02.07 Depth to the Water Table (Edition 2007)

Overview

Groundwater levels in a metropolitan area like Berlin are subject not only to such natural factors as precipitation, evaporation and subterranean outflows, but are also strongly influenced by such human factors as water withdrawal, construction, surface permeability, drainage facilities, and recharge.

The main factors of **withdrawal** include the groundwater demands of public water suppliers, private water discharge (cf. Map 02.11), and the lowering of groundwater levels at construction sites. **Groundwater recharge** is accomplished by precipitation (cf. Map 02.13.5), shore filtration, artificial recharge with surface water, and return of groundwater at construction sites.

In Berlin, there are two potentiometric surfaces (groundwater layers). The deeper level carries salt water and is separated from the upper potentiometric surface by an approx. 80 meter thick layer of clay, except at occasional fault points in the clay. The upper level carries fresh water and has an average thickness of 150 meters. It is the source of Berlin's drinking (potable) and process (non-potable) water supplies. It consists of a variable combination of permeable and cohesive loose sediments. Sand and gravel (permeable layers) combine to form the groundwater aquifer, while the clay, silt and organic silt (cohesive layers) constitute the aquitard.

The potentiometric surface is dependent on the (usually slight) gradient of groundwater and the terrain morphology (cf. Fig. 1).

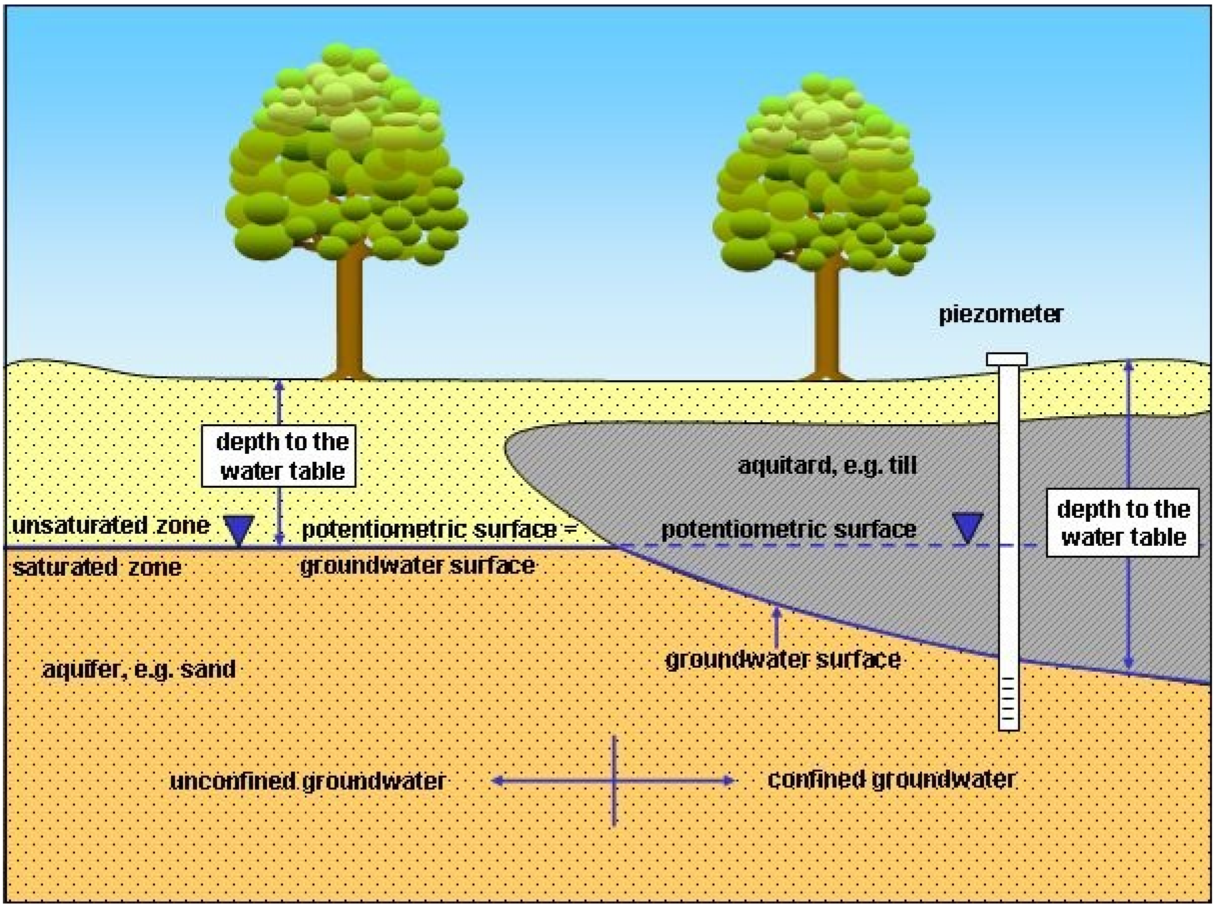

Fig. 1: Terminological definition of depth to the water table at unconfined and confined groundwater

The **depth to the water table** is defined as the perpendicular distance between the upper edge of the surface and the upper edge of the groundwater surface. If the groundwater aquifer is covered by relatively impermeable, cohesive layers (such aquitards as boulder marl), so that it is unable to rise to the level that its hydrostatic pressure would dictate, it is considered to be confined groundwater. In such a case, the depth to the water table is defined as the perpendicular distance between the upper edge of the surface and the lower edge of the groundwater-obstructing boulder-marl layer which covers the aquifer (cf. Fig. 1).

