02.07 Depth to Groundwater (Edition 2003)

Overview

Groundwater levels in a metropolitan area like Berlin are subject not only to natural factors such as precipitation, evaporation and subterranean outflows, but are also strongly influenced by such human factors as development, sealing of surface, drainage plants, withdrawals and recharge.

The main factors of **withdrawal** include the groundwater demands of public water suppliers, private water production, and the lowering of groundwater levels at construction sites (cf. Map 02.13.15). **Groundwater recharge** is accomplished by precipitation, shore filtration, artificial recharge with surface water, and return of groundwater at construction sites.

In Berlin, there are two groundwater layers. The deeper layer carries salt water and is largely separated from the upper groundwater layer by an approx. 80 m thick layer of clay, except at occasional fault points in the clay. The upper layer carries fresh water and has an average thickness of 150 m. 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 soils) combine to form the groundwater aquifer, while the clay, silt and organic silt (cohesive soils) constitute a groundwater-obstructing layer.

The groundwater table is dependent on the (usually slight) gradient of groundwater and the terrain morphology (cf. Fig. 1). The **depth to groundwater** is defined by calculating the perpendicular distance between the upper edge of the surface, and the upper edge of the free, unconfined groundwater table. When the groundwater aquifer is covered by relatively impermeable, cohesive soil layers (a groundwater-obstructing layer), the groundwater is unable to rise enough to reach the height of its hydrostatic pressure. It is under these conditions that the groundwater level becomes confined. Only drilling through the obstructing layer will permit the groundwater at a groundwater measurement site to rise to the level of the groundwater pressure area (Fig. 1). In such a case, the depth to groundwater is defined by calculating the perpendicular distance between the upper edge of the surface and the lower edge of the groundwater-obstructing marl layer which covers the aquifer.

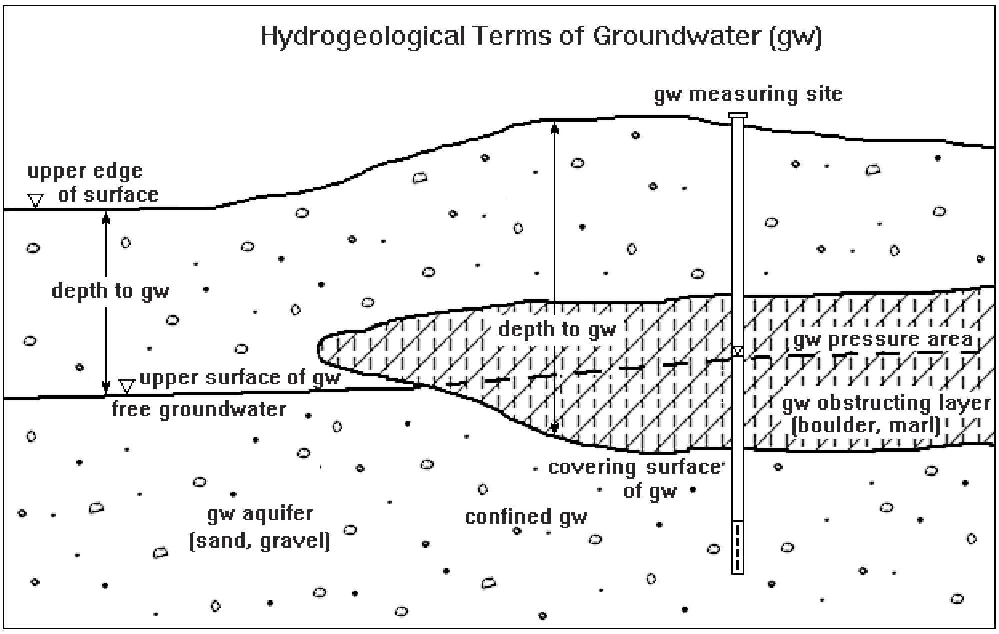

Fig. 1: Terminological Definition of the depth to groundwater at free and unconfined groundwater

