Groundwater-Monitoring
based on dynamic co-operative eGovernment-Processes

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Summary

As a result of the pilot-project "Grundwasser-Online" the supervision and the active controlling of large monitoring- and catchment-areas are realised by a co-operative integration of all related institutions, a synchronisation-process to combine all distributed data into one central server database, and a high-level eGovernment-Service to provide evaluated information over the internet. Based on this software system the local authorities are able to supervise the groundwater-levels and to find adequate decisions, which finally result in official permissions for the usage of groundwater-reservoirs by the water supply companies.

1 Introduction

Nowadays nearly all German cities and communities use internet representations in order to provide specific information to the public. Simple eGovernment-Services like formulas, e.g., parking permissions and clearance certifications, are offered to the public in order to save time and expenditure on both sides - the local authority and the public. Dynamically generated information is usually not provided in such internet representations because of the complexity of the dynamic information computing, the variety of required data, and the underlying workflows to keep the data in an actual state. Even in those fields, where the information is not provided for the general public but for restricted user groups with personalized accounts, no dynamic internet-based support of eGovernmental processes is given. Due to this fact the water supply companies in the south of the state of Hessen in co-operation with the local authorities, the Regierungspräsidium Darmstadt, initiated the common pilot-project to enable an efficient dynamic supervision and co-operative management of the groundwater situation.

1.1 Hydro-Geological Boundary Conditions

The geographical borders of the area in which this project is located are given the River Main in the north, the river Neckar in the south, the river Rhein in the west and the mountain chain Odenwald and the "Sprendlinger Horst" in the east. The described area, which is called "Hessisches Ried", has a size of about 1238 km² (Figure 1). In this area, about 800.000 people reside in 36 cities and townships. The Hessische Ried is a part of the "Rheingraben", a 300 km long and about 35 to 40 km wide fosse. Because of its geological genesis, the surface is very flat and the soil is predominated by gravel and sand. So, this region is one of Germanys most important groundwater reservoirs.

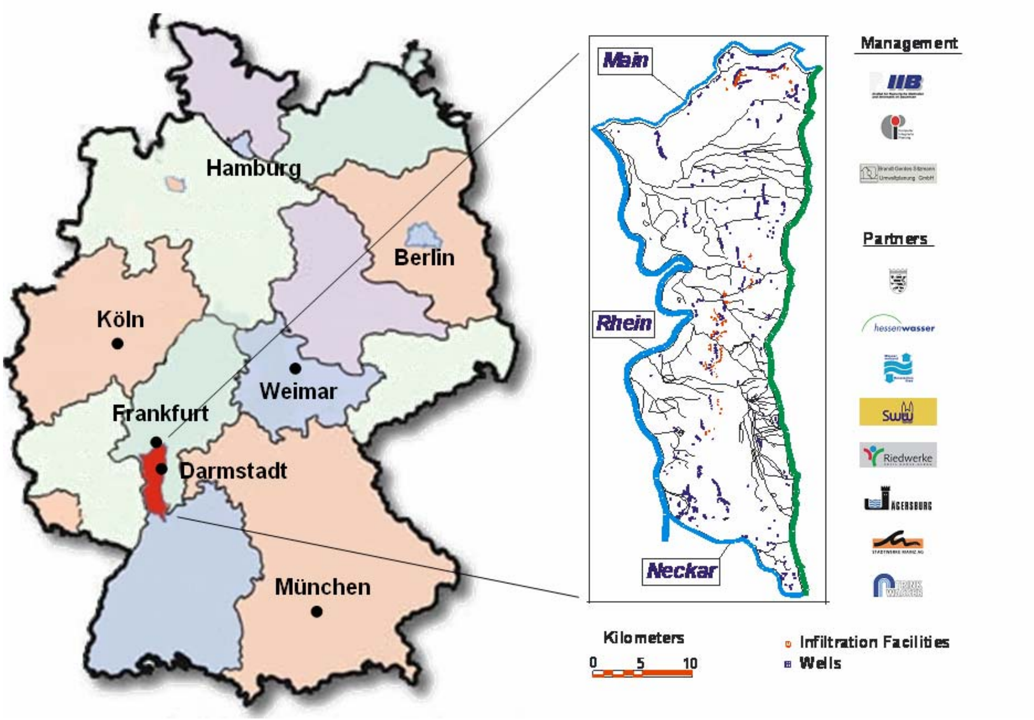

Figure 1: Map the project area and the involved partners

1.2 The groundwater situation

The management of groundwater resources for the supply of German cities and suburban areas has become a matter of public interest during the last decades. Negative headlines especially in the Rhein-Main-Area newspapers dealt with cracks in buildings as well as damaged woodlands and inundated agriculture areas as an effect of varying groundwater levels.

