Barredo Shaft arose. Concretely, the University of Oviedo was developing a hall of residence and a research centre. This situation allowed applying the ideas planned in the current study in a real pilot project. In this project, mine water from Barredo shaft could be used in order to generate thermal power (heat and cool) with heat pump technologies. Both buildings are located some 200 m away from the shaft so the temperature losses wouldn't be significant.

Then, the pilot project planned in this task (the geothermal energy supply to the new buildings of Barredo Campus, owned by University of Oviedo, by the use of mine water) became a real pilot project which emerged following the development of this research project.

The two new buildings (the Research Centre and the Hall of Residence) were in their early stages of construction when we decided to implement the project. Quite late for a pilot project because heating and cooling systems had already been designed but necessary changes were accepted in order to be provided with mine water as thermal energy supply.

Task 3.7 Feasibility of geothermal energy production

The planned activities within this task comprised a thorough analyse of the different variables that could influence in the feasibility of geothermal energy production system.

As planned, a detailed study about the thermal production costs was carried out comparing conventional systems (natural gas or diesel oil boilers) to geothermal heating/cooling system using mine water. Required investment for this kind of projects has been analysed such as an estimation of the operating costs due to system's characteristics. Likewise, for comparison of costs of conventional energy systems to the geothermal energy system prices of fossil fuels like diesel oil or natural gas have been considered besides electrical energy.

The task was accomplished as planned and it produced useful information about application costs for medium-sized buildings so that they can be extrapolated to public buildings without hot water consumption and power demand between 100 and 1000 KW of heating or cooling. Barredo university buildings are a good example for these.

WP 4 Application for management of gas emissions related to flooding process

Task 4.1 Monitoring of gases flux during coal mine flooding

As planned two monitoring stations have been constructed and put in service on two gas outflow points on La Houve Basin (Lorraine, France). Because of the complexity of the stations the network has been limited to these two stations measuring all parameters given in the proposal (concentration of gas, differential pressure between the surface and the ground, barometric pressure, gas temperature and gas flow rate). The stations ran during one year and all the results needed for interpretation and model input have been obtained with these stations.

In addition, at the beginning of the project, it was planned to perform two gas flux measurement campaigns at soil surface. These supplementary flux measurement campaigns have not been performed because in the framework of other studies developed on the Lorraine coal basin, it has been demonstrated that, in this context, gas flow is not flowing directly from old mining works but mainly driven by cracks (geomechanical origin) induced by mining works. La Houve basin being not affected by these kinds of cracks the measurement of gas flux at the air-soil interface has been given minor priority. Additionally, subsoil flux does not contain CH_4 but only CO_2 and isotopic signatures do not match with a mine origin.

Considering the geological context of Lorrain basin, it had to be assumed that the flux measurement as initially proposed were not a pertinent measurement method to evaluate methane migration to the surface at this site. That's why the investigations have been limited to direct access to old mining works (shafts). Additionally, due to several methodological problems arisen in the laboratory experiments, INERIS decided during the project to shift work capacity within the project and concentrate more efforts on laboratory experiments development (Task 4.2) and to leave out the minor promising gas flux measurement campaigns.

Task 4.2 Laboratory experiments

This task was not completed on time. This delay was induced by experimental development which took a lot of time due to the selection of the equipments, their acquisition and adaptation to our initial device. At the end, a new experimental device runs now at INERIS allowing to measure gas desorption from coal under different hydrostatic pressures. In the remaining project runtime it has been possible to test only one coal sample due to the delays token by experimental protocol development. For these experiments a Saar coal sample has been chosen whose composition and properties are quite similar to the Lorraine coal and which promised results better transferable to the investigated area compared to the other coal samples from the Ruhr Area.

Degassing properties were tested at four different pressures. The results obtained allowed to show that methane migration is possible under high hydrostatic pressure. Despite the delays and the possibility to perform only a part of initially planned experiments, these tests nevertheless gave the required data for the subsequent project steps with analytical analysis of mechanisms involved in the CH_4 desorption. These results are innovative and important for the understanding of gas behaviour after mine flooding. They will be useful for INERIS work on hazard evaluation at the surface of flooded coal mines.

Task 4.3 Modelling effect of water flooding on gas emissions

To investigate all the ways range of migration of CH_4 during post mining flooding (Task 1.2 and Task 4.1: gas migration during flooding, Task 4.2: capacity of coal to produce methane after flooding) we decided to change the target of task 4.3 at the beginning of FLOMINET project. That why modeling works has focused only on post-flooding case. Finally, the main aim of this task was to test the possibility of modeling gas migration under dissolved phase after mine flooding. The input data were results of laboratory test (Task 4.2).

WP 5 Reporting and Coordination

Overall there have been no deviations from the work plan neither in the reporting nor in the coordination activities. All contributions for reports haven been provided by partners and work package leaders early enough so that the reports could be sent to the commission on time.

There have been regular semi annual meetings to discuss and organise work progress. However the attendance by only one person per partner did not meet the requirements of practise so that mostly two members of staff responsible for different field of activities took part in the meetings in spite of travelling costs not covered. Additionally more workshops with the model users than originally planned proved essential and could be realised with the project budget. For these meetings the travelling costs also have not been covered by the project so that they had to be accepted completely by DMT and the coordinator.

Thereby the projected work programme could be completed until the end of the project in spite of some delays in several tasks progress. Problems with the work plan concerned especially the gas model for the Lorraine Basin (initial lack of data for gas modelling), the development of the optimisation tool (software development) and experimental program for methane sorption and release (requirements for the equipment). However the tasks have been completed without restrictions compared to the work plan.

Beside several publications covering particular aspects of the project a summary publication of the project has been placed in the International Journal of Coal Geology.

2.3 Description of activities and discussion

WP 1 Development of numerical site-models for mine water rebound in large underground mine networks

Task 1.1 Continued development of the box model

Enhancement of transport equation – heat transport

The transport-tool of the Boxmodel is considering the transport phenomena convection, molecular diffusion, dispersion, geochemical solution-/precipitation processes and sorption / desorption. The mass transport equation describes these processes or in case of partly filled boxes with use of total volume of the box and variable water table in the box. The Diffusion-term implements molecular diffusion and dispersion.

The Boxmodel is a multimigrant reactive mass-transport model. At the start level of the project 27 chemical components were considered, but not the temperature. To integrate the transport equation for heat direct into the mass-transport equation a factor F (product of density and heat storage capac-ity) has been introduced. Temperature is now the 28th transport unit. In case of "normal" chemical transport-units this factor is "1". The equation for heat diffusion (conduction) and convection for a porous media has been integrated. The numerical description of the heat transport is the basis for the calculation of temperature development in the water of a flooded mine and thus for the geothermal energy potential in a rock-water exchange system.

Heat exchange with rock

For heat exchange with surrounding rock the following assumptions are needed:

- The mean heat-content of a Box doesn't vary in case of heat exchange with the water in the drift system. The stable temperature at the boundary of a box is calculated from the geothermal gradient (i.e. 3° per 100 m).
- The temperature-profile from the surface of drifts (is a model result of transport with water and heat exchange) and the temperature at the box-boundary influences the heat flow between rock and water. It is calculated using a „radial-symmetric cylinder method" and implemented into the Boxmodel (Figure 1.1).

Heat conduction (solid): heat transfer (boundary solid – liquid):

$\Delta T/\Delta t = \lambda \cdot \Delta T/\Delta s$ $Q = w_{ü} \cdot \Delta T$

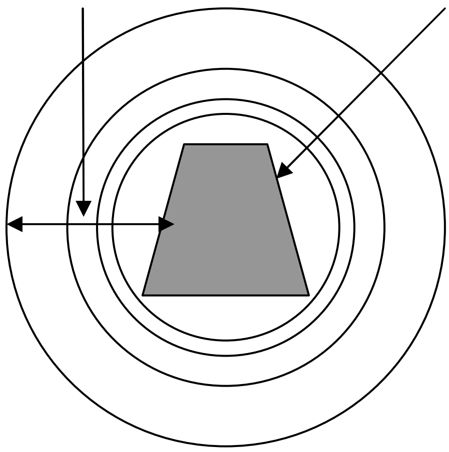

Figure 1.1: Scheme of radial Boxes surrounding a drift.

Figure 1.2 shows a test-calculation for the temperature profile between drift and rock.

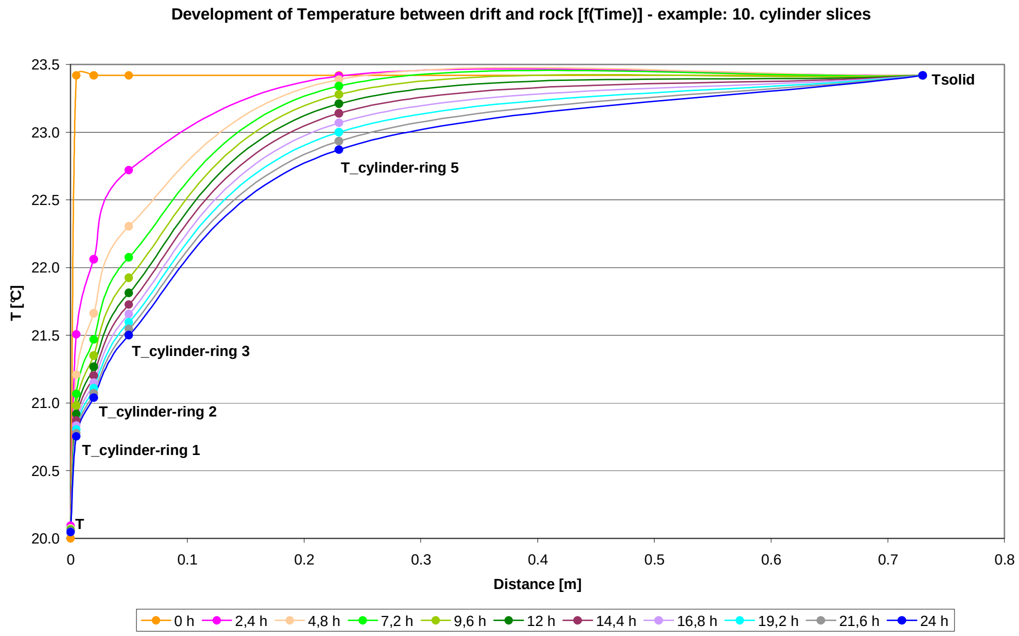

Figure 1.2: Temperature profile between drift surface and rock (example calculation).

Task 1.2 Enhancements of numerical model Lorraine Coal Basin

Conceptual model of gas flow

The following conceptual model for gas-flow-modelling was developed. The calculation method is described in Deliverable 3 (Coupling of gas and water flow) in the appendix. These equations have been programmed and implemented into the model.

Circular zone model for gas desorption and flow

The problems in calibration of the real examples lead to a second assumption: The big influence of pressure reduction of the gas flow is possibly caused by a more complex degassing profile of the coal seem. The assumption of "one" stagnant phase and a sorbed phase might be to simple to describe real relationships. In reality we expect a series of zones with several degassing intensities of methane. The effect of a higher degassing rate by pressure reduction results from the lower sorbed pressure near completely degassed seems: The relationship of the pressure difference in drifts against the absolute pressure in seems ($\Delta p_{drift}/p_{sorbed}$) is higher in degassed seems because the absolute sorbed pressure is lower.

This idea leads to a concept with more than one stagnant and sorbed phases and thus to a similar approach as for the heat transport (Figure 1.3).

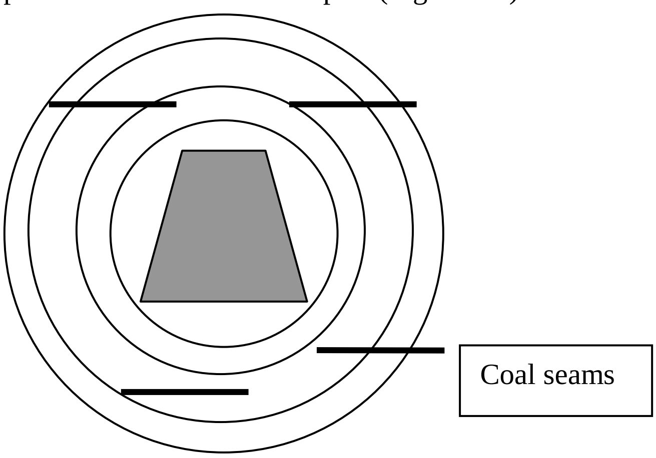

Figure 1.3: Concept of stagnant zones and sorbed phases surrounding drifts.

For realisation of this concept it is necessary to estimate the residual coal and the degree of degassing for each zone surrounding the drift system. The advantage of this assumption is the close relationship to the daily-practice method of gas prognoses basing on the distance of each coal seems to open drifts.

Task 1.3 Design of numerical model Asturias

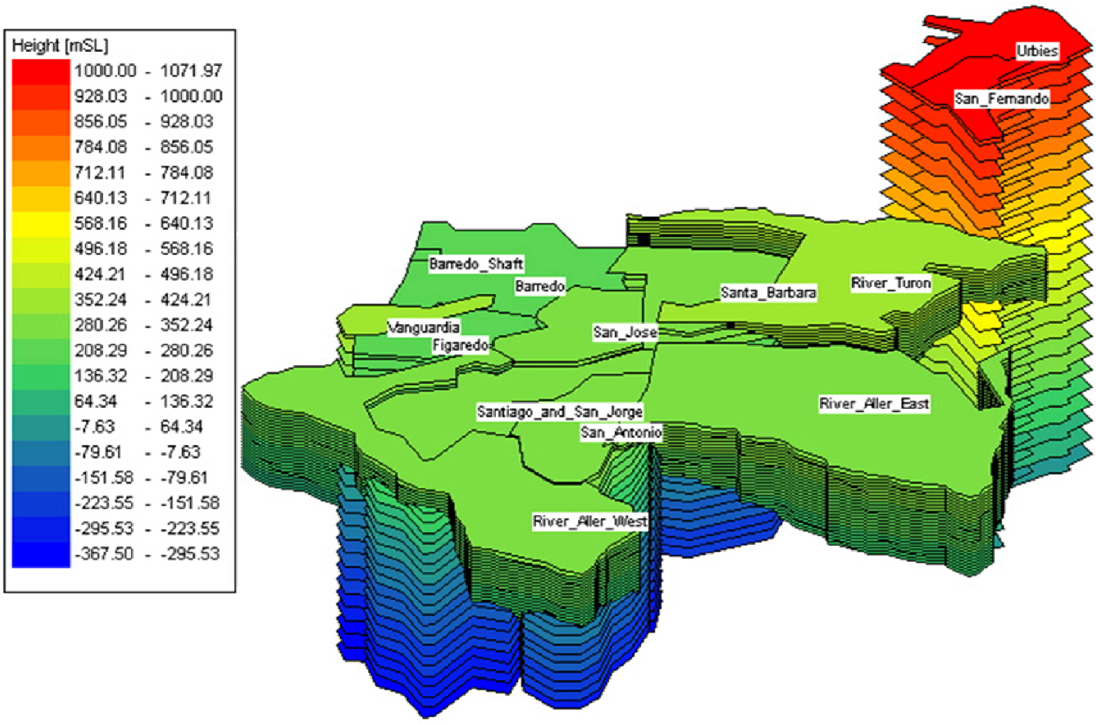

Figure 1.4: Adjusted model run: flooding of all mine fields with void volume modified.

On the basis of a complete new developed box model of Asturias (Figure 1.4) HUNOSA/AITEMIN have calculated the void space of the deposit (Barredo, Figaredo, Santa_Barbara, San_Jose, Santiago_and_San_Jorge, San_Antonio) and provided DMT with the data. DMT has summarized these data per box each with 26 slices.

On the given first water balance and the known pumping/flooding levels DMT carried out a calibration of the steady-state situation with the following assumptions:

- The starting water level corresponds to the deepest dry box.
- The inflow corresponds to the pumping rate in the last stage of active mining.
- The inflow is decreasing with the flooding level in a linear wise.

The first model run without any changes in basic data sets resulted in flooding curves showing discrepancies to the water table measurements in the shafts especially in the late stage of the flooding. Generally the calculated flooding was slower than the real (monitored) one. This corresponds to a lack of water for in the given model. So a probable reason for the discrepancy is an error in the void-calculation. AITEMIN/HUNOSA expected the produced coal volume plus shafts and drifts as equivalent to the residual floodable volume. The main argument for this assumption is the steep incline of the seams.

DMT adjusted the model void space for the following calculations (Figure 1.5) empirically to approach an acceptable flooding curve. The changes made for optimisation follow no general trend and can therefore not be assigned to an overall calculation method. This procedure is no substitute for a factual discussion of the reason for the discrepancies. However it might give some indications for an adjusted calculation of the void volumes.

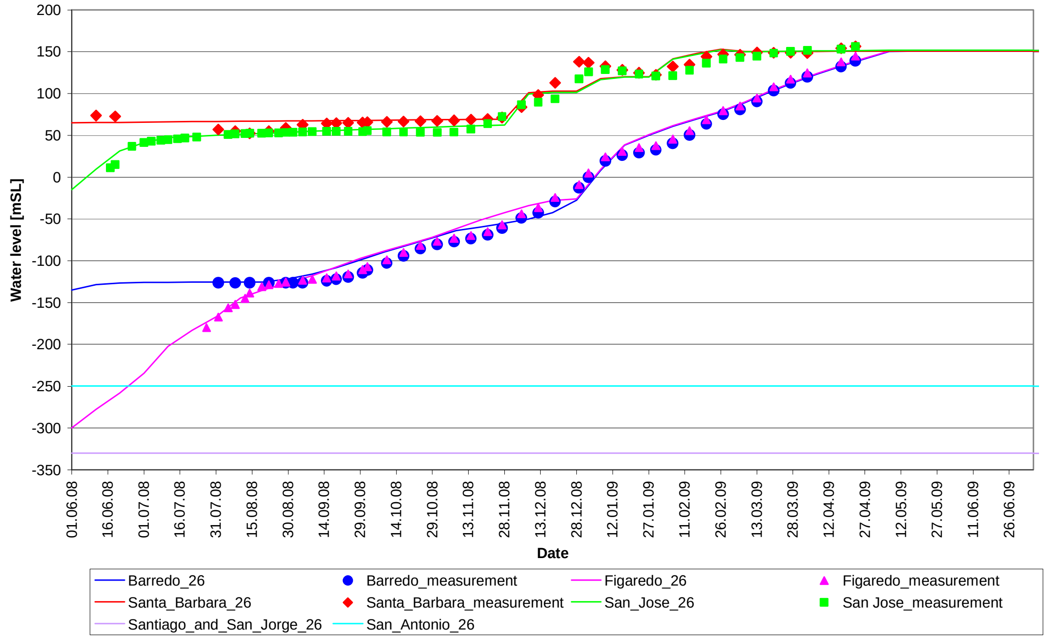

Figure 1.5: Adjusted model run: flooding of all mine fields with void volume modified.

To consider turbulent flow the simplified formula of „Strickler und Manning“ has been introduced into the boxmodel. The documentation is given in Deliverable 5 (Model extension to cover highly turbulent flow and storage processes) in the appendix and comprises the important steps during development of the tool for modelling turbulent flow. In case of very high hydraulic gradients the flow is not laminar as commonly used in the most flow models (e.g. Darcy law: permeability). In case of a water level difference of some hundred meters (mine field and river Turon) such turbulent conditions are given.

Finally with the transport tool of the boxmodel a prognosis for sulphate and iron concentration and temperature development has been calculated. As an example Figure 1.6 shows the development of iron concentration.

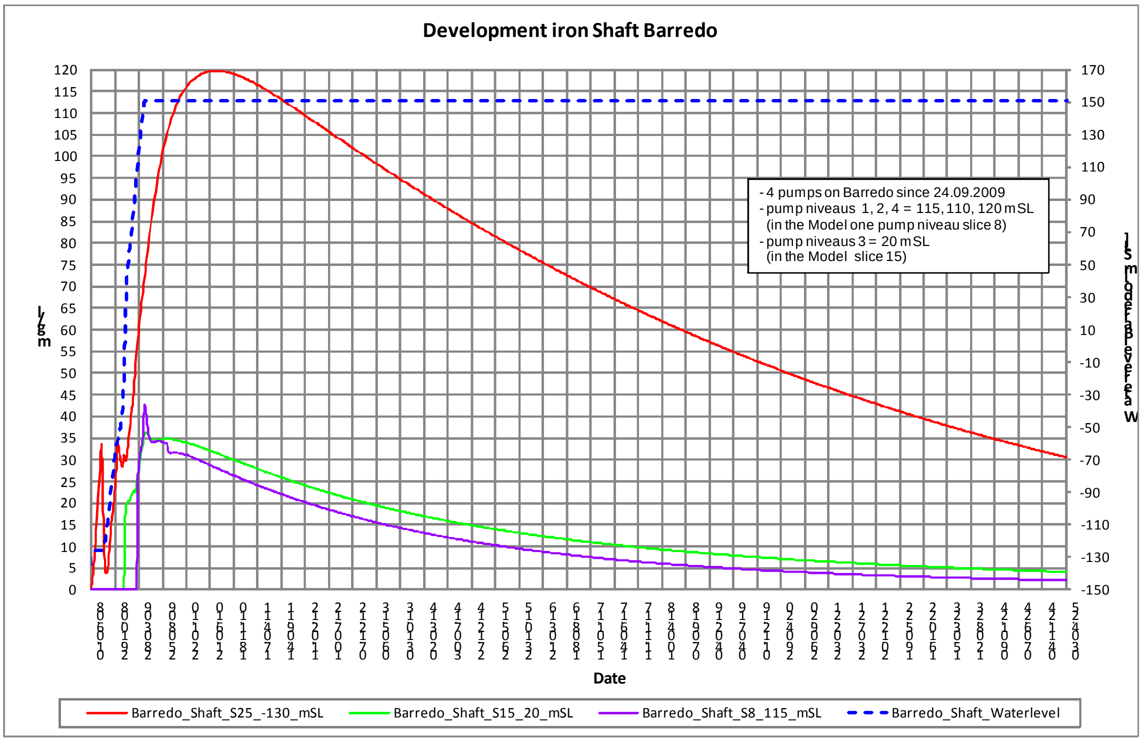

Figure 1.6: Adjusted model run: flooding of all mine fields with void volume modified.

