GROUNDWATER MANAGEMENT IN URBAN AREAS IN GERMANY

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Abstract - Huge building sites in urban areas can cause problems to the groundwater. In many cases raising or falling groundwater level can be observed.

To simulate the influence of building sites to the groundwater it is usefull to simulate the situation at different stages by groundwater models. In two cases studies of urban areas in Germany a succesfull use of these models are shown.

In the town of Berlin a lot of great building sites like underground routes and a lot of huge buildings in the area of Pariser Platz and Potsdamer Platz are related to the groundwater. The influence of these buildings to the groundwater is simulated by groundwater models. To minimize this influence to groundwater a Groundwater Management was installed. The task of this Groundwater Management is the reinfiltration of pumped out water in the underground, the monitoring of the groundwater level and the numerical modelling of different building states. With this Groundwater Management the risk to the vegetation of the recreationground "Tiergarten" and the foundation of huge buildings can be minimized.

In the town of Bochum it was necessary to simulate the influence of an underground line to existing buildings. This was also managed by a groundwater model, with which it was possible to simulate the influence of the new underground line on the groundwater. So it was possibel to find counter meassures.

Keywords - groundwater model, groundwater management

1 - PREFACE

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Huge building sites in urban areas cause in a lot of cases many problems. These could be for example problems related to the groundwater. So in many cases raising or falling groundwater levels can be observed. Furthermore the groundwater can be polluted by building activities. In the following two case studies in Germany will show how these problems can to be solved.

2 - BERLIN

2.1 INTRODUCTION

Berlin has to master many new tasks as a result of the reunification of Germany and its development to the Federal Capital of Germany. One of these tasks is to solve traffic problems in the central area of Berlin. To reach this aim, several construction measures have been started:

- Construction of a north-south main railway connection,
- Construction of a new underground road tunnel,
- Construction of a section of underground line U 5,
- Construction of a new section of underground line U 3.