The Map of Depth to the Water Table gives an overview of the spatial distribution of areas with the same depth classifications, at a scale of 1 : 50,000 (SenStadt 2006). It was calculated on the basis of the data of May 2006, and applies to the respective near-surface aquifer with an uninterrupted water supply. In Berlin, this in most cases means the main aquifer, which is used for water supply (Aquifer 2, according to the structure of Limberg und Thierbach 2002), and which is unconfined in the glacial spillway, but confined in the more elevated areas. In exceptional cases, the Aquifer 1 (e.g. in the area of the Panke Valley) or the Aquifer 4 (tertiary formations) were used to determine the depth to the water table.

Areas with a lesser depth to the groundwater table (to about 4 meters) are of particular importance. **Soil pollution** can quickly lead to deterioration of groundwater in these areas, depending on the nature of the mantle (permeable or non-permeable) above the groundwater. The Map of Depth to the Water Table is thus a significant basis for the preparation of the Map of the Protective Function of Groundwater Coverage (cf. Map 02.16). The spatial overlaying of depth to the water table onto geological characteristics of the covering mantle permits the delimitation of areas of varying protective functions of groundwater confinement).

Knowledge of depths to groundwater moreover permits an assessment of the effect of groundwater on **vegetation**. This depends on the root depths of plants and, depending on soil type, of the capillary climbing capacity of groundwater. The threshold depth at which groundwater can be used by trees under the conditions prevailing in Berlin is generally given as 4 meters. Vegetation in wetlands depends mostly on the groundwater, and requires a depth to the water table of less than 50 cm.

Fluctuation of Groundwater Levels

The groundwater level in the city is subject to various **anthropogenic influences**. The first lowering of the groundwater level and the destruction of wetlands in the Berlin area was caused by the drainage of such swampy areas as the Hopfenbruch in Wilmersdorf in the 18th century. The 19th and 20th centuries saw the drainage of other areas due to the construction of canals. The groundwater level was further lowered by the increasing demand for drinking and process water, and by restrictions on groundwater recharging caused by surface sealing, or was subjected to strong periodic fluctuations, with amplitudes of up to 10 meters at a site.

Up to the end of the 19th century, the mean groundwater level in Berlin was subject only to the annual fluctuation in precipitation. During the period between 1890 and the end of World War II, the rising water demands of the rapidly growing city, as well as unwatering operations, marked the water-supply picture. Large-scale unwatering of the subway and urban-rail networks (Alexanderplatz), and other major construction projects caused the groundwater level in the inner city to drop dramatically by up to 8 meters. With the breakdown of the public water supply at the end of the war, the depth to the water table was able to recover almost to its natural level (Fig. 2).

During the ensuing period, from the early ‘50s to the early ‘80s, the groundwater level **sank** continually and over large areas because of increased withdrawal. This was particularly noticeable in water discharge areas (waterworks facilities). The lowering was caused by the general rise in water consumption by private households, and by construction (rebuilding of the severely destroyed city, subway construction, and large-scale construction projects). The expansion of water discharge facilities in the West Berlin waterworks was completed by the beginning of the ‘70s. The expansion of the Friedrichshagen Waterworks in East Berlin began in the mid-‘70s, to supply water to the new residential areas in Hellersdorf, Marzahn and Hohenschönhausen.

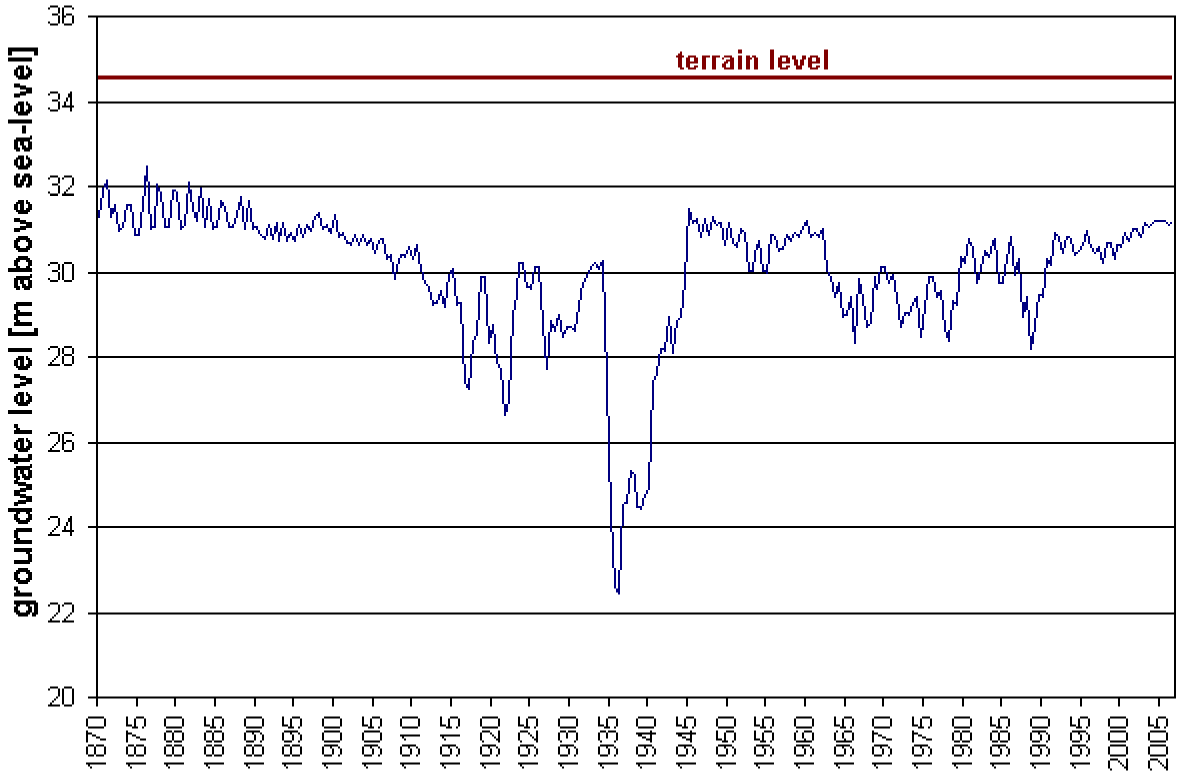

Fig. 2: Fluctuation of groundwater levels at measuring site 5140 in Mitte (Charlottenstraße), since 1870