Task 1.4 Design of numerical model USCB

Beside the detailed model setup the overall goal of this task was the development of a coupled groundwater-Boxmodel of the complete deposit of USCB. Figure 1.7 gives an impression of this model with 3 groundwater layers and 23 slices reserved for mining boxes.

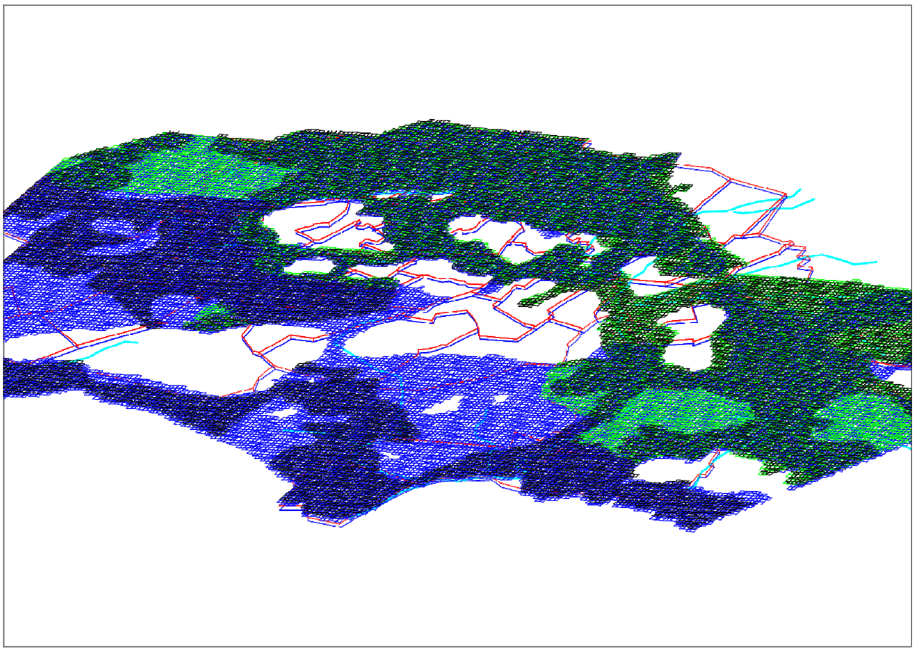

Figure 1.7: Structure of coupled groundwater layers and USCB boxmodel.

All boxes were filled with important mining data like void space and structure of hydraulically connections. Figure 1.8 shows the identified hydraulically connections between the mining fields.

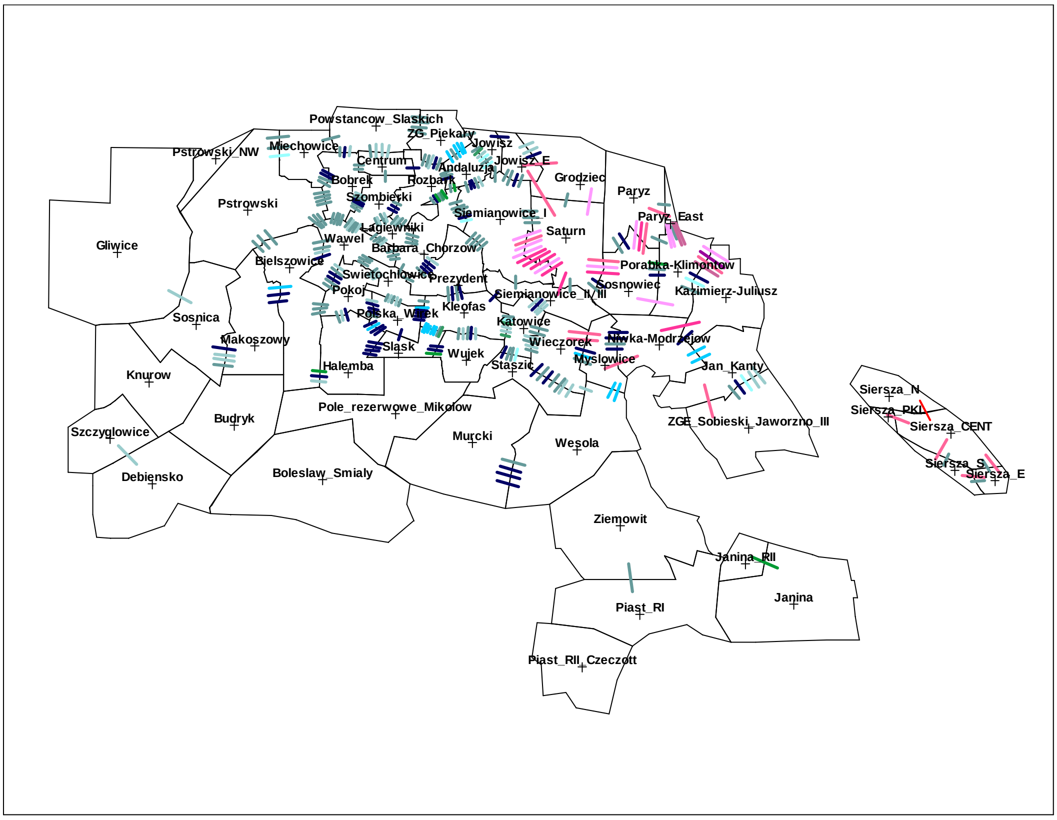

Figure 1.8: Structure of connections between mining fields, implemented in Boxmodel

Periodic pumping

After defining the basic concept of coupling mine water and groundwater models assembling of data has been concentrated to implementation of characteristic performance curves of pumps (Q against h and energy consumption) to support the Optimization tool. For this the calibration routine between mine and ground water has been revised.

The flow rate of a submersible pump is a function of the pressure-difference. This pressure difference is depending of the potential energy to lift the mine water and additional losses in the pump and the adjacent pipe system. To consider these dependencies, CZOK provided GIG with characteristic curves of real used pump systems of companies RITZ and KSB (Figure 1.9).

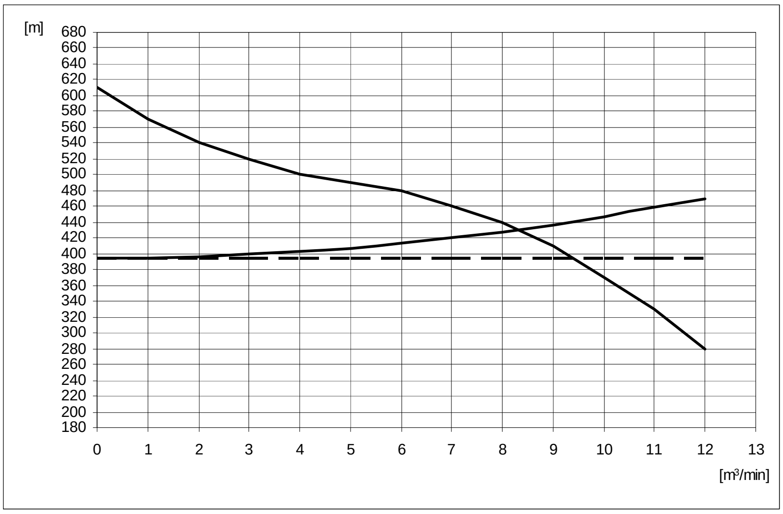

Figure 1.9: Pump and characteristic performance curve for KSB Type UPZ 160-228/9.

Interpolation routines have been defined allowing a description of the characteristic performance curves by a best-fit curve with 5 coefficients that is fine enough for further model application. Table 1.1 lists the identified curves and the required data-set for the model.

Table 1.1: Characteristic curves of pumps Q = f(H); Q in [m^3/h]; h in [m] (3 examples).

TypeNr	KoefP3	KoefP2	KoefP1	Cons	K_losses	Explanation
1	-1.93e-6	+8.6131e-4	-3.8694639e-1	+351.666	839.9	GrodziecHDM6716/5
2	-1.93e-6	+8.6131e-4	-3.8694639e-1	+351.666	1446.6	Sosnowiec
3	-1.93e-6	+8.6131e-4	-3.8694639e-1	+351.666	1371.6	Porobka-Klimontov

Beyond that it is necessary to define how the model recognizes pumps to use. For this reason an additional key word has been defined to use in the data-set: CharCurveX, with X representing the pump-number we see in Table 1.1. With these changes the Boxmodel is now able to calculate the right flow rates depending on the actual water table in the mine and additional pressure losses.

From practical point of view it was important to refine the calibration routine between mine and ground water and the whole procedure of data-flow. For this reason GIG provided DMT with a very detailed balance table (GWN_Leackage_from_Groundwater_DATE.xls).

Four different inflow-types into a mine are differentiated:

- Head depended boundary inflow to the mine. This inflow should not be coupled with the hanging groundwater layer by definition. Otherwise the inflow is part of the coupling procedure where each inflow point gets his direct partner-cell in the hanging groundwater layer.
- Head depended inflow at single points into the mine. This file is part of the coupling procedure to groundwater layers.

- Inflow into the mine from the groundwater layers, but not known and specified in detail. Only known as a residual sum of inflow to the mine after subtracting the specified inflows. These data are used for the coupled model and taken later for the calibration routine. The information is spread over all model-cells laying inside of a box.
- Direct inflow into the mine from outcrop of carboniferous.

Task 1.5 Enhancements of numerical model Ruhr area

Figure 1.10 gives an overview of the actual state of Boxmodel for the Ruhr coal area. The extension of the model reaches 110 km east-west and 55 km north-south. The magenta boxes on the right hand side in Figure 1.10 represent a mine field potentially suitable for calibration of the gas flow enhancement of the Boxmodel. This mine Westfalen was used for an intensive gas production over many years. In the last year the water table has reached the highest part of the drift system and so the gas production had to be stopped.

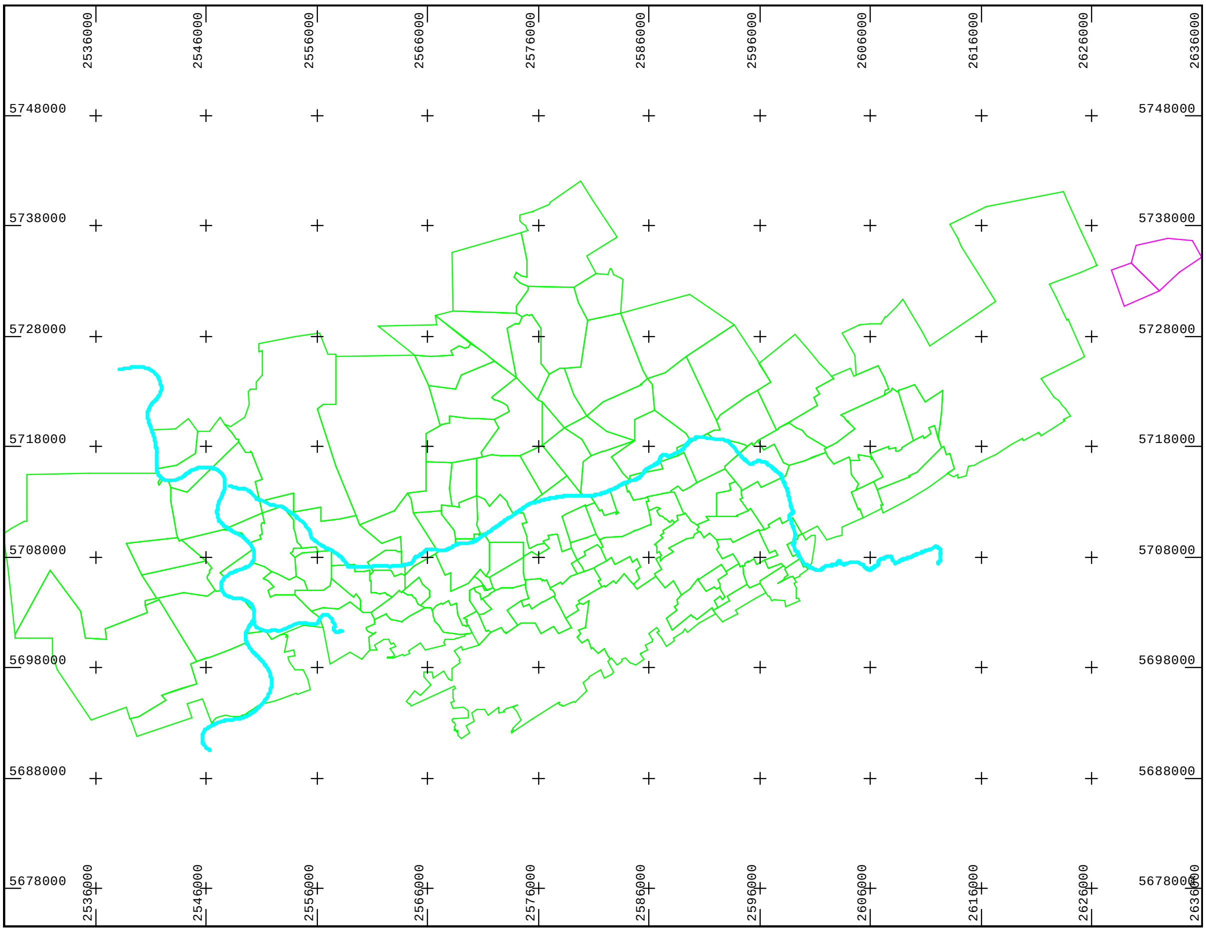

Figure 1.10: Boxes Ruhr-Coal Area (Magenta: Mine Westfalia: potential example for calibrating gas flow, River Rhine (N-S) and Emscher (E-W) are coloured in blue).

A further subject is the test of the Boxmodel-capability in coupling a huge surface near groundwater layer to the deep mine boxes. For many subzones of the covering groundwater layers sufficient data are actually not available. Therefore and because of the limited project budget the test of the coupling procedures can have only conceptual character. The central question is: which accuracy in grid resolution allows flexible but practical prognosis calculations with the coupled model "Mine – Groundwater-Layers". Figure 1.11 shows as an example an overlay-grid with a cell-width of 500 m (200 x 103 model cells (20600 cells per slice). An alternative could be a cell width of 250 m (400 x 206 model cells – 82400 cells per slice).

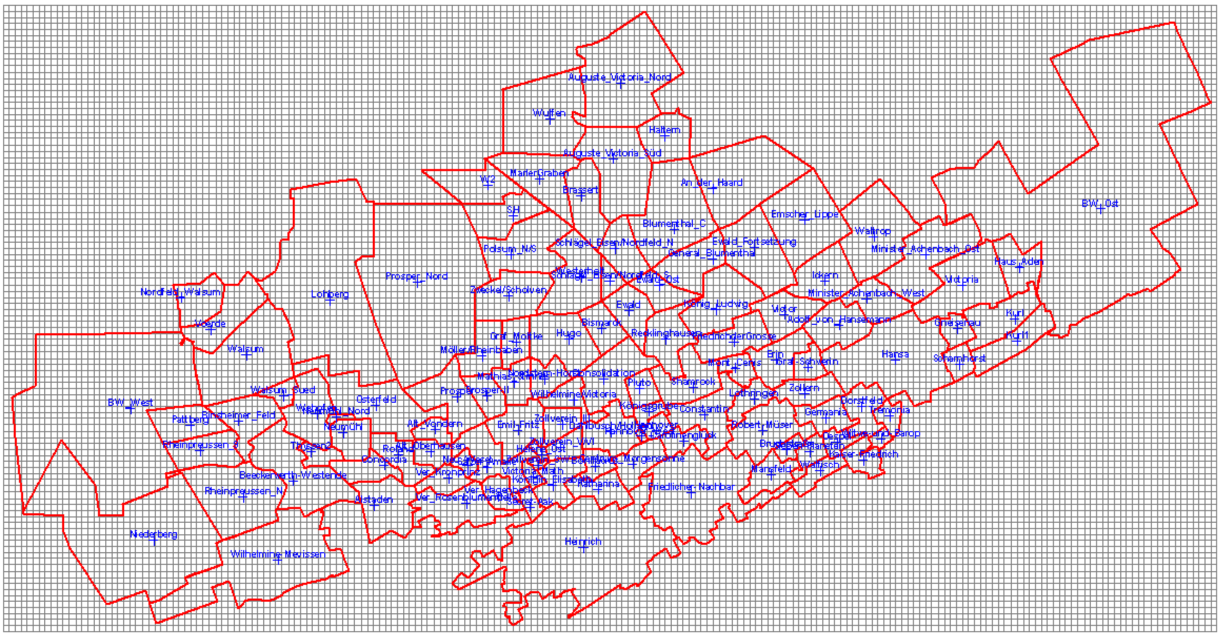

Figure 1.11: Boxes Ruhr-Coal Area and overlay-grid of groundwater model (cell size: 500 m).

In the coupled model two model slices are reserved for the representation of firstly the upper groundwater layer (weathered zone and part of Emscher-Mergel) and secondly the fractured groundwater layer of Labiatus-Mergel.

In the next step DMT has interpolated all available drill hole-information to construct the main model slices of the fractured groundwater layer of Labiatus-Mergel: the top of the “Essener Grünsand” and the bottom of the “Emscher-Mergel”. Figure 1.12 shows as an example the top of “Essener Grünsand”.

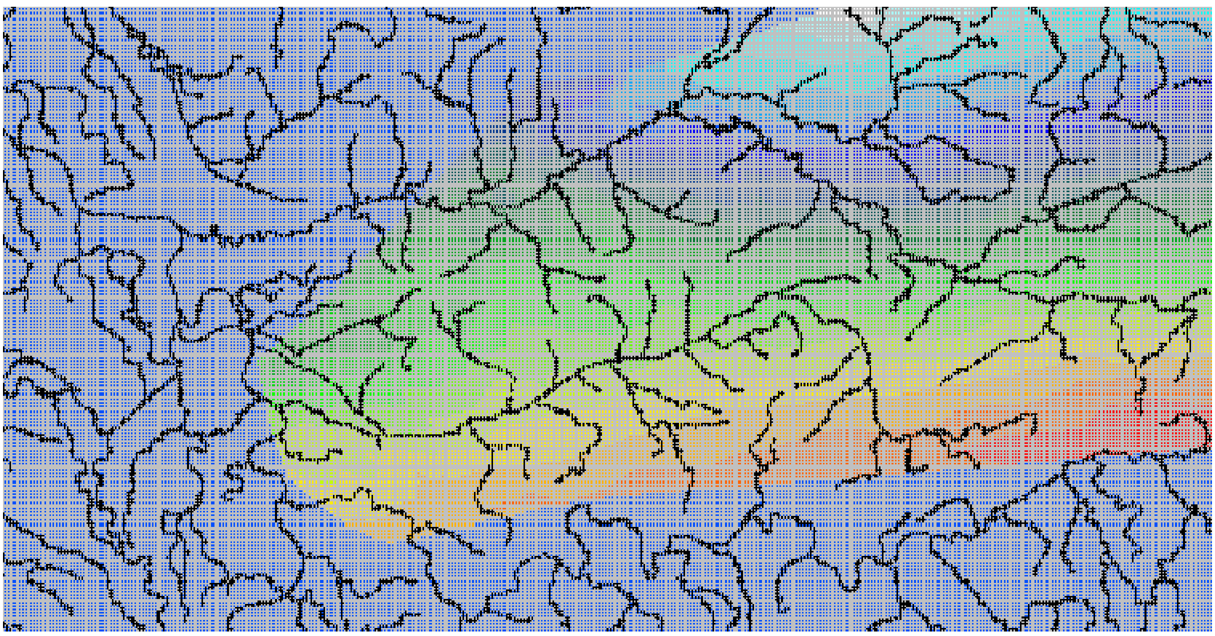

Figure 1.12: Top of “Essener Günsand” in a 250x250 m -grid.

Comparison with the main fault-system of the region indicates, that a rotated model grid can consider the anisotropy in permeability of the fractured groundwater layer of Labiatus much better compared to a North-East grid The is so far no decision for the final grid position because other aspects (e.g. practicability) have to be taken into account too. That's why all required data sets were constructed for a North-East and a 45^o rotated grid.

The test areas "Königsborn" and the "Complex Mine East" were chosen to

- implement and test the heat transport tool, developed in this project by DMT
- implementation of the expert-System to evaluate the efficiency of heat extraction, developed by AITEMIN in this project
- implementation of the Optimization tool, developed by GIG in this project, to evaluate pumping scenarios.

WP 2 Optimising of water management in areas of interconnected systems of underground coal mines

Task 2.1 Site characterisation and development of a suitable data base

The activities of this task are performed on the Polish test site of FLOMINET project. The test site includes the northern part of the Upper Silesian Coal Basin (USCB) in Poland (Figure 2.1).

Figure 2.1: Model localization over a contour map of Poland (with subdivision into regions).

A total of 29 mines out of 63 mines operating in whole USCB in 1990 have been shut down and most of the closed down mines are located in the northern part of the Basin. Within the defined project area (Figure 2.2) are 54 mines out of which 27 are already closed. This part of the USCB is characterized by very high mine water inflow rates and corresponding high discharge rates from abandoned and active coal mines. Even the closed mines have to be continuously pumped in order to prevent the water from flooding adjacent active mines. Currently there are several pumping stations in partially flooded mines in this area and there is a plan to reduce their number as well as pumping rates and depths in future.