The Map of Depth to Groundwater gives an overview of the spatial distribution of areas with the same depth classifications, at scale of 1 : 50,000 (SenStadt 2003). It was calculated on basis of the data of May 2002, and applies to the respective near-surface aquifer with an uninterrupted water supply. In Berlin, this in most cases means the main groundwater aquifer (GWL), which is used for water supply (GWL 2, according to the structure of Limberg and Thierbach 2002), and which is uncovered in the glacial spillway, but covered in the more elevated areas. In exceptional cases, the GWL 1 (e.g. in the area of the Panke valley) or the GWL 4 (tertiary formations) were used to determine the groundwater depth.

Areas with a lesser depth to groundwater (to about 4 m) are of particular importance. **Pollution of soils** 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 Groundwater is thus a significant basis for the preparation of the Map of the Protective Function of Groundwater Coverage (cf. Map 02.06). The spatial overlaying of groundwater depth onto geological characteristics of the covering mantle permits the delimitation of areas of varying protective functions of groundwater coverage).

Knowledge of groundwater depths enables an estimation of groundwater influence on **vegetation**. The influence of groundwater on vegetation depends on the root depths of plants and, according to soil type, the capillary climbing capacity of groundwater. The threshold depth at which groundwater can be used by trees is given at 4 m for general Berlin conditions. Vegetation in wetlands depends mostly on the groundwater, and requires a depth to groundwater of less than 50 cm.

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 until the end of the 19th century, the mean groundwater level in Berlin was subject only to the annual fluctuation in precipitation. The period between 1890 and the end of World War II was marked by rapid urban growth, the construction of rail networks (Alexanderplatz), and by major reconstruction projects. Because of this construction, the groundwater level in the inner city was dramatically lowered, resulting in an 8 m drop in the groundwater level. With the breakdown of the public water supply at the end of the war, the depth of groundwater was able to restore itself to naturally levels (Fig. 2).

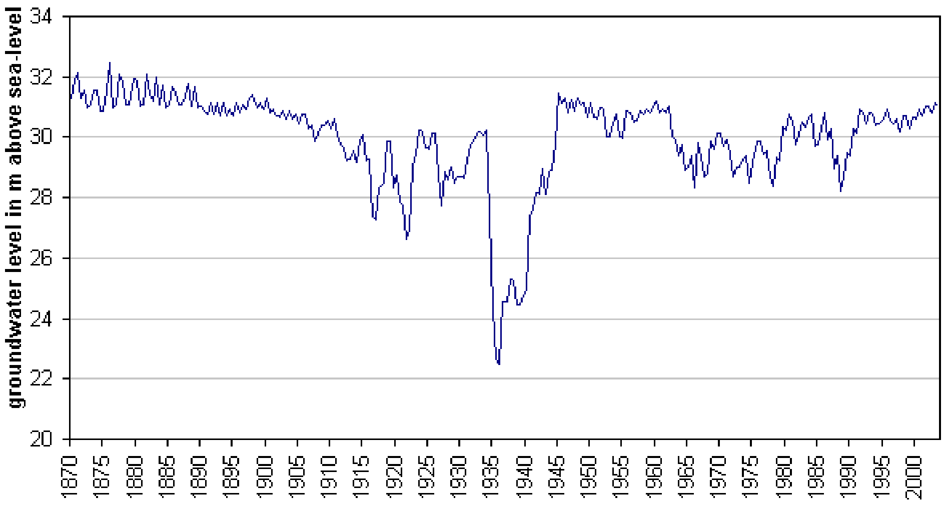

Fig. 2: Fluctuation of Groundwater Levels at Measuring Site 5140 in Mitte (Charlottenstrasse) since 1870

During the ensuing period, from the early ‘50’s to the early ‘80’s, the groundwater level **sank** continually and over large areas because of increased withdrawal. This was particularly noticeable in water production 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 production facilities in the West Berlin waterworks was completed by the beginning of the ‘70’s. The expansion of the Friedrichshagen Waterworks in East Berlin began in the mid-‘70’s, to supply water to the new residential areas in Hellersdorf, Marzahn and Hohenschönhausen.