Due to the growing population and the rapid industrial development in the late sixties, the big cities in the Rhein-Main-area like Frankfurt discovered the “Hessische Ried” as their groundwater reservoir. Many wells were built and huge amounts of water were pumped out of this area. The groundwater level sank dramatically in the early seventies. Cracks in houses as a consequence of settlements, dried out agricultural areas and damaged woodlands were the results (Figure 2).

Figure 2: Effects of low-state groundwater levels

As an effect of these circumstances, the quantity of the convey water was decreased. Furthermore, water-reduce-programs for the public were initiated and infiltration facilities which discharged Rhein-water into several areas of the “Hessische Ried” were built. These corrective measures took effect and the groundwater level recovered. (Figure 3)

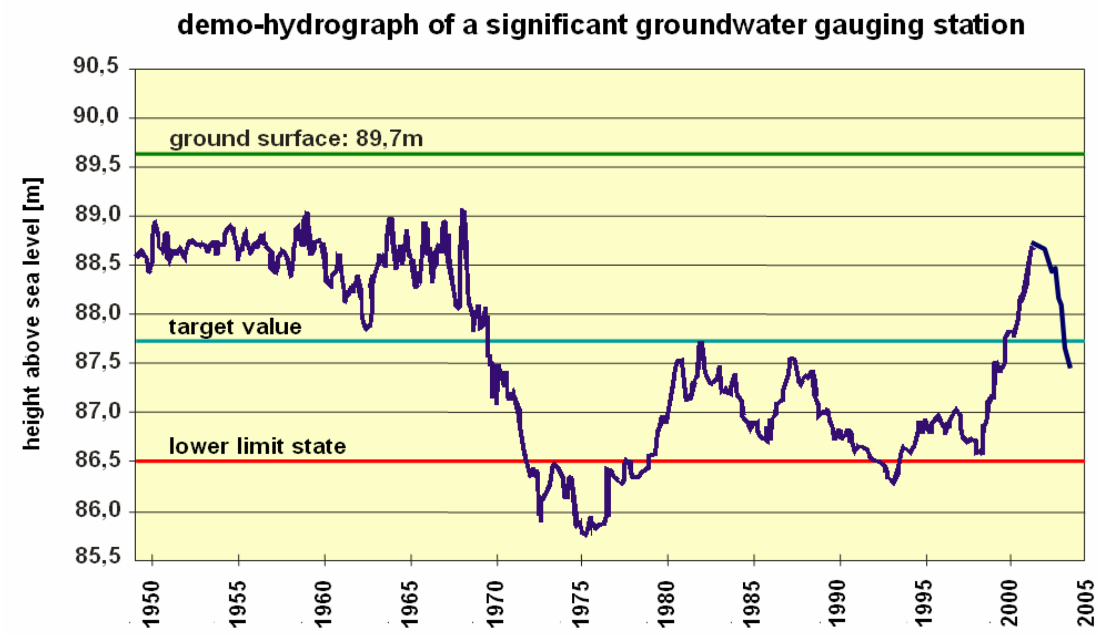

Figure 3: Development of the groundwater level in the past years

The fluctuations of the groundwater level in the following years were mostly a result of metrological circumstances. Nonetheless the water consumption declined. In the spring 2001 the groundwater level was extremely high, so inundated agriculture areas and overflown basements were the results in many parts of the "Hessische Ried" (Figure 4).

Figure 4: Effects of high-state groundwater levels

At present the groundwater-level declines, because of the low precipitation during spring and summer 2003. To avoid the negative consquences, the infiltration facilities are working again.

