02.20 Expected Mean Highest Groundwater Level (EMHGL) (2016 Edition)

Overview

The **planning, construction and administrative approval of percolation facilities for precipitation water** mandatorily requires the mean highest groundwater level (MHGL) to be taken into account. For instance, the distance between the bottom of the percolation facility and the groundwater surface has to be at least one metre, with the mean highest groundwater level or the expected mean highest groundwater level (MHGL/EMHGL) to be taken as the level of the groundwater surface in the State of Berlin – at least outside of the drinking water conservation zones (see also section Map Description below) (NWFreiV, Figure 1).
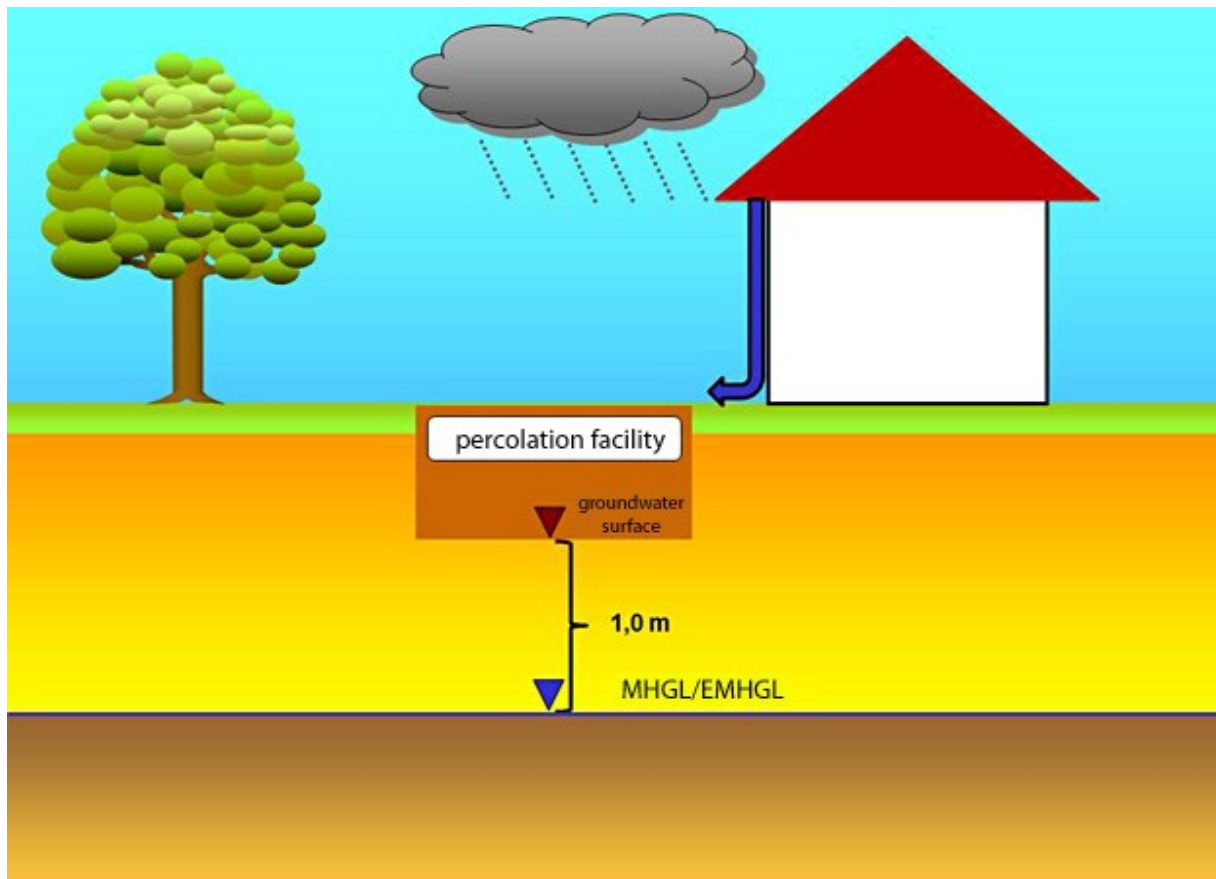

Fig. 1: Minimum distance between the bottom of the percolation facility and the mean highest groundwater level/expected mean highest groundwater level (MHGL/EMHGL)

Moreover, **in construction, the MHGL** can also be used for geostatical calculations in certain cases and may be relevant for other **issues of water management and ecology**.