A slight **rise** in groundwater levels has occurred in West Berlin since the end of the 70’s.

A number of reasons can be given for this rise: reduced withdrawal from private wells; reduced withdrawal at construction sites (a lower construction volume and enforcement of groundwater return); reduced withdrawal volumes by public waterworks; and, not least, effective anthropogenic **groundwater recharging** (cf. Map 02.11).

Following the political changes in 1989 (fall of the Berlin Wall), the level of water consumption in the eastern boroughs of Berlin was drastically reduced, and the production at the waterworks in those areas dropped an estimated 50 %. This resulted in a rise in the groundwater level throughout the city, east and west. Since then, it has kept relatively steady at this high level; a further increase has not been observed, however (cf. p. & Ch. Basic Data).

Those areas nearest to waterworks recorded level increases of as high as 3 m during the mid-‘90s. The Berlin Pleistocene Watercourse (or glacial spillway), which covers half the area of the city, has a very low depth to groundwater of only a few meters. Many of the cellars in some areas were not sealed appropriately, and therefore suffered damage through dampness due to a sudden increase in groundwater during this period. In two areas, the damage was so extensive that it was necessary to implement groundwater regulatory measures (Rudow, Kaulsdorf).

Permanent, wide and deep **cones of depression** have formed in water catchment areas around waterworks wells. The considerable differences observable among groundwater levels are directly related to variations in withdrawal requirements at the respective waterworks. Riemeister Lake and Nikolas Lake were dried out by the water withdrawals of the Beelitzhof Waterworks at the beginning of this century. The groundwater level of the Schlachten Lake fell by 2 m, and at Krumme Lanke by 1 m. Since 1913, water from the Havel has been withdrawn into the Grunewald lakes (inversion of natural flow) to balance this loss. The wetlands of Hundekehlefenn, Langes Luch and Riemeisterfenn, 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 m between 1954 and 1974, and at Pechsee in the Grunewald by about 4.5 m between 1955 and 1975. Well gallery withdrawals at 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, Teufelsseemoor, Neue Wiesen/Kuhgraben, Mostpfuhl, Thyrn, the lower course of Fredersdorfer Fliess).

Some wetland areas were flooded and given seepage of surface water to moderate negative effects caused by the lowering of groundwater levels. These were the West Berlin nature reserves Grosser Rohrpfuhl and Teufelsbruch in the Spandau Forest, and Bars Lake in Grunewald; 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 70’s. A groundwater recharging plant, operated since 1983, percolates purified Havel water in an attempt to gradually raise groundwater levels. The groundwater level in the Spandau Forest had been raised by an average of 0.5 - 2.5 m 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 withdrawal amounts of the Spandau Waterwork lowered the groundwater level again after 1990. In the following period, the groundwater level rose once more, due to the further reduction of withdrawal amounts.