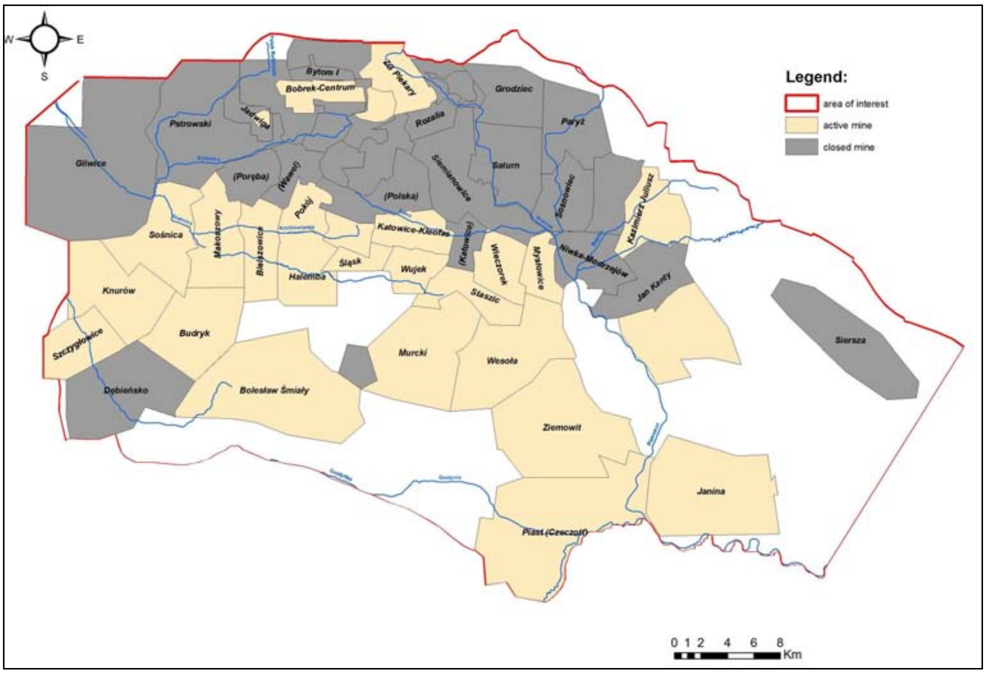

Figure 2.2: Map with active and closed mine areas inside model area.

The suitable database of the test site has been created including all relevant information important for the assessment of process of interconnected mine system flooding. This database have been used both in WP2 Task 2.2 "Development of optimization software tool and application for Upper Silesian Coal Basin, Poland" and in WP1 Task 1.4 "Design of numerical model USCB".

In FLOMINET project ESRI ArcInfo software has been used to create and manage a suitable database.
The database of USCB contains following information thematic layers;

- Map of land use zones,
- Relief of the top surface of the Carboniferous,
- Digital terrain model for top of Carboniferous,
- Geology maps with and without Quaternary,
- Rivers and water bodies,
- Map of fresh groundwater dynamics in the upper Silesian coal basin and its margin,
- Occurrence of deposits overlying the top surface of the Carboniferous,
- Digital terrain model (DTM) for area of interest,
- Map of mine area,
- Rivers,
- Topographic maps.

Information from these layers was gathered from regional study about Upper Silesian Coal Basin. Paper maps were scanned and in the next step the image maps were established location in our coordination system, this kind of action is called georeferencing process. From this part, maps are ready to vectorisation and built new information layer with database. Particular parts of database, especially geometric elements of information layers, were checked by spatial relation – this procedure is called topologycheck. Topology is used most fundamentally to ensure data quality and allow geodatabase to more realistically represent geographic features. A topology organizes the spatial relationships between features in a set of feature classes. The participating feature classes have been added to the topology and the rules defined, the topology is validated. Data quality managers use the topologycheck tools to analyze; visualize; report; and, where necessary, repair the spatial integrity of the database after it is initially created, as well as after editing. Topologycheck provides a set of validation rules for the topologically related features. It also provides a set of editing tools that let users find and fix integrity violations.

Coordination system which is used in USCB database is “1992 system”, it is homogeneous for whole country. 1992 system is base on one zone for Poland (in 10° wide meridian belt) in Gauss - Krüger map projection. Coordinate system "1992" has following parameters - axial meridian L = 19º E, base point: x = -5 300 000 m, y = 500 000 m, factor scale m_0=0,9993. This coordinate system is legally accepted in Poland.

All existing GIS layers have been preliminary converted to MODFLOW model format. The transfer from database to MODFLOW model is described in details in section WP1, Task 1.4.

Task 2.2 Development of optimisation software tool and application for Upper Silesian Coal Basin, Poland

Development of application

OptTool was developed on basis of Dr. Michel Eckart BoxModel from DMT software for modelling turbulent flow in coal mines in shafts and corridors. OptTool integrates with BoxModel – it changes and monitors configuration files of main two BoxModel programs: Praebox and Box3d (pre-processor and modeller). OptTool does not resolve automatically problem of optimization but in quick and comfortable manner gives insights in different solutions – pumping plans for many years forward.

Main features

OptTool was developed in Java – open-source and operating system independent environment.

OptTool is an analytical overlay over modelling BoxModel software.

Criteria

Five main criteria are calculated analysed and presented to end user. These are cost dependant: Operating costs – electrical energy for pumping, Environmental Costs – payments for loads of chemicals dumped to the rivers, Environmental fines – fees for contamination exceeding limits. Potential income criteria: Selling clean water – calculates amount of water that can be sold, and Geothermal criteria – shows possibilities of using water in heating or cooling installations.

Operation costs

Main operating cost of dewatering is cost of electric energy for running pumps. It is usually the main cost considered during optimization process. On Operation costs tab user can view optimization criteria results for each year calculated for chosen energy cost tariff. Tariffs are defined with form opened from Menu Setting\Dictionaries\Energy costs

In the upper table summary of pumped out water per each pump is displayed. Three types of energy tariff are calculated: Regular cost, Cost out of peak, Weekend cost. According to defined tariffs. Below table is summary of these costs dependent on tariff type for all pumps in pump stations. On chart are dis-played summarized cost types for all pumps in each pump station.

Algorithm of reducing operation costs criteria:

For each pump energy demand is calculated as sum of energy required to pump out daily Q with BoxModel's Q(bound).csv data.

Converting units from Q[m^3/minute] to Q [kg/second]

$$Q_{mass}[kg/s] = Q_{BoxModel}[m^3/min] * 1000/60$$

$$E_{day}[kWh] = Q_{mass}[kg/s] * 9.81[m/s^2] * \Delta h[m] / 1000/60 * 86400$$

$E_{year\,pump}\,[kWh] = \sum_{n=365}^{n=1} E_{day}\,[kWh]$

RegularCost $[€/year] = E_{year\,pump}\,[kWh] *$ SingleTariffCost $[€/kWh]$

OutOfPeakCost $[€/year] = E_{year\,pump}\,[kWh] *$ OutOfPeakTariffCost $[€/kWh]$

WeekendCost $[€/year] = E_{year\,pump}\,[kWh] *$ WeekendTariffCost $[€/kWh]$

Cost depends on pumping depth. Pumping height is calculated by difference between water table level and topmost box. Pumping in deeper mines is more expensive, pumping in shallow shafts is cheaper. Sum of costs for all pumps is calculated and the cost for each pump station is calculated as a sum of costs of all pumps in pump station.

<u>Environmental costs</u>

In many countries there are specific payments related to the load of chosen compounds introduced to the surface water environment while pumping. For example in Poland there is a fixed rate payment for each gram of salts (chlorides + sulphates). In optimization tool this payment is introduced as default, however the tool is flexible and user can edit the environmental payments according to country specific conditions. In the Environmental cost tab cost estimation for load of chlorides and sulphates is displayed. Table contains costs for each pumping station, below is text field with sum of costs for each pump and on chart summary for each pump station is presented. Environmental payments are defined in menu Criteria\Environmental payments.

Algorithm:For each pump averageQ is calculated as sum of Q (read from Q_bound.csv) divided by number of Q in period.

$$\Phi Q_{year}[m^3/min] = \left(\sum_{n=1}^{n=Q_{number}} Q\right) / Q_{number}$$

Then Q per year is calculated:

$Q_{year}\,[g] = \Phi\,Q_{year} *\ 24_{hour} *\ 60_{minutes} *\ Q_{number}$

$$\Phi Cl_{year}[g] = \left(\sum_{n=1}^{n=Q_{number}} Cl\right) / Cl_{number}$$

$$\Phi SO_{4\,year}[g] = \left(\sum_{n=1}^{n=Q_{number}} SO_4\right) / SO_{4number}$$

Finally costs are calculated with payments for chlorides and sulphates

$Cl_{load}\,[g] = \Phi\,Q *\ 24_{hour} *\ 60_{minutes} *\ \Phi\,Cl$

$SO_{4load}\,[g] = \Phi\,Q *\ 24_{hour} *\ 60_{minutes} *\ \Phi\,SO_4$

$Cl_{cost} +\ SO_{4cost}\,[€] = (Cl_{\,load} *\ Cl_{\,price}\,[€]) +\ (SO_{4load} *\ SO_{4\,price}\,[€])$

<u>Environmental fines</u>

There are usually fines for exceeding the environmental limits. For example in Poland there is a so called “running fine”. It is calculated for each day with unacceptable concentration. In optimization tool this fine is introduced as default (only days with excessive loads are taken into a count), however the tool is flexible and user can edit the environmental fines according to country specific conditions.

<u>Income from selling water</u>

On Sell water income possible income from selling home or industrial use water is calculated and displayed.

Calculations are performed according to drinking water limits which can be edited in menu:

Criteria\Water uses.

Algorithm

qAverage = Math.abs(qSum/number);

$$\Phi Q_{year}\left[m^3/min\right]=\left(\sum_{n=1}^{n=Q_{number}} Q\right)/Q_{number}$$

income = qAverage * pumpingPeriod WHEN clMax and SO4Max is less than clNorm and SO4Norm

Water Income $[€]=\Phi\ Q*\ 24_{hour}*\ 60_{minutes}\ IF(SO_{4\ max}[g]<SO_{4norm}[g])\wedge(Cl_{max}\ [g]<\ Cl_{\ norm}\ [g])$

Geothermal energy use

Potential income from gaining heating or cooling energy from discharged water is shown. Profitability calculations for geothermal energy investments are complicated because many parameters have to be taken into account. Within optimization tool itself only a simplified graph is calculated, which shows typical line of 0 profitability for given pumping H depending on energy demand and distance to energy receiver. In case of more detailed analyses user can open from OptTool special program for geothermal calculations developed by HUNOSA.

Application in USCB

Primary application of the Optimization Software was performed on the example of Upper Silesian Coal Basin site in Poland. Since Optimization Software bases entirely on Boxmodel, the application was strictly connected to the development of relevant model of USCB. At first calibration of the model was performed on monitoring data and then four future flooding scenarios have been applied - all with help and cooperation of CZOK (Central Mine Dewatering Department) which is responsible for dewatering of abandoned mines.

Application of basic model and calibration on monitoring data

Major changes in dewatering of system of interconnected mines in USCB have taken place in the last years of XXth and first years of XXIst century. Many of the mines that were working before have been closed down and in most of them partial flooding started. More or less since 2001 CZOK has a good record of daily monitoring water level data from most of the abandoned mines. In the year 2002 water balance of the entire USCB could be assessed with the best precision, therefore steady-state variant have been applied and calibrated for this year. Then, first transient model have been applied for the time interval 2000 – 2010. The model has been calibrated using the daily monitoring data on water level in several mines. The calibration went quite well, showing that model is able to reflect most of major hydraulic phenomena in the USCB (Figure 2.3).

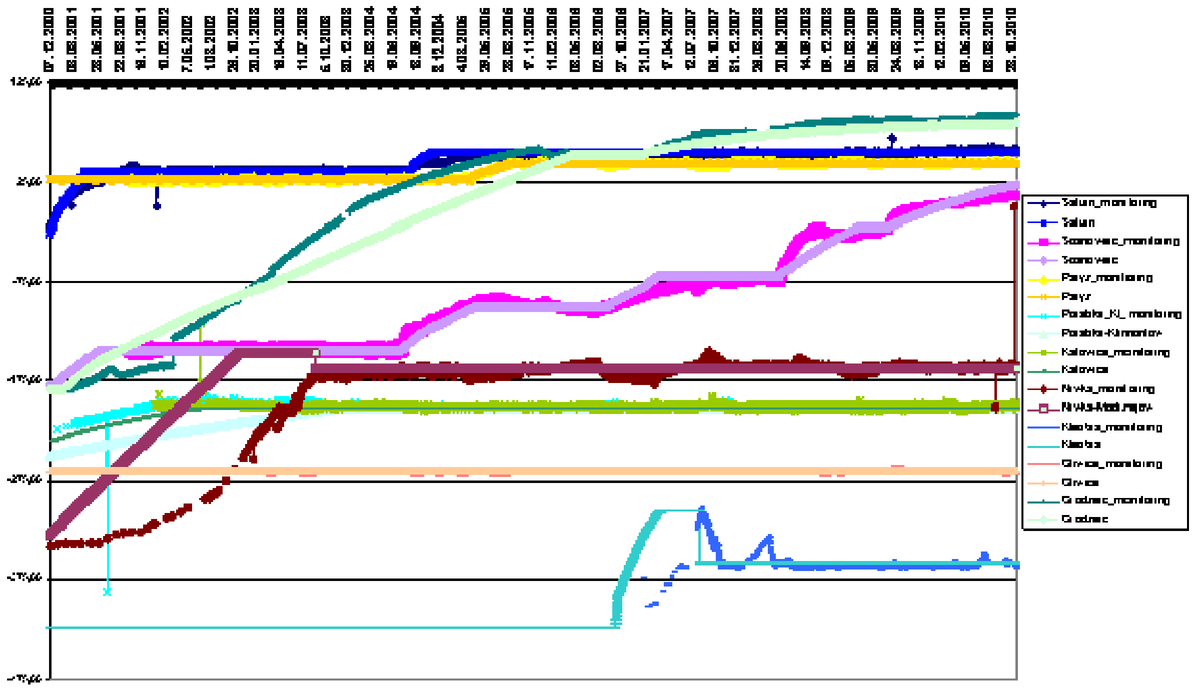

Figure 2.3: Application for Upper Silesian Coal Basin; flooding curves from the model compared to the monitoring data.

<u>Flooding scenarios</u>

Future situation in Upper Silesian Coal basin have been modelled through application of hypothetical scenarios of future flooding of abandoned mines. Two areas are suspected to be significantly flooded in the near future: “Dąbrowa mines” in North-East and “Bytom mines” in the North. In both cases relatively minor coal production is accompanied by significant costs of pumping in adjacent mines paid from the public funds via CZOK. However, at present the real future scenario is still not clear, therefore four main hypothetical scenarios were developed:

1 – flooding of North – East part of USCB

2 – flooding of North part of USCB

3 – flooding of both North and North – East part of USCB

4 – flooding and abandoning all coal mines in USCB

The last scenario is purely fictive, as it is not expected that in all mines (active and abandoned) all pumping stations stop working in the same day. However, such variant is very important for the model test.

Since the time of any major future change in the pumping system is still unclear 1st January 2012 has been used as a default date of stopping the pumping in some mines in all scenarios. The resulting flooding curves of the four considered scenarios are shown on the Figure 2.4 - Figure 2.7.

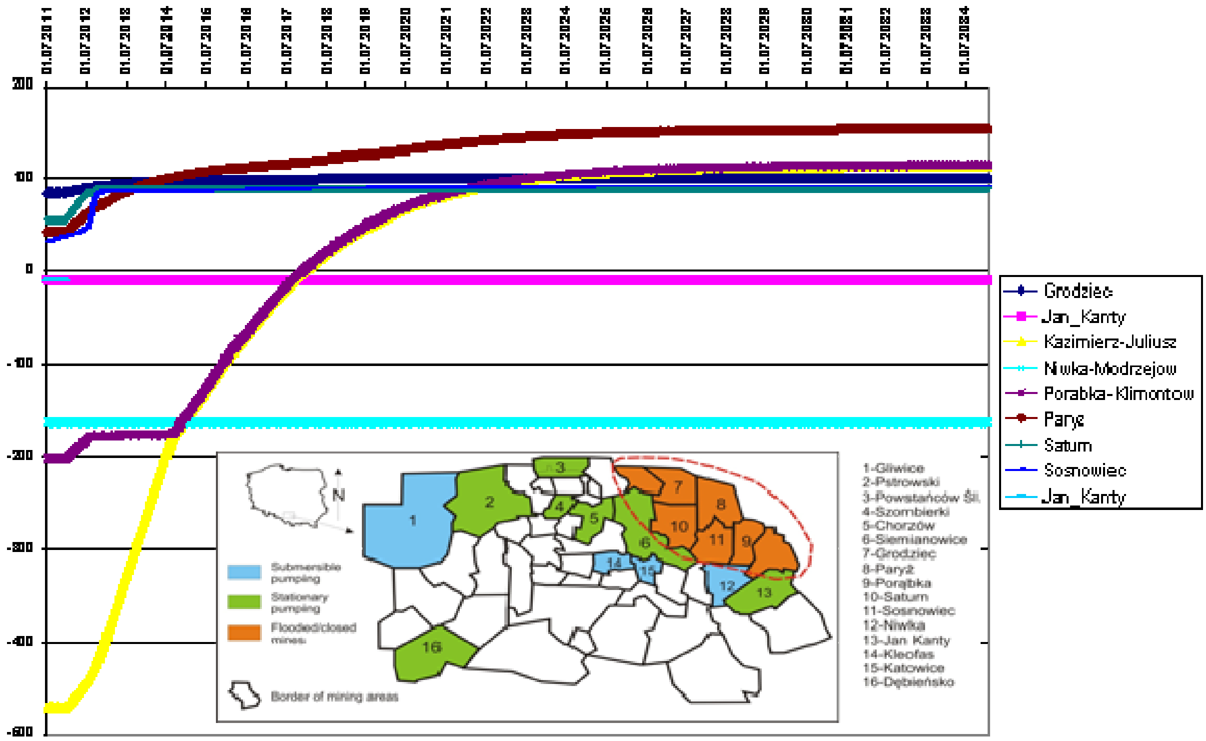

Figure 2.4: Application for Upper Silesian Coal Basin; flooding curves from the scenario 1 – flooding of North – East part of USCB.

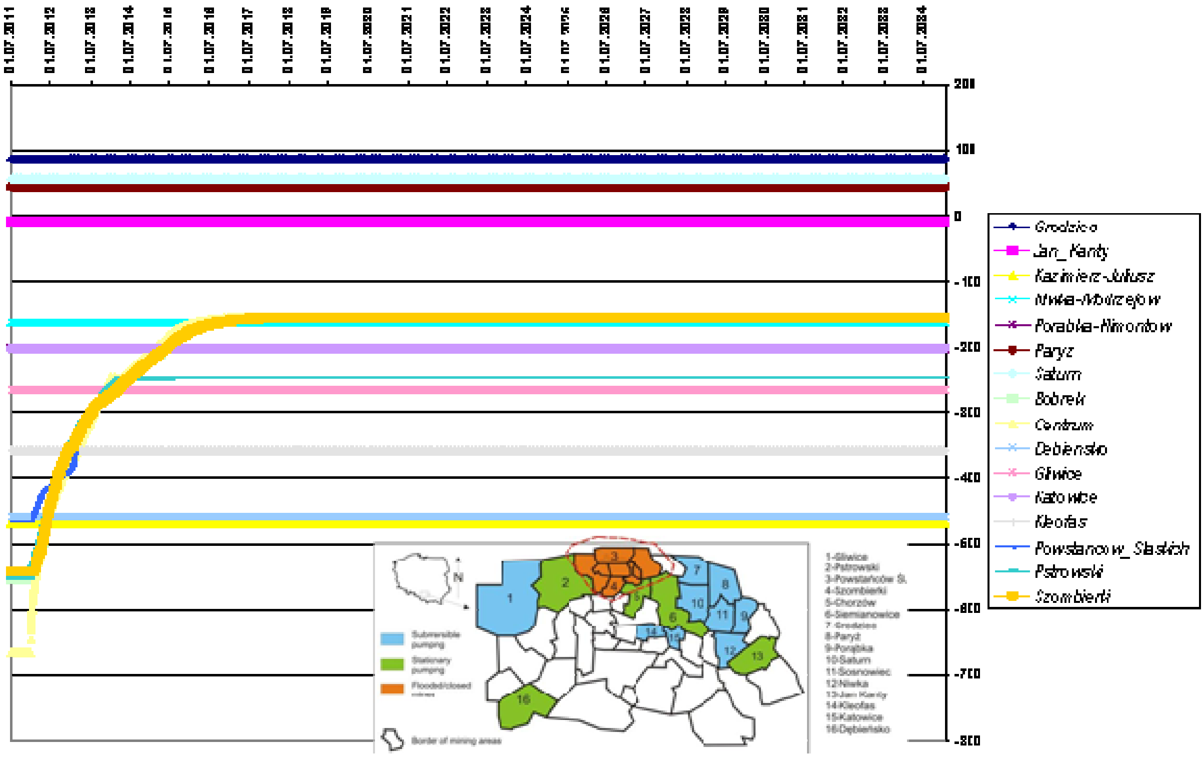

Figure 2.5: Application for Upper Silesian Coal Basin; flooding curves from the scenario 2 – flooding of North part of USCB.