Permanent, wide and deep **cones of depression** have formed in water catchment areas around the wells of the waterworks. Moreover, parallel to the variations in withdrawal requirements at the respective waterworks over the course of a year, often considerable fluctuations in groundwater levels are observable there. Riemeister Lake and Nikolas Lake were dried out by the water withdrawals of the Beelitzhof Waterworks at the beginning of the 20th century. The groundwater level of Schlachten Lake fell by 2 meters, and at Krumme Lanke by 1 meter. Since 1913, water from the Havel has been withdrawn into the Grunewald lakes (inversion of natural flow) to balance this loss. The wetlands Hundekehle Fen, Langes Luch and Riemeister Fen, as well as the shore areas of the lakes, have been saved by this measure.

The cones of depression around well galleries at the Havel Lake have effects deep into the Grunewald (forest). The groundwater level at Postfenn sank by 3.5 meters between 1954 and 1974, and at Pech Lake in the Grunewald by about 4.5 meters between 1955 and 1975. Well gallery withdrawals at the banks of the Havel have caused severe drying out of root soils of plants in the direct vicinity of the Havel.

About 90% of the wetlands around Müggel Lake in southeastern Berlin are threatened (Krumme Laake, Müggelheim, Teufelssee Bog, Neue Wiesen/Kuhgraben, Mostpfuhl, Thyrn, the lower course of Fredersdorf Stream).

Some wetland areas were flooded and fed with surface water to percolate, in order to moderate the negative effects of the lowering of groundwater levels. These included the West Berlin nature reserves Großer Rohrpfuhl and Teufelsbruch in the Spandau Forest, and Bars Lake in Grunewald, and also, in East Berlin, Krumme Laake in Grünau and Schildow in Pankow.

Large-scale lowering of groundwater levels has also occurred in the Spandau Forest, caused by the higher withdrawals by the Spandau Waterwork since the ‘70s. With the aid of a groundwater recharging plant, operated since 1983, attempts have been made to gradually raise groundwater levels again by allowing purified Havel water to seep in. The groundwater level in the Spandau Forest had been raised by an average of 0.5 - 2.5 meters by May 1987. Groundwater recharging in this area has been restricted again because water has appeared in cellars of near-by residential areas. The simultaneously increase in the withdrawal quantities of the Spandau Waterworks lowered the groundwater level again after 1990. During the ensuing period, the groundwater level rose once more, due to the further reduction in withdrawal quantities.

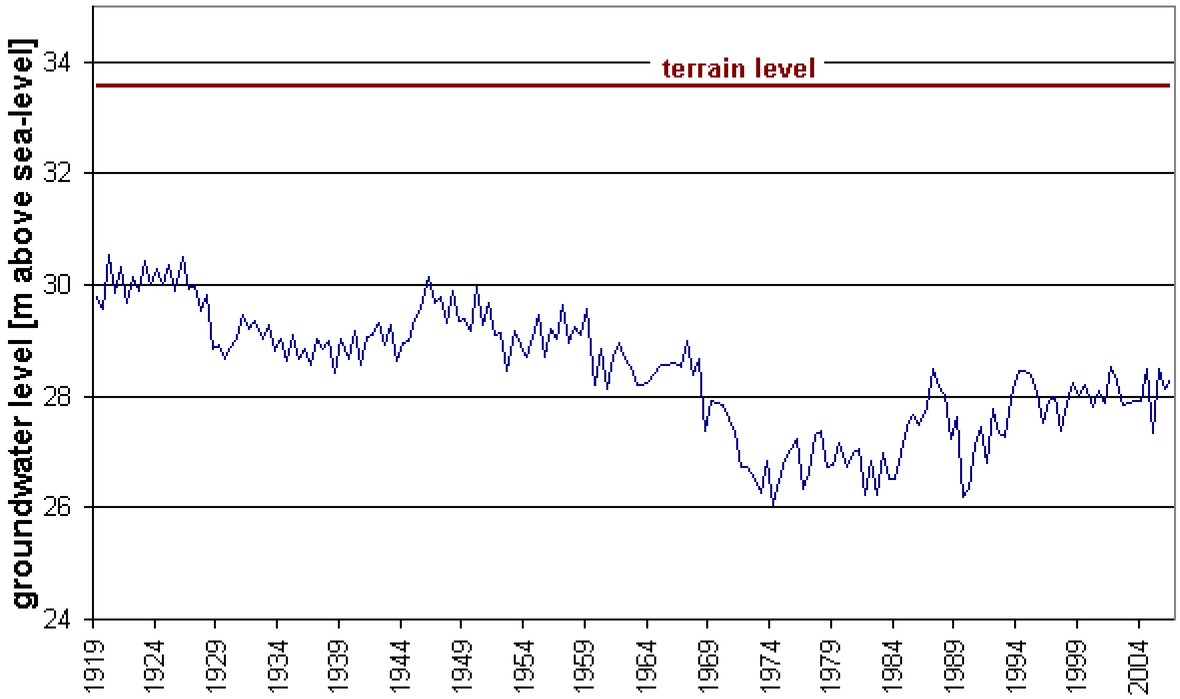

Fig. 3: Fluctuation of groundwater levels at measuring site 1516 in Spandau Forest

Generally, a **rise** in groundwater levels has been observable in West Berlin since the end of the ‘80s. Three measures against the trend of dropping groundwater levels were the primary reason for this:

- The rise in artificial **groundwater augmentation** with cleaned surface water in areas near the waterworks (Spandau, Tegel and Jungfernheide) led to reductions in the amounts of lowering (cf. Map 02.11)
- The **enforcement of groundwater return** in cases of groundwater reservoir measures connected with major construction projects reduced the burden on the basic water balance.
- The introduction of the **groundwater withdrawal fees** led to thriftier management of groundwater resources.