2 Demands on the Groundwater Information System

At present a holistic management of groundwater resources suffers from the large number of involved groups and their divergent interests on the one hand and a lack of essential information and the complexity of the geological system on the other. Various hydro-geological, climatic, water-economical, chemical and biological interrelations have to be taken into account. Thus, the traditional approaches in information retrieval and management, e.g. single reports in hardcopy form, isolated data maintenance and hardly automation which are characterized by a high staff and time expenditure, aren't sufficient. Necessary information has to be collected and processed currently.

In order to integrate these processes holistically, the existing water management has been analysed. A typical workflow-process is shown in the following image (Figure 5).

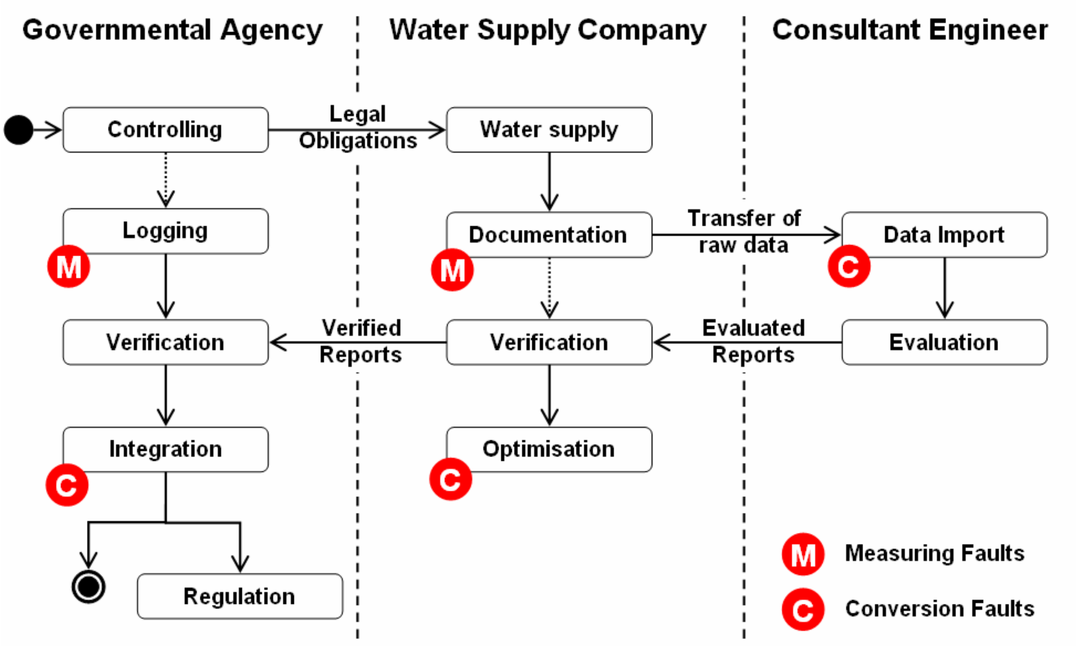

Figure 5: Present workflow-process (including fault types)

The following weak points have been revealed:

- The data entry is done by the water supply companies in different systems with nonuniform formats.
- The professional evaluation of the data like lists, charts and spatial maps requires much processing time.
- The format and the layout of these evaluations are done individual by each water supply company. So it is difficult for the local authorities to compare and to interpret the delivered results.
- The transfer of the evaluated data in the form of monitoring reports has a time-delay of about six month (from the day of the data entry till the day the local authorities can work with it).

As a consequence of these facts, the local authorities are often working on “out-dated” data sets, so that an active controlling of the groundwater situation is not possible.

3 The “Grundwasser-Online”-System

The management of groundwater is a difficult and sensitive task for all involved groups, especially the different water supply companies, the consultant engineers, the scientists and the governmental agencies. On initiative of the University of Technology in Darmstadt, these groups co-operate on the development of a network-based information system for an efficient groundwater management inside the pilot-project “Grundwasser-Online”.

An actual, persistent and verified level of the groundwater is one of the most important aspects of the project. For this purpose a widespread system of groundwater-gauging stations and climate points of measurement were developed to guarantee a comprehensive groundwater supervision. The collected information has to be represented with regard to their master data and their quantity data. Furthermore, the geological, legal and logical relationships have to be taken into account in one holistic data model. The described aspects of the data model have to be transferred in a relational database model, so that a variety of interrelations can be built up. The consistency of the information collected by different partners can be guaranteed. This consistent hydro-geological database is the basis for the subsequent evaluation-, simulation- and visualisation-processes.