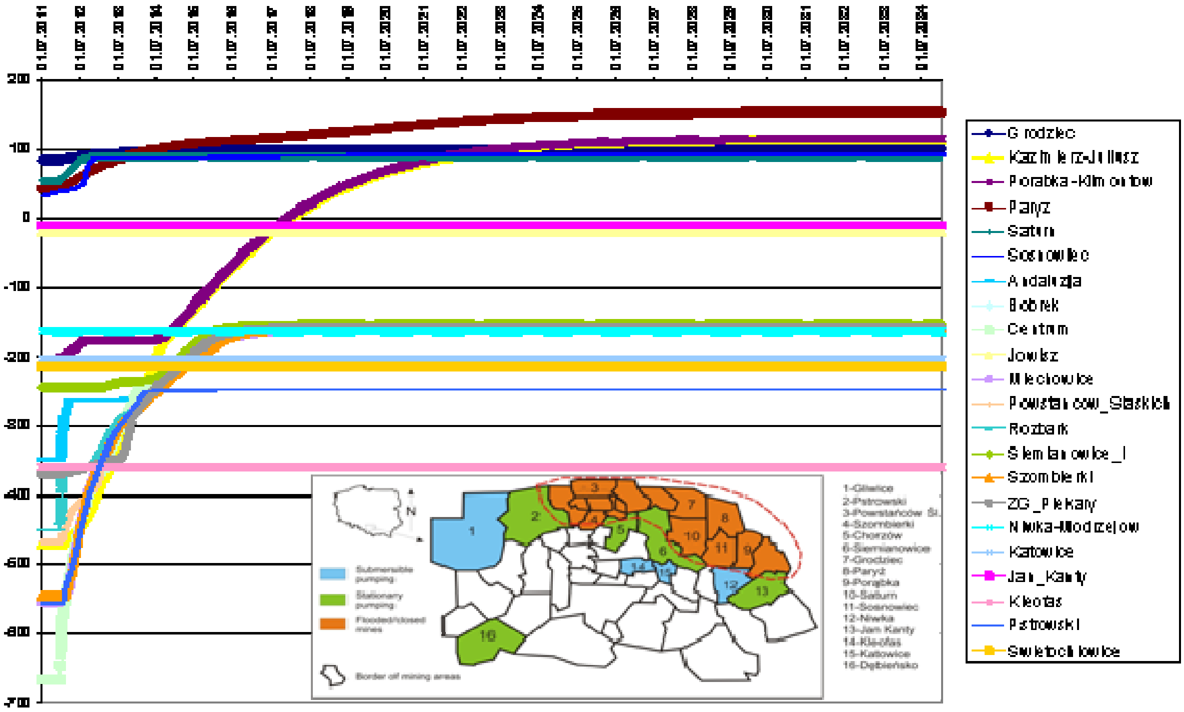

Figure 2.6: Application for Upper Silesian Coal Basin; flooding curves from the scenario 3 – flooding of both North and North – East part of USCB.

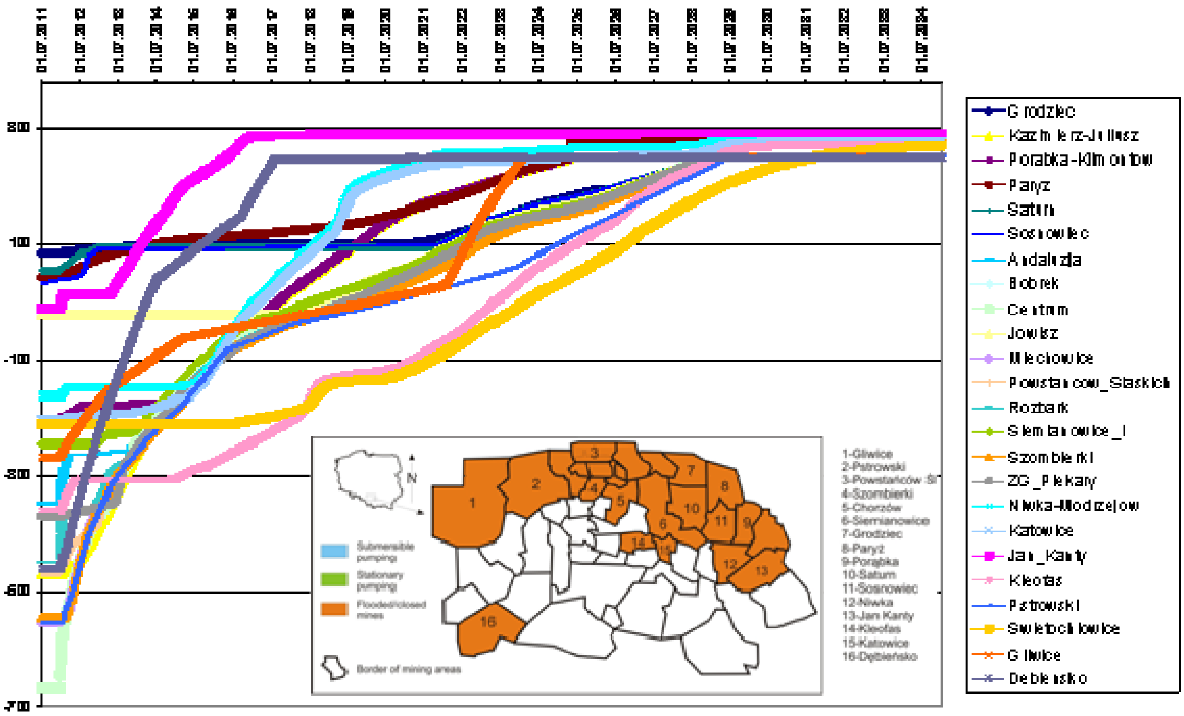

Figure 2.7: Application for Upper Silesian Coal Basin; flooding curves from the scenario 4 – flooding and abandoning all coal mines in USCB.

In case of the scenario 1 – flooding of North – East part of USCB (Figure 2.4) several mines that are now pumped separately would be pumped in one central point on Saturn mine at the level +90 m. A precondition for that is closing down the only active mine in the area Kazimierz-Juliusz. One can see that in such case mines Grodziec, Paryż, Saturn and Sosnowiec would reach relatively quickly the new dewatering level (within around 2 years), however not in all mimes equal level could be maintained through pumping only at Saturn. Especially at Paryż higher level is expected. It is not a surprise, as during years 2000 – 2001 much higher level at Paryż was observed even if much lower level were there at adjacent mines. Obviously, connections of Paryż mine wit the adjacent mines are not totally open and some pressure difference can be built over them. This has to be considered while considering the flooding of NE mines with pumping only at Saturn. As regards Kazimierz-Juliusz and Porąbka-Klimontów – these mines are pumped quite deep now and it is expected that their flooding up to level +90 would take around 10 years. Then also some pressure difference could be expected compared to Saturn, but lower than in case of Paryz. However, the hydraulic connection between Po-rabka-Klimontów and Kazimierz-Juliusz has not been in fact hydraulically tested, therefore no-one can say if Kazimierz-Juliusz would not be flooded higher than expected. Measurements during first years of flooding would help a lot in prediction the latter situation.

In case of scenario 2 – flooding of North part of USCB (Figure 2.5) very deep mines in the area of Bytom would be and flooded with only one pumping station at Pstrowski (level -250 m.) in order to protect the active mines in the South. A precondition for that is to stop exploitation in few quite small but very deep mines in the area of Bytom. One can see that in such case it would take some years to flood the "Bytom mines" to the level around -150, which means that a pressure difference would be build in relation to Prstrowski pumping station. Flooding curves show that all the deep mines would flood quite simultaneously as a result of their good interconnection. However, these connections have not been yet tested in flooding situation; therefore no-one can say at present if the flooding would really go simultaneously. Measurements during first years of flooding would help a lot in prediction the latter situation.

In case of scenario 3 - flooding of both North and North – East part of USCB (Figure 2.6) one can see from flooding curves that both systems are in fact flooding separately. The shapes of the curves for individual mines are in general the same as in the scenario 1 for NE mines and I scenario 2 for N mines. This is because the only assumed connection between the two systems is at Saturn mine at the level above +90 m. that is why, as long as level + 90 at Saturn is kept, the two system are in fact independent from each other. This is important fact for any future flooding scenarios. It means that the flooding of North and North – Eastern mines can be planned independently as the systems should not influence each other during parallel flooding, as long as level +90 at Saturn is kept.

In case of scenario 4 – flooding and abandoning all coal mines in USCB (Figure 2.7) one can see that complete stopping of pumping in entire USCB (purely hypothetical scenario) would result in very different rates of flooding in various mines. For some mines complete flooding is expected very quickly - within few years. For other mines it could take up to 25 years to be flooded. The graphs helps to understand how complicated the whole system of USCB mines is in reality.

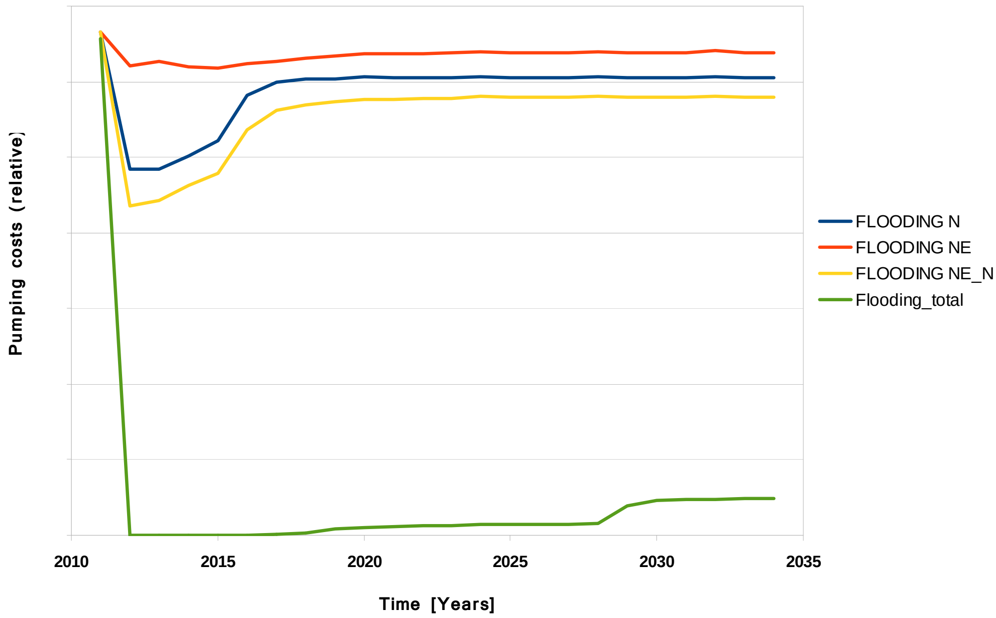

Figure 2.8: Application for Upper Silesian Coal Basin; comparison of pumping costs for all four scenarios calculated by Optimization tool.

The graph of pumping costs for all scenarios (Figure 2.8) obtained from optimization software tool shows the comparison of pumping costs helps to understand which scenario brings more savings on pumping costs. During first few years flooding of mines in North brings much more savings than flooding of mines in North-East. This is because during first years mines in North are just flooding few hundred meters without any pumping needed, while level +90 on Saturn in North-East is just a little bit above the current level and is reached quickly. However, after few years the savings are more balanced for the two variants, as pumping from Pstrowski at -250 is much deeper than pumping on Saturn at +90. Still the savings in North are bigger than in North-East. In scenario 3, which is combined flooding of North and North-East mines, the savings from scenario 1 and scenario 2 are just adding; as it was mentioned before, the two systems can flood quite independently. For total flooding scenario the savings are of course 100% at first, as no active mine has to be protected anymore, but after some years one should consider some pumping costs in order to avoid surface flooding. One should also run the model focussing on each mine separately in details in order to assess how high the mine can be in fact flooded, taking into account the threats for the surface, but also for the quality of surface water as well as groundwater in the aquifers above the mines.

Task 2.3 Application of the optimisation software tool for further test sites

The Optimisation software has been used with the Boxmodels for the Barredo water province (Asturias, Spain) and BW-Ost (Ruhr, Germany). The Barredo Boxmodel project is quite small and was therefore very practical for testing software purposes. It consists of eight pump stations with a total of 15 pumps installed. The following illustrations are dedicated to analyses of flooding Barredo pump station.

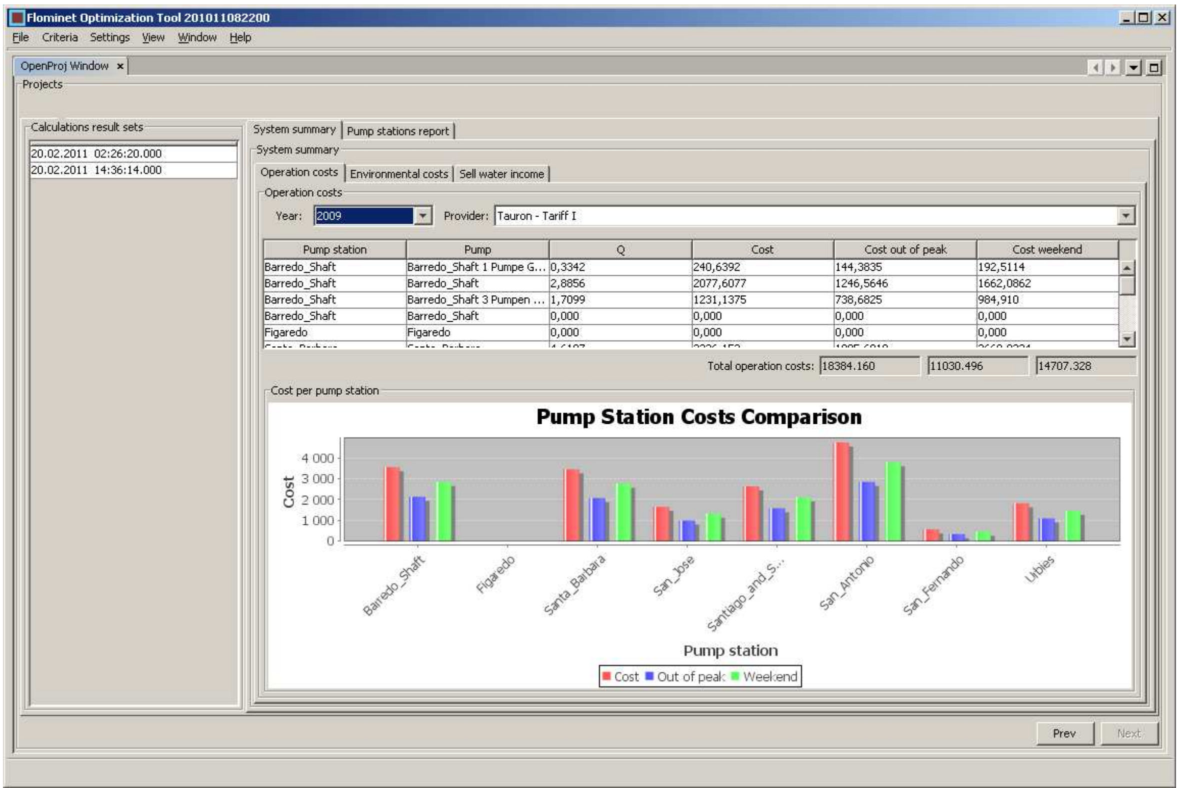

Figure 2.9: Operation costs criteria year 2009.

Figure 2.9 provides year dependent pumping. Costs can be reduced by reduction of pumped water volume and higher water level. Compared to the USCB Spanish coal mines are not affected by environmental costs for discharge of salt loads. This might be due to the fact that in general mine water mineralisation is very low. However the Environmental_costs tool can also be used for calculation of potentially required water treatment measures for example.

Possible income from selling clean water can be seen on the Sell_water_income_tab. Analysing yearly data on table and with chart we can notice that only few pumping sites can provide drinking water for home use.

The complete Ruhr Boxmodel project is very large. Furthermore it can and must be subdivided in water provinces which are hydraulically independent areas with a defined water balance. These water provinces will be the relevant units until the final flooding after termination of mining is started. Therefore a water province in the eastern part of the Ruhr area has been evaluated with the Boxmodel. It consists of eight pump stations with a total of 18 pumps installed; some of them are inflow pumps. This pump inventory includes not only pumps still active but also pumps required to reproduce the water management in the past.

In this water province actually three pumping stations are active which will be replaced in future by one central pumping stations. The pumped volume of more than 20 m^3/min points the impact of the water level on pumping costs. In addition it is known from the past that high iron concentrations have to be expected after flooding in this mining area. So the optimisation tool will be used for calculation of environmental costs for water treatment (corresponding to contaminant load) for the period of flushing of mobilised oxidation products.

Optimisation tool reporting shows that no income from selling clean water is to be expected because of the poor water quality.

WP 3 Application for recovery of energy from mine water rebound

Task 3.1 Selection of sites potentially suitable for energy generation

In this task, a detailed review of the mining structures in Caudal Coal Basin (Asturias) was carried out in order to select the most adapted sites to development hydroelectric and geothermal energy systems. Several activities were carried out like an inventory of abandoned coalmining structures, a compilation of drainage data of these mining facilities and a general evaluation of its water quality, an evaluation of those shafts that still have pumping stations with important long term output flows and big heights of pumping, a selection of those shafts that still preserves the accesses to the galleries and are available to work, or a study of the shafts and associated mining voids with significant water storage capacity.

A large inventory of technical geological and hydrogeological information concerning mining works in this area has been generated, covering documents on vertical shafts, drifts, mountain adits, opencast collieries. Likewise, a compilation of drainage, pumping, temperature and outflow data was done. All data about the mining connections existing between the different minefields has been gathered in order to establish their possible hydraulic communication (Figure 3.1).

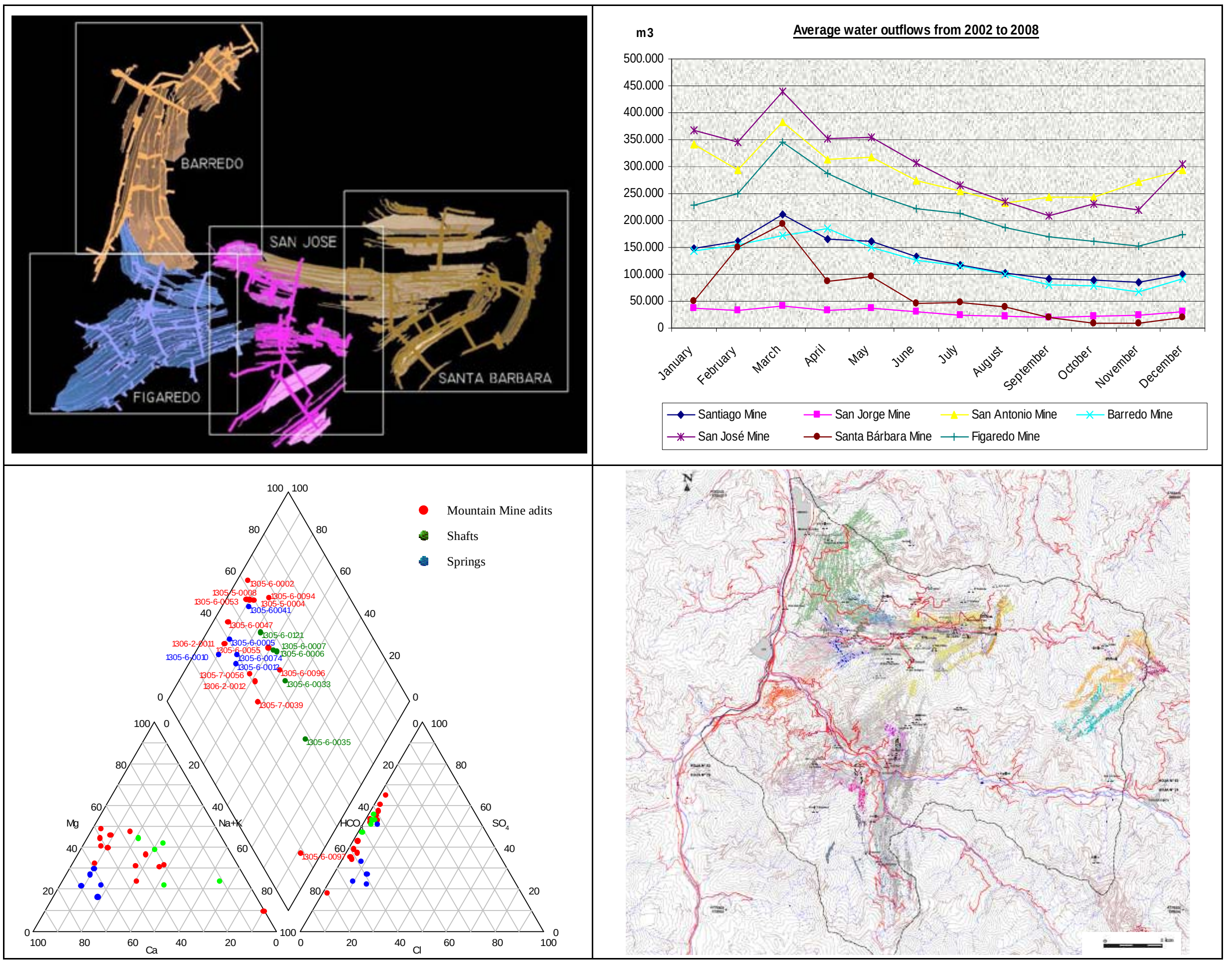

Figure 3.1: Some information gathered in task 3.1.

Based on all the information gathered, two sites were selected for a more detailed study, one intended at hydroelectric exploitation (San Fernando and Urbiés mountain mining structure) and the other one for geothermal use (Barredo shaft).

Task 3.2 Hydraulic characterisation of the site selected for hydroelectric production and model development

San Fernando is an underground mine located in Aller valley. The mine is abandoned and has a vertical shaft and 4 levels. The shaft's mouth is located at +660 m a.s.l. and the lower discharge point at +430 m a.s.l, in San Fernando adit. Through this adit (called "Socavón") the coal was extracted easily and nowadays, this point still is open. This is the reason why the galleries of this mine never have been flooded after close the mine (Figure 3.2). According to the documentation gathered and the field works carried out around the area, except for San Fernando adit, the mining works of this mine never have been connected with the topographical surface. This mine would have a total void volume about 0,6 Hm^3 available for water storage.

On the other hand, Urbiés is an ancient mountain mine with 13 exploitation levels closely connected to the topographic surface through which a large amount of rainfall infiltrates. The mine is located in the contiguous valley (Turón valley) and its lower discharges points are Molinón and Urbiés adit, at the same level, and a little higher, Mosquil adit (Figure 3.2). According to the dimensions of this mountain mine and taking into account the space left by the exploited layers the void volume would be about 0,5 Hm^3.

