02.12 Groundwater Levels of the Main Aquifer and Panke Valley Aquifer 2020

Introduction

Exact knowledge of the current groundwater levels, and hence also of the groundwater resources, is crucial for the State of Berlin, since the water for the public water supply of Berlin (233 million m³ in the year 2019) is provided from groundwater. The groundwater is pumped at nine waterworks, almost entirely within the city area, with the exception of the waterworks Stolpe. It is located on the northern outskirts of the city and pumps water from wells that are located in Brandenburg (approx. 9 % of the total annual pumping volume) (Fig. 1).

Fig. 1: Location of the waterworks which supply Berlin with drinking water, as of May 2020

Additionally, groundwater is pumped from individual wells (like garden wells) and for industrial use, but also in the context of construction sites, groundwater remediation projects and for geothermal usage. In Berlin, numerous cases of soil and groundwater contaminations are known and the information about the hydraulic situation is fundamental for their remediation.

The map of the groundwater levels for the month of May, with the highest groundwater levels throughout the year is published in the Environmental Atlas.

Definitions Regarding Groundwater

Groundwater is underground water (DIN 4049, Part 3, 1994) which coherently fills out cavities in the lithosphere, and the movement of which is caused exclusively by gravity. In Berlin, as in the entire North German Plain, the cavities are the **pores** between the sediment particles in the loose sediments. Precipitation water which percolates (infiltrates) into the ground first fills these pores. Only that part of the percolating water which is not bound as adhesive water in the non-water-saturated soil, nor used up by evaporation, can percolate to the **phreatic surface** and form groundwater. Above the phreatic surface, capillary water is present within the unsaturated soil zone; it can rise to various heights, depending on the type of soil (Fig. 2).

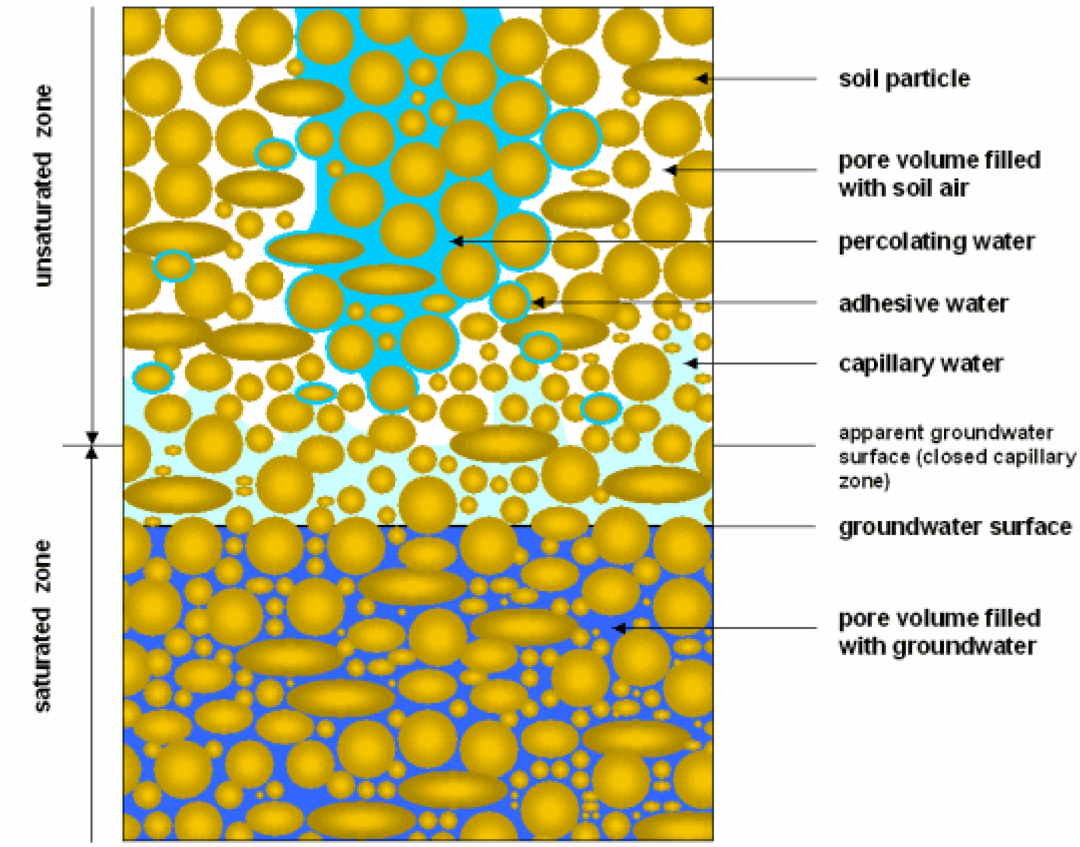

Fig. 2: Types of appearance of subsurface water (modified after Hölting 1996)

Aquifers consist of sands and gravels, and, as incoherent material, make the storage and movement of groundwater possible.

Aquitards consist of clay, silt, peat clay and glacial till and, as cohesive material, hinder water movement.

Aquicludes consist of clay which is virtually impermeable to water.

If the potentiometric surface lies within an aquifer it is known as **free** or **unconfined groundwater**. The phreatic and the potentiometric surfaces coincide. In cases of **confined groundwater** however, an aquifer is covered by an aquitard so that the groundwater cannot rise as high as it might in response to its hydrostatic pressure. Under these conditions, the potentiometric surface is located above the phreatic surface (Fig. 3).

If an aquitard (e.g. a layer of glacial till) is located above a large coherent aquifer (Main aquifer), shallow groundwater may develop in sandy segments above the aquitard and in islands within it, as a result of precipitation. This is unconnected with the main aquifer, and is often called **stratum water**. If an unsaturated zone is located below the glacial till, it is called **floating groundwater** (Fig. 3).

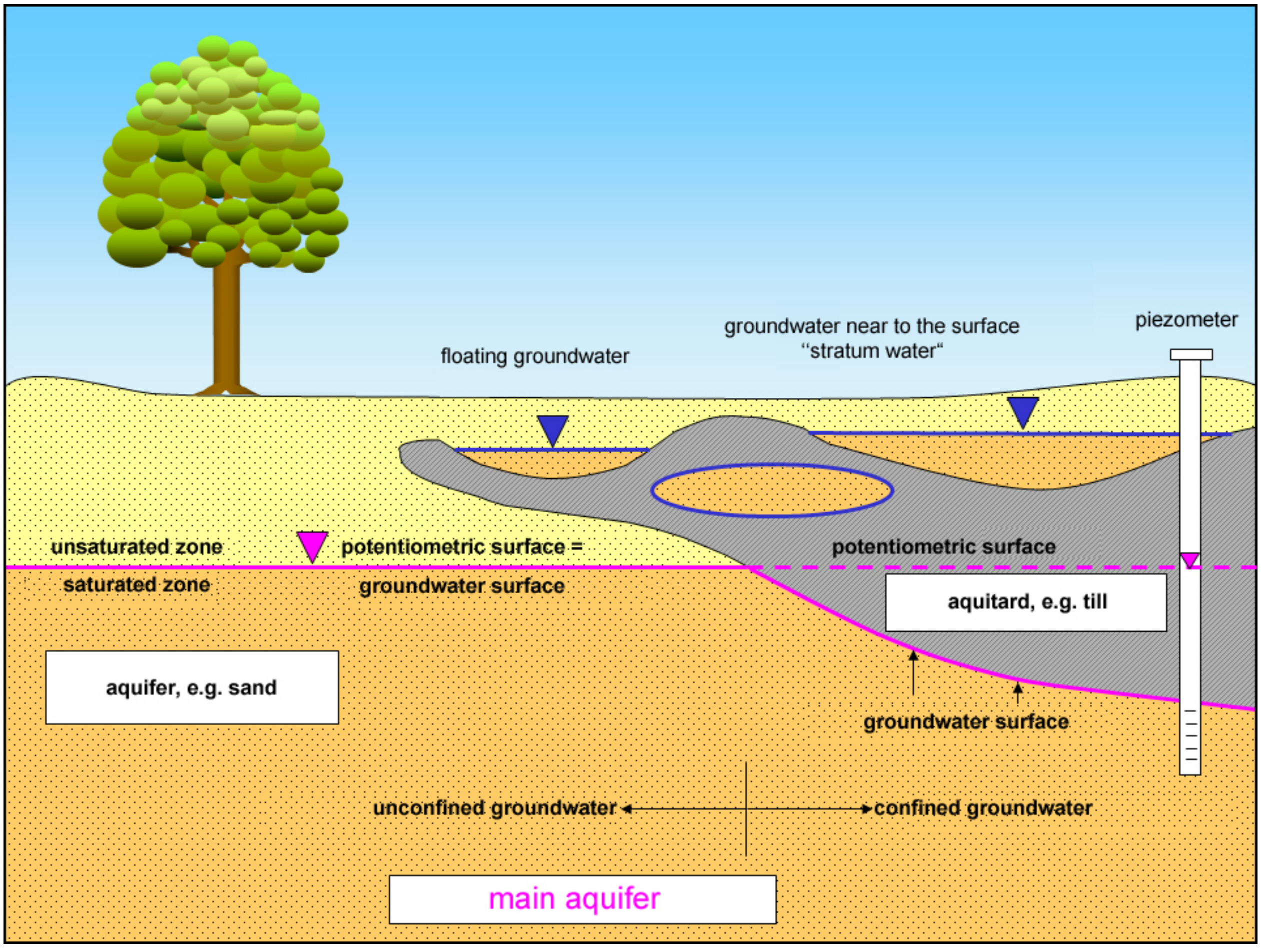

Fig. 3: Hydrogeological terms

Typically, groundwater flows with a small gradient into rivers and lakes (“receiving channel”) and infiltrates into them (effluent conditions; Fig. 4a).