Therefore, tools for collection, storage, evaluation and visualisation of groundwater-relevant information using network-based technologies have been analysed and implemented.

3.1 Distributed Databases

The first step for the integration of information was the development of an uniform relational database model, which is used by the waterworks of each water supply company to collect and administrate all their data by specific front-ends. The developed database contains all attributes, which were defined by the "Hessische Landesamt für Umwelt und Geologie" (HLUG).

3.2 Logging and storage of groundwater-relevant information

In order to manage the collection of required information, the developed groundwater information system consists of three different components.

The local collection in the distributed waterworks is realised by using specific frontends. All required master data can be stored as well as the measured data. The measured data can always be verified by various arithmetic, hydro-geological and visual control mechanisms (plausibility checks).

The same control mechanisms improve the quality of the logged data over the other collection components: The internet- and the mobile component. For the aggregation of time-dependant groundwater-relevant information, modern technologies of GPS-based mobile computing (e.g. high-end Notebooks and Personal Digital Assistants) have been embedded in order to provide an integrated approach in the management of large groundwater systems (Figure 6).

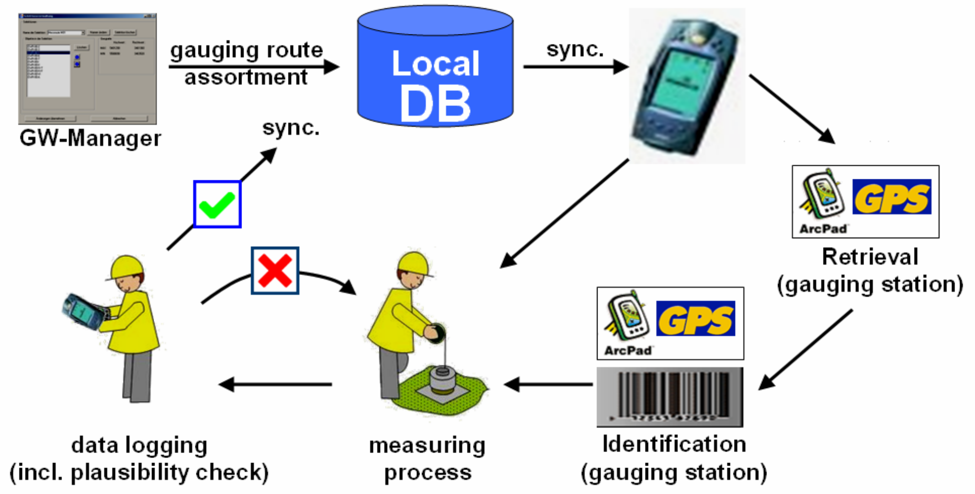

Figure 6: Concept of mobile logging processes

The aggregation over the internet is realised with ASP and stores the data direct in the central server database.

3.3 Trigger-based Replication Mechanisms

To combine the data from the distributed, local databases with the central server database, trigger-based replication mechanisms had to be developed. This was necessary because the local databases based on different database systems (e.g. Oracle, MS SQL-Server, MSDE). The replication process contains two steps (Figure 7). In the first step, all added, updated or deleted information is automatically indicated by the use of database triggers. The triggered information is stored in an XML-file. The second step - the replication process between the local and the server database - can be started manually or using pre-defined intervals.After the replication process has been started, the local XML-file will be compared with the triggered XML-file from the server and the changed data will be updated in both databases.