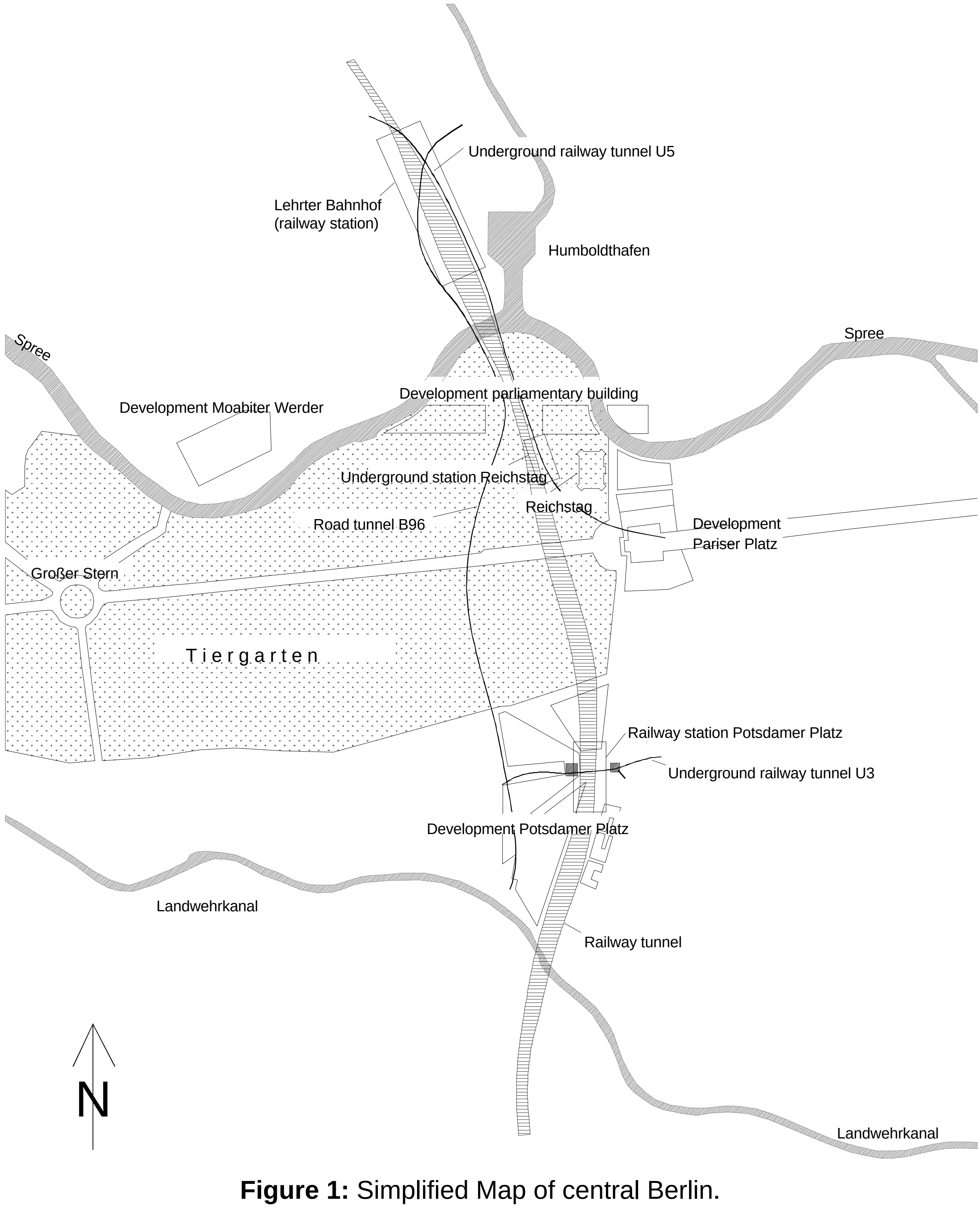

Figure 1: Simplified Map of central Berlin.

Three parallel tunnels will be built in the area of the river bend of the Spree (Spreebogen).

Within the area between Tiergarten and Landwehrkanal the railway tunnels are to be built using mechanical tunneling. The technique is also used for a part of the tunnels of the underground line U 5. The other excavations involve the virtually watertight ”wall-base method”. These environmentally friendly construction methods benefit the ecological conditions of the eastern part of the recreation area ”Tiergarten” and the foundations of older buildings like the Reichstag.

According to legal regulations construction projects of this large scale require an assessment of environmental impact. In order to assess the effect of the constructions on the surface water and the groundwater, base line data and predictions are required. In this regard the Tiergarten vegetation, which is dependent on groundwater, is particularly important.

The building permission contained several water resources management conditions for the building phase. The permission also requires consideration of the following related projects which are implemented at the same time:

- Development of Potsdamer/Leipziger Platz,
- Development of parliamentary buildings,
- Development of Pariser Platz.

At the Potsdamer Platz high-rise buildings, built by the investors debis, Sony, Hertie and ABB/RE, penetrate deeply into the groundwater-containing deposits. For buildings of the Federal Government at the Spreebogen (the building of Federal Chancellery and the office buildings for the members of the parliament) an extraction of large amounts of groundwater is also necessary. The same hydrogeological conditions apply to the building projects at the Pariser Platz (several embassies and buildings of investors, for example Dresdner Bank, DG-Bank, Haus Liebermann , Haus Sommer, Hotel Adlon), which are also associated with quite extensive groundwater extraction, and which, in some cases, may result in a lowering of the groundwater table.

2.2 - GEOLOGY AND HYDROGEOLOGY

The construction techniques referred to above are all executed in the groundwater-containing deposits of the Quaternary era. And so a closer look to these layers will be given here.

In the deposits of the Pleistocene era of the investigation area, which is part of the Warschau-Berlin ice main valley, three different glacial phases can be recognised: Weichsel, Saale, Elster. Each separated by interglacial phases (times of warmer climate): Eem and Holstein. Because of their genesis the sediments are very diversely developed both in their horizontal and vertical distribution. Additionally they vary extensively in their granulometric composition. They consist of boulder clay, sand, gravel and banded clay. The sediments of the interglacial phases in particular consist of sand and clay. The total thickness of the Pleistocene sediments in the Berlin area usually amounts 50 to 80 m and up to 250 m in the glacial channels.