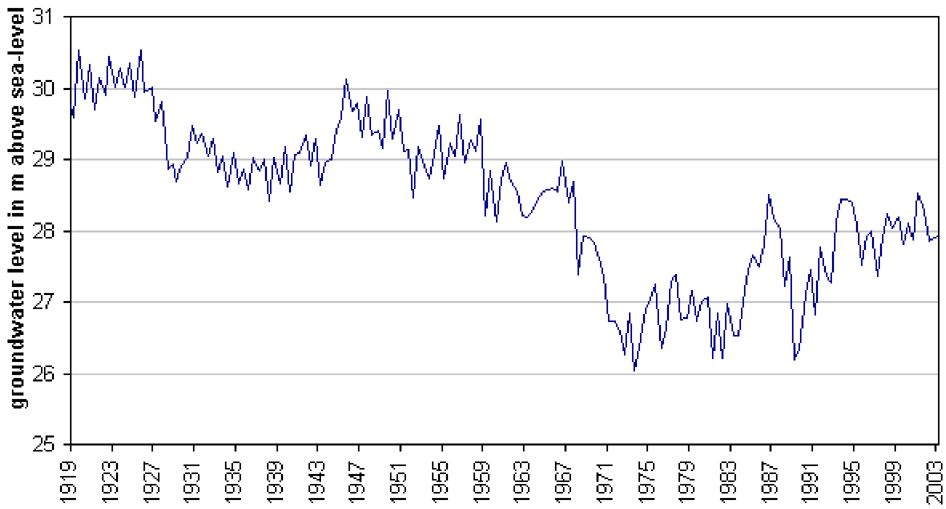

Fig. 3: Fluctuation of Groundwater Levels at Measuring Site 1516 in Spandau Forest

However, in May 2002, the groundwater surface was, all in all, at a relatively high level, as it had been during the previous seven years. The reason for this was declining water consumption, which can be seen from the reduced raw water intake by the Berlin Water Utility. Five small Berlin waterworks discontinued their production completely during the period between 1991 and 1997: Altglienicke, Friedrichsfelde, Köpenick, Riemeisterfenn and Buch. 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 SenStadtUm groundwater management, groundwater is, however still withdrawn at both locations, so as not to endanger current local waste disposal and construction measures. The overall intake of the waterworks for drinking water purposes has dropped by over 40% in Berlin during the past 13 years: In 1989, 378 million m³ were withdrawn, as opposed to 220 million m³ in 2001. 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 between 1989 and 2000, 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 2000.

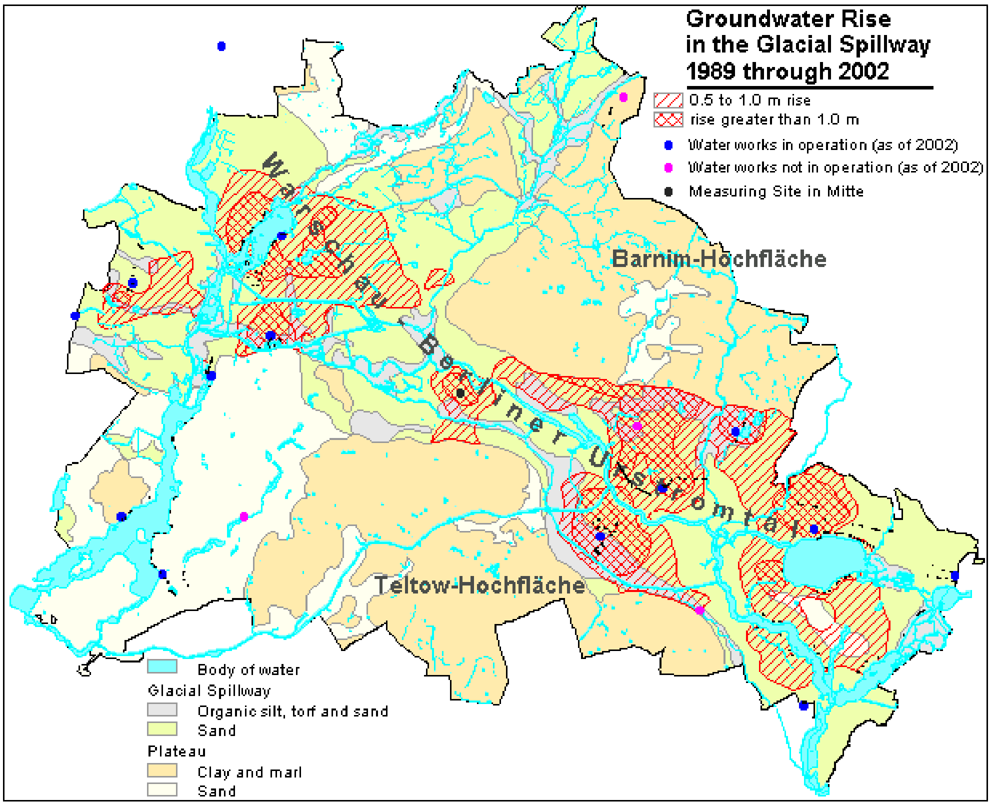

Fig. 4: Groundwater Rise during the Period 1989 through 2000.