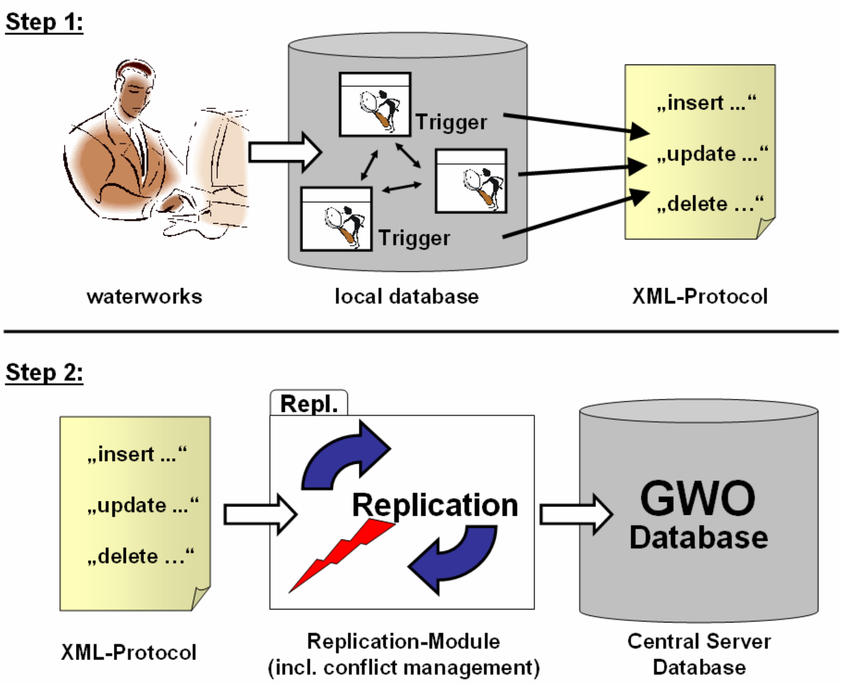

Figure 7: Two-tired replication mechanism

3.4 Dynamic Access-Concept

To realise a dynamic data transfer from one water supply company to another or to governmental agencies, it was necessary to define a specific contol layer. Over this control layer all individual assignments can be determined. It also administrates the access rights of all involved groups, who are interested in the stored information. Because of the sensibility of the information, the control layer has to guarantee a specified access and view (Figure 8). For instance, the public has just the right to behold the public information. The water supply companies, the governmental agencies and related consultant engineers have extended rights to behold, change and evaluated their information and the released information of the other partners.

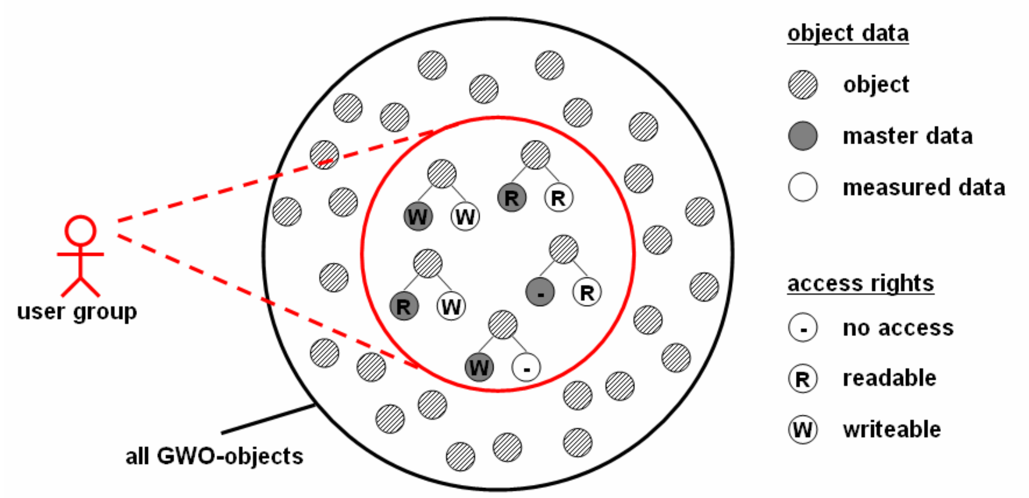

Figure 8: Access-concept (user-view)

3.5 System Architecture

In order to manage the collection of the required information the developed groundwater information system consists of different network-based components (Figure 9).