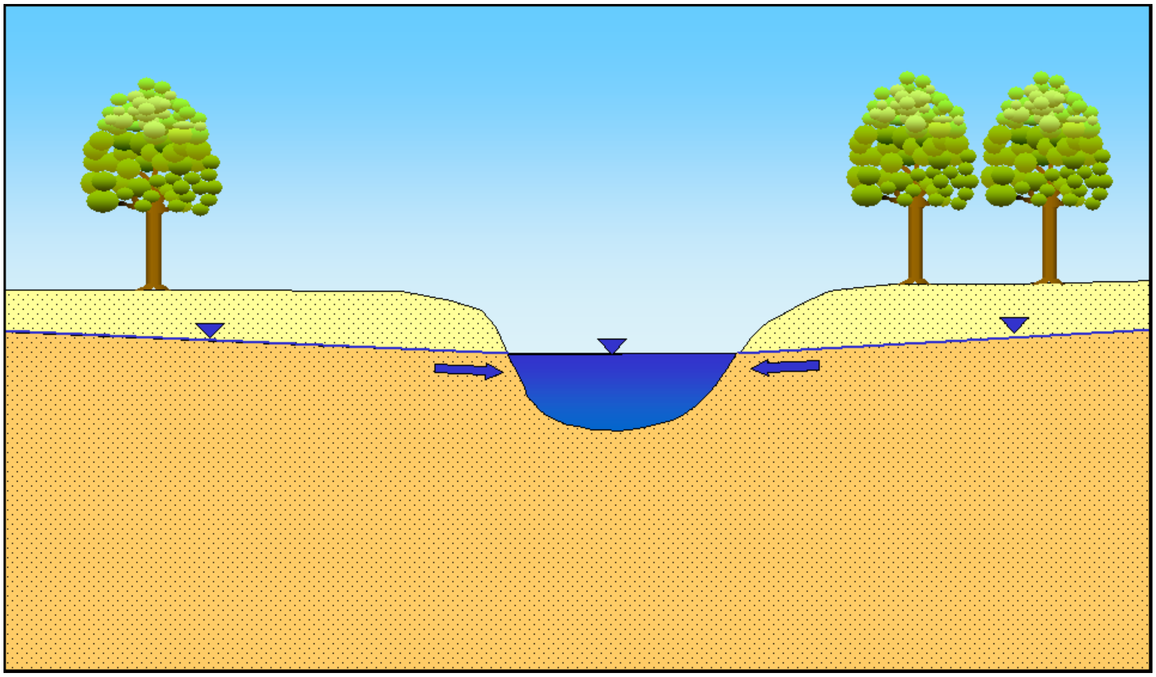

Fig. 4a: Groundwater infiltrates into the surface waters (effluent conditions)

In times of flooding, the water surface is higher than the groundwater surface and surface water infiltrates into the groundwater (influent conditions). This is known as **bank infiltration** (Fig. 4b).

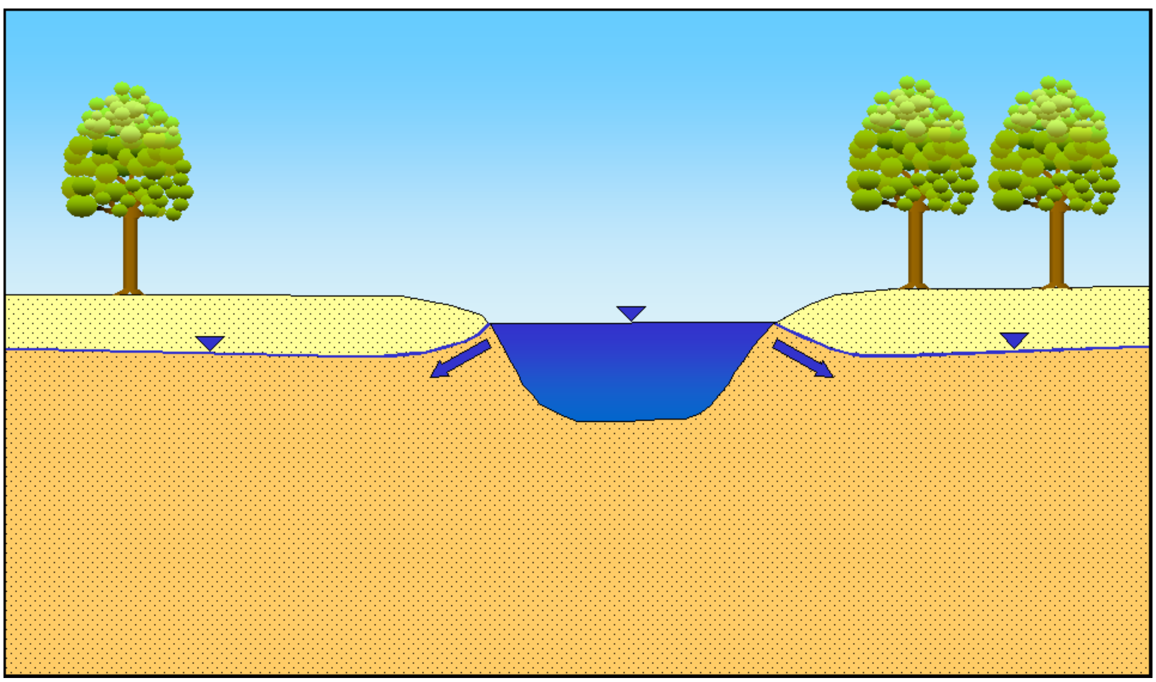

Fig. 4b: Bank-filtered water caused by flooding: Surface water infiltrates into the groundwater (influent conditions)

If pumping of groundwater in the vicinity of surface water bodies is leading to a drop of the phreatic surface drops below the water table of the surface water body, the body of water will also feed bank-filtered water into the groundwater (Fig. 4c). The amount of bank filtration is between 50 and 80 % of the total water obtained in Berlin, depending on the location of the wells.