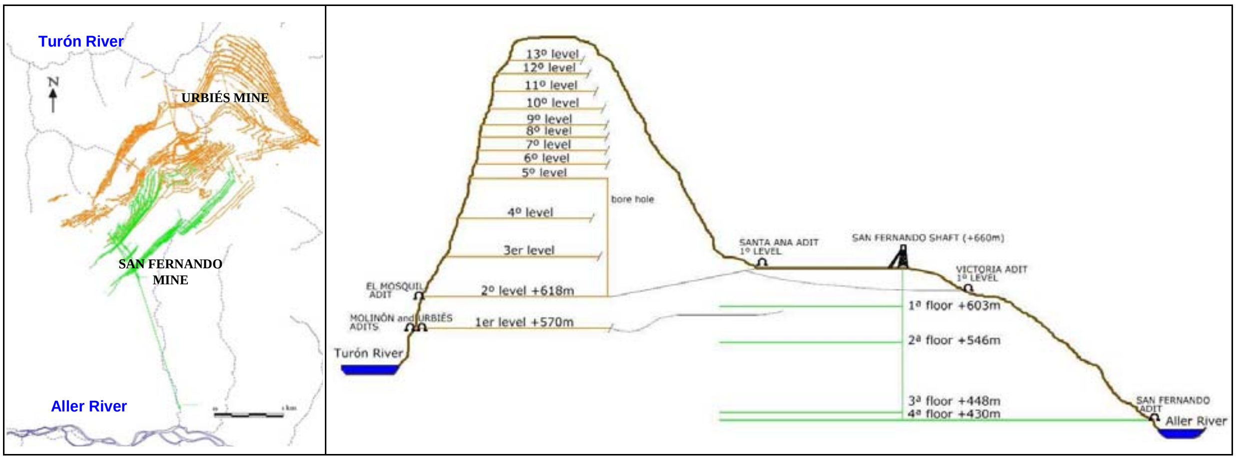

Figure 3.2: Urbiés and San Fernando mining structures (plant and profile).

In order to estimate the water volume that could be stored in each mine, detailed water balance was carried out and several Parshall weirs were installed in the main discharges points to take accurate water outflow measures. Likewise, chemical analysis of the water has been carried out in order to control the water quality.

Taking into account all this information, the possibility of using the water storage capacity of these mines to generate hydroelectric energy by means of a micro-hydroelectric plant has been developed. Three options were planned; to use only Urbiés mountain mine structure, to use only San Fernando mine, or to use a combined system with both mines due to the structures are interconnected, at least, through a gallery. For each case the hydraulic head, the average flow and the total electric power have been calculated. The data obtained can be seen in Table 3.1.

Table 3.1: Hydraulic conditions and electric power available in each case.

	Urbiés	San Fernando	Urbiés - San Fernando
Net Head (Hn)	40 m	120 m	170 m
	Including Head losses (ΔH) around 5% of Gross Head (Hg)		
Average Flow (Q)	42 l/s	13 l/s	55 l/s
	(or 84 l/s during 8h per day)	(constant flow. 24h)	(constant flow. 24h)
Electric Power (Pe)	19.8 kW	9.2 kW	55 kW
	Including an equipment efficiency (turbine-generator-transformer) around 60%		

Depending of each case would be necessary to close some adits and to install the micro-hydroelectric plant in the lowest mine water discharge point.

Task 3.3 Technical feasibility of hydroelectric energy production

Once the potential energy for each case was defined and characterized a study of the equipment needed to the electricity production test was carried out. A micro hydroelectric plant is formed of various components and equipment that can be classified into three groups: civil works, electromechanical equipment and auxiliary equipments. In order to know the technical feasibility of the system each of these items was studied separately with special focus on the study of both the turbine and the plug.

Different kind of turbines has been analyzed. Figure 3.3 shows the efficiency of each turbine (Pelton, Kaplan and Francis) according to the different hydraulic head and the available flow. The colour lines show each system proposed.

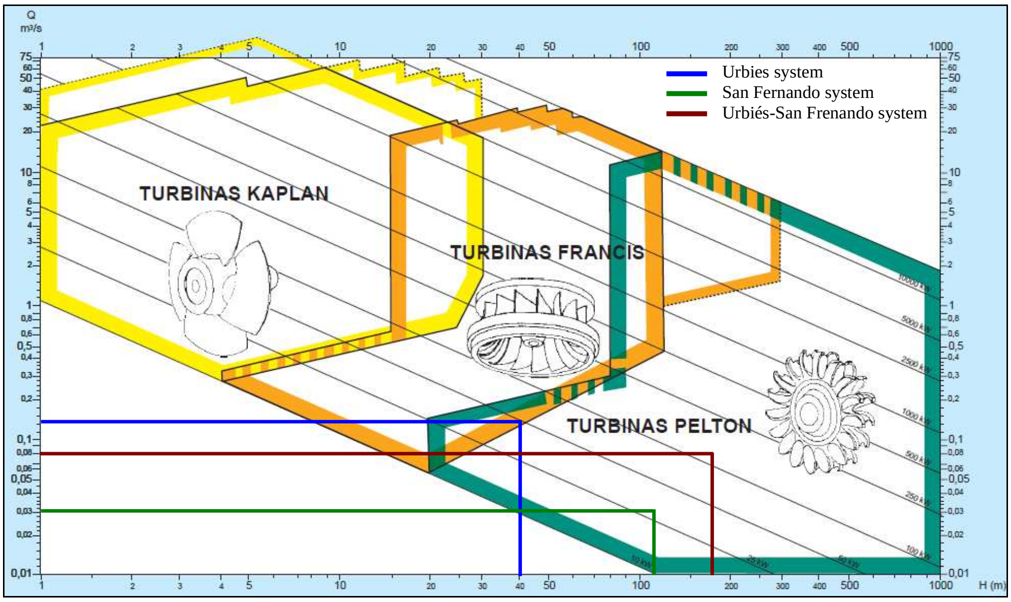

Figure 3.3: Turbine application chart.

The evaluation of each system showed that the Pelton turbine is the most adequate for any case. This turbine works with a vertical axis generator and its operation is based on the transverse flow through a series of stainless steel buckers attached to a bun. For example, a Pelton turbine with a highly versatile flow was selected to Urbiés case. This kind of turbine would allow for 24 hours a day working cycles (when the flow in the mine is high) or on a discontinuous pattern (with 8 or 16 hours of water storage) on a dry period, trying always to keep the water level constant.

Related to the generator, in micro hydroelectric plants with isolated turbines, a single-phase synchronous generator is usually used. The generator is separated from the turbine by means of a special shield which avoids any contact with the water. Also, a load dissipation system is necessary (either by water or air) in order to maintain constant both the load as the frequency.

On the other hand, a complete study of the plug needed to store the water and the mine gallery conditioning has been carried out too.

The plug is an essential element to store the water inside the mining infrastructure and to allow a much easier control of the water flow in the structure and forward it to the turbine properly. This plug would be a concrete, monolithic parallel-type and would transmit the rock pressure with no anchoring. A possible design for this kind of galleries would be a circular section of 3.5 m diameter and 5 m of total length. On the part in which the water pressure would be applied, a domed concave form was designed in order to improve the transmission of the tensions to the rock and the closing of the rock/concrete interface.

This plug would be crossed by the turbine water suction pipe which diameter will be designed according to the water speed limit that depends on the turbine valve (v<4m/s in all cases). A second pipe will be included in order to allow for drainage of sludge. Motorized valves would be installed on both pipes. Likewise, the plug would be provided of different instruments (pressure probes and movement, flow-meters, etc) in order to monitor and supervise it when operating (Figure 3.4).

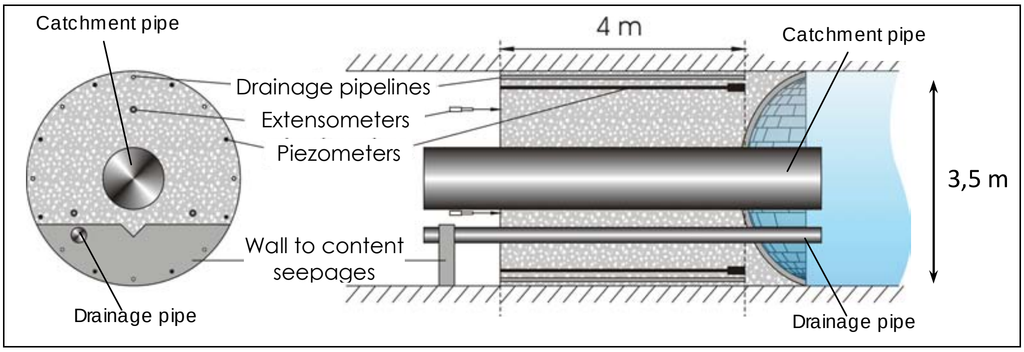

Figure 3.4: Some characteristics of the concrete plug required.

Related to the mine gallery conditioning, several activities have been taking into account in order to adequate the exploitation site. The most important activity would be the waterproofing of the gallery upstream from the blockage because the plug should withstand high pressure levels. Although each gallery is different, a minimum length of 20 m would be necessary to waterproof it in order to avoid any hydro-fracturing induced by the water pressure. Additionally of the plug installation, conditioning and cleaning activities would be required into the gallery selected (appropriate illumination and ventilation, anti-fire system, electric supplier lines, etc.).

In Urbiés case, plug construction would be easier because the maximum net head is much lower and the plug dimensions would be smaller.

Task 3.4 Economic viability of hydroelectric energy production

Once the technical parameters are defined, the Pelton-kind turbine was selected and the plug is designed, it is time to think about the economics of the projects.

It is wise to consider the most unfavourable case, which is San Fernando adit that develops only 9.2 KW as the combined use of both mines depends a lot on the inner structure of the mountain mines and it is hard to define an accurate regime of water movement inside them.

The initial investment regarding mostly to both the civil works and the price of the turbine, and also the exploitation costs (continuous) due to the maintenance, security and insurances are the main points which could represent the problem at the time of making the project feasible. The breakdown of the initial investment is shown in Table 3.2.

Table 3.2: Breakdown of the estimation costs of investment.

Concept	Urbiés case
Civil works	35.000,00 €
Turbine, generator y supports.	15.000,00 €
Civil works direction	5.000,00 €
Authorizations, permits and taxes	2.500,00 €
Overheads / Industrial profit	10.000,00 €
TOTAL	**67.500,00 €**

Exploitation costs related to maintenance, insurance or personal costs are hard to calculate. Taking a look to other hydroelectrical projects, and following the recommendations of an important institution as it is the "Ente Vasco de la Energía" (Basque Country Energy Institute) annual costs should be considered among 2% and 5% of the initial investment. In our case 4% (2700 €) is taken as we are working with mine water (although Urbies and San Fernando mine water has proper chemical parameters to use).

About the economical incomes, Spanish energy law locate Micro plants of hydroelectric power in the group b.4 (these groups are set depending on the cleanliness or renewability) defined as hydroelectrical plants with less than 10 MW of power. This law provides a price for the energy selling of 8.4237 c€/kW·h for the first 25 years, and 7.5814 for the following years.

Although with this parameters the project shows profitable, as the initial investment is returned in amongst 13 and 14 years, the main problem is the tending of this law to lower its prices (as this is a very high selling price compared to other energy sources). This fact turns this project into a risky investment, as the price of the energy is the only parameter to set the incomes for the company.

Task 3.5 Characterisation of the sites selected for geothermal production

Barredo shaft was initially the selected site in order to provide geothermal energy, in terms of mine water, to the surrounding buildings. It is important to remark that Barredo shaft has many direct connections (gallery) with Figaredo shaft, and also with two other shafts (San Jose and Santa Barbara) which connections are less clear but surely present. That makes much larger volume of water in case of flooding. Water discharge is carried out in Barredo shaft. The characterization was done based on different criteria:

- Water flow rates and its availability. This work was carried out by measuring the water discharges on the mine during the last 6 years. The average outflow was about 4 Million m^3 per year. Not only this is a high amount of water in order to carry out geothermal projects with mine water, but also re-injection of water could be possible in case of lack of water.
- Water temperature monitoring. Many sensors were installed in the four shafts mentioned above in order to have a continuous measurement of the water temperature and therefore, be able to set the actual geothermal potential. Sensors were installed at 250 metres deep in Barredo (Figure 3.5), Sta Barbara and Figaredo; San Jose shaft has its sensor at 240 metres below the surface. Temperature was measured also manually in Barredo shaft, where, after the installation of the discharge pumps (Bilge pumps) reached an steady state within 23.5ºC and 24.5ºC
- Void volume of the reservoir was also calculated by means of digitalisations of old maps. Calculation took into account both the void created by the mining structures and the void generated by the coal extraction. This parameter will allow us to know whether the mine water reservoir is much larger than the actual discharge. This will also help to develop a flooding process model. The void volume was estimated on 5 Million m^3.
- Chemical parameters were also measured mostly with the aim of guarantee the proper work of the equipment. Main problem came with the hardness that sometimes reaches a value of 1000 mg/l. Also scaring could represent a problem as the Ryznar Index was set on 5.27, so that CaCO3 precipitation may occur. It was finally set that no corrosion would appear as the water is mainly bicarbonate sodium with a medium pH (around 7).

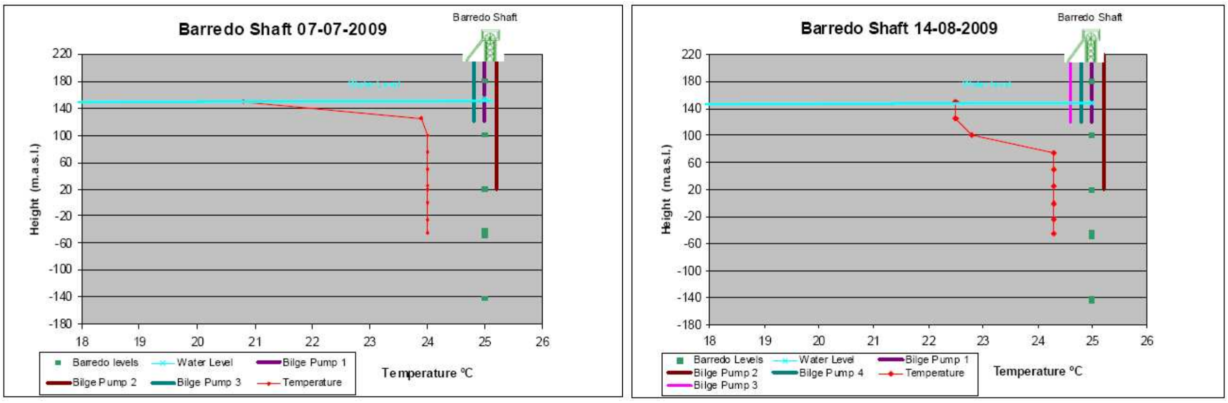

Figure 3.5: Temperature profiles Barredo Shaft, water table and pumping level.

Not only the water height and the temperature are important, but also the amount of available water and its chemistry are needed to be taken into account when a geothermal project is up to be developed. Considering the 4 Mm^3 per year, the potential (as a cold source) could be calculated by this formula:

$$\mathbf{Pf = (\Delta T \cdot V \cdot Ce \cdot \rho)\ [MW_{th}] = 2.65\ M\ W_{th}}$$

- ΔT= Thermal gap. 5 ºC (On conventional heat pumps)
- V= Water Flow per year. 4 Mm^3/year.
- Ce= Water Specific heat. 4186.8 J/Kg ºC
- ρ= Density. 1000 kg/m^3

Energy consumption (**W_e**) for this potential, considering a heat pump COP of 5, would be as follows:

$$\mathbf{COP = Pc / We = (Pf + We)/ We = 1 + Pf /We > 5}$$

$$\mathbf{W_e \approx 0.66\ MW}$$

So that, the hot geothermal potential will reach:

$$\mathbf{Pc = Pf + We = 3.31\ MW_{th}}$$

Task 3.6 Design of a geothermal pilot project

By June 2009, the geothermal pilot project design started. The main obstacles faced where the selection of the client site and the demand from this client, that would need to be high enough to make the project feasible but low enough to consider it as a pilot project.

Two new buildings closer to Barredo shaft, opened an opportunity to provide geothermal energy. Those buildings were a Research Centre and a Hall of Residence, and both of them belong to the University of Oviedo. Estimating the energy consumption of the buildings were a hard task, but finally that problem was tackled considering the original heating/cooling projects that involved gas boilers and air chillers, so that, the solution was installing heat pumps that could provide the same power to the building than the original ones.

Figure 3.6: Vertical infrastructure on Barredo Shaft.

After these preliminary tasks, the main points of the design are the following:

- Pumping System in Barredo Shaft, which provides the water flow necessary for the geothermal system: The bilge pumps installed in Barredo shaft by June 2009 were used for the discharge of water and they were also the source of water for the geothermal project. A concrete seal was built on the top of the shaft to keep the water collector. Four pumps with a water flow rate of 215 $m^{3/}h$ each were installed and allowed the geothermal project to develop as the needs from the buildings did not reach even 200 m^3/h (120 m^3/h for the Research Centre and 60 m^3/h for the Hall of Residence). The pumps were installed at different heights (one of them was installed at 200 m depth from the surface and the rest at 100 m) (Figure 3.6). These pumps collect the water and send it to the surface through flexible pipes.
- Water distribution system to the buildings: The relatively small distance among the shaft and the buildings (250m) made the project easier on its design, as the larger the distance, the harder the design. The idea was carrying the mine water below the road from the shaft to the buildings' equipment room, where two heat exchangers were placed (one for cooling energy and the other one for heating energy). Polypropylene pipes (6" diameter for Research Centre and 4" for the Hall of residence) were installed in order to prevent both corrosion and heat losses. After mine water is used, also another pipe carries the water to the discharge point so that the original discharge system is not changed due to the geothermal project.
- Heating and cooling generation systems (heat pumps and the auxiliary equipment required for operation): Apart from the heat exchangers mentioned above, also two heat pumps are needed in the Research Centre and another one for the Hall of Residence. The heat pumps installed in the Research Centre allow for heating and cooling at the same time, so that storage tanks are also needed in the equipment's room). Mine water acts not only as the energy provider but also as a balancing fluid, which means lowering the temperature of heat circuit in summer and dispelling the cold water in winter when not a huge amount of cooling energy is needed. The system consists of two heat pumps RTWB 210 (heating power of 362 KW each unit). Both heat pumps produce hot water at 50ºC (Return at 45ºC after being used for heating) and cold water at 7ºC (Return at 12ºC). So that, each heat pump can work steady with a thermal gap of 5ºC on each focus.

Task 3.7 Feasibility of geothermal energy production

Defining the economic terms of the geothermal project is about initial investment and operative costs. As these calculations involve too many parameters, it was decided to develop a software where the investment, costs and incomes are designed depending on the conditions of any particular site. Data is introduced in the software and many calculations considering parameters such as prices of energy (electrical, natural gas, diesel…), height of mine water (cost of pumping), distance among the client and the mine water source (civil works price), thermal energy consumption (incomes for the company provider of geothermal energy) and many other parameters that are taken into account when feasibility of geothermal energy production is studied.

Feasibility hardly depends on the initial investment, as it does in hydroelectrical production. Investment for this project considers both the costs related to the mine water pumping system (costs of pumps, concrete flagstone over the surface, pipelines…) and the cost of the structures needed to carry out the civil works. Not only the distance is important but also the width, which is directly related to the amount of water required and therefore to the diameter of the pipe. Also the pipe material is important as the thermal conductivity and the head losses play an important role.

Operative costs consist mostly on electricity needed to pump up the required amount of mine water, which is directly related with water height. Also the maintenance of this system is required.

The heat pump costs when working must be undertaken by the customer such as the acquisition of the equipments.

Table 3.3: Comparison between conventional systems to geothermal one in terms of power.

System	Efficiency	Price of combustible (€/kWh)		100 kW	1000 KW
				Cost of thermal energy (5000 h/yr)	
Diesel oil boiler	0,7	**Diesel oil**	0,08	57.142,86 €	571.428,57 €
Natural Gas boiler	0,8	**Natural Gas**	0,038	23.750,00 €	237.500,00 €
Propane	0,9	**Propane**	0,0558	32.823,53 €	328.235,29 €
Geothermal system	4,2	**Electricity**	0,1177	14.015,48 €	140.154,76 €

Once all data is collected and calculations for the investment and operability are done, the savings offered to the client are based on comparison among geothermal energy and other regular systems. Table 3.3 compares the incomes of the geothermal system to the conventional systems most commonly used. COP or efficiency is for geothermal heat pump is considered 4.2 although usually this value is 1 point higher.

As a last point, CO_2 emissions should be considered as the remission of these represent such a big advantage for geothermal energy compared to others. Those are shown in Table 3.4.

Table 3.4: CO_2 emissions for 1MKW•h consumption for each system.

CO2 emissions for 1MKW·h consumption			
System	**Emissions ratio (gr/kWh)**	**Total Emissions (Ton/yr)**	**Reduction reached (%)**
Chiller	600,00	260,87	**45,24%**
Natural Gas	230,00	287,50	**50,31%**
Diesel oil	318,00	397,50	**64,06%**
Geothermal sys.	600,00	142,86	

WP 4 Application for management of gas emissions related to flooding process

Task 4.1 Monitoring of gases flux during coal mine flooding

In this task, two monitoring points (SDEC Ouest and Barrois shaft) have been installed at the surface of La Houve Basin. The measurement period lasted from 12/09/2008 to 11/08/2009. All the measurements were recorded with one hour time step, except for radon which was monitored every half hour. Characteristics of the monitoring stations are described in Table 4.1 (For more detail information on the monitoring protocol please report to deliverable M12).

Table 4.1: Monitoring stations characteristics.