The boulder clay belongs to the bottom moraine, which was formed at the base of the advancing ice. It consists predominantly of a sandy loamy marl, in which many larger stones are stored. The fine-grain components may have been subsequently washed out so that only a horizon enriched with boulders remains. The bottom moraine frequently contains material of older relocated layers, for example remnants of lignite of the Miocene era. Sand and gravel are either remnants of the bottom moraine or have a glaciofluviatile origin.

The banded clay is a clayey loamy fine sand, which consists of an alternate bedding of light and dark layers. During the Elster glacial phase they had been deposited primarily in basins without outlets.

Beside glaciofluviatile sand and gravel the deposits of the oldest glacial phase (Elster) in Berlin’s area contain at least one horizon of boulder clay and of banded clay. The Elster-sediments can be defined relatively easily to the recent ice-age deposits by the Holstein interglacial phase. These layers are particularly characterised by thick sapropel, which are so called because of the high content of conchyliums (Paludina) as "Paludinenbank". The Holstein interglacial phase only indicates larger proportions of sand in the top and bottom transient areas.

In the sediments of the Saale glacial phase several boulder clay horizons can be differentiated, but they are not consistent.

The Eem interglacial phase is incomplete is thin in the area of Berlin. Therefore a differentiation between Saale and Weichsel glacial phase is not possible in all places. In this Interglacial phase peat clay and meadow chalk had been built up in depressions.

Beside fluvial sand and gravel the Weichsel glacial phase consists of two inconsistent boulder clay horizons.

The valley sediments consist of sand with layers of gravel, which change towards the top into fine-grained sand.

In the Holocene (recent post-glacial time) humous sediments (peat of the highmoor and the fen, anaerobic sludge) were deposited in basins and channels.

Because of the high density of construction a lot of the inspected area is covered with overburden materials, predominantly building debris.

2.3 - BUILDING METHODS

In order to minimize the impact of the numerous building projects on the hydrologic budget, following processes will be used:

- Mechanical tunnelling
- ”Wall-base method”

Parts of the tunnel sections are constructed by using mechanical tunnelling. Therefore a so-called Hydroshield using a bentonite suspension is employed, which stabilises the headwall of the tunnel. After excavation the new section is sealed by placing tubbings, prefabricated arched elements made of concrete.

In excavations, the "wall-base method" works by using so-called diaphragm walls as outer limits. Alternatively, ”one phase slit walls” or ”drilled pillar walls” may be employed. A diaphragm wall will be stabilised against external pressure. The excavation-zone of the diaphragm walls is stabilized by a slurry of bentonite. Finally the filling of concrete displaces the slurry. The anchored sheet wall is created by driving a steel wall into an excavation stabilized by bentonite slurry. The diaphragm walls can be recognised as very watertight. If carried out properly, water can seep in only at vertical joints and anchor holding points in the walls. The volumes of water leakage is directly related to the quality of the work carried out.

Unless there are several sealing layers at the bottom of foundation, it is necessary to create waterproof bases with connection to the surrounding walls. According to actual plans, underwater concrete bases and ”jet stream bases” are preferred. Softgel bases, which are created by injecting Natronsilica- and Natron-aluminate solvents into the soil, will be made only in some areas.

Underwater concrete bases have to be anchored by ”strain pillars” placed deeply in the ground to counter forces of buoyancy. On very deep levels uplift of the base will be avoided by placing large loads.

After excavation and placement of the anchors the underwater concrete base will be constructed between the walls. The jet stream process displaces outcropping soil with cement slurry. This process allows – like the softgel method – the creation of the base even before excavation.

Excavation of the building pits is carried out using shovel-excavation. Employing suction dredgers is impossible, because hydraulic filling areas are not available.

In comparison with other base sealing measures in deep niveaus, the subaquatic concrete bases represents a measure that is save and can be well controlled.

Jet stream and soft gel basis are produced successfully for several years. A dense frame of pressing holes provides a high proofness.

For base installations high quality construction assurance is required as much as good control of the completed base. Fine cracks running through the base and the walls can lead to water leakage. The design of the building areas needs to be prepared in order to avoid large or numerous cracks (in walls and bases).