In May 2006, the potentiometric surface was, all in all, at a relatively high level. The reason for this was declining water consumption, which can be seen from the reduced raw-water intake by the Berlin Water Utility since the political change in East Germany, especially in the eastern boroughs. Five small Berlin waterworks discontinued their production completely during the period between 1991 and 1997: Altglienicke, Friedrichsfelde, Köpenick, Riemeisterfenn and Buch. As a result, the groundwater levels rose again citywide through the mid-‘90s. During this period, numerous cases of water damage occurred locally due to sudden groundwater resurgence in cellars which were not properly sealed. The damage was so extensive in two areas (Rudow, Kaulsdorf) that groundwater-regulatory measures had to be carried out.

In addition, drinking-water production at the two waterworks Johannisthal and Jungfernheide was discontinued temporarily in September 2001; at the latter, the same was true for artificial groundwater amplification. In the context of groundwater management of the Senate Department for Urban Affairs, groundwater is however still withdrawn at Johannisthal, so as not to endanger current local waste disposal and construction measures. At the Jungfernheide site, groundwater maintenance has been carried out by Siemens AG since January 2006, in order to protect the buildings.

The overall intake of the waterworks for drinking water purposes has dropped by over 40% in Berlin over 17 years: In 1989, 378 million cu. m were withdrawn, as opposed to 218 million cu. m in 2006.

The drop in groundwater intake by the Utility in the eastern boroughs was even considerably higher – at 60% – during this period. The result was a city-wide groundwater level rise since 1989, which most strongly affected the areas near the wells of the waterworks in the glacial spillway, with their deep cones of depression.

Fig. 4 shows the extent of the large-scale rise in ground-water levels since 1989. The map shows the rise in ground-water levels between 1989 and 2002.

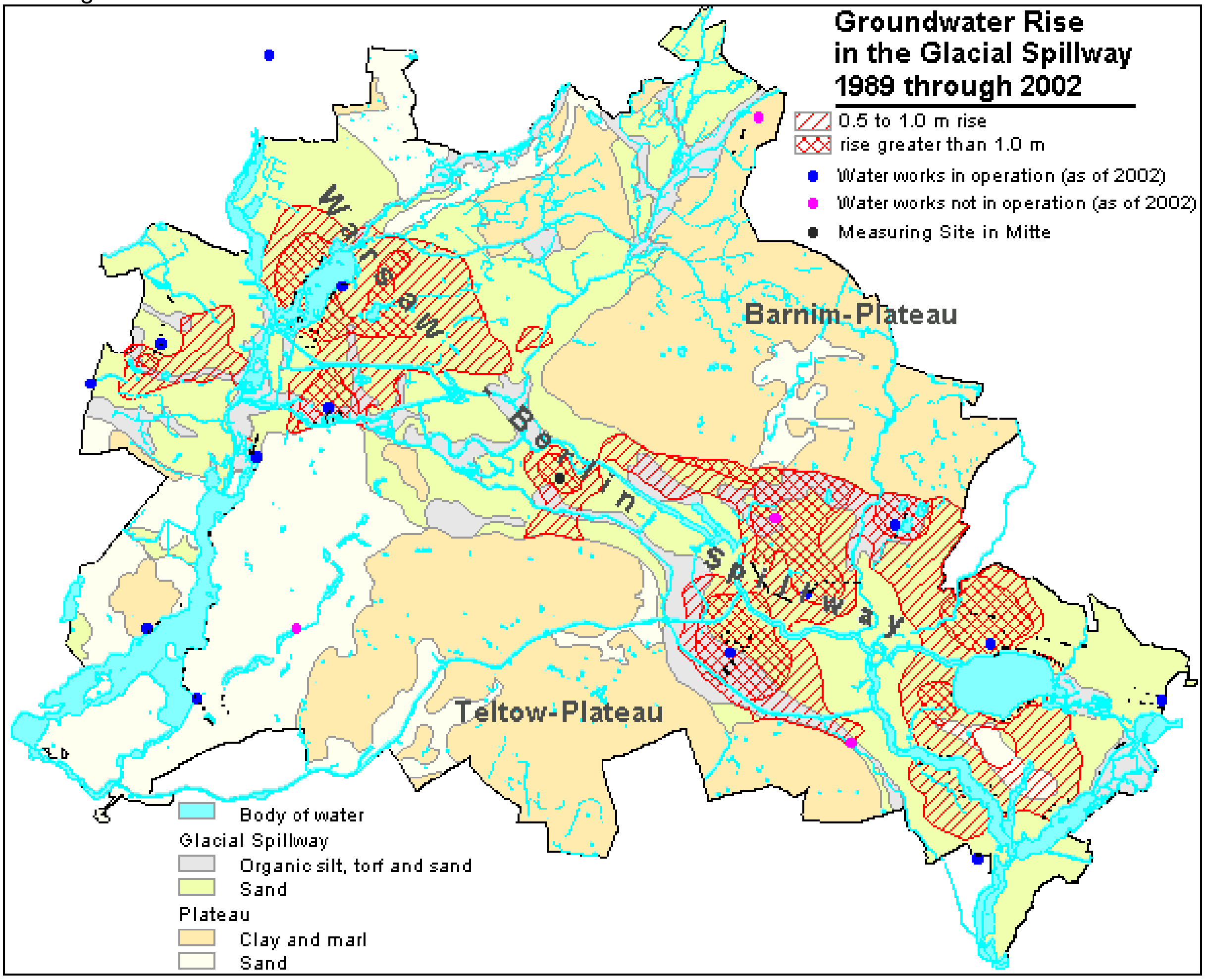

Fig. 4: Groundwater Rise during the Period 1989 through 2002.