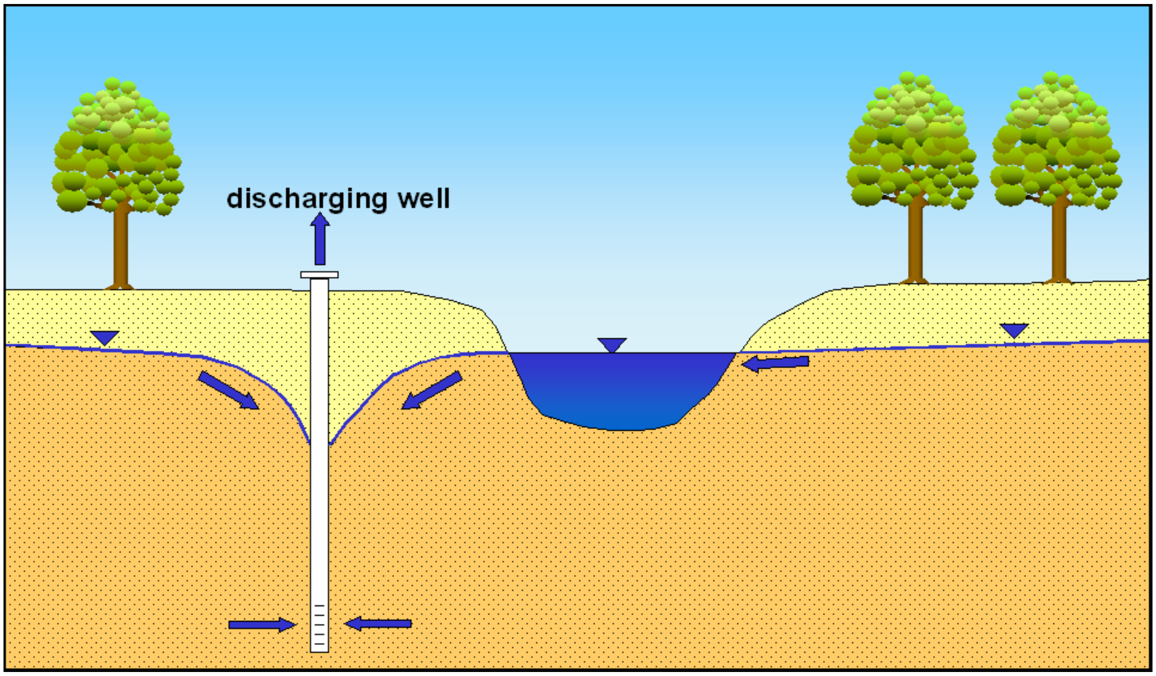

Fig. 4c: Bank-filtered water caused by discharge of groundwater: due to the drop in the groundwater caused by wells, surface water infiltrates into the groundwater

The **groundwater flow velocity** in Berlin is approx. 10 to 500 m per year, depending on the hydraulic gradient and the transmissivity of the aquifer. However, in the surrounding flow field of the well galleries, these low-flow velocities can increase significantly.

Morphology, Geology and Hydrogeology

The present surface of Berlin is mainly a result of the Weichselian glaciation, the most recent of the three major quaternary inland glaciations. It has determined the morphology of the city (Fig. 5): the low-lying Warsaw-Berlin glacial spillway and its side valley, the Panke Valley, which consists predominantly of sandy and gravelly sediments; the neighbouring Barnim Plateau to the north; and the Teltow Plateau with the Nauen Plate to the south. Both plateaus are covered in large parts by the thick glacial till and boulder clay of the ground moraines (Fig. 6). The morphological appearance is supplemented by the depression of the Havel chain of lakes (Fig. 5 and Fig. 6). For more information on the geology, see LIMBERG & SONNTAG (2013) and the Geological Outline.

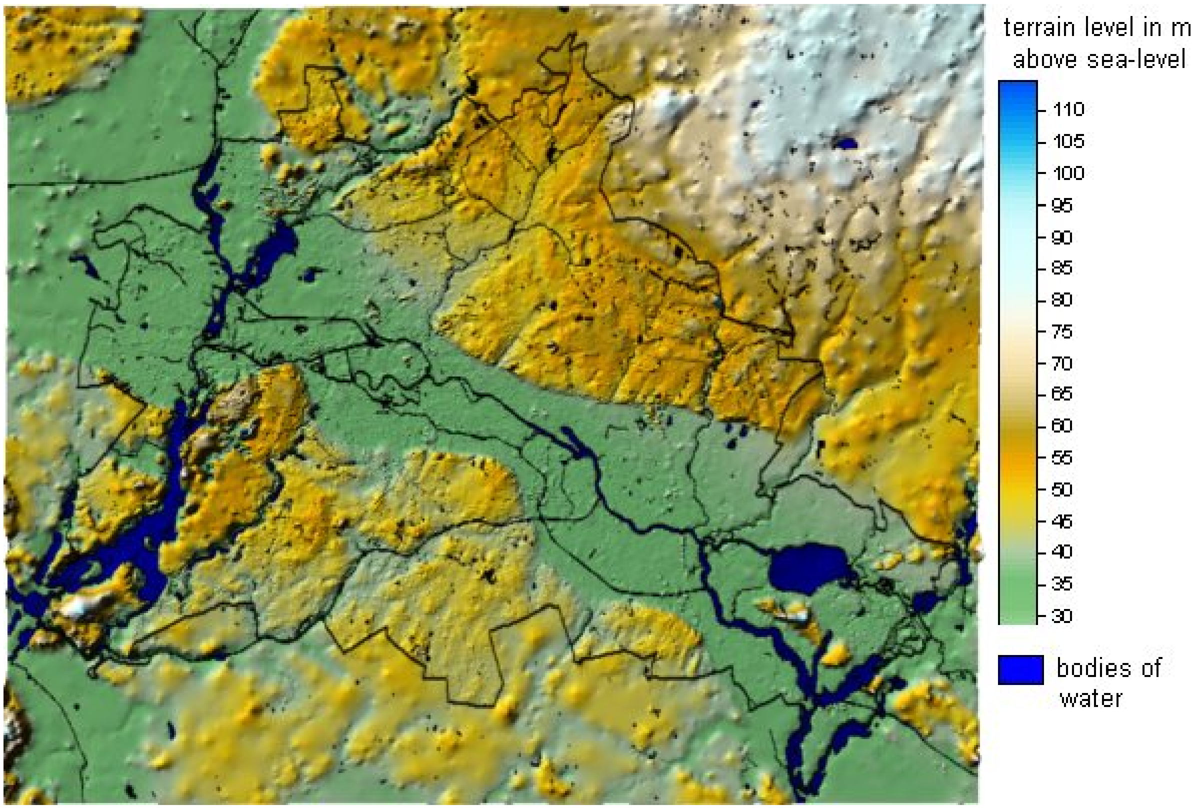

Fig. 5: Morphological map of Berlin

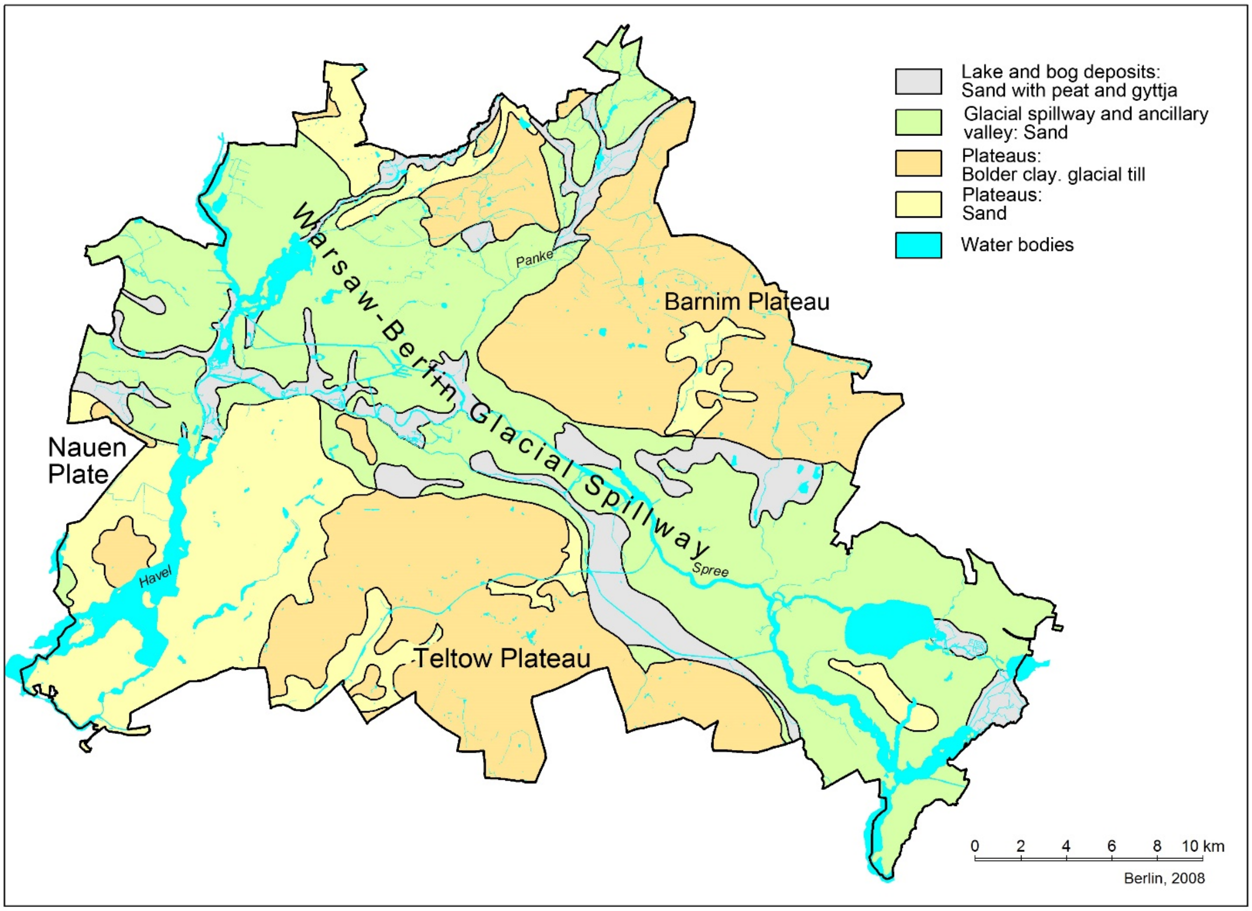

Fig. 6: Geological map of Berlin

The unconsolidated quaternary and tertiary sediments show a thickness of approx. 150 m and the pore volume is often filled with groundwater up to ground level. These layers build the freshwater reservoir that is used for the public water supply for the city state of Berlin. Numerous waterworks (see also Fig. 1) and other pumping stations have lowered the groundwater table in Berlin for more than 100 years in some areas.