2.4 - INFLUENCE OF BUILDING ACTIVITIES ON GROUNDWATER

During the construction of the wall-base-pits the water encountered can be divided into:

- Excavation water
- Pumped water
- Residual water

Excavation water occurs only under construction of the subaquatic concrete bases. During submerged excavation of soil groundwater can flow through the as yet unsealed bottom of the pit. Assuming 30% of the soil volume is "groundwater", about 70% will flow from adjacent ground to fill the void while excavating the pit. After finishing the subaquatic concrete base, the building pit will be dewatered. For jet stream bases at deep levels pumped water results only from the soil because excavations are made under dry conditions. Small volumes of water can also enter the building pit through the base. This water is called residual water and it has to be collected by drainage systems and pumped off.

The assumed influx of water for a damp building pit of 1000 m² in this part of Berlin is considered to be 1,5 l/s. If carried out carefully, this influx can be reduced especially at visible part of the walls. In addition the joints can be secondary sealed comparatively easily by injection. It is important to know that the given volume of influx of residual water has been developed on building pits penetrating to the maximum of about 10m beneath the groundwater table. Experience on pits as deep as those designed in Berlin is rare and so sealing might be necessary, especially in parts deeper than 10m below the groundwater table.

In terms of hydrogeological effects of the advanced building process, excavation and residual water are important. The pumping water has no effect to the height of the groundwater table.

2.5 - GROUNDWATER MODELLING

Despite environmentally friendly building processes, 14 million m³ of groundwater (pumped and residual water) will be taken from all the building pits.

To measure the consequences of this groundwater extraction to ecology of the Tiergarten and neighbouring buildings (like the Reichstag), the working pool ARGE Umweltgeologie und Geotechnik VZB Berlin (Deutsche Montan Technologie GmbH, Essen and GUD Geotechnik und Dynamik Consult GmbH, Berlin) developed a 3-dimensional numerical groundwater model based on software system SPRING using finite elements. The model incorporates data regarding depth and distribution of hydrogeological boundaries, levels of groundwater table, topographical informations, permeability values (of the soil), and groundwater regeneration. These data related to different parts of the ground and sites which from groundwater is taken in different volumes.

To verify local hydraulic parameters, large scale pumping tests were carried out. By re-calculation of the existing situation all hydrogeological and hydraulic parameters were related to each other. After calculation of the base line situation (”Variation Zero”) several stages of building and post construction have been simulated and evaluated.

The following stages of construction were recognised as having relevance to groundwater management, each providing parameters for calculations:

- Construction stage of maximum residual water extraction (worst case) and reinfiltration during complete building period at Tiergarten. (see figure 2),
- Construction stage of maximum residual water extraction (worst case) access of groundwater due to excavation of building pits.
- Construction stage of maximum ingress of groundwater due to excavation of building pits,.
- Construction stage maximum extraction of residual water and reinfiltration along the street tunnels running through the ecologically sensitive area of Tiergarten,

  Construction stage maintaining the groundwater table at a constant level with respect to buildings (like the Reichstag) which would remain,
- Following completion of all building measures.