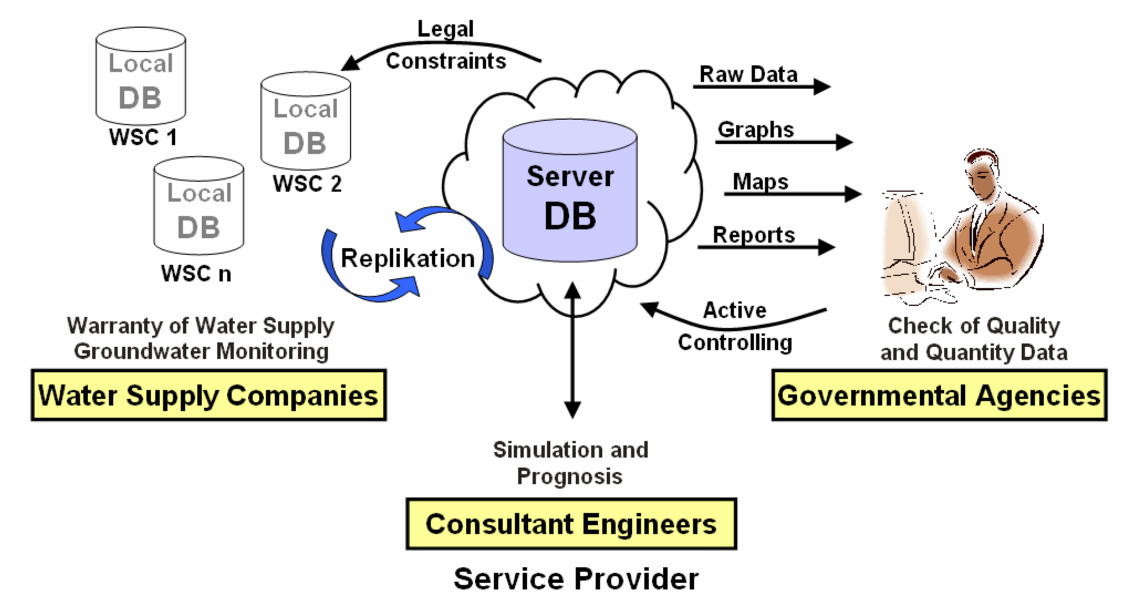

Figure 9: System architecture of the groundwater information system

By the use of trigger-based replication-mechanisms, the distributed databases are combined within one central server-database. Authorised users can work on all of the unblocked data sets (even of external data) and start professional evaluations via internet. These evaluation tools have been developed and integrated into the system to allow professial analalysis and realise an active controlling of the groundwater situation (especially for the governmental agencies).

4 Evaluation Tools

4.1 Diagrams, Lists and Tables

To analyse and evaluate the actual groundwater situation or the historic trend, it is possible for authorised and qualified persons to generate diagrams semi-automatically (e.g. a hydrograph of groundwater gauging stations and stacked bar charts of conveyance or infiltration quantity) within the internet browser. Several software tools have been analysed and adapted to the specific requirements.

In order to generate lists and tables, actual technologies as e.g. XML in connection with XSL and FOP (Apache), are used. The connection to the server database is realized with Active Server Pages (ASP) and the database connection ActiveX Data Objects (ADO). Over specific software assistents a dynamic pre-selection of the required information is possible. The result is a PDF-file, which can be printed or sent in a digital format to other involved partners.

4.2 Spatial Evaluations and GI-Functionality

Spatial coherences of the groundwater situation are usually visualised by professional evaluated maps. Therefore consultant engineers are being authorised by the water supply companies to collect the relevant data from the concerned area and the specific date and start their evaluation with specific software programs. The water supply companies use these evaluated maps to optimise their internal optimisation of water extraction and infiltration to guarantee a continuous groundwater level. For the governmental agencies these maps are essential to observe and to control the regulation properties of all involved water supply companies of a catchment area and to define their legal obligations.

The visualisation of geo-scientific databases in the internet, considering their geographic reference, is performed with an internet-based map server (ESRI ArcIMS). According to the communication between the map server and the underlying geo-scientific database, it is necessary that the requested data can be filtered interactively in an internet browser using chronological and logical criteria. There are three supported types of 2½-dimensional spatial evaluations (Figure 10).