The clayey Oligocene layer from the Septarienton Formation ("Rupelton") is situated in a depth of 150 to 200 m below ground level and is approx. 80 m thick. It serves as a hydraulic barrier against the underlying saltwater aquifer (Fig. 7).

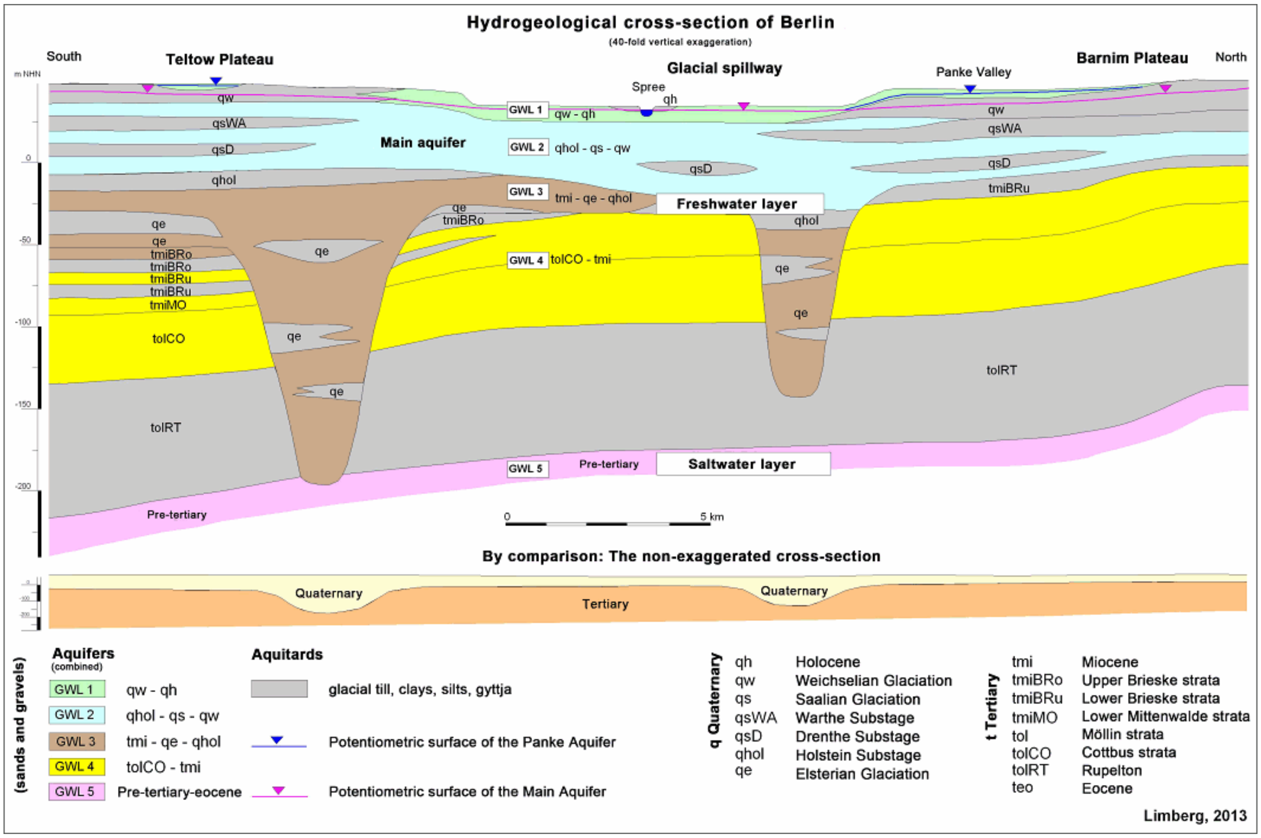

Fig. 7: Schematic hydrogeological cross-section of Berlin, from south to north

Due to the alternation of aquifers (green, blue, brown and yellow in Fig. 7) and aquitards (grey in Fig. 7), the freshwater reservoir in the Berlin area is broken down into four distinguishable hydraulic aquifers (LIMBERG, THIERBACH 2002). The second aquifer is built up predominantly by sediments of the Saalian glaciation and is known as the **Main Aquifer**, since most of the water for the public water supply is pumped from it. The fifth aquifer is found below the Septarienton Formation and is a saltwater aquifer.

The groundwater conditions of the Main Aquifer are shown in the groundwater contour map in violet; in the Panke Valley Aquifer (Aquifer 1) in the north-western area of the Barnim Plateau, they are shown in blue. The Panke Valley aquifer is situated above the main aquifer and is separated from it by the glacial till of the ground moraine (Fig. 7 and Fig. 8).

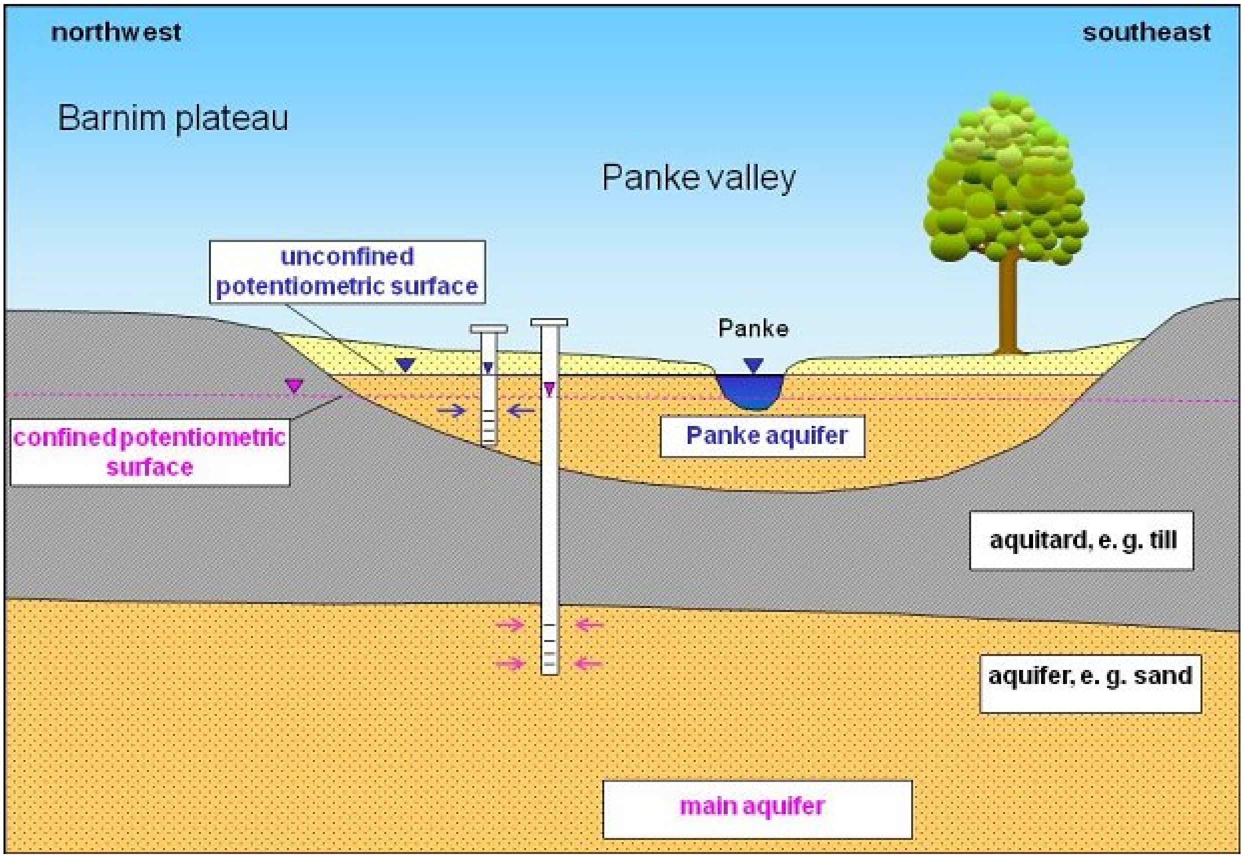

Fig. 8 The unconfined Panke Valley Aquifer (Aquifer 1) in the north-western area of the Barnim Plateau is situated above the Main Aquifer (Aquifer 2), which is confined in this area

In the north-western area of the Barnim Plateau, the ground moraines are so thick that no main groundwater aquifer exists, or occurs only in isolated places, with a thickness of a few meters. For those parts of the Berlin city area, no groundwater contours can be shown.