The **mean highest groundwater level (MHGL)** is defined as the mean value of the annual maximum values of the observed groundwater level.

The MHGL is calculated using groundwater levels recorded at groundwater measuring points. In order to obtain statistically reliable values, the groundwater hydrographs should be based on a measuring frequency as high as possible. If the MHGL is required for a location where no or no suitable groundwater measuring point is available, the MHGL can be interpolated from the values of

neighbouring measuring points. In both cases, the mean highest groundwater level is a value that is determined from groundwater levels observed in the past.

In practice, the MHGL is mostly needed for questions directed towards the future. Accordingly, it is only meaningful if the groundwater level can be assumed to behave similarly in the future as in the past. However, this is not the case in large parts of the Berlin city area since the **groundwater level has been artificially changed**, sometimes permanently, sometimes temporarily.

The **permanent measures**, which modified the natural geohydraulic conditions to locally different extents in the past and also began at different times, include:

- rainwater sewerage, which may have the effect of reducing new groundwater formation and thus lowering the groundwater level;

- decentralised rainwater disposal in percolation facilities, which may locally raise the groundwater surface, depending on the precipitation events;

- drainages and ditches that were intentionally used to lower the groundwater level locally;

- hydrological construction measures (impoundments, shore revetments, straightening of watercourses), which may lead both to a rise and to a drop in the groundwater level;

- structures protruding into the groundwater, with the effect of groundwater afflux in the direction of inflow and lowering in the direction of outflow.

The **temporary measures** and those that may vary considerably in duration include:

- groundwater extractions for the public and private water supply and for keeping water out of construction pits or for remediation, which lower the groundwater surface;

- groundwater replenishments for increasing groundwater availability for the public water supply, which raise the groundwater level in the vicinity of the replenishment facilities;

- reinfiltration of extracted groundwater, e.g. in the context of groundwater preservation measures for construction purposes, which also raise the groundwater surface – usually only locally.

This multitude of possible artificial measures that affect the groundwater illustrates that in some cases it is difficult even for specialists to judge whether and to what extent observed annual maximum groundwater levels from which the MHGL is calculated are anthropogenically influenced and thus to what extent the MHGL can be assumed to be valid in the future. Another problem results from the fact that both the observation periods and the measuring frequencies of the individual groundwater measuring points often differ. On the one hand, there are measuring points which have already been observed for more than 140 years; on the other hand, some have only existed for a few years. The measuring frequency varies between daily measurements, as is the case today for most measuring points of the Senate, and bimonthly and less frequent measurements, which cannot record the actual history of the groundwater level and thus its maximum values as reliably. The MHGLs of the individual measuring points are thus not directly comparable, which is, however, necessary, particularly for interpolation. In practice, the State Geological Service has therefore conducted a rather time-consuming assessment and selection of data for calculating the MHGL in each individual case. (Note: The earlier specification of the 90th percentile value of the groundwater level data of a measuring point for determining a design value for percolation facilities corresponds approximately to the mean highest groundwater level.)