The groundwater rise is shown only in the glacial spillway, since this where it is relevant for buildings, due to the low depth to the groundwater table. On the plateaus, depths to groundwater are greater.

Statistical Base

The depths to groundwater are calculated from the difference between the terrain elevation and the level of the potentiometric surface, or, in the case of confined conditions, the covering surface.

The ascertainment of groundwater levels is based on data taken from 1456 groundwater measurement sites (piezometers) of the Berlin State Groundwater Service, from water-supply companies and from the Brandenburg State Environmental Agency in May 2006.

Areas in Berlin with confined potentiometric surfaces were investigated using the digital information on hydrogeological sections of the Geological Atlas (SenStadt 2002) of Berlin, as well as selected bores (ultimate depth >10 meters) from the drilling archives (cf. Fig. 5). At these measurement points, it was not the water levels, but rather the lower surfaces of the aquitards that were ascertained digitally.

The terrain elevations were taken from the altitude model of the City and Environment Information System, as of 2006. The data bases and methodologies for this model are described in the text accompanying Map 01.08.

Moreover, numerous support points for water levels along the surface waters were included in the determination of the regional distribution of the potentiometric surface. These points were used only in areas undisturbed by water-utility activity. In Berlin, such locations are found exclusively in the outlying areas (e.g. along the Dahme of the upper Havel). The reason for the inclusion of these points is to avoid calculating groundwater levels above the table along these waters. Thus, even such small streams as the Große Kuhlake in the Spandau Forest or the Tegel or Neuenhagen Mill Streams (Erpe) were considered in this context.

The derivation of the two-dimensional information on groundwater confinement here described is based on the one hand on the existing invariant data on the spatial distribution of subsurface aquifers and aquitards, and on the other, on the data, which is variant in time, on the free top surface of the groundwater in areas without impeding surface layers for the near-surface groundwater. Since the level of the unconfined potentiometric surface can vary in these latter areas by several decimeters to a meter, depending on the intervals of comparison, it is also possible that there could be an area marked as "unconfined" in May 2002 which could prove to be "confined" in May 2006, and vice-versa.

For this reason, the above-mentioned analysis of the spatial distribution of groundwater confinement had to be checked with the aid of the information on the groundwater levels in May 2006, or repeated. The result is shown in Figure 5.