Statistical Base

The basic data that is needed for the preparation of the groundwater contour map is provided by the State Geology workgroup of the Senate Department for the Environment, Transport and Climate Protection, by the Berlin Waterworks [*Berliner Wasserbetriebe*] and by the federal state of Brandenburg.

The first regular recording of groundwater levels was initiated in Berlin as early as 1869, at 27 groundwater measurement points

The Berlin groundwater monitoring network grew rapidly. By 1937, there were already more than 2,000 observation wells. The monitoring network of, the State Geological Survey contains approx. 3,400 observation wells that are installed in five different aquifers.

In the inner-city area, which is not within the area affected by the waterworks, groundwater conditions have been influenced strongly by anthropogenic processes for over 100 years now. This can be shown by way of the example of the hydrographic curve of groundwater level at the observation well 5140 (Fig. 9) in the borough of Mitte, as following:

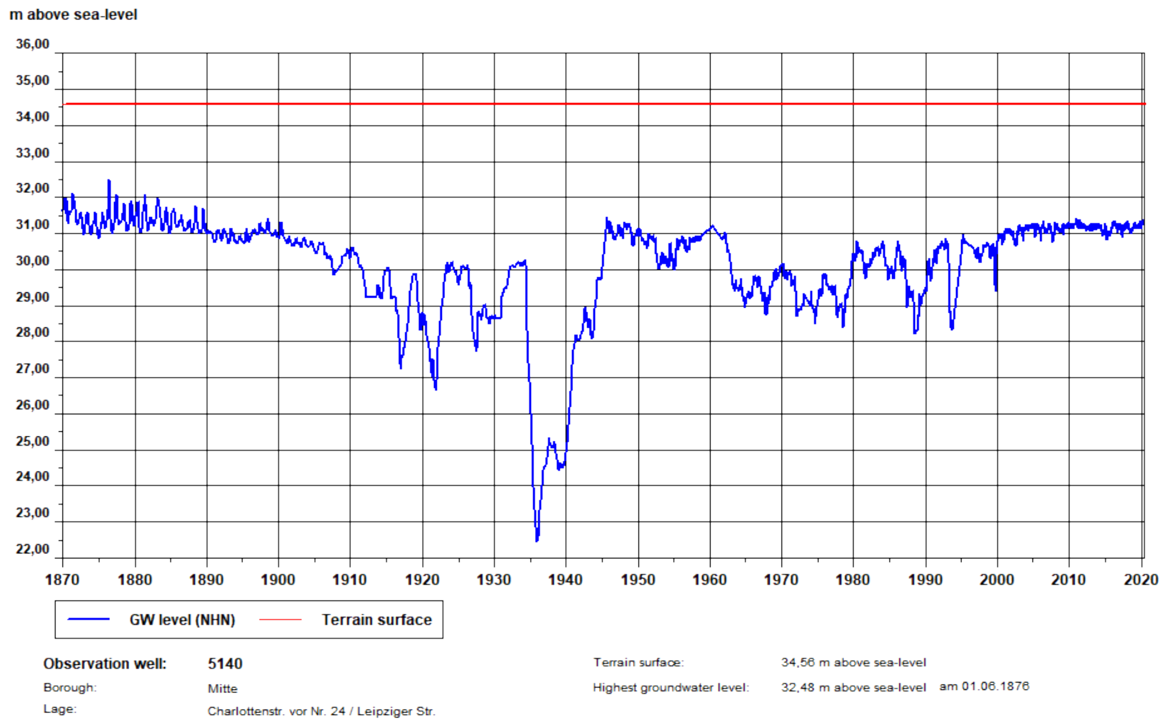

Fig. 9: Hydrograph of the groundwater level at an observation well in the borough of Mitte, since 1870. The highest groundwater level (HGW) was measured here on June 1, 1876. Since 1905, the groundwater level has been highly affected by numerous drawdowns (SenUVK)

Until 1890, the largely natural seasonal fluctuations of the groundwater level remained apparent. With the growth of the city, increased impervious coverage, and the construction of small wells for drinking water, the amplitude was reduced, and the groundwater level had, by 1905, been moderately lowered. Thereafter, the large water retention operations connected with major construction sites, e.g. for the underground/ subway and the urban rail lines (S-Bahn), for the construction of the Reichsbank (today, the Foreign Ministry) and for bunkers, etc., with their deep cellars reduced the level of the groundwater by another 10 m over a large area. In 1945, at the time of the collapse of the infrastructure after the Second World War, the groundwater level quickly rose back almost to its original level. During the years of reconstruction, it was then repeatedly lowered again. Since the termination of major construction projects with groundwater retention, the groundwater is now back to a high level, and major precipitation events rapidly lead to a short-term rise in the level. Here, as in other areas of the city, in buildings which have not been sealed against the maximum expected groundwater levels this causes damage from penetrating groundwater.

In around 1,000 groundwater observation wells, data loggers are installed since the late 1980s, which record the groundwater level on a daily basis. About 10 % of these data loggers are equipped with a remote data transmission module so that the data is sent to the Geological Survey of Berlin on a daily basis. The data from the rest of the data loggers is retrieved manually from the logger on a monthly to three-monthly basis and then imported into the database. The measured values of the city state wide groundwater measuring network are published on the website of the “Wasserportal” and are freely accessible to everyone.

In addition to the data from the network of the Berlin geological survey, the Berliner Wasserbetriebe and the Brandenburg State Environmental Agency as well as other waterworks operators in Brandenburg provide groundwater level measurement data for the Berlin area and the surrounding areas. If the groundwater has a direct connection to surface water (effluent situation, Fig. 4a), additional level data from surface-water measurement points are used.

For the present map, the water level data of 1,418 groundwater observation wells within Berlin, of 247 groundwater observation wells from Brandenburg and of 29 surface-water measurement points is used for the main aquifer. For the groundwater level map of the Panke Valley aquifer (Aquifer 1) on the Barnim plateau, the water level data of 94 groundwater observation wells and 11 surface-water measurement points is used. In groundwater observation wells with daily measurements, the value of May 15th, 2020 was used, while for the other cases, the value was taken from the day that was closest to May 15th, 2020.

The distribution of the groundwater observation wells is irregular: The monitoring network is densest in the city centre and in the immediate intake areas of the waterworks, and less dense at the outskirts of the city, especially in the surrounding areas in Brandenburg.

Methodology

The groundwater contours of the main aquifer as well as the Panke Valley aquifer were calculated using an interpolation method (Point-Kriging). In order to gain information about the correlation of the spatial distribution and the groundwater level of the measurement points a variogram analysis was performed. Since the groundwater level map of May 2018, active wells of the Berliner Wasserbetriebe that pump from the main aquifer are taken into account. The status of the wells was set to active based on the recorded pumping volume. The water levels in the wells were derived from the surrounding observation wells.

The geostatistical parameters as a result of the variogram analysis for the main aquifer the Panke Valley aquifer are shown in Tab. 1.

Geostatistical parameter	**Main aquifer**	**Panke Valley aquifer**
ETRS89 easting (min. / max.)	360685.2 / 424199.1	388657.5 / 402242.1
ETRS89 northing (min./max.)	5794266.1 / 5845998.1	5823424.1 / 5837402.5
Spacing	about 50 m	about 200 m
Number of grid lines	x = 1200 / y = 1000	x = 69 / y = 71
Variogram model type	linear	linear
Slope	0.0011	0.001615
Anisotropy ratio	1	2
Anisotropy angle	-°	128.6°
Kriging type	point	point
Drift type	none	none
Interpolation type	linear	linear
Number of sectors	4	
Max. no. of data in all sectors	128	
Max. no. of data per sector	24	
Min. number of data in search radius	8	
Number of max. free sectors	3	
Search ellipse, radius	R1=10,000 / R2=10,000	
Search ellipse, angle	136.7°	
Smoothing	3	

Tab. 1: Input data for the interpolation with the Kriging method (SenUVK)

A program for calculating and plotting surfaces (Software: Surfer 13 by Golden Software Inc.) was used to convert the spatially irregular distributed groundwater and surface water level data into an equidistant data grid with a spacing of approx. 50 m. This was conducted by an interpolation according to the point kriging method. The groundwater contours are shown with the basis of this grid after smoothing with the factor 3.