The rise shown reflects that in the observation pipes of the groundwater measurement sites, i.e., in the confined areas, the increase in groundwater pressure area, and not the actual groundwater surface. Due to the low density of data for the Barnim Plateau, the increase here could not be shown.

Statistical Base

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

The calculations of groundwater levels are based on data taken from approximately 1,400 groundwater measurement sites of the State Water Service in May 2002, in areas with free groundwater surfaces.

Areas with a confined groundwater surfaces in Berlin were investigated using the digital information on hydrogeological sections of the Geological Atlas (SenStadt 2002) of Berlin, as well as selected (ultimate depth > 10 meters) bores from the drilling archives (cf. Fig. 5). In these areas, not the water-levels of the measurement sites but rather the lower surfaces of the Groundwater obstructions were ascertained.

The terrain elevations were taken from the altitude model of the Environmental Information System (slightly modified by the inclusion of altitude readings from the geological sections of the Geological Atlas). The data bases and methodologies for this model are described in the text accompanying Map 01.08.

Moreover, numerous supporting points for water levels along the surface waters were included in the determination of the regional distribution of the groundwater 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. Dahme, upper Havel). The reason for the inclusion of these points is the goal of avoiding of calculated ground-water levels above the table along the waters. Thus, even such small streams as the Grosse Kuhlake in the Spandau Forest or the Tegel or Neuenhagen mill streams (Erpe) could be into account.