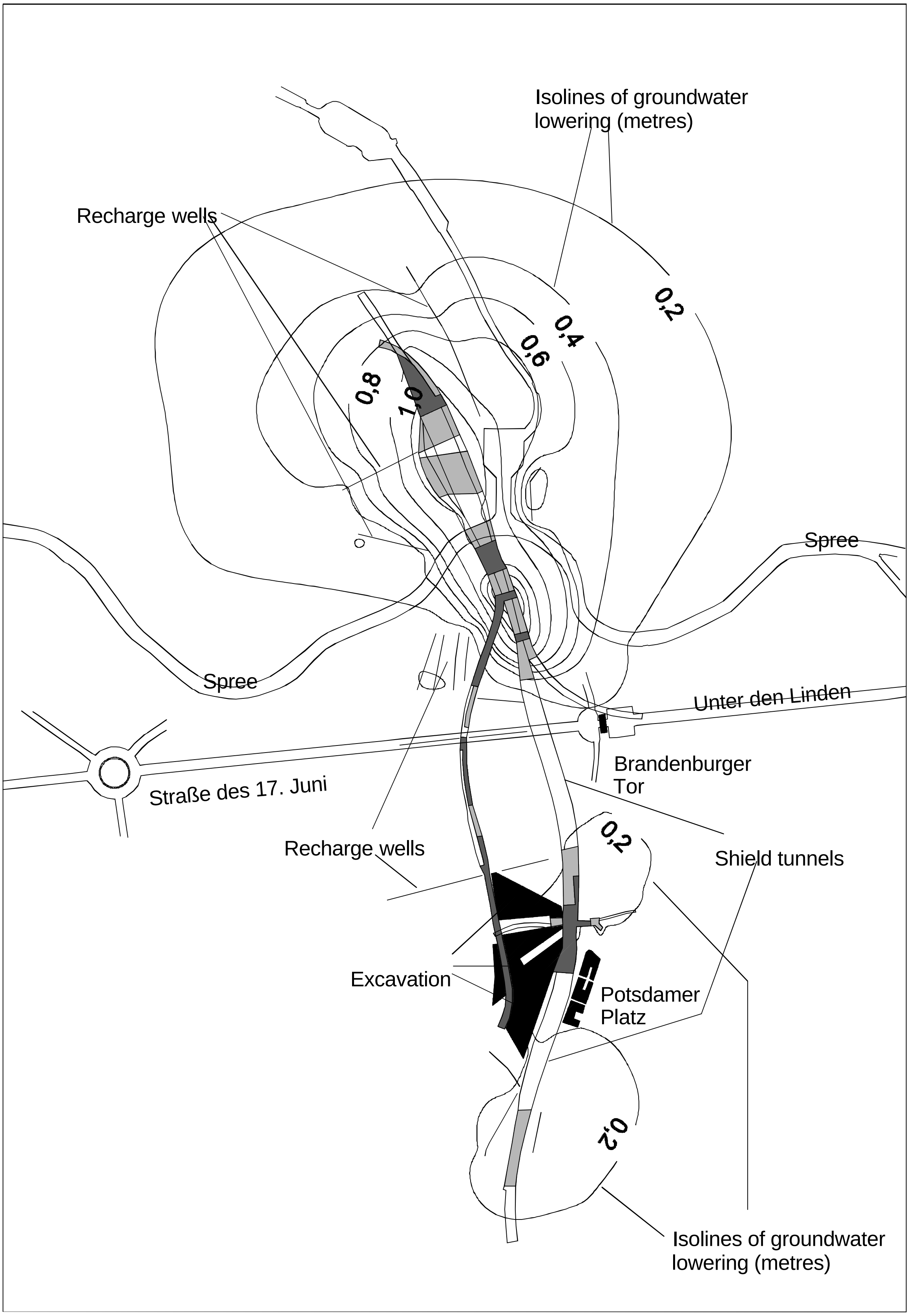

Figure 2: Difference of groundwater table between base line situation and an version of a construction stage with 72% of reinfiltration.

The modelling showed that due to the environmentally friendly building processes employed, there would be only low consequences. They report that detrimental lowering of the groundwater table would be well avoided in all ecological important areas (Tiergarten, Charité, Hamburg-Lehrter Güterbahnhof and others).

All Versions of the modelling were able to verify that the range of groundwater table variations permitted by authorities can satisfied, by optimal reinfiltration.

2.6 - GROUNDWATER MANAGEMENT

Based on the evidence from the modelling, the conditions set by authorities, and the planned building projects, a groundwater management plan was prepared.

Essential regulations made by the groundwater authorities are:

- Continuously checks of quality of the pumped waters,
- Installation of an decontamination plant, if necessary,
- Establishment of an extensive network of monitoring wells,
- Continuous measurement, registration, storage and analyses of pumped volumes of water and volumes of water to be reinfiltrated,
- Maintaining the ecologically necessary groundwater levels by methodical reinfiltration,
- Prediction of necessary volumes of water needed to reinfiltrate by real time groundwater modelling,
- Construction of a plant for removing iron and manganese system to prepare water for reinfiltration.
- Reporting evidence (quarterly).

The general purpose of groundwater management is the reinfiltration of water abstracted by companies on their building projects. Reinfiltration is achieved by using recharge wells, a process that is monitored by groundwater observation wells and recorded continuously. Excess water is discharged to streams (see figure 3).