Especially for the Panke Valley aquifer it was necessary to adjust the geostatistical calculated surface to the hydrogeological situation manually in order to display the effect of the surface water bodies such as the "Panke", the "Buchholzer Graben" and the "Nordgraben" realistically. Additionally it was crucial to adjust he hydraulic flow conditions of the boundaries of the Panke Valley manually and with a scientific.

Map Description

The present groundwater contour map describes the groundwater situation of the main aquifer with violet groundwater isolines and the Panke Valley aquifer in north-eastern Berlin with blue isolines. The interval between the groundwater isolines is 0.5 m. These show the potentiometric surface area of the unconfined and confined groundwater, respectively (see also Fig. 3). In areas of the main aquifer with confined groundwater, the groundwater contours are displayed in broken lines. In areas with no main groundwater aquifer, or with an isolated main groundwater aquifer of low thickness, no groundwater isolines are displayed. Those areas are shown with black dots.

The map is based on the topographical General Map of Berlin, scale of 1 : 50,000, in grid format, and the geological outline for the Berlin state territory, at a scale of 1 : 50,000, which was derived from the geological General Map of Berlin and Surrounding Areas, scale of 1 : 100,000. In addition, the used groundwater observation wells, as well as the individual waterworks are indicated, with their active wells and the water protection areas.

Hydrogeological Situation

On the plateaus, the main aquifer is extensively covered by the glacial till and bolder clay (aquitards) of the ground moraines. Wherever the potentiometric surface of the main aquifer lies within such an aquitard, groundwater conditions are confined. In sandy segments above the till or in isolated sand lenses, near-surface groundwater may be formed, which is also called stratum water (see also Fig. 3). After extreme precipitation, it may rise to the surface. The groundwater levels of these locally highly differentiated areas have not been separately determined and portrayed.

In the Panke Valley, on the northern side of the spillway, the Barnim plateau, a major independent coherent aquifer has developed. It is located above the main aquifer, which is covered by the glacial till of the ground moraine (see also Figs. 7 & 8). On the present map, this aquifer is indicated by separate blue groundwater isolines. The glacial till is thinning out toward the Warsaw-Berlin glacial valley and the Panke Valley aquifer is interlocking with the main aquifer.

For more information, see the Groundwater Brochure:
https://www.berlin.de/sen/uvk/_assets/umwelt/wasser-und-geologie/publikationen-und-merkblaetter/grundwasser-broschuere.pdf (only in German)

In general, the hydraulic gradient in Berlin, and hence, the flow direction, is from the Barnim and Teltow plateaus and the Nauen Plate toward the rivers of Spree and Havel. Depression cones have formed around the wells that were active during the measurement period, and have lowered the groundwater level below the level of the neighbouring surface waters. Thus, in addition to inflowing groundwater from the landside, the water pumped here includes groundwater formed by infiltration (bank-filtered water) from these surface waters (see also Fig. 4c).

Current Situation in May 2020

Figure 10 shows the general development of the groundwater levels as a deviation from the 20-year median from a total of characteristic observation wells in different hydrogeological areas. The reference date for every year is the date for which the groundwater level map is created (May 15th) for the period 2000 to 2020. The location of the hydrogeological areas of the Teltow plateau, Barnim plateau, Warsaw-Berlin glacial valley and Nauen Plate/Grunewald is shown in Figure 11.

Positive deviations from the median indicate high groundwater levels (such as in 2008, 2012 and 2018). Negative deviations represent low groundwater levels (such as in 2007, 2017 and 2020).

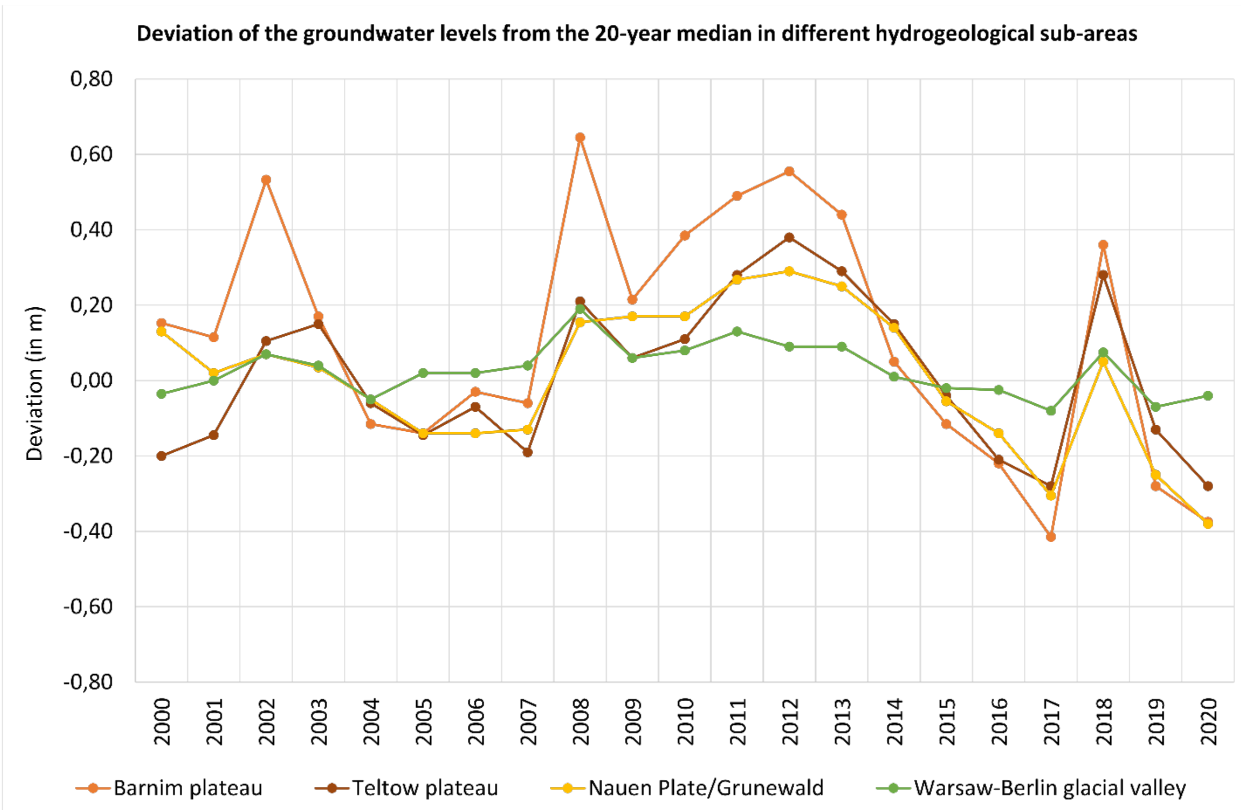

Fig. 10: Deviation of the groundwater levels from the 20-year median from a total of characteristic observation wells in different hydrogeological sub-areas of Berlin on the reference date of May 15th in the years 2000 to 2020 (SenUVK)

In the areas Barnim plateau (orange), Teltow plateau (dark red) and Nauener Platte/Grunewald (yellow), the groundwater conditions are predominantly confined, which is why the levels show larger fluctuations. The influence of the dry weather years is apparent.

In the Warsaw-Berlin glacial valley (green), on the other hand, there are unconfined groundwater conditions and the groundwater levels are subject to less fluctuation. In addition, the groundwater hydraulics in this area are dampened by the regulation of the surface waters.

On the reference date of May 15th 2018, the groundwater levels in all four areas showed still positive deviations due to the heavy rainfalls in 2017. As a result of the dry years 2018 to 2020, the groundwater levels on May 15th, 2020 (as well as on May 15th, 2019) are lower than in the 20-year comparison period.