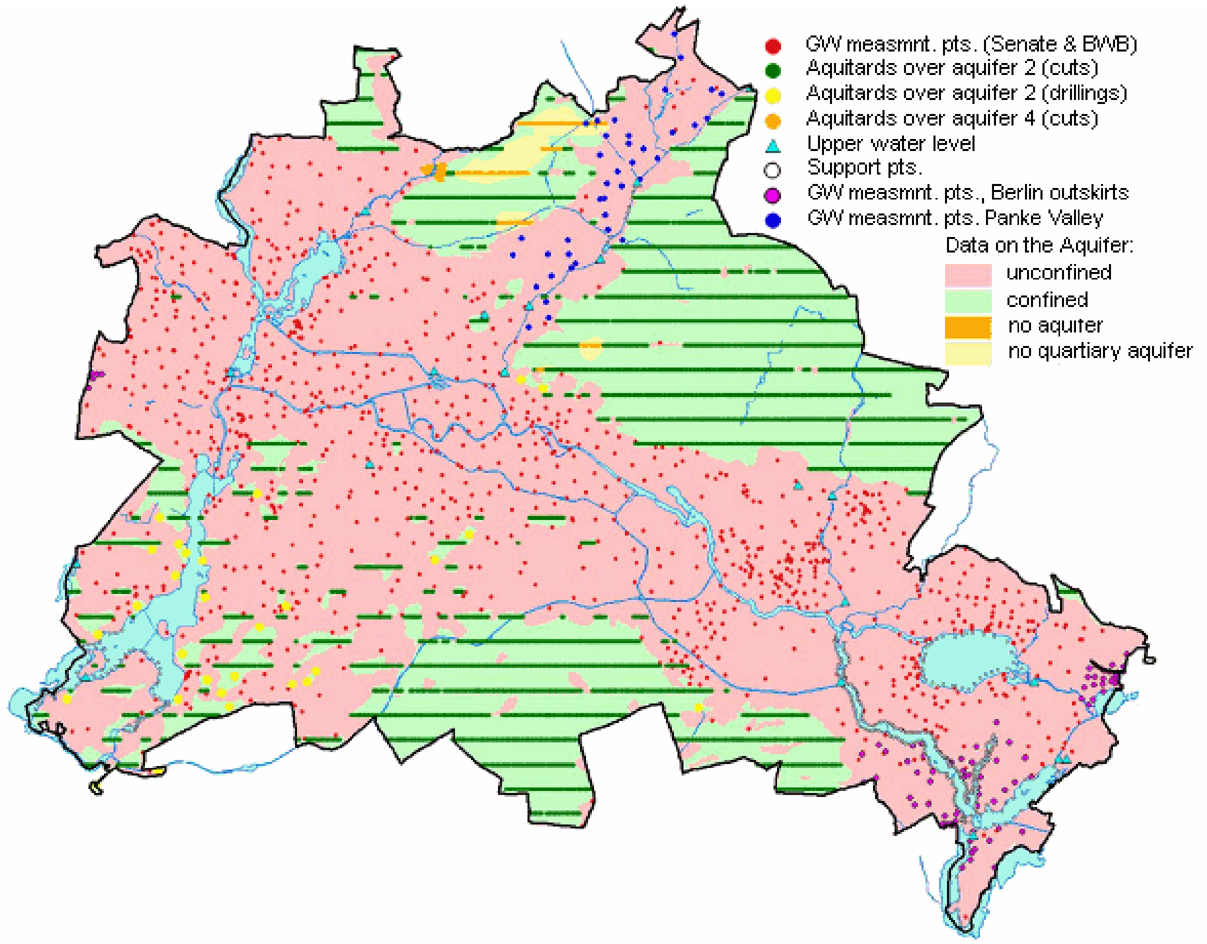

Fig. 5: Distribution of selected measurement information points for the investigation of the potentiometric surface

The differences in the results of the analysis for the two time periods are only slight, with 2% more confined areas state-wide. Some areas which were unconfined as of 2002 and shown as confined in 2006 can be seen in the area of the Barnim Plateau, and also of the Teltow Plateau in the south. The reverse case is recognizable on the western edge of the Panke Valley, where unconfined states have now been ascertained. This is however connected with a modification of the limits of the "Panke aquifer" in this area, which has changed the reference horizon.

Methodology

For the ascertainment of depths to groundwater, a model of the altitude of the free potentiometric surface level above sea-level was first calculated for the month of May 2006, from data collected at the groundwater measuring sites. The procedure is described in the text of the Map of Groundwater Levels for May 2006 (cf. Map 02.12).

For areas with confined groundwater, the depth to the water table is defined as the distance between the lower edge of the covering mantle (or the upper edge of the groundwater aquifer) and the surface of the terrain. In these areas, the groundwater-level data of the measurement sites were therefore replaced by the support points which represent the lower surfaces of the covering layers (Fig. 5). A small area in the north of Berlin, where the cohesive rupelium formations are present directly at the earth's surface (near the *Ziegeleisee* ["Brickworks Lake"] in the Hermsdorf and Lübars areas,) and hence no usable aquifer is available, was exempted from the calculation, so that no groundwater depths were determined here.

The drafting of the uniform stock of grid data on the potentiometric surface from the basic data described was carried out in the course of several work steps. During processing in 2003, it had become apparent that the uniform regionalization of the entire base of support points, consisting of the groundwater-level measuring points in the unconfined areas and the support points to the subterranean levels in the confined areas, can result in an effect exceeding the limits between various confinement states recognized as significant, which can locally in some cases be very far-reaching. Since however there are also usually major differences between the depth positions of the surface of the groundwater at these limits (the surface is usually considerably deeper on the confined side than on the unconfined side), the uniform regionalization proceedings here yield unsatisfactory results.

For this reason the Kriging procedure was carried out separately in unconfined and confined areas, and the two separate partial grids then brought together. In this way, the hydrogeologically caused differences, or "jumps," at the groundwater-confinement borders could be better shown. This had a positive effect primarily on the edges of the glacial valley, where it borders the adjacent plateaus to the north and south areas, since the potentiometric surface is no longer "pulled down" in the unconfined areas.

The potentiometric surface model was then drafted from this aggregated data base. It depicts the contour lines showing the altitude of the potentiometric surface (Fig. 6). For the interpolation, a variogram analysis was carried out, and the Kriging method applied with the aid of the program Surfer, version 8.0.