Measurement types		Sensor type	Resolution	Measurement range
Mine gas| parameters	*Oxygen (O_2)*	Electro-chemical sensor	0.1%	0 to 30% vol.
	Carbon dioxide (CO_2)	Infrared sensor	0.025%	0 to 20% vol.
	Methane (CH_4)	Infrared sensor	0.1%	0 to 100% vol.
	Radon (Rn) volumic activity	BARASOL® probe	-	0 to 1 GBq.m^{-3}
	Anemometer	Spinner	0.1 m.s^{-1}	0 to 40 m.s^{-1}
	Gas temperature	Pt 100	0.1°C	- 40 to + 60°C
External param.	*Temperature*	EE06 Pt 1000	0.1°C	- 40 to + 60°C
	Barometric pressure	Ptb 101b VAISALA®	0.1 hPa	600 to 1060 hPa
Differential pressure(mine gas - atmosphere		FCO332	5 Pa	-7000 to + 7000 Pa

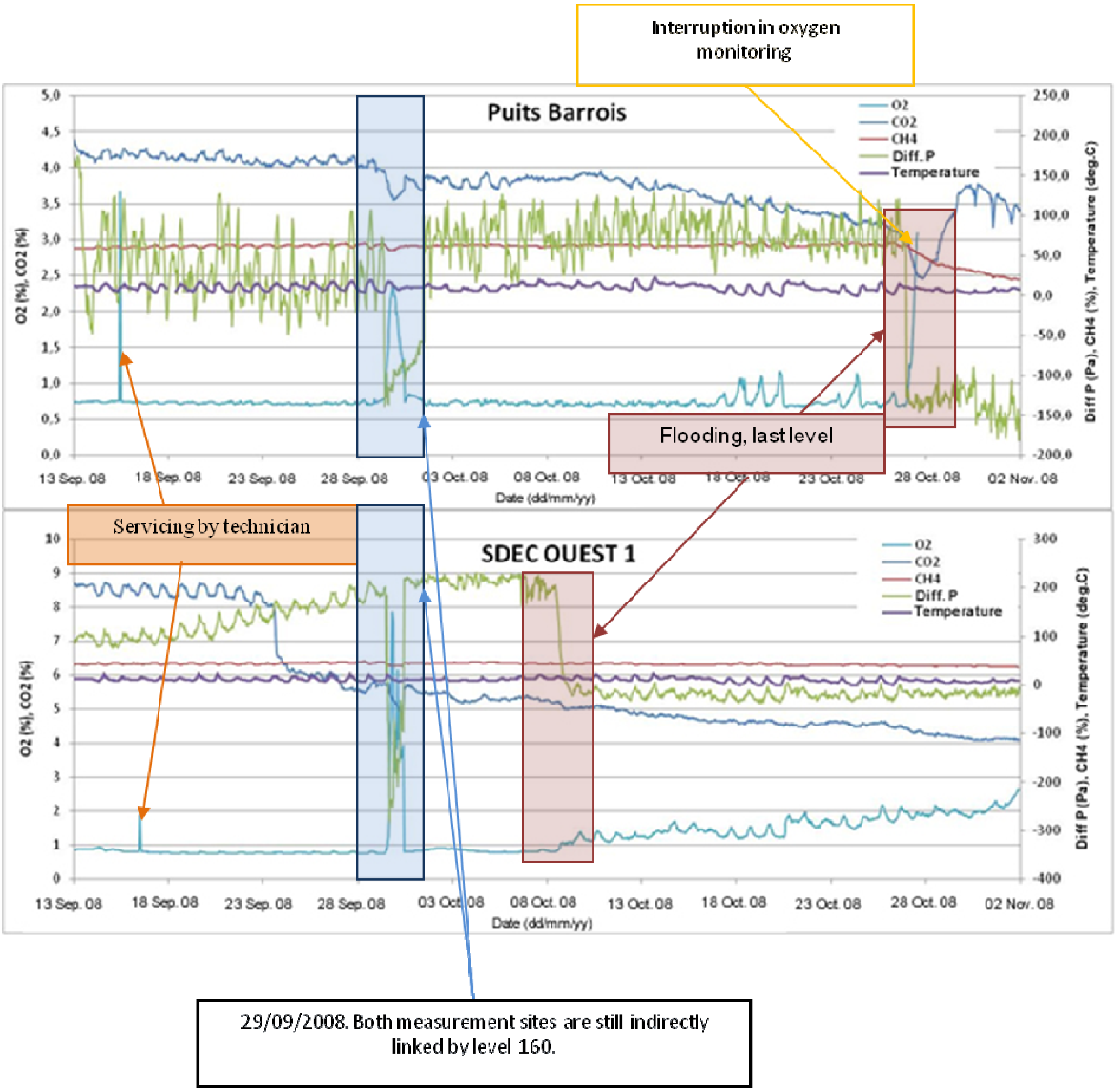

Figure 4.1: Monitoring from 12 September to 2 November 2008 at the instrumented sites at Puits Barrois and SDEC OUEST 1.

A detailed analysis of the results, presented Figure 4.1 and Figure 4.2, taking into account the context of measurements, allowed us to highlight two behaviours at the beginning and the end of the flooding separated by a transitional behaviour phase:

- From July 2005 to May 2008 (the shafts only flow out when the atmospheric pressure fell, leading to a sufficient pressure difference between the old mine and the outside atmosphere (in excess of 220 Pa) thereby triggering the opening of a no-return valve. Water drainage was stopped on 11/12/2006. The data forwarded by BRGM-DPSM shows that site behaviour does not change overnight, even though flooding starts. The preliminary measurements made by INERIS on 09/10/2007 also illustrate this stability and the importance of the barometric pressure value on gas emissions as the volume represented by the mining voids remains significant (For more detail information please report to deliverable D13).
- From September to November 2008 (Figure 4.1) the water level reached and flooded out the highest mine voids. This situation was complete on 08/10 at SDEC OUEST 1 and on 27/10 at Puits Barrois. Flooding the last stages immediately leads to a fall in differential pressure that then tends towards 0. A progressive fall in mine gas content (methane and carbon dioxide) is observed while the oxygen content continues to rise.

- From 12 February 2009 until the end of the monitoring performed by INERIS (Figure 4.2) (on August 11th 2009), the gasses observed follow the same trends until the end of the flooding phase. The same applies to differential pressure which remains constant, except during specific episodes relating to technical servicing. This is because the atmospheric pressure no longer has any influence on differential pressure variations unlike temperature.

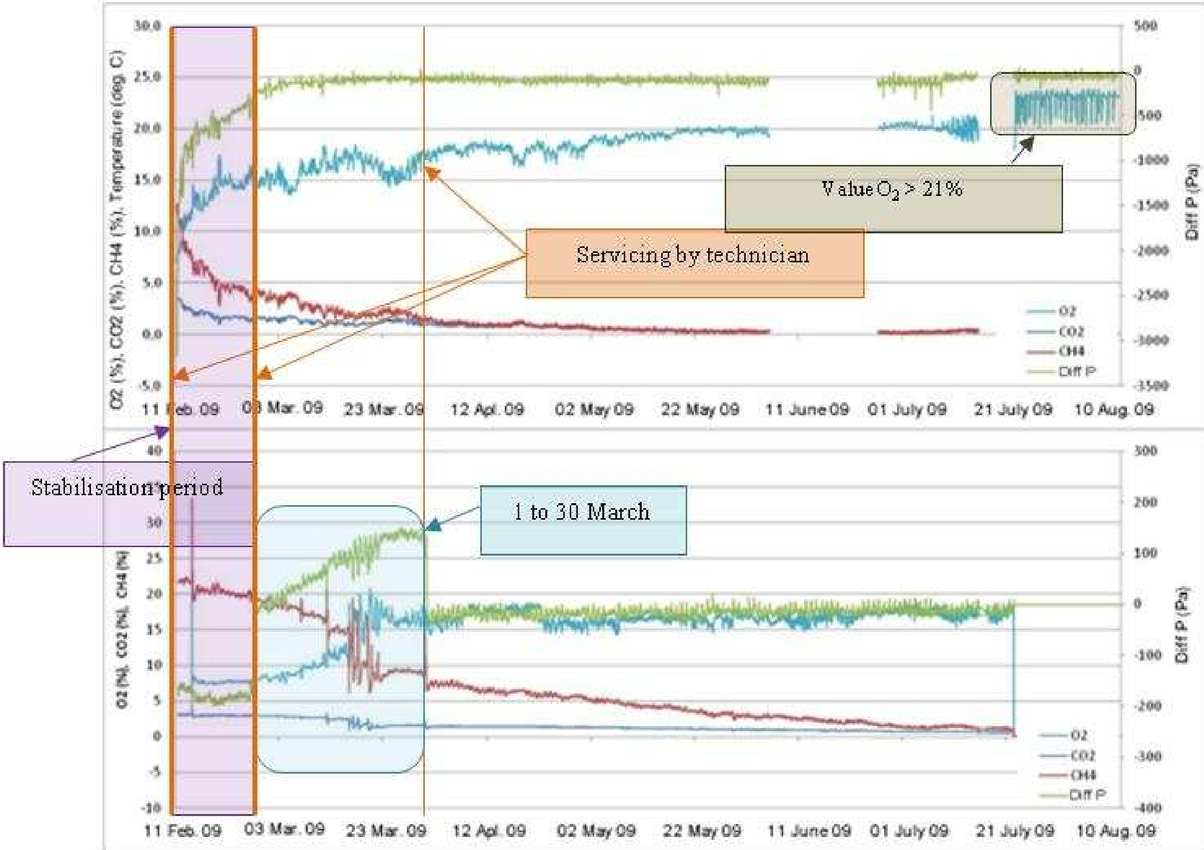

Figure 4.2: Monitoring from 12 February to 11 August 2009 at the instrumented Puits Barrois and SDEC OUEST 1 sites.

To resume, the monitoring of Puits Barrois and the decompression borehole at SDEC OUEST 1 since the end of dewatering in 2006 showed that gas emissions in a coal mine environment are primarily determined by atmospheric pressure variations (Figure 4.1). Flooding the old mine workings does not trigger any significant change in behaviour (we do however note that differential pressure fluctuations are less significant) until the last voids levels are flooded, at which time gaseous emissions are significantly reduced. This rise in the water level along with the addition of atmospheric oxygen may, under certain conditions, trigger geochemical or biochemical reactions that produce gas as was the case for carbon dioxide at Puits Barrois (Figure 4.1) (For more detail information please report to deliverable D13). Nevertheless, this study shows that flooding has a positive short term impact on emissions of gasses like radon and mine gasses such as carbon dioxide and methane. However, we cannot rule out that in future, CO_2 will be produced or that methane producing bacteria present in the flooding water could play a part in anaerobic reaction (see R. Moletta, 2002) thereby playing a part, in the short or long term, in the production of methane.

The presence of methane within the Upper Silesian Coal Basin is influenced by two factors that determine the conditions for migration and accumulation of gas (Kidybiński A., Siemka J. (red.), 2006):

1) exposure of Carboniferous deposits. In the southern part were uncovered until the Miocene in the northern part they are uncovered to the present. This resulted in the entire USCB degassing of the rock to a considerable depth,

2) covering the Carboniferous deposits in the southern part of USCB by impermeable or poorly permeable gas deposits of the Skawinska formations (Miocene), which limited or even suspended the process

of escaping gases to the atmosphere and caused accumulation in the upper parts of the Carboniferous. As a result, there has been a re-saturation of gases in coal seams, which migrated from deeper lying coal seams, or even established of free gas accumulations.

Therefore, in the USCB especially in his southern part the collieries are rich in methane. During the structural changes in the Polish coal industry, the collieries (also these with extensive gas emanations) were closed. The research on gas migration carried out by Krause (2001) in the USCB pointed to the fact that gas emanation has been decreasing exponentially since exploitation stopped. It diminished fivefold during the first month. The gas emanation will gradually decrease over the next 10 to 15 years. Gas accumulation may occur locally during closure works (Cabal et al., 2004).

However methane rises to the ground surface within the Polish part of the USCB are not such a significant problem yet. Future closure of coal mines, should be preceded by preparation of sufficient prevention against this phenomena (Gremla et al., 2006).

Task 4.2 Laboratory experiments

In this task, in order to evaluate the exact influence of hydrostatic pressure increase, during mine flooding, on the capacity of coal to release CH_4, we developed a device called CASPER (sorption capacity at high pressure after rock flooding, Figure 4.3).

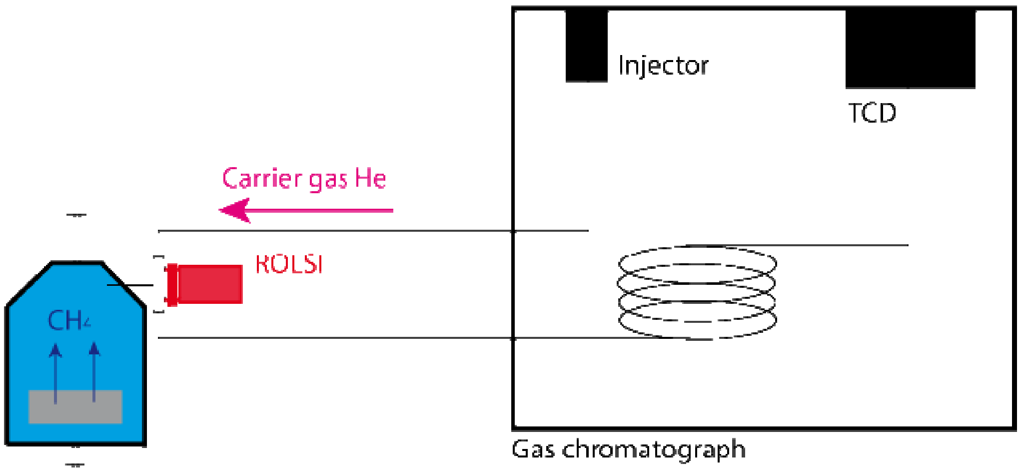

Figure 4.3: Functional scheme of the current device CASPER.

The initial device, developed at INERIS 10 years ago was constituted of three parts: a piston, a buffer volume and an autoclave cell containing a gas saturated coal sample flooded. During the last two years, the device was tested, in order to identify the different points to improve, then several apparatus had been added, thus a new experimental protocol has been defined.

Between summer 2009 and summer 2010, an analysis system has been added to the initial system. Indeed, the cell has been equipped with a micro-sampler ROLSI™ (Rapid On-Line Sampler) which is connected to a gas chromatograph. This whole system makes it possible to have a monitoring of the $CH_{4(aq)}$ content in the cell, moreover without disturbing the pressure. A rubber heater is also used, fixed at the bottom of the cell, to create a light convection stream in the cell, thus to enhance the homogeneity of the water in the cell. It makes also possible to diminish the impact of ambient temperature on pressure inside the cell. The monitoring of $CH_{4(aq)}$ content provides more information about the time needed for sorption equilibrium under high hydrostatic pressure.

The new protocol developed in this task of FLOMINET project includes the following steps:

- Coal preparation : crushing at a 0.5-1 mm fraction and drying at 80°C during 3 days at least;
- Measurement of "free" volume in the cell using an helium pressuring system and an inverse burette;
- Vacuum pumping during 3 days to evacuate all the residual gaseous pollution from the surface of the coal (He, air);
- CH_4 saturation: the crushed sample, in the cell, is submitted to an initial CH_4 pressure of 30 bar;
- Flooding: increasing the water pressure to a chosen level;
- Sampling and analysis with the ROLSI and the gas chromatograph. Several samples are made with a chosen time step, in order to insure the validation of the estimated contents.

This protocol has been tested and validated during autumn 2010. An experiment ran on a 10 g crushed coal sample from the Saar mine (provided by DMT) between March and May 2011 (For more detail information please report to deliverable D14).

During the first phase of coal saturation by methane we measure a global decrease of the pressure in the cell of 1.3 bar in 8 days, then a sorption equilibrium was reached, even if some second order variations are obvious, with an amplitude of 0.2 bar (Figure 4.4). These ones are due to the outside temperature variations.

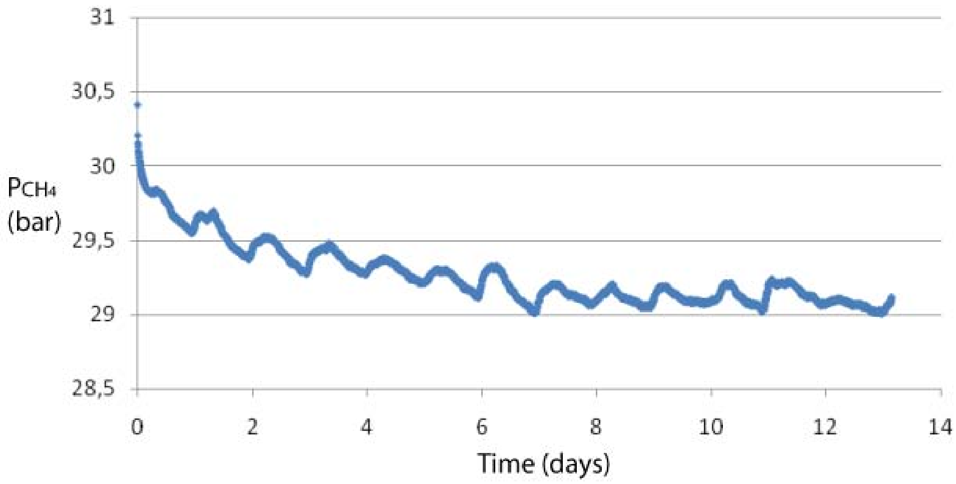

Figure 4.4: CH_4 sorption curve. The global decrease is 1.3 bar, the equilibrium is reached in 8 days.

After checking that this decrease is in accordance with the potential of adsorption capacity of coal, the amount of adsorbed CH_4 was deduced from the calculations of free CH_4 at the beginning and the end of this phase. Two equations were used to estimate the adsorbed amount: equation of state of real gases, taking account of a compressibility coefficient calculated thanks to the semi-empirical Hall-Yarborough equation and the Peng-Robinson equation as presented by Régnault (2008). The both results converge: 6.67 and 6.72 mmol, respectively.

After the flooding phase, we apply three different hydrostatic pressures and realized several samples a day, to insure the consistence of the calculated contents (Figure 4.5). At the beginning of this experiment, we chose a 35 bar pressure, but it drops during fifteen hours to 27 bar, and the same phenomenon was repeated each time we increased the pressure. Thus, the three levels of stable pressure were 27, 29 and 31.5 bar.

For each stable pressure the gas content reached the solubility equilibrium, as it is highlighted by the Figure 4.6 and according to the solubility model of Duan and Mao (2006). The first equilibrium, at 27 bar, was reached in 2 days; the following needed 24 hours. Nevertheless, there is a significant drift of the content values per day especially during the second and the third level of pressure: they oscillate 0.036 and 0.051 mol/L for 31.5 bar.

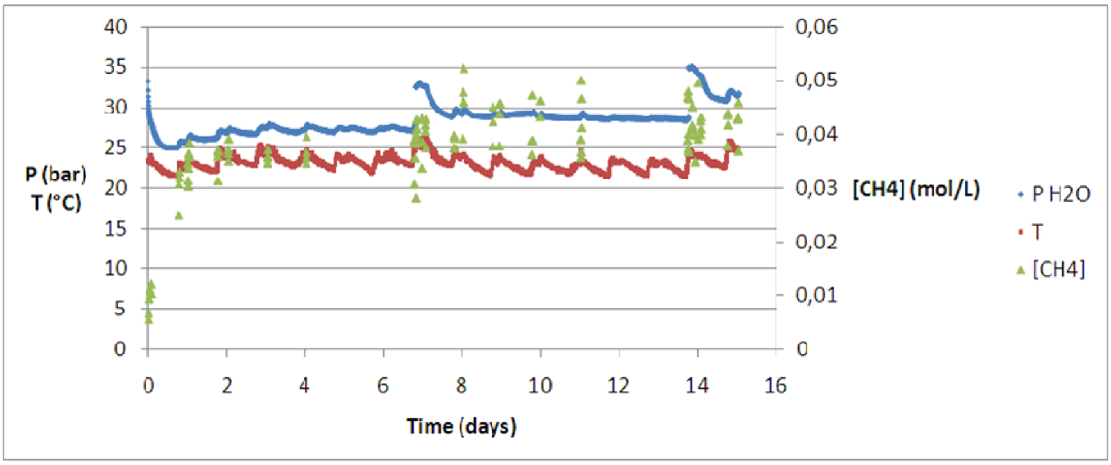

Figure 4.5: Evolution of water pressure (blue curve), temperature (red curve) and sampling contents (green triangles).

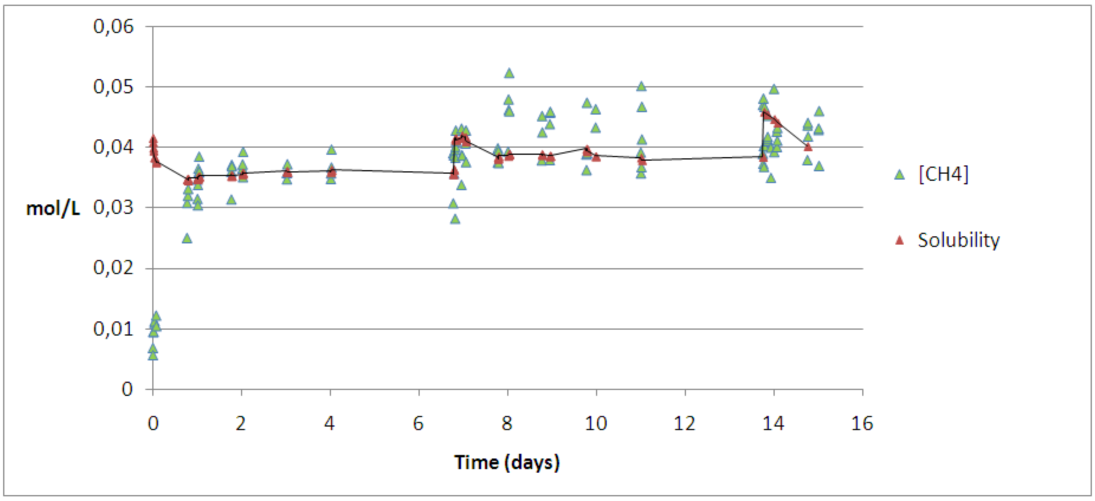

Figure 4.6: Evolution of the monitored CH_4 content (green triangles) compared to the theoretical solubility (red triangles) at the recorded conditions of pressure and temperature.

This first experiment has been analysed in detail. This analysis shows that quantity of that CH_4 released into the cell was to large compared to CH_4 adsorbed by coal. Finally, we deduce from these data that gas remains trapped between the coal grains during the flooding phase and its subsequent dissolution affects significantly the final aqueous CH_4 content measured in the water. That's the reason why (see Figure 4.6) CH_4 content measured in the cell is very close to solubility curve.