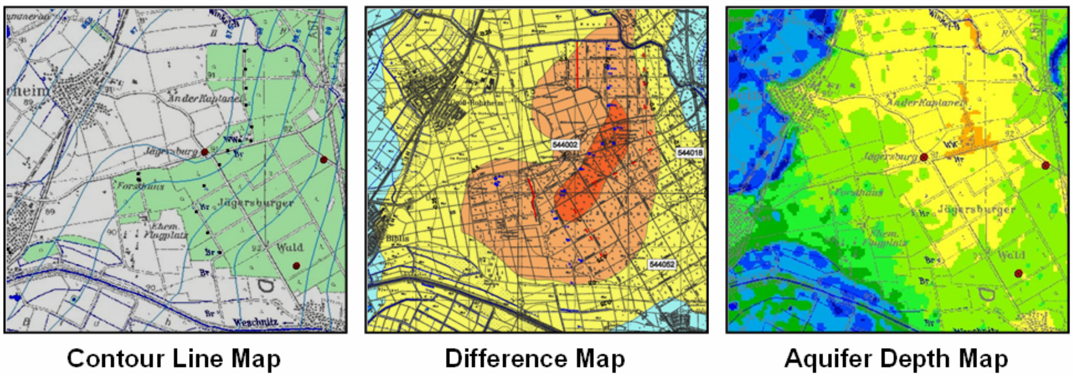

Figure 10: Spatial evaluated map types

Each of the described maps can be generated with the specific input data and an appropriate significance. A groundwater contour line map describes the level of the groundwater table. With this map it is possible to determine the flow direction, the gradient, the current velocity (with regard to the permeability of the aquifer) or even the source of a contamination. A difference map visualise the difference between two groundwater levels at different dates. The drawdown of the groundwater table (e.g. as an effect of a new well facility) can be represented. If a digital surface model (DSM) of the required area is available, an aquifer depth plan can be created and visualised in the internet browser, too. A aquifer depth map presents the vertical altitude difference between the surface and the groundwater table. With an aquifer depth map e.g. the landuse can be planed and controlled.

To enhance the accuracy of the 2½-dimensional maps, the virtual measuring point method has been chosen, especially in regions where the influence of wells or rivers has to be taken into account.

All stages of the groundwater management from the collection of the raw data to the evaluation and visualisation of all the information are realized in an internet portal. Within this project, these processes have been automated. Authorised persons have now the possibility to select the relevant area over topographical maps in the internet mapserver, choose the map type, define the requested time-period and start the interpolation process. If there are enough groundwater gauging stations with data for the required time-period, the interpolation module creates equidistant nodal points. Depending on the type of map, the interpolation module can generate groundwater contour line or difference maps and transfer a vector graphic (in a shape-file format) to the mapserver, where it is visualised and can be analysed by the authorised user.

5 Groundwater-Monitoring

5.1 Generation of Digital Monitoring Reports

With this system the water supply companies have the opportunity to fulfil the legal obligations with a high efficiency rate (Business to Government / B2G). These are defined by the local authorities and include reporting commitments. The major form of the reporting commitments are the so-called “monitoring reports”. These reports have to be generated by the water supply companies (or an authorised engineering society) and transferred in regular intervals (e.g., four times a year) to the responsible governmental agency. These reports contain specific predetermined components like charts, maps, or estimated engineering-evaluations in textual form. The composition of these components can be stored in “Grundwasser-Online” in flexible schemes so that the composition can be reused for the subsequent report. The content of each component includes firstly a specific range of raw data. Secondary it includes a configuration of the data range and the layout-style. The configuration properties can be stored by using user defined objects. As a result of this semi-automated generation, the produced reports can be stored as a PDF-file. This can be distributed to the responsible users at the local authorities with the document management component.

The digital monitoring reports, which can be generated in the “Grundwasser-Onlie”-system are a part of the actual legal obligations (Grundwasserrechtsbescheide) and replace the manual developed reports.

5.2 Notification Mechanisms

Using this system it is also possible for the local authorities to supervise the legal obligations. These are defined by the local authority according to the conveyance- and infiltration-mass of the water as well as for the water-levels. If one of these boundary values is going to be exceeded, the responsible users of the water supply companies respectively the local authority can be notified by the system, where a complete workflow can be designed (Government to Business / G2B).

The fundamentals of the required notification values are defined in the groundwater cultivation plan “Grundwasserbewirtschaftungsplan” which is valid since 1999 in this region. In this plan an optimal groundwater level (target value) and a minimum (lower limit) is defined for responsible gauging stations (Figure 3).