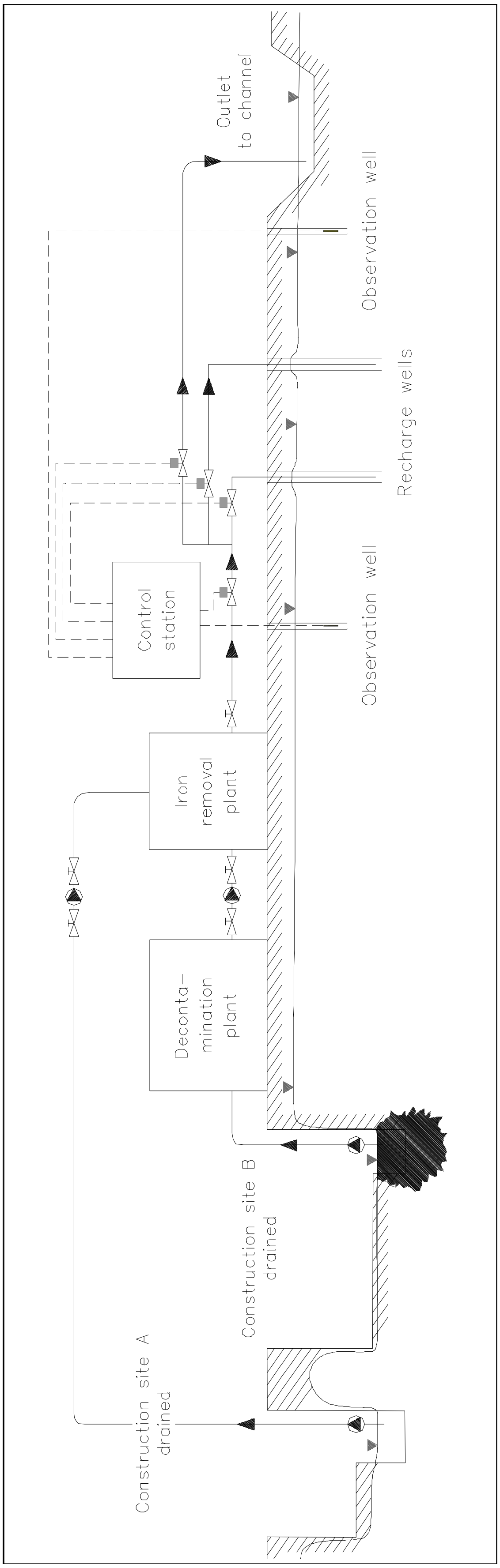

Figure 3: Design of reinfiltration.

The following tasks have to be done:

- Design of abstraction and reinfiltration of groundwater on large scale building projects (tunnels, channels, and high rising buildings),
- design of an iron and manganese removal plant,
- Conception to handle groundwater.
- Conception of systems necessary to reinfiltrate water.
- Management of monitoring data by software integrated for analyses,
- Control of ecological and water-resources risks to the security of vegetation and buildings as a resulting of falls in groundwater levels,
- Service for the measuring points (like measurement of groundwater table, and volumes of pumped and reinfiltrated water),
- Numerical modelling of the state of the groundwater throughout the whole building phase,
- Analysing and monitoring of the quality of water.

To carry out these actions, the following factors have to be taken into account:

- Decisions of authorities,
- Hydrogeological situation (geological structure, permeability etc.),
- Hydrological circumstances (depth to groundwater),
- Quality of groundwater (pollution, iron and manganese content),
- Planning aspects (area required),
- Ecologically sensitive areas,
- Buildings sensitive to changes in groundwater levels (e.g. the Reichstag and others).

The hydrological circumstances at the area modelled are generally/thoroughly good for reinfiltration. Original depths of the groundwater table to surface should be maintained as much as possible.

Quality of Groundwater plays an important role, because the iron and manganese contents are generally very high. If iron and manganese are precipitate, it may lead to clogging of recharge wells. Removing of iron and manganese from groundwater is therefore necessary for economical reasons. In areas, where groundwater is contaminated, it will be cleaned.