To avoid this discrepancy we decided to add a new phase to the experimental protocol. Before flooding the cell, a helium flush is now performed to avoid methane trapping between the coal grains. The new protocol is detailed at Figure 4.7.

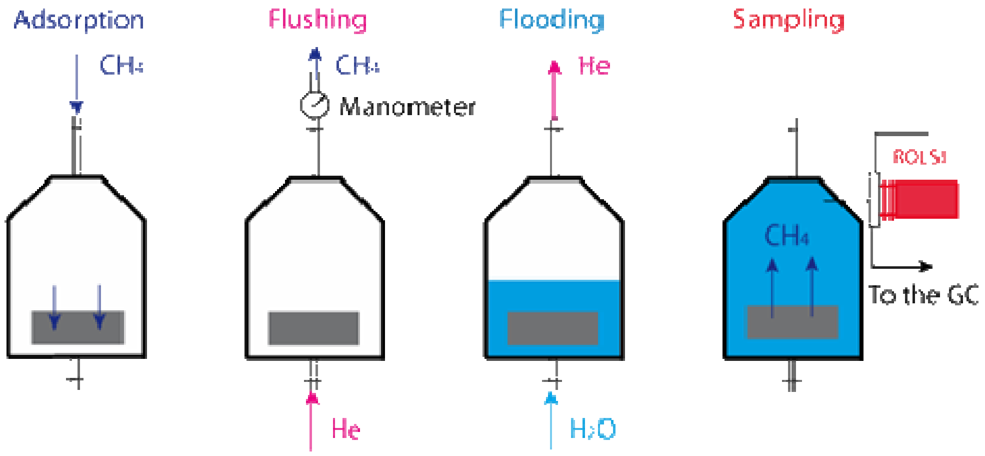

Figure 4.7: Schemes of the different steps of the final protocol. The dark rectangle represents the coal sample. The side valve is not shown; it is drained before the top valve during the flooding step. The micro-sampler is only shown on the last scheme, but is actually fixed to the cell during the whole experiment.

All these protocol enhancements were not planned at the beginning of the project. These necessary enhancement steps and the duration of experiments (20 to 30 days each!) did not let us the time to test different coals. Therefore only one coal was tested; the Saar coal sample promised the best consistency with the Lorraine coal in composition and properties compared to the other available coal samples from the Ruhr Area. However despite these successive delays the current protocol is now able to provide considerable improvement on previous methods to assess desorption of gas from water-flooded coal cores.

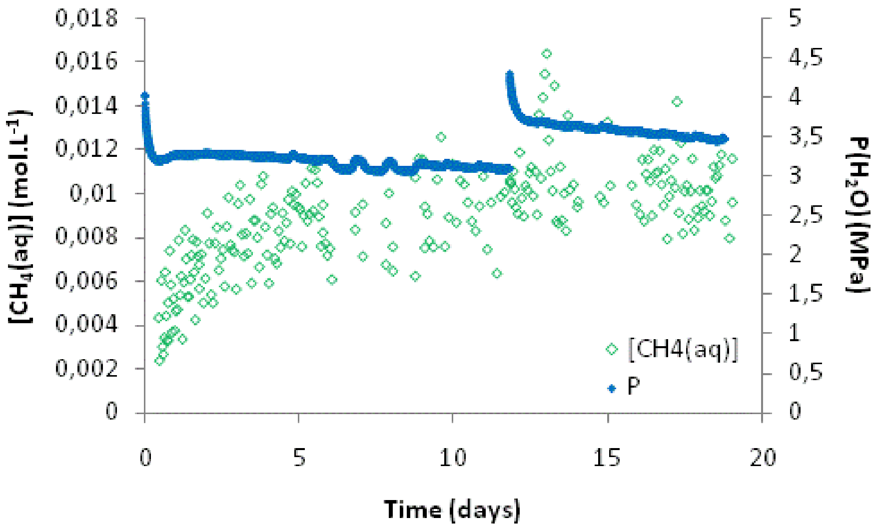

Figure 4.8: Evolution of methane concentration (green) and pressure (blue) recorded in the cell.

During this project INERIS also performed two additional experiments with this protocol. Results of one of these two experiments are detailed in the article published in the International Journal of Coal Geology (Deliverable 14, see annex). The curve of pressure evolution and methane content is presented in Figure 4.8. More detailed results are also presented in Le Gal, 2012 (PhD student implied in FLOMINET project). All the new experiments present the same results concerning evolution of pressure and gas content. With the protocol presented in Figure 4.7 the quantity of released gas is now coherent with gas adsorbed on coal and methane content in water stays far from saturation curve Figure 4.6.

We now explain the drop of pressure (Figure 4.5 and Figure 4.8) at the beginning of each level by the penetration of water in the coal, given the fact that the coal is dry at the end of gas-saturation step. A further experiment has verified this hypothesis: without preliminary gas saturation, flooding a coal sample at 30 bar has resulted in a 20 bar drop of pressure in approximately 16 hours. The kinetics of the reaction is the same of what has been observed before. The noticeable drop of pressure is related to a better availability of the pores given the fact there is no adsorbed CH_4 filling them. Taking account of these last results, the water penetration hypothesis seems to explain the drops of pressure measured.

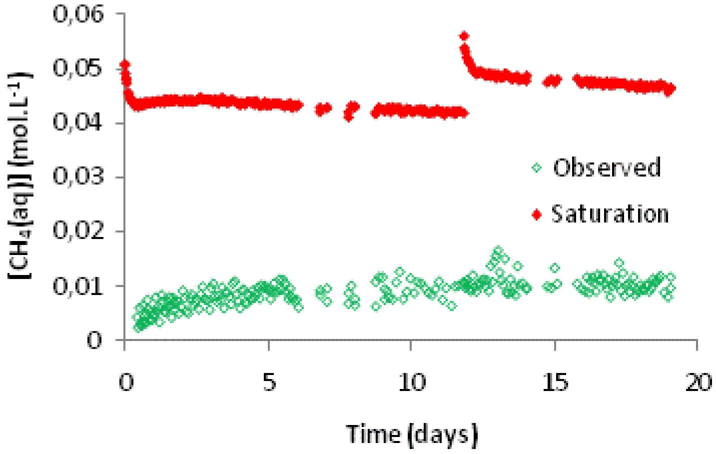

Figure 4.9: Evolution of methane concentration measured in the cell (green) and calculated saturation value for methane taking into account at the recorded conditions of pressure and temperature (red).

Concerning the evolution of CH_4 water content, the first results highlighted by the experiments suggest that the amount of CH_4 released from coal depends on the hydrostatic pressure. We assume that the emitted fraction of CH_4 is mainly due to gas desorption. For the last two experiments 68% and 85% respectively of the CH_4 adsorbed on coal was not taken in solution at the end of the experiments.

The second phenomenon highlighted by the experiments is the behaviour of pressurized water inside the crushed coal. The penetration of water in the pores results in an additional solubilisation of the gaseous CH_4 contained in the pore space. Of course, this process depends on water pressure, initial moisture of the crushed rock, porosity and surface properties.

Desorption constants have been calculated for the two last experiments (Figure 4.10). For both experiments the constant increases with pressure. The second experiment shows a lower constant because less methane was adsorbed on coal for this experiment. The blue points represent the desorption constant in the case of no methane dissolution in the pore flooding by water and the green points show the desorption constant considering that water will flood pores and dissolve all methane initially present. We can notice the increase of methane dissolved with pressure.

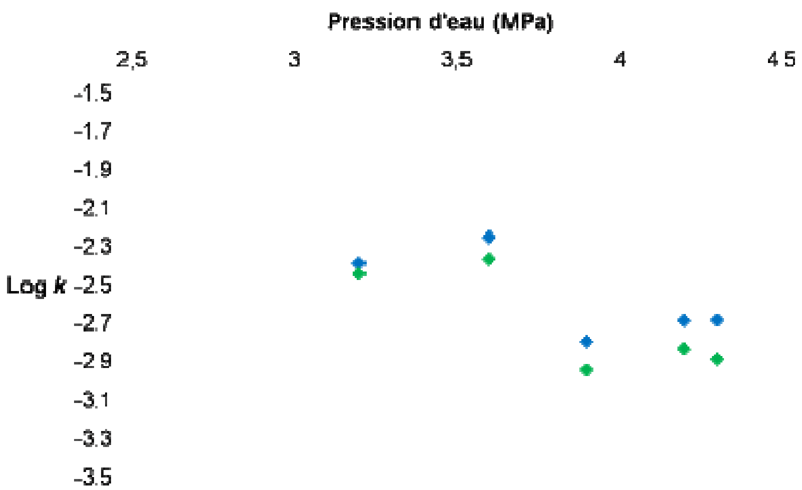

Figure 4.10: Calculated desorption constant calculated for the two last experiments and four different pressures 3.2; 3.6; 3.9; 4.2 and 4.3 Mpa.

To resume: These laboratories experiments put in evidence a significant release of CH_4 from coal to water under high hydrostatic pressure after a few days of flooding. The experimental work in this task allowed the quantification of this gas transfer from coal to water. The amount of CH_4 released depends on water pressure and coal pore size. With high pressure more water will penetrate the coal and dissolve the CH_4 contained in these pores. Therefore the pressure does not limit gas release from the coal but even has an enhancing effect.

It's the first time that these types of measurements have been performed. Even if the absolute values are probably depending on the coal type, the results obtained show general correlations and prove that CH_4 transfer into solution is possible after flooding. This result is evaluated as important for the long term management of flooding coal mines.

Task 4.3 Modelling effect of water flooding on gas emissions

In this task, we decided to focus on gas migration in flooded mine structures, considering only aqueous CH_4 migration under high hydrostatic pressure, similar to those we chose for our laboratory experiments (e.g. 30 bar), and so representative of flooded mine pressures. For that we use the reactive transport code HYTEC (HYdrological Transport coupled with Equilibrium Chemistry)

Description of CH_4 source

Describing CH_4(aq) migration through flooded coal mines induce to take account of the sorption on the coal. First, we defined in the model a mineral species corresponding to the coal, thanks to experimental and bibliographic data. In the simulations, the CH_4(aq) emission from coal is calibrated with the results of observed desorption in the CASPER cell. The sorption constant of the specific sorption sites is determined for every conditions of pressure the coal is submitted (so its depth). Considering the experimental results, it is assumed that the release/sorption equilibrium is determined by the solubility of CH_4 (calculated with the thermodynamic model of Duan and Mao, 2006). For each model simulating CH_4(aq) transport, the sites of the coal are considered initially saturated and so are its pores(the coal porosity is supposed homogeneous in our models). In the geochemical module CHESS, the CH_4 sorption on coal is considered as a chemical reaction, although it is in fact a physical phenomenon.

Dimensions and hydrodynamic parameters

For all the models we choose a hectometrical scale which includes cross-section of gallery, caved zone and wells (Figure 4.11). The boundary conditions set to induce water flow are hydraulic heads or no-flow boundary, considering a stationary state. In the last case currently developed, presented inFigure 4.11, the model is axisymetrical, in order to evaluate the impact of a pumping zone.

The hydrodynamic parameters are picked up in or defined from bibliographic data. It is relatively easy to find these data for the Trias sandstones of the Lorraine basin (e.g. Pilch and Salmon, 2004; Pokryszka, 2005), nevertheless it is not the same for the Carboniferous formation (Table 4.2). That is why its parameters are chosen according to other measurements (e.g. Fabre and Gustkiewicz, 1997). For each zone, the pore diffusion coefficient **D** is calculated from the porosity **ω** and the effective diffusivity of CH_4 in water: 1.62^e-9 m^2/s (Lide, 2008), according to the equation $\mathbf{D = D(CH_4)_{eau}*\omega^2}$ .The developments of the models aim to simulate CH_4(aq) transport in the Carboniferous, where the old mine structures (caved zones, galleries) are (Figure 4.11, Table 4.2). Assuming that the Permian formation which separates Trias and Carboniferous is impermeable and so that there is no connection between the two aquifers, our models are focused on CH_4 transport in the Carboniferous.

Impact of water pumping

The currently developed model aims to approach realistic case of coal basin of Lorraine. Several pumping wells, in this area, are controlling the mine water flooding in order to avoid the contamination of the Trias aquifer. A conceptual scheme of the hydrogeological context is shown by Figure 4.11. Assuming that the two aquifers have no interaction due to the Permian formations and in order to simplify the calculations, only the Carboniferous zone is represented in the model. The boundary conditions are as follows: upstream we set a constant hydraulic head, but downstream, there is a no-flow boundary because it is considered as the center of the pumping wells. This model is axisymetrical: the axis is the downstream limit of the domain. This configuration is the best to simulate and characterize flow and transport around the pumping wells. However, concerning the flow in the caved zone and in the damaged zone, it is more consistent to induce a gradient between the boundaries, especially if the structures are distant from the wells; for now we worked with in a axisymetrical case.

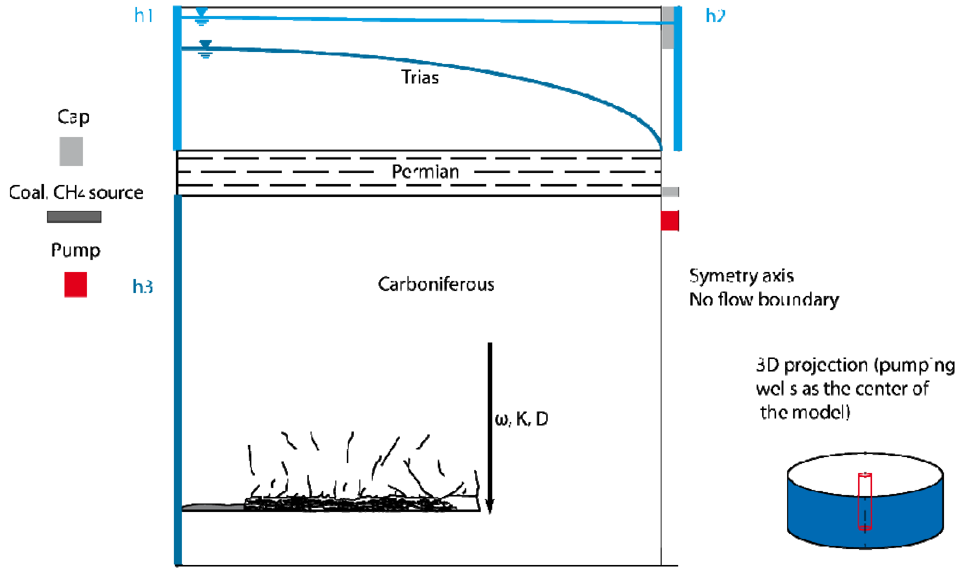

Figure 4.11: Conceptual scheme of the hydrogeological context of the current conceptual model. Although this figure shows two aquifers our simulations concern only to the carboniferous zone.

Table 4.2: Chosen parameters for the different zones of the models.

Zones	ω	K (m/s)	D (m^2/s)	d (m)	S (m^{-1})	Notes
Carboniferous	0.2	$1e^{-7}$	$6.48e^{-11}$	1	$1e^{-4}$	ω, K: consistent with limestones (Fabre and Gustkiewicz, 1997) and molasses of Bas-Dauphiné (de la Vaissière et al., 2006)
Pumping wells	1	$1e^{-4}$	$1062e^{-9}$	0.5	$1e^{-7}$	D, d : pure water values
Damaged rock	0.25	$5e^{-6}$	$1,0125.10^{-10}$	0.7	$1e^{-4}$	Intermediate values
Caved zone	0.3	$5e^{-5}$	$1,98.10^{-10}$	0.7	$1e^{-7}$	Arbitrary values deduced from the previous ones

Before to take account of CH_4(aq) transport, we validated the simulated hydrogeology comparing the head profile of a simplified model with analytical calculations for which the Dupuit solution was used. We considered a head of 190 m as the upstream boundary condition, corresponding to the 90 m of water pressure at the top of the Carboniferous zone, and a 0.36 m3/h equivalent pumping rate (adjusted to obtain realistic head profile).

Presently we are looking at the CH_4(aq) migration, and the necessary time to reach the well, as illustrated by Figure 4.12. In these simulations, the difference to Figure 4.11 is that the caved zone is connected to the pumping well.

In both cases presented below the parameters are all the same except for the permeability of the caved zone. In the more permeable case, it is obvious that even with a shorter period, the CH_4(aq) plume is practically filling the caved zone. On the other hand, a lower permeability of the caved zone (1.10^{-5} m/s) enhances the penetration of the plume in the damaged rock over the caved zone (Figure 4.12).

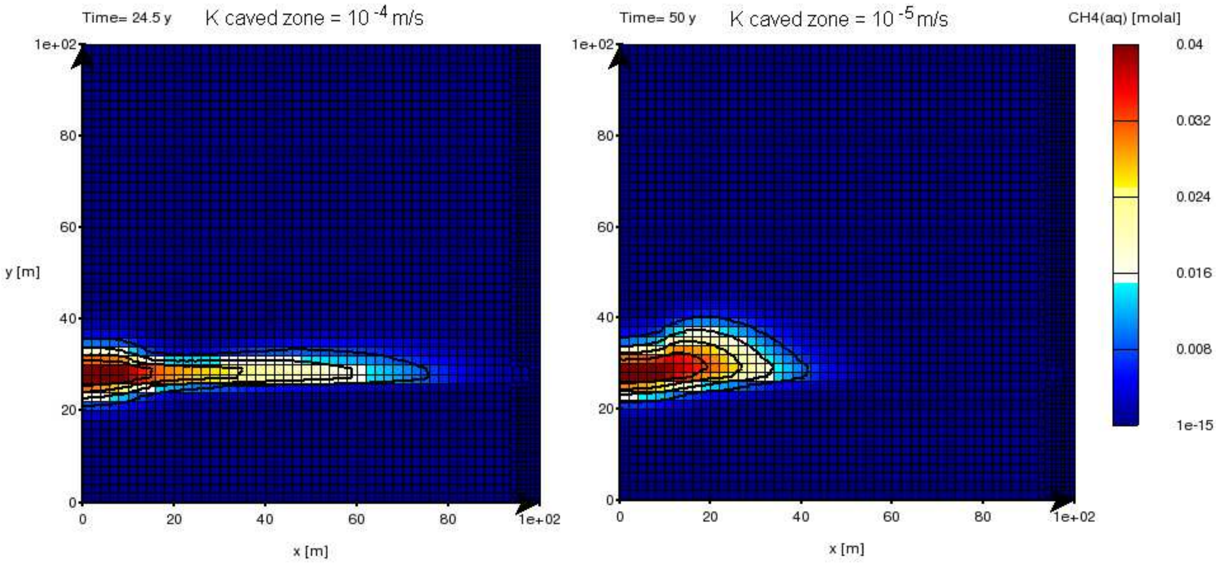

Figure 4.12: Migration of $CH_{4(aq)}$ from a source zone through a caved and a damaged zones. Comparison of the results obtained with a permeability of $1 \cdot 10^{-4}$ and $1 \cdot 10^{-5}$ m/s for the caved zone. The $CH_{4(aq)}$ content in the source zone is overestimated toward the solubility at the simulated condition of pressure (hydraulic head = 190 m).

Figure 4.13 illustrates the case of CH_4(aq) migration from two source zones on either side of a caved zone ($K = 10^{-5}$ m/s) disconnected to the wells, and considering a pumping rate of 18 m^3/h. The hydrodynamic parameters are the same as previous. The aqueous CH_4(aq) content is different to the scenario shown in Figure 4.12, due to the fact we consider a lower solubility, adjusted to the water pressure the coal is submitted. It shows that the intensity of pumping has a great influence on CH_4 migration, as a function of rock properties and distance.

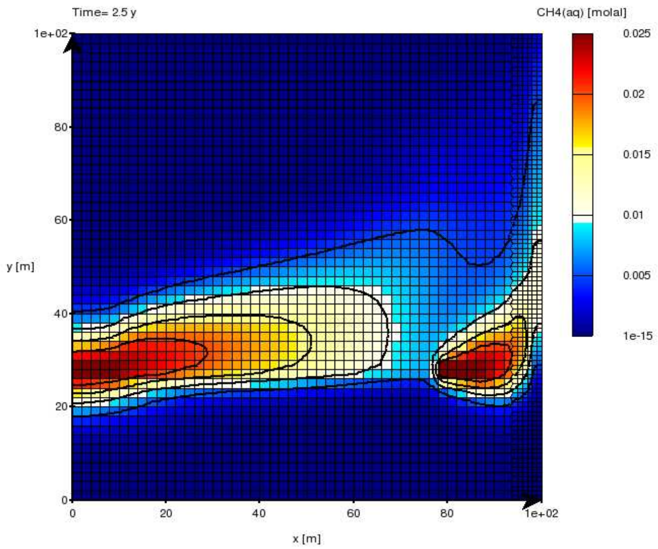

Figure 4.13: Migration of $CH_{4(aq)}$ from residual coal through a caved zone and considering a pumping rate of 18 m^3/h.

The modeling study start during FLOMINET project is still in progress. During the FLOMINET project, many possibilities to use HYTEC in simulating CH_4 migration in old mine structures were considered. Several conceptual models have been validated and thus ensure the possibility to apply them in different configurations. Other models are in development to precise the influence of the permeability gradient and the necessary time for the CH_4(aq) to reach the pumping well. The works performed in this task show that the modeling tools developed with HYTEC are able to be to extend their application at different conditions of pressure, dimension and hydrodynamic properties in mining context.

WP 5 Reporting and Coordination

Within this project intensive interaction of all Partners with the central role of DMT in developing the different site models has been realised for the processing of the individual tasks. For realisation of this standard the first coordination meeting has been held in Essen 15th – 16th Sept 2008. The presentations and discussions included the individual work programs and concepts for the Box-model development and implementation with the partners. For initial start-up the meeting included site visits of a mine gas exhaustion system at Gelsenkirchen (Hugo Mine) and of the Design School Zollverein with a mine water climate control system installed 3 years ago.

Following this meeting references and guidelines for data collection for the particular model types have been distributed to the partners. For quick and easy dissemination of reports, results, data and software a FTP (File Transfer Protocol) server has been installed by DMT. FTP is the protocol to transfer data between server and client. Access to this data storage unit is possible using address and password known to FLOMINET partners only.