Figure 2 shows three examples of groundwater hydrographs with MHGL values in the Berlin glacial valley: The groundwater measuring points 5476 and 8979 show strong influences from groundwater extractions up to the 1990s; the end of the influence cannot be determined exactly but has to be specified by the specialist in order for the mean highest groundwater level to be calculated. Measuring point 137 has a significantly longer history without influence, from around 1980 on but also in the period from 1965 to 1975. It only makes sense to use the data from the periods without influence for determining an MHGL which is to be used e.g. for planning a percolation facility.
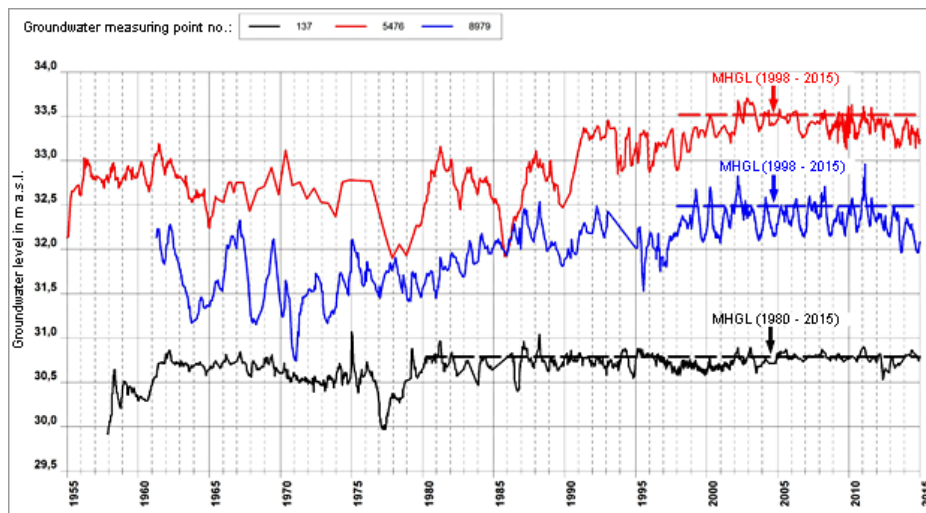
Fig. 2: Groundwater hydrographs from measuring points in the glacial valley with MHGL values for periods with apparently no or only little artificial influence through groundwater extractions or discharges.

For the purpose of both significantly reducing the effort for determining the MHGL and eliminating the problem of artificial, temporary influences on the groundwater level which can result in MHGL values that cannot be used for future calculations, the working group State Geology of the Senate Department for Urban Development and the Environment has developed a map of the **expected mean highest groundwater level**, or **EMHGL** in short, from which the desired value can be read off directly. The EMHGL is defined as follows:

The expected mean highest groundwater level (EMHGL) is the value that is to be expected for the future as the mean value of the annual maximum values of a long-term groundwater hydrograph, if the groundwater level in the vicinity is neither lowered nor raised by artificial interventions.

According to this definition, the EMHGL is to be expected based on the current state of knowledge under the following geohydraulic conditions:

- the natural conditions (e.g. water permeability of the subsoil);

- the permanently artificially modified conditions (e.g. impoundments of the watercourses, see above);

- new groundwater formation whose size and temporal changes approximately correspond to the current one.

A higher mean highest groundwater level than the EMHGL can occur in principle, but only as a result of further artificial interventions. Of course such interventions (e.g. discharges into the groundwater) are not predictable in the long term. However, they do not need to be taken into account for most questions, as they require a permission from the water authority in any case.

Currently the EMHGL map has been completed for two areas of Berlin. In geological terms, these are the area of the Berlin glacial valley and the area of the Panke valley. Both (see Figure 3) are characterised in that near the surface their subsoil is composed predominantly of sediments (soils) with high water conductivity and the groundwater surface is generally not deep below ground (depth to the water table of a few metres, sometimes even less than one metre).

Fig. 3: Area of validity of the EMHGL map for the glacial valley and the Panke valley

Statistical Base

The EMHGL map for the Berlin glacial valley, which was developed using a numerical groundwater flow model (see Methodology in explanation of EMHGL map, and LIMBERG, HÖRMANN & VERLEGER (2010)), has an extraordinarily comprehensive statistical base.

57 geological sections from the State Geological Service were available for capturing the hydrogeological structure of the main aquifer in the Berlin glacial valley. They were supplemented by evaluating numerous deeper **boreholes** from the database of the State Geological Service.

The configuration data of over 800 **groundwater measuring points** and their groundwater level data were used for calibrating and verifying the groundwater model. Moreover, information on the **groundwater withdrawals** of all Berlin waterworks, on **groundwater replenishments** and on **other groundwater extractions** (unwatering, private water supply plants, remediation) was available.