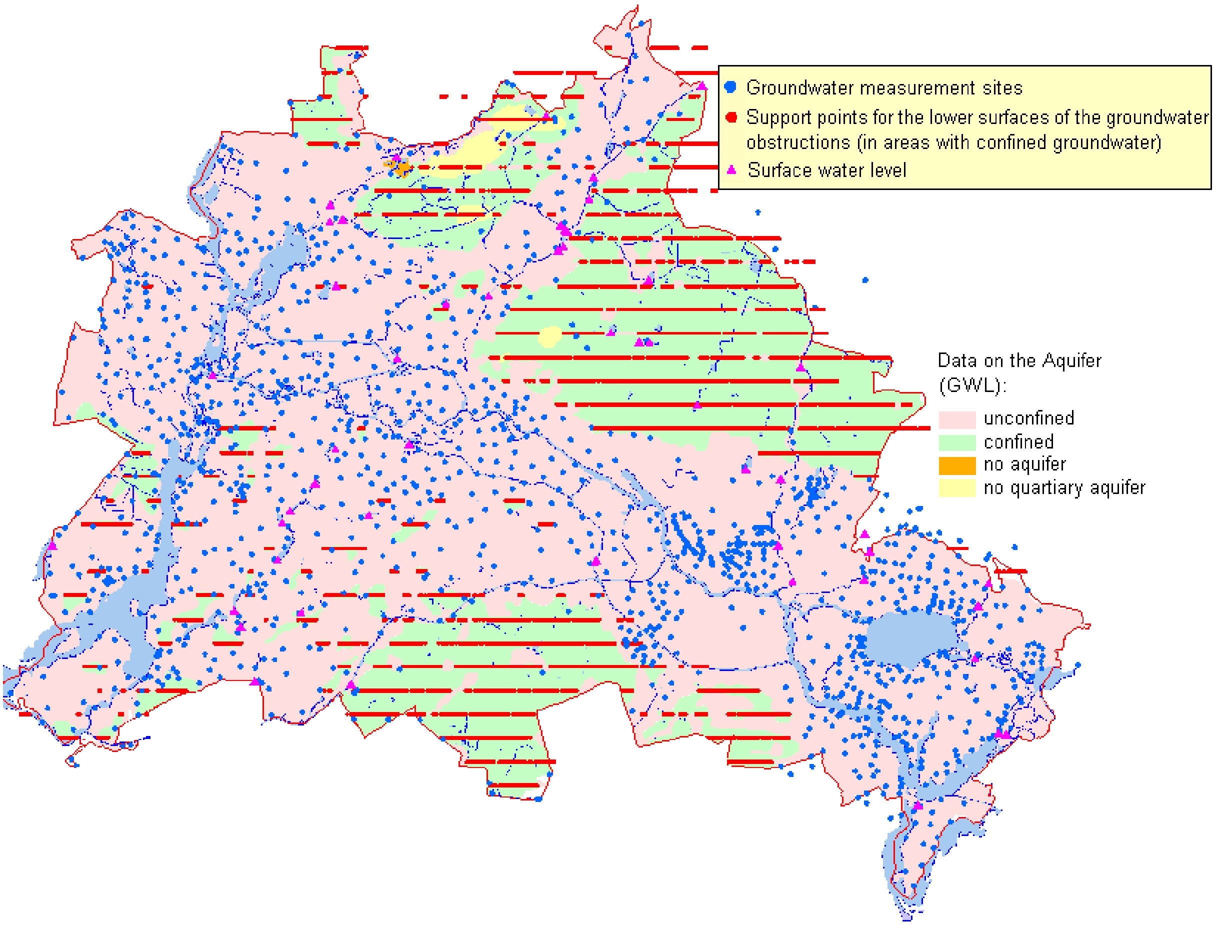

Fig. 5: Distribution of selected measurement information points for the investigation of the groundwater surface

Methodology

For the ascertainment of groundwater depths, a model of the altitude of the free groundwater surface level above sea-level was first calculated from data collected at the groundwater measuring sites in May 2002. The procedure is described in the text of the Map of Groundwater Levels of May 2002 (cf. Map 02.12).

For areas with confined groundwater, the depth to groundwater 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 ground-water level data of the measurement sites were therefore replaced by the support points which represent the lower surfaces of the covering layers (cf. Fig. 4). A small area in the north of Berlin, where the cohesive formations of the rupelton clay 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.

With this compiled data base, the model of the groundwater surface which can be shown in the form of isohypses (lines showing the same altitude of groundwater level; cf. Fig. 6) was then constructed. For the interpolation, a variogram analysis was made, and the Kriging method was used with the aid of the program Surfer, version 8.0.