All water supply companies have regard these requirements. The system notifies the responsible persons of the waterworks, which can reduce the conveyance-value of the wellsystems in the critical area and enhance the value in another region with a higher groundwater level. It is also possible to start or to enhance the infiltration value. All corrective measures and the effects can directly be supervised over the internet-based system by all authorised persons.

5.3 Allocation Groundwater Information to the Public

A special service is presented to the public by providing an internet-based mapserver (Government to Consumer / G2C). Over this GIS-tool actual and historic groundwater information can be provided by generating a dynamic hydrograph curve of a selected, geo-referenced gauging station. Particular architects and geotechnical societies can use this software tool to estimate the building land. This also relieves the local authorities and the water supply companies on the duty to give environmental information to the public.

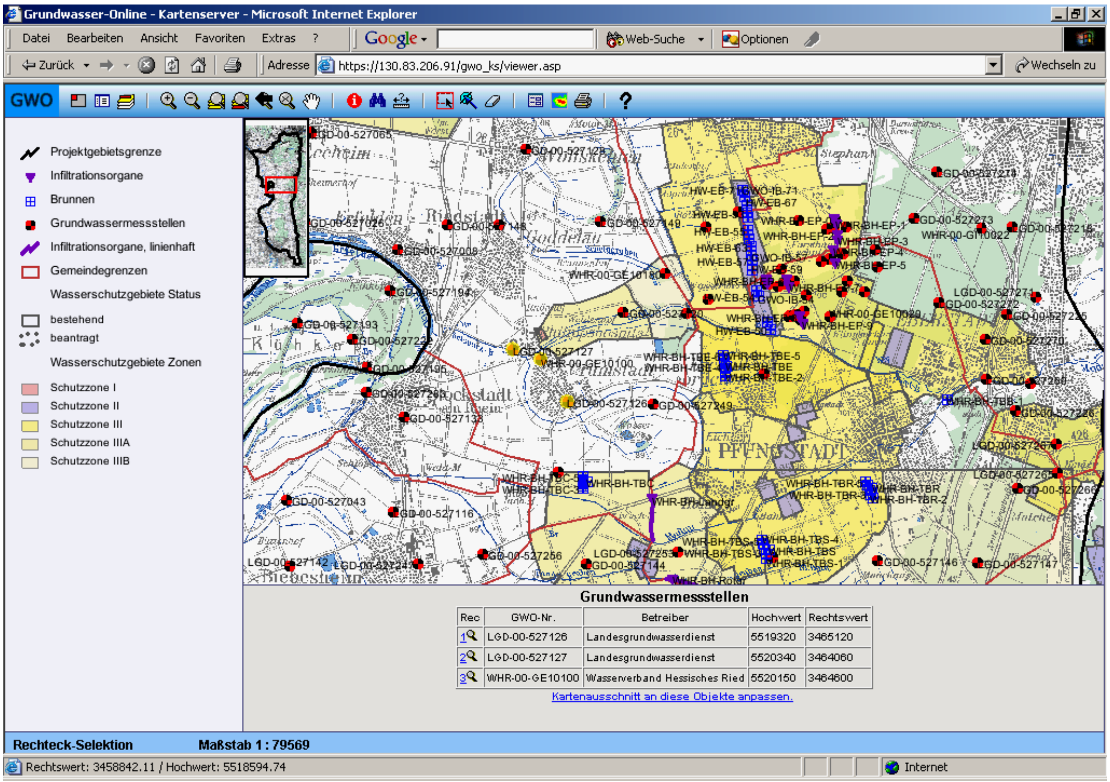

Figure 11: Graphical user interface of the GWO map server

6 Conclusion and perspective

For the holistic management of all required data the server database of the internet based groundwater information system was designed. Because of the use of modern internet information technologies, the groundwater-relevant data can be accessed in an actual digital form. Standardized tools for pre- and post-processes including interfaces for import and export enable a fast exchange of relevant information between the water supply companies, the enterprises, the governmental agencies and to the public. For these diverse communication relationships detailed access rights have been defined which offer a protection against unauthorized access of the geo-scientific data. Considering these access rights the internet based visualisation of spatial structures and processes, e.g. of maps with groundwater information in map servers, is a new method for decision support and network-based co-operation in the field of groundwater monitoring.

The actual status of this project can be referred at: http://www.grundwasser-online.de.

7 References

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