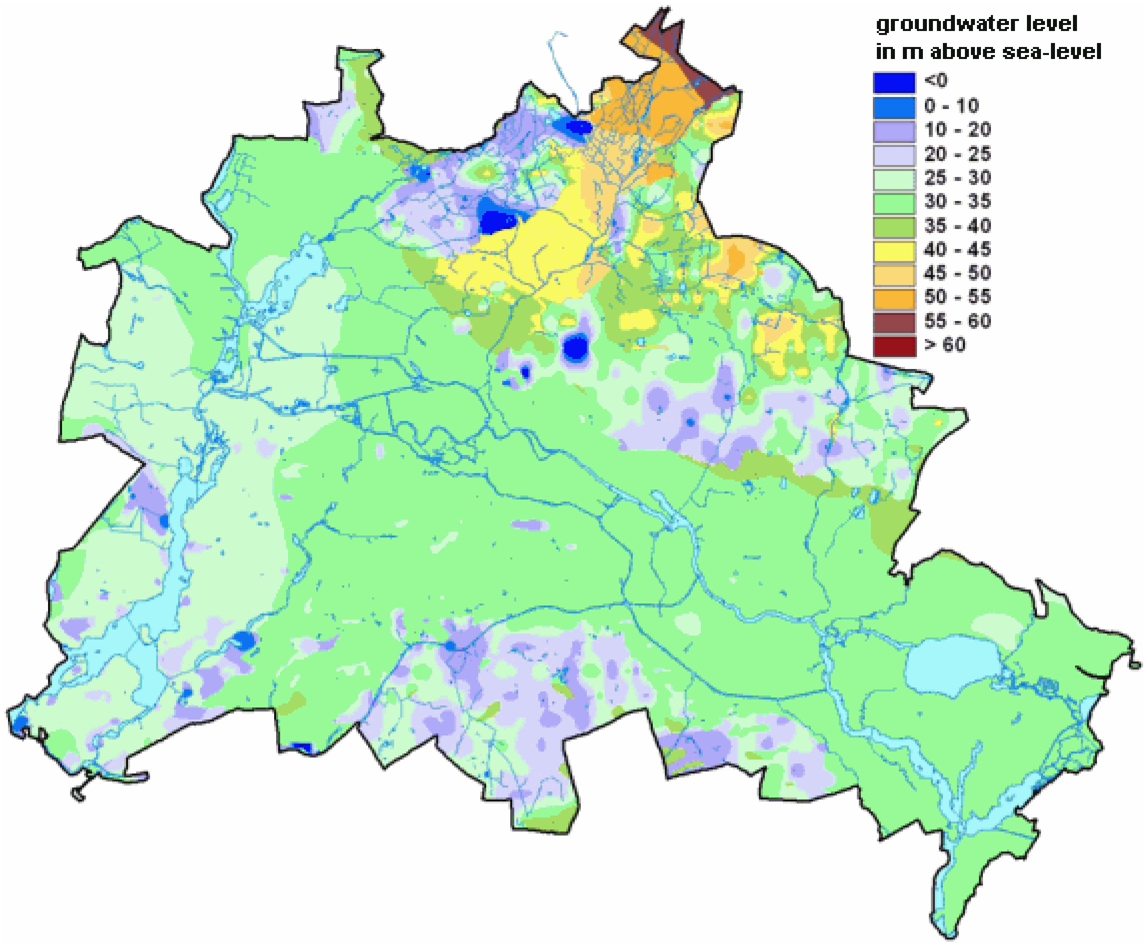

Fig. 6: Groundwater level in Berlin, in meters above sea-level

This overview of the potentiometric surface is a synthetic calculation result, and hence an intermediate result. The representation and interpretation of this intermediate result is moreover an important plausibility check for the determination of the depth to the water table, since by the integration with the altitude model incorporates new, independent information into the model. Any uncertainties in this result may then stem from implausibilities in one or the other of the two independent information sources.

By the inclusion of the lower edges of the aquitard layers, the areas in which the confined potentiometric surface is located under a thick boulder-marl cover at a great depth are shown. At the same time, the "jumps" of the potentiometric surface are also recognizable at the edges of the confined-groundwater areas.

On the Barnim Plateau, the deep areas are located particularly in the northeast (Rosenthal) and along the southern edge of the ground-moraine plate (Lichtenberg). Here, the confined potentiometric surface lies near to, or, locally, even deeper than sea level. These are also mostly areas in which there is no quaternary main aquifer. Here, the potentiometric surface is formed by the bottoms of the layers of quaternary boulder marl, above the tertiary aquifers. However, within the confined areas in Frohnau, the potentiometric surface dips to only about 15 meters above sea level.

The southern part of the Teltow Plateau (Marienfelde, Buckow) is characterized by maximum depths of the potentiometric surface of about 10 meters above sea level. Very deep-lying areas are also recognizable in the area of the plateau sands of the Teltow Plateau east of the Havel; locally they drop roughly to sea level here. This is also the case west of the Havel; mostly however, the potentiometric surface in the confined areas here is between 10 and 25 meters above sea level.

The highest levels of the groundwater are found at altitudes between 55 and 60 meters above sea level in the northeastern, unconfined area of the Panke Valley in Buch, on the Brandenburg state line. The unconfined area of the Panke Valley contrasts sharply with the surrounding confined areas, with altitudes of the potentiometric surface of mostly 40 to 50 meter above sea level. The largest "jump heights" in potentiometric surface are also recognizable at the edges of the Panke valley, locally reaching up to 40 meters in vertical difference over a horizontal distance of only a few hundred meters (e.g. on the eastern edge, at the level of Blankenburg). Thanks to the initially separate calculation of depths to groundwater which were then aggregated, no mutual effect due to the regionalization process – which does not exist in nature – occurred here.

The potentiometric surface reflects the groundwater contour lines in the glacial spillway. It shows a continuous drop of the potentiometric surface in the direction of flow for both the significant tributaries to the main aquifer, the Spree and the Havel, i.e., from east to west and from north to south, respectively. This reflects the hydraulic contact between the surface and the groundwater, which exists everywhere in this area.

Subsequently, a difference model was calculated from the **Model of the Upper Surface of Groundwater** and the **Terrain Elevation Model**. The grid width was 100 meters. The depths to groundwater were broken down into seven depth classifications and published as a map of different levels of groundwater. In order to differentiate depths to groundwater in the range of up to 4 meters, especially in areas important for vegetation, an irregular classification was chosen.

For smaller areas, it is possible to obtain more precise results with the digitalized data available, using smaller grid widths to interpolate the data, provided that the density of the Terrain Elevations Model permits this. The classification boundaries between the categories of depths to groundwater can also be chosen arbitrarily, and are also available with discrete information in the calculated data base.

The exactness of the data collected for the Groundwater Depth Model is directly dependent on the quality of the Terrain Elevations Model. Therefore, any miscalculations in the Terrain Elevations Model also apply to the Groundwater Depth Model.

The following points should be considered, to avoid false interpretations:

- Narrow strips at the edge of surface waters, which in some cases are connected to groundwater, cannot be portrayed in the scale used here, 1:50,000.
- Because of the state of the data, the Terrain Elevations Model will show some inaccuracies. This relates on the one hand to areas in the outlying districts (forests and agricultural areas) with not enough points of elevation, and on the other to areas that were not yet developed at

the time when the measurements were taken. Because of aggradation during construction projects, some of the depressions shown on the map, with a low depth to the water table, no longer exist.