A further restriction to reinfiltration is a lack of suitable areas. This concerns not only to areas which are built on, but also to areas which can't be used because of environmental and landscape protection.

During the whole building phase monitoring will be carried out by groundwater management, to adapt reinfiltration to match the needs of vegetation.

Groundwater management in central Berlin will be made by 2 independent Organisations:

- At the area north of Straße des 17. Juni by "Groundwater Managenent Spreebogen", consisting of the working pool ARGE Preussag, Pollems and Harbauer for removing of water and Deutsche Montan Technologie GmbH for organisation,
- At the area south of Straße des 17. Juni by "Groundwater Management Potsdamer Platz", consisting of IMS Ingenieurgesellschaft mbH and GCI Grundwasser Consulting Ingenieurgesellschaft mbH by order of Baustellenlogistik Potsdamer Platz GmbH (Baulog).

3 - BOCHUM

3.1 - INTRODUCTION

The community of Bochum plans to build a new underground (E). Because of the existance of several underground car parks and the close neighbourhood to the existing underground line (D) it was important, to find out if the additional tube for line (E) causes a raising groundwater level and therefore basements of buildings can become wet. Based on the fact that several house owners already took legal action relating to groundwater problems, a numerical groundwater model had to be assembled in order to simulate the effects of underground line (E) on existing buildings.

To install this numerical groundwater model it was necessary to evaluate extensively documents and data given by the authorities. In addition 39 boreholes were carried out, 4 of them reaching Quartenary layers, 35 reaching Cretaceous layers underneath. 36 boreholes were extended to groundwater observation wells. To determine the rock permeability 6 pumping tests and 4 recharge tests were performed.

3.2 - GEOLOGY AND HYDROGEOLOGY

The deeper underground is build up by Carboniferous aged strata. The period of layers consists of interbedded and folded slateclay, sandstones and charcoalseams aged middle Upper Carboniferous. The Carboniferous is overlain by Cenomanian (Upper Cretaceous) aged layers.

The basement of Cenomanian contains a base conglomerate consisting of clayironstone- and carboniferous detritus cemented by a silty binder. Above follows the “Essener greensand”. This greensand is developed with an alteration of clay and sand. Because of its high share of glaukonite it is intensively green. The thickness of this greensand amounts 5 - 10 m. Above Cenomanian follows Turonian. The Lower Turonian (Labiatus-marl) consists of lightgrey and hard marlstones and limemarlstones, which are highly fissured because of their strength. The thickness amounts 10 – 20 m.

Because of its petrographic composition the Cenomanian is watertight. This prevents groundwater to flow from the Cretaceous aquifer into the Carboniferous layers. The Turonian layers represent an important aquifer because of their jointing and are used for water-supply. As an opposite the “Essener greensand” represents a aquiclude.

Quaternary layers overlie the Turonian layers. They consist of sandy siltgrains. The thickness and the petrographic development of deposit varies in a high grade.

Because of intensive construction work Quarternary and Cretaceous are hydraulically connected. The Quarternary is only partially groundwater filled, the hydraulic conductivities amount $k_f = 2 * 10^{-6}$ to $k_f = 1 * 10^{-6}$ m/s.

3.3 - GROUNDWATER MODELLING

The groundwater model was assembled using the software system SPRING using finite elements. Based on a developed water table contour lines map the testfield was seperated.

Beside geological and hydrogeological data the groundwater model contains all buildings, where the basement might reach the groundwater table.

Before the groundwater model was ready to use a stationary calibration was necessary. The determined values of hydraulic conductivities resulting from the pumping tests were held constant, while the values of hydraulic conductivity were varied in the remaining area until a good fitting approximation was achieved.

After calibration was done several stages were simulated, so for example the situation without any additional measures. Looking at the results of this simulation a raised groundwater level can be observed in front of the new tube (see figure 4).