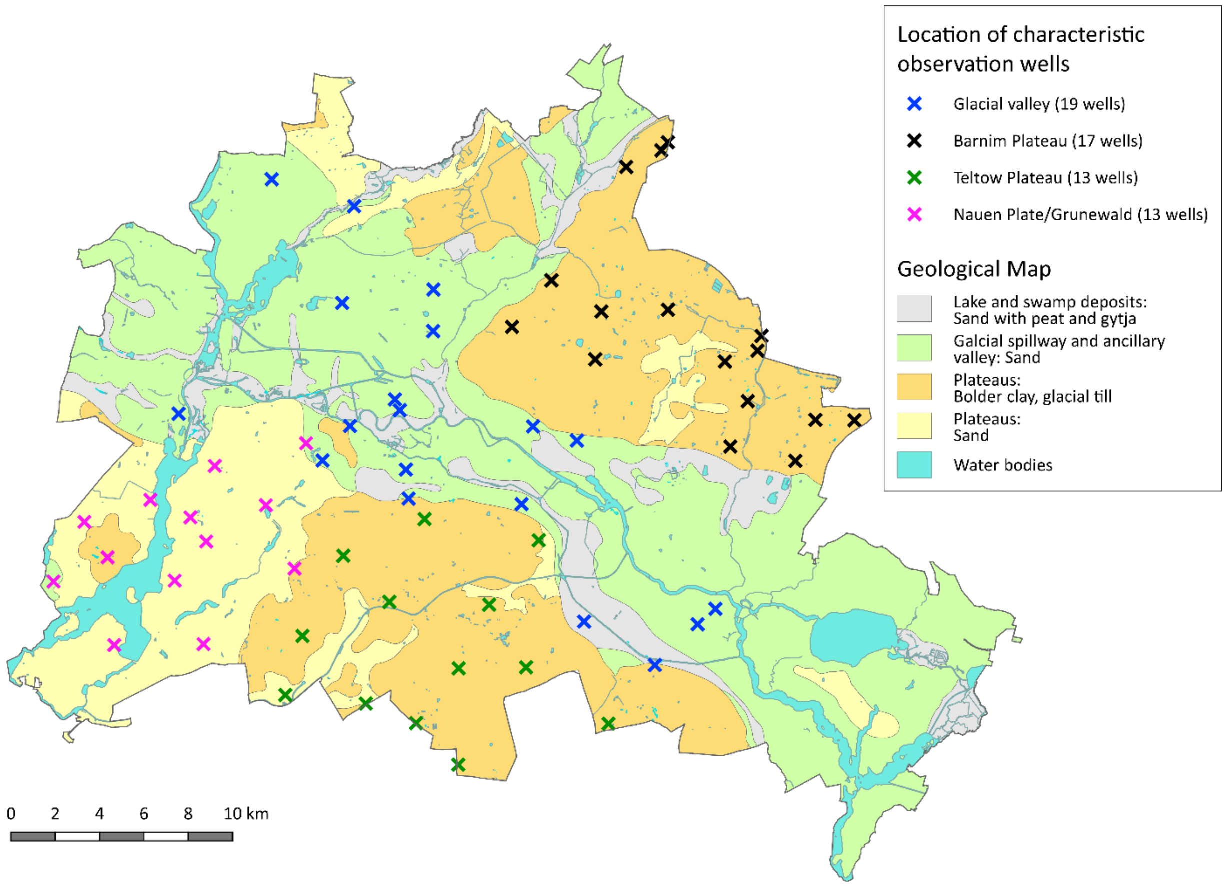

Fig. 11: Location and number of characteristic observation wells in the different hydrogeological areas (SenUVK)

Figure 12 shows the monthly deviation from the 20-year median for the years 2018 (orange), 2019 (light red) and 2020 (dark red). Each hydrogeological sub-space is shown in a separate diagram (a to d).

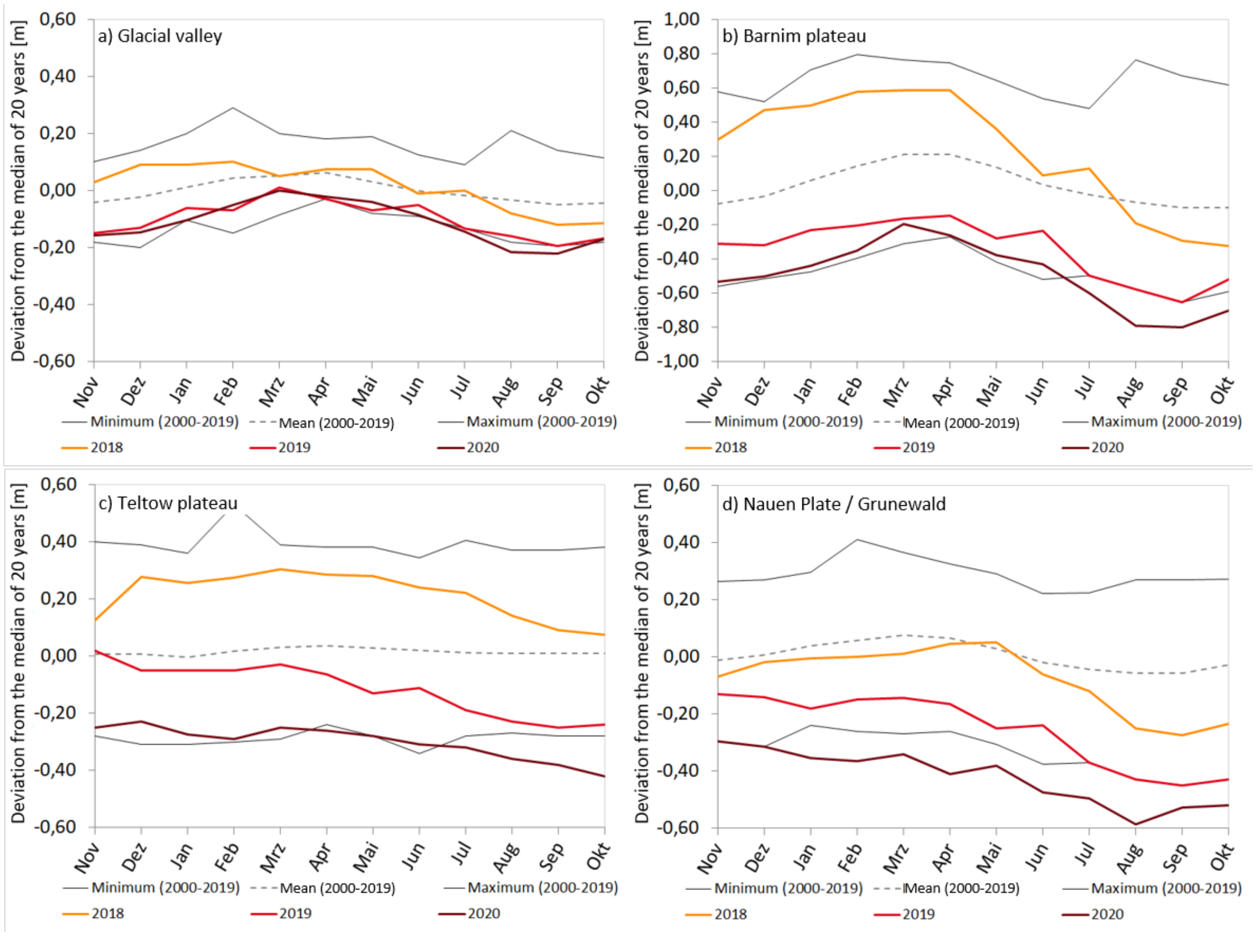

Fig. 12: Monthly deviations from the 20-year median from a total of characteristic groundwater measuring points for the years 2018 (yellow), 2019 (light red) and 2020 (dark red) for the hydrogeological areas Warsaw-Berlin glacial valley (a), Barnim plateau (b), Teltow plateau (c) and Nauen Plate/Grunewald (d). The months of the hydrological winter (November to April) are shown first on the x-axis, followed by the months of the hydrological summer (May to October) (SenUVK)

In the Warsaw-Berlin glacial valley (Figure 12a), the low groundwater levels throughout the entire observation period are mainly a result of the dry year 2018. During 2018, groundwater levels decreased by around 0.20 m. This deficit was not restored in 2019 and 2020, which is why the groundwater levels were still below average in these years.

On the Barnim Plateau (Figure 12b), the groundwater levels decreased in the summer period 2018 three times stronger and in the summer period 2020 twice as strong as on average. As a result, the groundwater levels have also been extremely low here in recent years, despite the light saisonal increase during the winter months.

On the Teltow Plateau (Figure 12c), the groundwater levels measured for the hydrological year 2018 were approximately 0.10 to 0.30 m above the long-term mean. Since the hydrological year 2019, the groundwater levels are steadily decreasing and fall below the 20-year minimum groundwater level from July 2020. In October 2020, the groundwater levels were 0.42 m below the mean and thus 0.14 m lower than the lowest values measured in the entire reference period.