Main focus of the initial project period was the model Asturias with no precursor model existing. Because site data have been available at an early stage work on this model could start earlier in comparison to the work plan. Work on most of the other Tasks planned for the first project period started immediately after receipt of the contract.

In order to support this process a bilateral workshop has been held in Oviedo (10th – 12th Feb 2009) with the partners from HUNOSA and AITEMIN to discuss the geological und hydrogeological setting of the mining site in Asturias. With a field trip to all shafts and main mine water discharges in the investigation area the site conditions of the coal bearing strata and the hydrological properties have been demonstrated for an overall understanding of the site. The key points for the built up of the Boxmodel Asturias were arranged.

A second DMT workshop took place in Katowice (27th – 30th Apr 2009) with the partners from GIG. During this workshop DMT gave an introduction into the Boxmodel and the GIG dataset has been discussed. The basic structure of the Boxmodel for the USCB including mine boxes and upper groundwater layer in the overburden was fixed. Possibilities for integration of the optimisation tool and transfer of GIS data into the Boxmodel were discussed. A meeting with staff from CZOK (Central Mine Dewatering Department) was held.

The first Technical Report has been completed and sent to the Commission in March. These results of the first reporting period were presented by the Coordinator to the TGC1 Technical Group in Katowice 13th May 2009. The report was recommended for approval. The results of the discussion have been forwarded to the partners. The second Technical Report has been completed and sent to the Commission in September 2009.

After a project runtime of one year the work progress on most of the Tasks had been on schedule. Main delays had been related to data collection for mine gas extraction in the Lorraine coal basin but this could be compensated by using extraction data from the Ruhr area for calibration calculations. Work on Task 2.2 started delayed during the GIG workshop in Katowice after discussion of the general model set-up.

The second coordination meeting was held at INERIS in Verneuil-en-Halatte 2nd – 4th June 2009. After a field trip showing mining influences to the surface and mine gas exhalations the meeting comprised the presentation of the actual work status and the discussion of the first Technical Report. The third day a workshop was held by DMT showing the mode of operation of the Boxmodel and basic and advanced tools.

The third coordination meeting took place in Oviedo organised by HUNOSA 19th – 20th Nov. Focus has been the work progress near halftime of the project with regard to the Mid-term report. Handling of water balances at the Upper Silesian Coal Basin and in Asturias gave reason to intensive discussions. Highlight of the field trip was the visit of the geothermal pilot project already realised and far beyond project schedule.

The Mid-term Report has been completed and sent to the Commission in March 2010. The project results have been presented by the Coordinator to the TGC1 Technical Group in Marl 6th May 2010.

The report was recommended for approval. The results of the discussion have been forwarded to the partners.

A further DMT-workshop took place in Katowice February 15th - 18th 2010 with the partners from GIG. A calibration routine for the large scale coupled ground water - mine water model has been jointly developed with focus on the calibration of the sinking rate from ground water layer into the mines. The results of Boxmodel und intermediate MODFLOW model runs could be compared and promptly converged. Another topic was the implementation of realistic pumping scenarios of CZOK especially the implementation of characteristic pumping curves and pipe pressure losses.

The fourth coordination meeting was held at GIG in Chorzów 8th – 9th June 2010. Beside the presentation and discussion of the projects results special focus was on the presentation of FLOMINET software optimisation tool. The future user of this software Centralny Zakład Odwadniania Kopalń (CZOK) was involved in the meeting and into the field trip the next day. This included a visit to the underground stationary pumping station at Barbara-Chorzów Mine and to the submersible pumping station at Grodziec mine. This gave occasion for discussion of the USCB water management concept.

The project status after two years showed two main topics for project management in the last project year. This was the completion of the optimisation tool and its application for further testing and the enhancement of the gas modelling. The realisation of these tasks required a longer period than scheduled. Furthermore a delay of laboratory experiments on gas emissions arose by requirements for the equipment.

These problems have been counteracted by several additional workshops starting with a further bilateral DMT – INERIS workshop at Verneuil-en-Halatte (Nov 30th – Dec 1st 2010) for support of Boxmodel application on gas modelling. Beside adjustment of the model approaches of DMT and INERIS and the particular input data, the calibration of the Lorraine Boxmodel with respect to prognosis of gas extraction has been discussed. Different coal samples from German coal mines in the Ruhr and Saar area have been purchased by DMT and provided to INERIS for use in their experimental program.

The DMT model support has been continued with a supplementary workshop with GIG in Katowice in the beginning of April 2011 (4th – 8th). Main topics were the final calibration of the USCB Boxmodel (combined model of mines and overlaying aquifer, quality prognosis) and the coupling with the Optimisation tool. Beside that the newest version of the Optimisation tool has been be applied to the Boxmodel Ruhr and GIG as the tool developer gave a training course on installation and application.

The fifth coordination meeting was held at the AITEMIN office in Toledo 16th – 17th June 2010. All results presented have been discussed with regard to completion of the work and if necessary adjustment of the work. The reporting procedure with a special focus on reporting of the deliverables has been discussed.

There has been no field trip but again a special workshop on the Optimisation tool (WP 2). GIG has presented the recent version of the program tool. After installation of the program to the computers all partners had the chance to test the software with their individual Boxmodel. Bugs have been identified and a working schedule with functional requirements has been developed. Following that a workshop with DMT, AITEMIN and HUNOSA has been held on the Asturias Box-model. Some model enhancements could be realised and a collaborative test of model functions and use has been conducted.

The sixth and last coordination meeting has again been organised by DMT 17th – 18th May 2011 in Essen. This meeting focussed on a last review of the work status for definition of work corrections. In advance of the meeting the partners have checked their work status and discussed corrective actions with the coordinator. Furthermore procedures for the final reporting (technical and financial) have been agreed.

The second day has again been used for several workshop groups: After presentation of a new version of the Optimisation Tool GIG instructed implementation and use to the partners. The application on the Ruhr area has been discussed intensively. DMT gave support to GIG in implementation of the Boxmodel mass transport tool. The feasibility of projects of hydroelectric and geothermal energy production in the Ruhr area has been verified by a calculation tool programmed by HUNOSA. The development of concentrations and flow rates at Barredo shaft for calibration of mobilisation and mass transport in the Asturias Boxmodel have been checked by DMT and HUNOSA.

2.4 Conclusions

WP 1 Development of numerical site-models for mine water rebound in large underground mine networks

The Boxmodel concept proved as a variable and capacious tool for many different applications. After developing the mass transport properties in precursor project the focus of this work package was the integration of an additional gas phase and heat as transport parameter. The other challenge has been the implementation of the specific spatial settings different from the hitherto main application in the Ruhr Area. It can be stated that all demands could be met required for the model results. Main advantage of the Boxmodel is still the geometric variability specific to mining applications. However also conventional surface near aquifers can be modelled and coupled to the mine voids. This allows for a closed groundwater – mine water balance.

WP 2 Optimising of water management in areas of interconnected systems of underground coal mines

Work package 2 consisted of 2 main parts. In the first part the site characterization and development of a suitable database have been performed. The work consisted mainly in in-depth survey of existing maps, cross-sections and profiles of shafts and boreholes. Also large amount of data about the water level and pumping rates as well as some data about chemistry all over the model area have been gathered. In the second part, optimization software has been developed tailored according to the needs of mining industry and the water managers. The main feature of the software is to group all important aspects of mine water management under one umbrella of user-friendly software interface. The software was then applied primarily in Upper Silesian Coal Basin with several scenarios for future mine water level development. In the end the software has been successfully coupled with local Boxmodels and applied in the Barredo water province (Asturias) and a water province in the Ruhr area.

WP 3 Application for recovery of energy from mine water rebound

The works carried out in WP3 show the real possibility of developing renewable energy from water rebound in abandoned coal mines. Many data collected from several mine sites in the region of Asturias (northern Spain) enabled to carry out a detailed characterization of the mines and a study of these structures in order to use them as systems of hydroelectric and geothermal use.

Taking into account the interesting hydrogeological characteristics of San Fernando-Urbies mining structure a Micro-hydroelectric plant (power output less than 100 KW) was designed. The analysis of investment and exploitation costs carried out in this case shows that the development of this hydroelectric plant would only be economically feasible when the Spanish regulations and the special discounts (bonus) can be applied. Nevertheless, this exploitation system could be extrapolated to other sites with similar hydrogeological characteristics and special conditions of demand and pricings.

Furthermore, the abandoned and flooded mine of Barredo was characterized in order to develop a geothermal exploitation. This was based on the fact that this mine receives an important underground mine water flow over the year and has temperature range of up to 5ºC between the top level and the lower water layer within the shaft. The excellent results obtained during the characterization of this mine drove to the implementation of a real scale project even though only a desk study was initially planned. This expertise was applied to a real scale for geothermal energy supply by means of water from the mine to two new buildings built at the Barredo Campus of the University of Oviedo, located very close to Barredo Shaft. A detailed study on the thermal production comparing conventional systems (natural gas or diesel oil boilers) to geothermal heating/cooling system using mine water showed that a geothermal system with commercial heat pumps using mine water can be technical feasible and economic viable.

In conclusion, a detailed study of the different abandoned mining structures in European coal basins could allow development of interesting exploitation systems using the geothermal potential of the mine water and the big hydraulic head that occur in some mines. These renewable energy systems could solve energy shortage that exist in many places taking advantage of what it used to be a problem in the mines (water rebound and drainage). Likewise, these exploitation systems could help to reduce the atmosphere CO_2 emissions.

WP 4 Application for management of gas emissions related to flooding process

Field experiments show that at short time scale flooding stop gas emissions from coal. To investigate gas behaviour at larger time scale we develop the experimental device CASPER. It makes it possible to monitor an aqueous CH_4 concentration under different hydrostatic pressures, with minimal disturbance in the cell. The results highlight the possibility to release CH_4 from an initially saturated coal even under a hydrostatic pressure corresponding to more than 300 m water column. In the experiment presented here, the difference of pressure levels remains relatively low; therefore, the impact of pressure increase on CH_4 release is not significant from one pressure equilibrium to another. However, the results suggest that the amount of CH_4 released from coal depends on the hydrostatic pressure. According to the experimental data and the modelling works, flooding coal mines could trigger a release in CH_4, depending on the amount of gas contained in the coal seams.

WP 5 Reporting and Coordination

There have been two focuses of coordination activities:

- Instruction of Partners and control of interaction by DMT developing the different site models with the partners.
- Identification of gaps in the work realised and adjustment with the work program given in the Technical Annex.
-

Both items have been realised by workshops organized by DMT either bilateral during specific meetings or within the frame of the regular coordination meetings:

1. Oviedo (February 10th – 12th 2009) with HUNOSA and AITEMIN
2. Katowice (April 27th – 30th 2009) with GIG
3. Verneuil-en-Halatte (June 2nd – 4th 2009) during second coordination meeting: mode of operation of the Boxmodel and basic and advanced tools.
4. Katowice (February 15th - 18th 2010) with GIG
5. Toledo (June 16th – 17th 2010) during fifth coordination meeting: a) Optimisation tool by GIG with all partners b) with AITEMIN and HUNOSA on the Asturias Box-model.
6. Verneuil-en-Halatte (Nov 30th – Dec 1st 2010) with INERIS
7. Katowice (April 4th – 8th 2011) with GIG
8. Essen (May 17th – 18th 2011) during sixth coordination meeting: a) Optimisation Tool instruction by GIG b) Implementation of the Boxmodel mass transport with GIG c) Calculation tool instruction for geothermal energy feasibility

The partners have been regularly pointed to weak spots in their results. A detailed check of the work program with the results achieved so far and the comparison of actual situation with initial planning has been discussed during all routine coordination meetings. Some solutions have been developed during the meetings and the workshops often associated with. Others have been developed subsequently and transferred to the partners via email or ftp-server. The additional often bilateral meetings proved as essential for the project progress and can be considered as main reason for the results achieved.

2.5 Exploitation and impact of the research results

WP 1 Development of numerical site-models for mine water rebound in large underground mine networks

The achievements of WP1 consist - beside of the scientific developments, described in the sections above – in 4 running boxmodel applications at all sites of the partner countries. The models were not only implemented but also used by the partners for prognoses calculations and are available for further application.

The boxmodel with the now higher practicability and the new features – triggered by demand of the partner's sites – is a useful tool for all large mining areas in Europe. The results of the development were presented at the mining academy in Freiberg in 2010, at the European coal conference in 2010 (Darmstadt). The developed tool "high turbulent flow" was accepted by the German mining authority in North-Rhine-Westphalia to evaluate sudden break-through scenarios between abandoned and active mining areas and is now in daily use at DMT.

WP 2 Optimising of water management in areas of interconnected systems of underground coal mines

The main impact of WP 2 is the availability of the developed optimization software. The main feature of the software is to group all important aspects of mine water management under one umbrella of user-friendly software interface. The aspects are: operational costs for running the pumping station used for mines dewatering, calculation of loads of contaminants discharged to surface and groundwater, possible income from the use of good quality mine water and the possibility of use of the geothermal energy from mine water. Providing all these aspects under one user-friendly umbrella will allow for effective transfer of innovative expert knowledge towards decision-makers. As a consequence, this will assure that the decisions of regional impact are made with proper consideration of up-to-date knowledge.

WP 3 Application for recovery of energy from mine water rebound

It seems evident that taking into account the results obtained from the work performed, in a near future HUNOSA could face the construction of a micro-hydroelectric plant at San Fernando-Urbiés mining complex, as long as the Spanish energy law maintains a high sales price due to the bonus for renewable energies compared with other energy sources, although nowadays the tendency is to lower this bonuses from year to year. Besides it, AITEMIN could support the project developing several engineering activities like the plug construction, the mine gallery conditioning or the monitor and control system of the installation set.

It is important to remark that this kind of hydroelectrical production system could be easily extrapolated to any other mining region where standard mountain mining exploitation systems were or are being carried out; no matter if the extracted mineral is coal or any other one. The only condition in order to plan a similar system is to allow for a proper discharge outflow of water. However, the most profitable situation occurs for old mountain mines connected to the surface only with galleries on the lower floors. These structures are relatively common in old exploitations in mountain areas in Europe as well as other regions. Nevertheless, to apply this technology in other regions it would be necessary also to have a favourable energy sale bonus. Likewise, developing an accurate study of the hydrogeological behaviour of the mining structure for each case is an important task.

Concerning the geothermal use, the exploitation system developed at Barredo mine water in order to condition the University buildings is a great innovation that could be applied in many other places and countries. In fact, HUNOSA is planning to apply this technology in a new hospital located in Mieres (Asturias) in order to both reduce energetic and economic cost, and develop an environmentally friendly system to provide heating and cooling, taking advantage of the mine water which was considered as a waste.

Likewise, according to studies carried out by GIG, in the area of Upper Silesian Coal Basin there are 29 active and 30 former inactive mines at present. After a preliminary analysis its can say that some of them are potential source of geothermal energy from water pumped out to the surface. These inactive mines are optimal places for the use of geothermal energy for big objects for example shopping malls, sports halls, etc. It is because of normalized legal situation and a lack of mining activity in inactive mines. In the terms of economy there is a possibility for use of geothermal energy but only if two basic conditions are fulfilled:

- it is confirmed that the water will be pumped from an inactive mine to the surface for a long time with stable quantity
- close to a pumping station there will be modern or renovated building for which costs of heating by using geothermic energy will be cheaper than by using traditional energy.

Taking above-mentioned conditions into consideration GIG can to include former inactive mines: Jan Kanty, Saturn, Katowice, Centrum, Piast, Ziemowit and Sobieski into perspective areas for potential use of geothermal energy. More attention should be paid to the whole region of Katowice where, with no major obstacles, it is possible to use geothermal energy for heating of two objects: the entertainment-sports hall called Spodek next to the shaft of inactive mine Katowice and the shopping mall "Silesia City Center" that is built directly next to the shaft of inactive mine Kleofas.

Recently there are plans to create a few large pumping stations from which a significant quantity of mine water will be pumped (mine water coming from many adjacent inactive mines). This project includes mines: Saturn and Pstrowski. This should be considered while creating long term plans of geothermal energy use.

These technologies would allow for decreasing the CO2 emissions that is currently one of the most important environmental concerns. All these results and their industrial applications could be exposed in futures mining congress like IMWA 2011 that will be hosted in Aachen (Germany) in September.

WP 4 Application for management of gas emissions related to flooding process

Results of WP 4 are of two orders:

On the one hand, now, at the end of FLOMINET project INERIS own laboratory de-vice and modelling tools to study gas migration (CH_4) in a post-flooding context, under dissolved phase. The research works developed to obtain these new tools are complementary of modelling tools developed by DMT in WP 1. Indeed box model allowed to studying gas flow during the flooding phase. The works realized during FLOMINET project prospect the whole migration mode of gas during the flooding of a coal mine.

On the other hand, the results of the investigations show that the gas flow is maximal during the flooding. During this phase it's possible to performed gas recovery for energy production.

After the flooding, at short time scale, flooding stop gas emission from old mining voids. So considering public safety, flooding of mine is a way to avoid gas migration from old mines and to reduce hazards at surface. But at longer time scales, first research works allowed by FLOMINET project show that a put in solution of gas from coal is possible, and that migration under dissolved phase of these gases is possible in the mine aquifer.

WP 5 Reporting and Coordination

A first presentation of project related results could be realised during the 61. "Berg- und Hüttenmännischer Tag" June 10^{th} – 11^{th} 2010 in Freiberg (title: Qualitätsentwicklung der Grubenwässer bei der Flutung von Steinkohlen- und Erzbergwerken): M. Eckart, P. Rüterkamp, C. Klinger, H. Kories, G. Gzyl: Qualitätsentwicklung der Grubenwässer bei der Flutung von Steinkohlen- und Erzbergwerken.- 61. Berg- und Hüttenmännischer Tag am 10. und 11. Juni 2010 in Freiberg/Sachsen, TU Bergakademie Freiberg.

Results on the gas migration modelling have been presented at the IMWA (International Mine Water Association) Congress in Sydney, Sydney, Nova Scotia, Canada Sept. 5th – 9th 2010. The presentation has been published in the Conference Proceedings:

Le Gal, Nils; Lagneau, Vincent; Charmoille, Arnaud (2010): Mechanisms of gas migration in flooding post-mining context. – In: Wolkersdorfer, Ch. & Freund, A.: Mine Water & Innovative Thinking. – p.483 – 487; Sydney, Nova Scotia (CBU Press).

Additionally the results of Laboratory work have been published in the International Journal of Coal Geology and as PhD:

LE GAL, N.; LAGNEAU, V.; CHARMOILLE, A. (2012): Experimental characterization of CH_4 release from coal at high hydrostatic pressure. - International Journal of Coal Geology, 96-97, pp. 82 – 92.

LE GAL, N. (2012): Libération et migration du méthane depuis le charbon dans un contexte hydrogéologique post-minier Développement d’un protocole expérimental et approche numérique. - PhD, Ecole supérieur des mines de Paris.

The entire FLOMINET project has been presented at the European Coal Conference 2010 as part of the Conference GeoDarmstadt 2010, October 10th – 13th. An abstract has been published in the Conference Proceedings:

KLINGER, C., CHARMOILLE, A., BUENO. J., GZYL, G., GARZON SÚCAR, B. (2010): Strategies for follow-up care and utilisation of closing and flooding in European hard coal mining areas.- In: Hoppe, A., Röhling, H.-G., Schüth, C. (eds.): GeoDarmstadt2010 – Geowissenschaften sichern Zukunft, SDGG (Schriftenreihe der Deutschen Gesellschaft für Geowissenschaften), 68, S. 316 – 317, Stuttgart.

A full article publication with the same title has been published in an ECC8 special volume of the International Journal of Coal Geology. The paper is be peer-reviewed and has been published online and as print version:

KLINGER, C., CHARMOILLE, A., BUENO. J., GZYL, G., GARZON SÚCAR, B. (2012): Strategies for follow-up care and utilisation of closing and flooding in European hard coal mining areas.- International Journal of Coal Geology, 89, Special Issue European Coal Conference 2010, 51 – 61.

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APPENDICES

LIST OF ACRONYMS AND ABBREVIATIONS

CASPER	CApacité de Sorption à hautes Pressions lors de l'Ennoyage des Roches / sorption capacity at high pressures during rock flooding
CHESS	CHemical Equilibrium of Species and Surfaces (geochemical calculation module)
CZOK	Central Mine Dewatering Department
EER	Energy efficiency ratio
EVE	Ente Vasco de la Energía (Spanish energetic agency
H	Hydraulic head
HYTEC	Hydrological Transport coupled with Equilibrium Chemistry (Mines ParisTech, Hydrodynamic and Reactions laboratory)
kW	Kilowatt
L	Litre
Q	Volume (e.g. in m^3/min)
ROLSI™	Rapid On Line Sampler Injector
s	Second
TIG	Tungsten inert gas welding
USCB	Upper Silesian Coal Basin
$_{(g)}$	Gaseous
$_{(aq)}$	Aqueous

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The Boxmodel has been enhanced for innovative processes like coupled gas-water flow, energy production, turbulent flow and heat transport. Coupling of mine water and surface water models allows now for examination of closed water balances. All site models have been supplied with the required functionalities. The model calculations have been used for prognosis calculations and planning.

An Optimisation software tool has been developed and the programming includes data exchange with the site-Boxmodels. Therefore the impact of strategic options of mine water management on costs and environment can be better predicted an evaluated.

It has to be highlighted the realisation of the geothermal pilot project by the Spanish partners. This activity adds a new example for use of mine water for production of renewable energy in Europe. Feasibility checks show however that in spite of general cost benefits of the recoverable mine-related energy sources site specific development costs might compensate the cost advantage. Model calculations for hydrothermal energy use have proved the importance of correct design of the hydrothermal regime for stable temperature conditions.

The laboratory experiments on gas sorption on coal have provided coal specific data which can be used for gas transport calculation in the flooded mine now. The gas transport model has been developed for small scale realistic settings and is under preparation for a larger scale. Therefore two models describing the gas history starting with active mining, flooding up to the after flooding phase are available now.

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