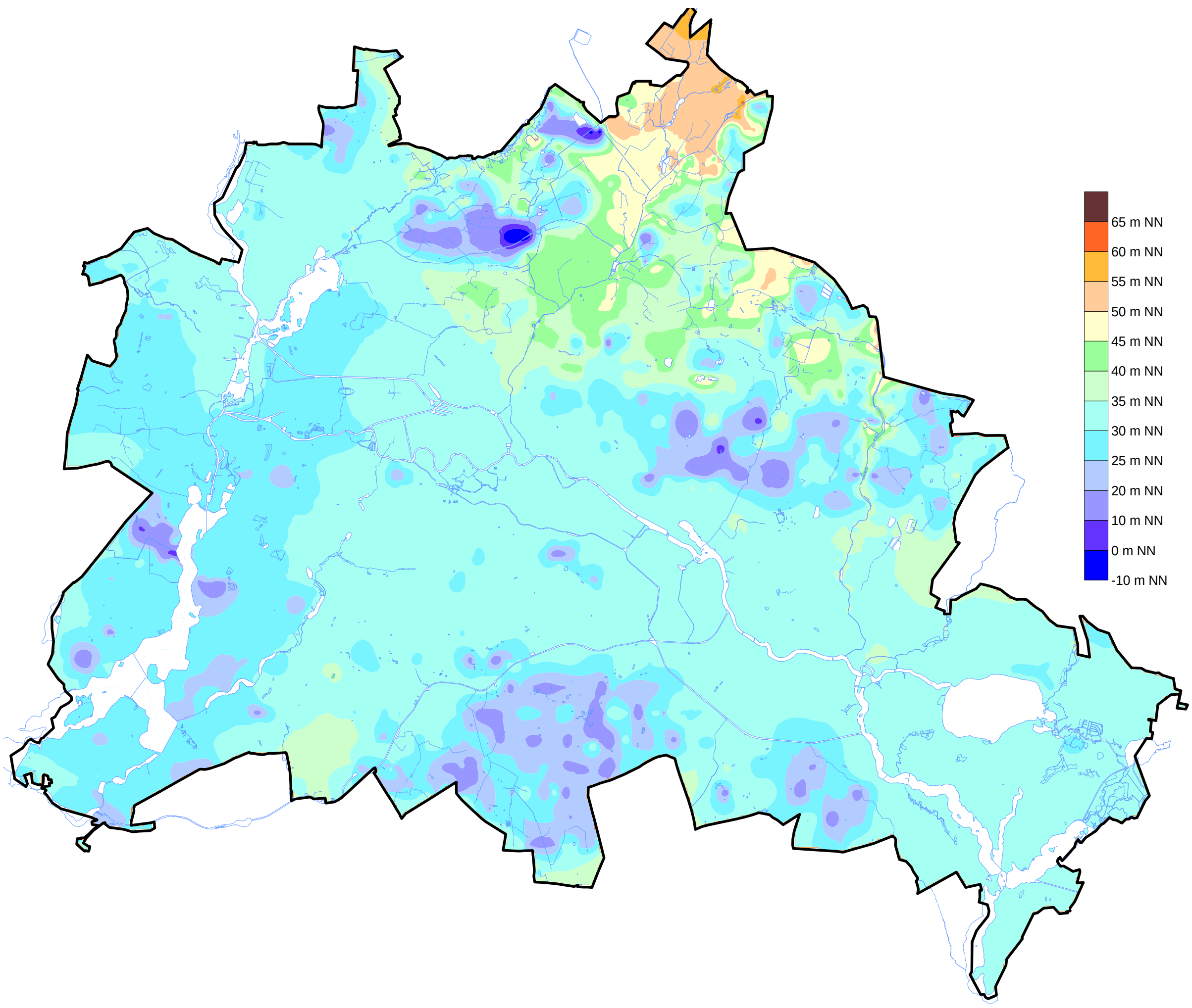

Fig. 6: Groundwater Level in Berlin, in meters above sea-level (NN)

In the unconfined areas, the free measured groundwater pressure area is represented; in the confined areas, it is the lower level of the obstructing covering layers. This corresponds exactly to the actual conditions in nature. The groundwater surface in a bore or an excavation is tapped exactly at a certain altitude above sea-level, as can be seen from the Fig. 6. The representation and interpretation of this intermediate result is moreover an important plausibility check toward the determination of the groundwater depth, since by the integration with the altitude model incorporates new, independent information into the model. Any uncertainties in this intersection result may then result from implausibilities in one or the other of the two independent information sources.

By the inclusion of the lower edges of the obstructing surface layers, the areas in which the (confined) groundwater surface is located under a thick marl covering at a depth of roughly 0 m above sea-level are shown very clearly in Fig. 5, with the dark blue colors.

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). The southern part of the Teltow Plateau (Marienfelde, Buckow) is characterized by maximum depth of groundwater surface of about 15 meters above sea-level. The locations of greatest altitude of groundwater surface, about 50 m above sea-level, are found in the northeastern, unconfined area of the Panke valley (Buch). In the glacial spillway, there is a continuous drop of the groundwater surface in the direction of flow of the two main receiving streams, the Havel and Spree, in an east-to-west and a north-to-south direction, respectively. This supports the posited hydraulic contact between the surface and groundwater.