- In areas where groundwater is located under thick, relatively impermeable, boulder-marl aquitard layers, and is thus usually confined, the depths to groundwater can be assumed to be more than 10 meters, and often even more than 20 meters. The lower edge of the aquitard is assumed to be the upper surface of the groundwater. Sandy interstratifications in and on these boulder-marl layers, within which near-surface confined groundwater can also appear, are very limited spatially, and their sites can hardly be localized; they have therefore not been taken into account in the determination of depth to the water table.
- The upper surface of the groundwater is subject to strong fluctuations in areas near wells, depending on withdrawal quantities. For this reason, locally higher depths to groundwater can occur here. The sizes of these areas cannot be portrayed in the scales used here, either.
- It is to be noted that not all wetland areas potentially valuable for the protection of biotopes and species can be gleaned from the Map of Depth to the Water Table (depth to groundwater less than 1.0 meter). This includes areas which, e.g., have no connection to groundwater and are watered by dammed water or periodic natural flooding (such as the Tiefwerder Meadows).

Map Description

The depth to the water table classes “2 to 4 meters,” “4 to 10 meters,” “10 to 20 meters” and “20 to 40 meters” each account for approx. 20% of the surface area. Groundwater-proximate areas with depths to groundwater < 2 meters make up approx. 12% of the area. Very high depths to groundwater > 40 meters occur only occasionally at morphological high sites, on approx. 1% of the area.

Within the glacial spillway, depths to groundwater are predominantly in the range of 2 to 4 meters below the surface. Groundwater-proximate areas with less than 2 meters’ distance from the groundwater to the top edge of the terrain are generally found in the neighborhood of a number of surface waters. Large areas with depths to groundwater of between 1 and 2 meters are also found in the southern villages of the Borough of Treptow-Köpenick (north and south of Langer See ["long lake"]) as well as in the Spandau Forest at Heiligensee east of the Havel, and also both to the north and to the south of Rummelsburg Bay.

Greater depths to groundwater (> 4 meters) have either morphological causes (e.g. the dunes in the Tegel Forest or in the *Rehberge* [“deer hills”]), or they are located in the intake areas of water-works wells (e.g. Spandau, Tegel, Friedrichshagen, Johannisthal), caused by the present lowering. In the glacial spillway, small areas can also be found with increased depths to groundwater, where confined groundwater conditions occur. Here, the groundwater depths are formed by the lower edges of the Vistula Moraine via Aquifer 2.

The depths to groundwater generally increase strongly in the plateau areas. Here, they are for the most part above 10 meters. The southern edge of the Barnim Plateau stands out particularly prominently. In the eastern area of the Barnim Plateau, depths to groundwater of less than 10 meters appear occasionally (e.g. in the area around Malchow Lake or in the headwaters of the Wuhle). Otherwise however, depths to groundwater of above 20 meters, some even in excess of 30-40 meters, are predominant here. The northern area of the Barnim Plateau – cut by the valley of the Panke, with the very low depths to the groundwater of the surface-proximate Aquifer 1 – is characterized by very high depths to groundwater of in some cases more than 50 meters. The ground moraine reaches a very great thickness here. Below the moraine formations (in places, the Vistula Moraine is directly on top of the Saale Ground Moraine), Aquifer 4 is in some cases even immediately present here. In the northwest, by contrast (Frohnau), the groundwater depths are mostly in the range of 20 to 30 meters, and, in the western areas, such as Bieselheide, often even less than 20 meters, where they are unconfined.

In the Grunewald Forest, as well as generally west of the Havel in Kladow and Gatow, there are extensive depths to groundwater of more than 20 meters. Here, the conditions are predominantly unconfined within the surface plateau sands; the high figures are caused by morphological elevations (the Teufelsberg [“devil’s hill”], the Schäferberg [“shepherd’s hill”], the Havel Hills at the Grunewald Tower), and also in the Müggel Hills.

The western area of the Teltow Plateau between the Grunewald chain of lakes and the Teltow Canal is characterized by strongly variegated depths to groundwater of between 5 and 30 meters. There are also differing regional conditions with respect to the confinement of the groundwater here. To the southeast of the Teltow Canal however, depths to groundwater are for the most part above 20 meters, with confined groundwater. This area is again subdivided by the valley of the Rudow Stream. To the east, in Bohnsdorf, there are once again depths to groundwater of more than 20 meters.

Compared with the depths to groundwater calculated in May 2002, considerably higher depths to groundwater are to be found only in the confined areas of the Barnim and Teltow Plateaus. These are areas which in May 2002 had been labeled as “unconfined” due to changed ground-water levels, and thus had a considerably higher potentiometric surface

Considerably lower depths to groundwater are, however, predominant in the unconfined areas, especially on the edges to the areas which were confined as of in May 2006. This effect is achieved by the current practice of separate calculation of the potentiometric surface in confined and unconfined areas (see above). This ensures that the calculation is not influenced by factors from outside the confined areas. This is e.g. particularly apparent to the south of the Teltow Canal in Adlershof, at the border of the Teltow Plateau, where currently, depths to groundwater of 1 to 2 meters pertain, while depths to groundwater of more than 4 meters were still calculated in 2002. The edges of the Barnim Plateau, e.g. east of the Wuhle or west of the Panke valley, also show this effect very clearly.

Apart from these methodologically dictated modifications, there are for the most part only insignificant deviations in comparison with May 2002, with differences which generally do not exceed one meter. Areas with greater depths to groundwater (up to 50 cm or even one meter), largely predominate, which is due to the slight drop in groundwater levels in May 2006, compared with May 2002, which was caused by climate-related factors.

There are however also areas in which the depth to groundwater has decreased by up to 50 cm or a meter. This is predominantly the case in inner-city areas in which the groundwater is exposed to other effects in addition to those caused by climatic influences. These effects may overlap, so that the depths to the water table in the unconfined areas of the glacial spillway remained relatively constant when comparing them over the course of these four years.

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