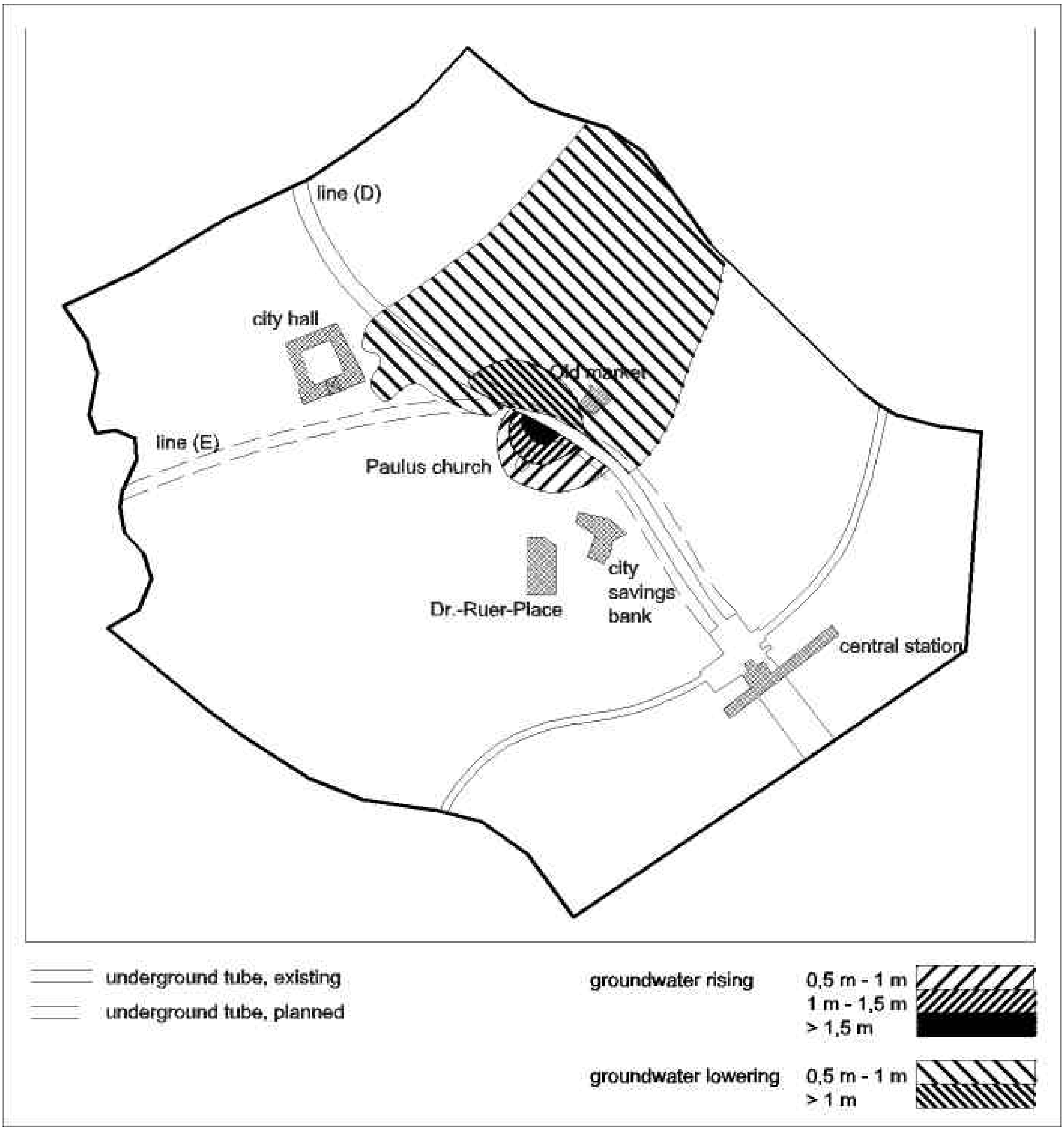

Figure 4: Raised water level in front of the planned tunnel

Following a number of hydraulic counter measures were calculated. Among the calculations the influence of

- horizontal well
- vertical well
- side-tracking boreholes

was simulated.

4 - RESUMÉ

Groundwater models are a well fitting tool to handle groundwater problems in urban areas. Falling or raising groundwater levels caused by building activities can be predicted. Using a numerical groundwater model to calculate the effects of counter measures enables to find the best fitting measure to solve a problem and to avoid expensive supplementary construction works.