In the hydrogeological area Nauen Plate/Grunewald (Figure 12d), the groundwater levels show as well a strong negative trend. At the end of the hydrological year 2018, the levels were around 0.20 m below the long-term mean, at the end of the hydrological year 2019 already around 0.40 m below the long-term mean and at the end of the hydrological year 2020 around 0.50 m below the long-term mean. From January 2020, the values in this area were 0.12 m lower than the lowest values measured in the entire reference period.

The lack of precipitation in 2018 and 2019 results in a delayed reaction of the negative trends in groundwater levels in 2019 and 2020. Because of the drought years, and contrary to the normal seasonal course, there was no increase in groundwater levels between November and April in the hydrogeological areas of the Teltow Plateau and Nauen Plate/Grunewald (Figure 12d) in 2019 and 2020. This suggests that no significant groundwater recharge took place in these areas during the dry years.

The data of the groundwater level measurements and hydrographs of various observation wells are published on the website of the "Wasserportal"

From 2000 to 2007, the raw water supply of the Berliner Wasserbetriebe for the public water supply initially decreased. In the years 2007 to 2014, between 202 and 207 million m³ of raw water was pumped per year. Since 2015 there has been an increase in raw water extraction. (Fig. 13).

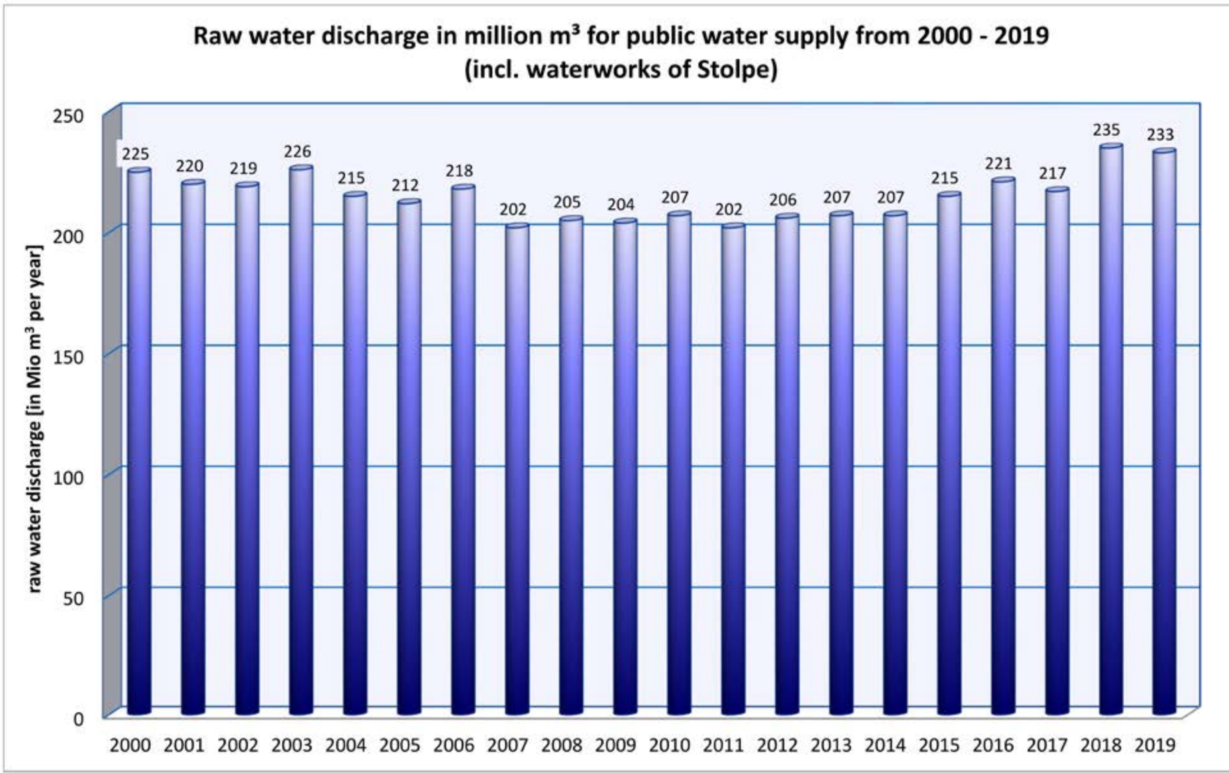

Fig. 13: Development of the raw water discharge since 2000 (SenUVK)

From June 2019 until May 2020, the cumulative precipitation amount of 539 mm at the climate station "Berlin-Tegel" was similar to the long-term mean (1981-2010) of 549 mm.

In the months of June, July, September, October and February, the monthly amounts of precipitation exceeded the long-term monthly averages. However, in the months of June and July, the excess can be linked to a few isolated heavy precipitation events while the monthly distribution of precipitation was more balanced in the months of September, October and February.

Deviating from the explanations of the last years, in these years explanations the data from the DWD measuring station Tegel are shown, as there is no data available for the months of May and June 2019 for the otherwise shown measuring station of "Berlin-Tempelhof".

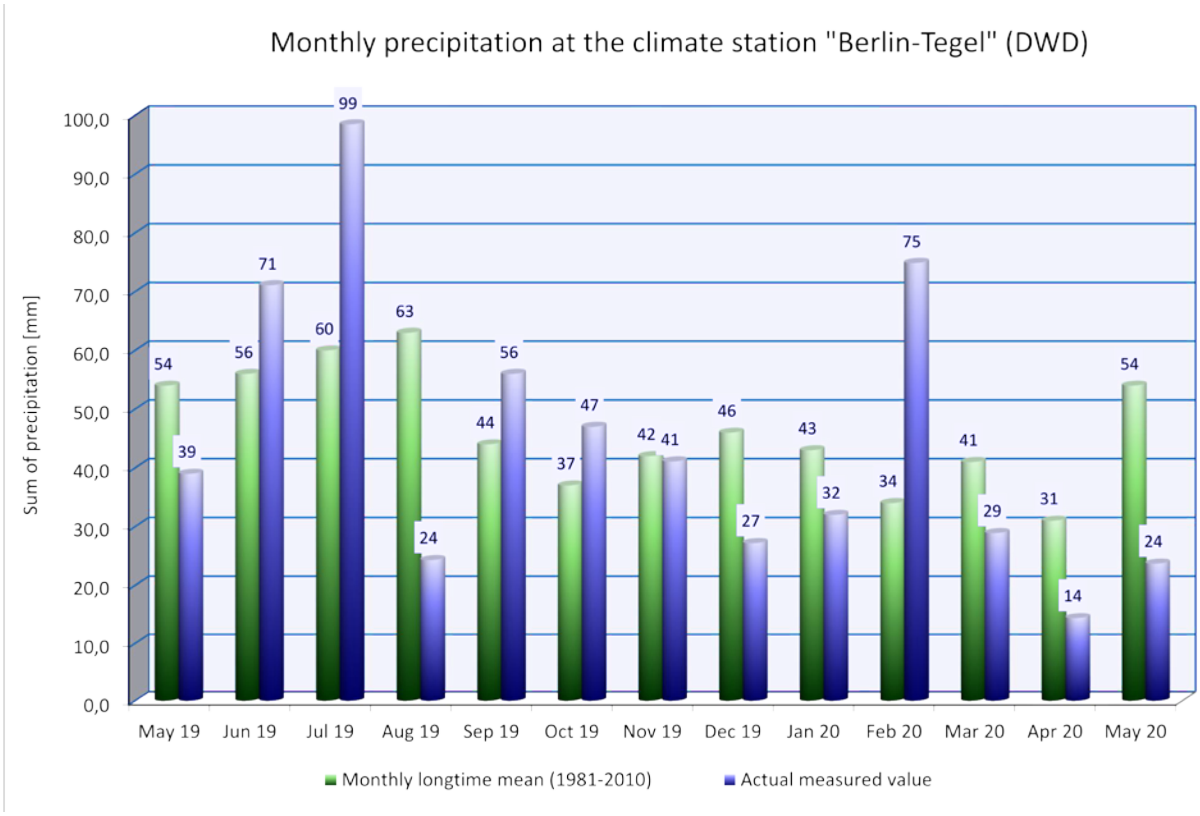

Fig. 14: Monthly precipitation between May 2019 and May 2020 at the climate station "Berlin-Tegel", compared with the long-term mean, 1981 through 2010 (SenUVK)

Information on the expected highest groundwater level (EHGL), which is an important basis for planning the design of buildings, can be found in the Environmental Atlas under: Map EHGL (Limberg et al. 2015).

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