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

For smaller areas it is possible to obtain more exact 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. Value limits used for classification 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 hand to areas that were not yet developed at the time when the measurements were taken. Because of landfilling during construction projects, some of the depressions shown on the map, with a low depth to groundwater, no longer exist.
- In areas where groundwater is located under thick relatively impermeable, obstructive boulder marl layers (and is then usually also confined), the depths to groundwater can be assumed to be more than 10 m, and often even more than 20 m. The lower edge of the groundwater-obstructing layer is assumed to be the upper surface of the groundwater. Sandy interstratifications in these boulder marl layers, within which near-surface confined groundwater can also appear, are narrowly limited spatially, and their sites can hardly be localized; they have therefore not been taken into account in the determination of depth to groundwater.
- The upper surface of the groundwater is subject to strong fluctuations in areas near wells, depending upon withdrawal amounts. 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 Groundwater (depth to groundwater less than 1.0 m). 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 groundwater depths in the glacial spillway are for the most part approx. 2 to 4 meters below the surface. Groundwater-near areas with less than 2 meters depth to groundwater are generally located near those surface waters the shorelines of which have been used as support points for the calculation (e.g. the Erpe, the Panke and the Wuhle). Relatively large areas with groundwater depths of between 1 and 2 meters are located in the southern areas of the borough of Köpenick (north and south of the Langer See [“long lake”]), in the Spandau Forest, and north and south of the Rummelsburg Bay.

Within the glacial spillway, greater groundwater depths than about 5 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 work wells (e.g. Spandau, Tegel, Friedrichshagen). In the glacial spillway, small areas can also be found with increased groundwater depths, where confined groundwater conditions occur. Here, the groundwater depths are formed by the lower edges of the Vistula moraine.

The groundwater depths 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, groundwater depths of less than 10 meters appear occasionally (e.g. in the area around Malchow Lake or in the headwaters of the Wuhle). Otherwise however, groundwater depths of above 20 meters, or even above 30-40 meters, dominate here. The northern area of the Barnim Plateau – cut by the valley of the Panke, with the very low groundwater depths of surface-near Aquifer 1 – is characterized by very high groundwater depths of in some cases more than 50 meters. The ground moraine reaches 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 often even less than 20 meters in the unconfined areas.

South of the glacial spillway there are extensive groundwater depth areas of more than 20 meters in the Grunewald, as well as generally west of the Havel in Kladow and Gatow. There are predominantly unconfined conditions within the surface plateau sands; the high values are caused by morphological elevations (the Teufelsberg ["devil mountain"], the Schäferberg [shepherd's mountain], 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 groundwater depths of between 5 and 30 meters. There are also differing regional conditions with respect to the conffinement of the groundwater here. To the southeast of the Teltow Canal, however, groundwater depths 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 groundwater depths of more than 20 meters.

In a comparison of groundwater depths of May 2002 with those of the last groundwater depth map of the Environmental Atlas of May 1995, current data indicate groundwater depths more than 10 meters higher. These are predominantly areas with confined groundwater in the Barnim and Teltow Plateaus, in which the groundwater depths have increased considerably due to the more detailed inclusion of the lower edges of the strata.

Within the glacial spillway, the groundwater depths are mostly around half a meter to one meter higher, in the current overview. This can be explained by climatic differences and also in some cases on the basis of progress-line observations of select measurement sites of the State Groundwater Service. By comparison of 2002 with 1995, there are areas with in some cases up to a meter or more lower groundwater depths, in the catchment areas of the well galleries of the waterworks (e.g. the Jungfernheide and Tegel WW, and single galleries of the Friedrichshagen WW) which have now been shut down or cut back strongly in their withdrawal levels.

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