The surface waters, which are the recipients for the groundwater, determine essential hydraulic conditions. A multitude of data – mostly **gauge heights** – and information on the state of development of the water bodies was used in this regard.

The data for new groundwater formation were implemented into the model from the map of the Environmental Atlas (SenStadtUm 2012).

The selection of the groundwater level data that were suitable for the model simulation of the EMHGL was based on about 2,200 groundwater measuring points.

In addition, the map of the expected highest groundwater level (EHGL) for the area of the Berlin glacial valley and the Panke valley was available for checking the plausibility of the results.

The hydrographs of about 150 further groundwater measuring points were evaluated for developing the EMHGL map for the Panke valley (see Methodology in explanation of EMHGL map, and HÖRMANN & VERLEGER (2016)). Comprehensive data on the geology of the Panke valley aquifer that are available at the State Geological Service were also used. Gauge heights were available for the Panke and some of its tributaries.

Methodology

Different methodologies were applied for the two areas glacial valley and Panke valley.

Glacial valley

For the area of the **Berlin glacial valley**, the EMHGL map was computed using a numerical **groundwater flow model**. This was necessary because due to the long-standing and sometimes strong anthropogenic influence on the groundwater surface, the computation of such a map is not

possible in the sense of the above EMHGL definition solely on the basis of measuring groundwater levels and then calculating the mean.

The basis of the EMHGL model consists of the model which has already been used for developing the map of the expected highest groundwater level (EHGL). This model is described in LIMBERG, HÖRMANN & VERLEGER (2010) and is summarised here:

The numerical model, for which the software system MODFLOW was used, is designed to encompass the entire area of Berlin (Figure 4).
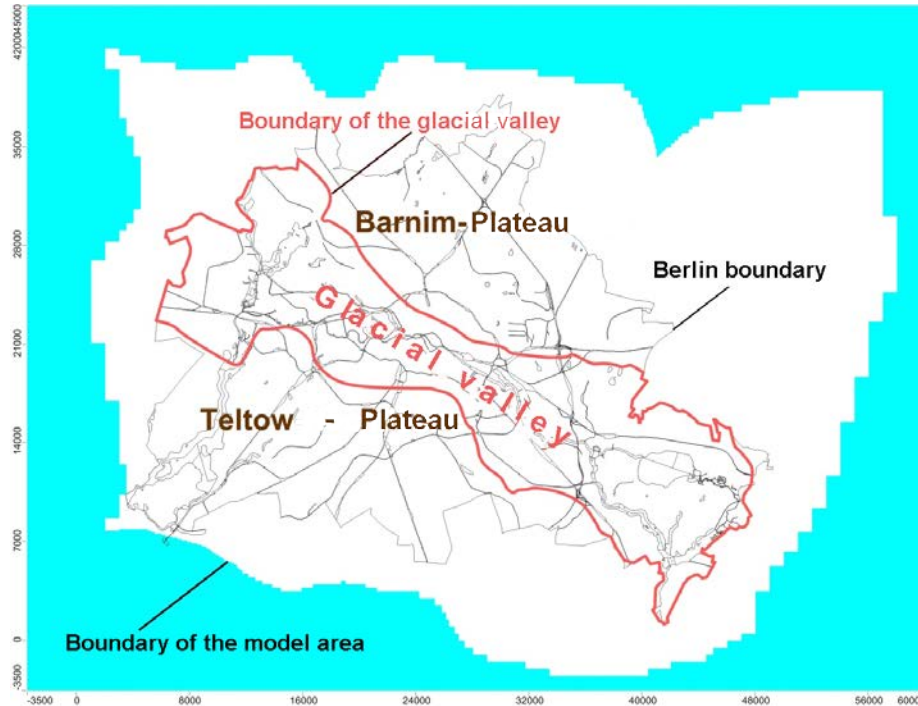

Fig. 4: Area of the groundwater flow model for developing the EHGL map and the EMHGL map for the Berlin glacial valley

The area of the Berlin glacial valley is vertically divided into several model layers, of which the uppermost represents the – here usually unconfined – main aquifer, whose EMHGL is to be calculated (see Figure 5).
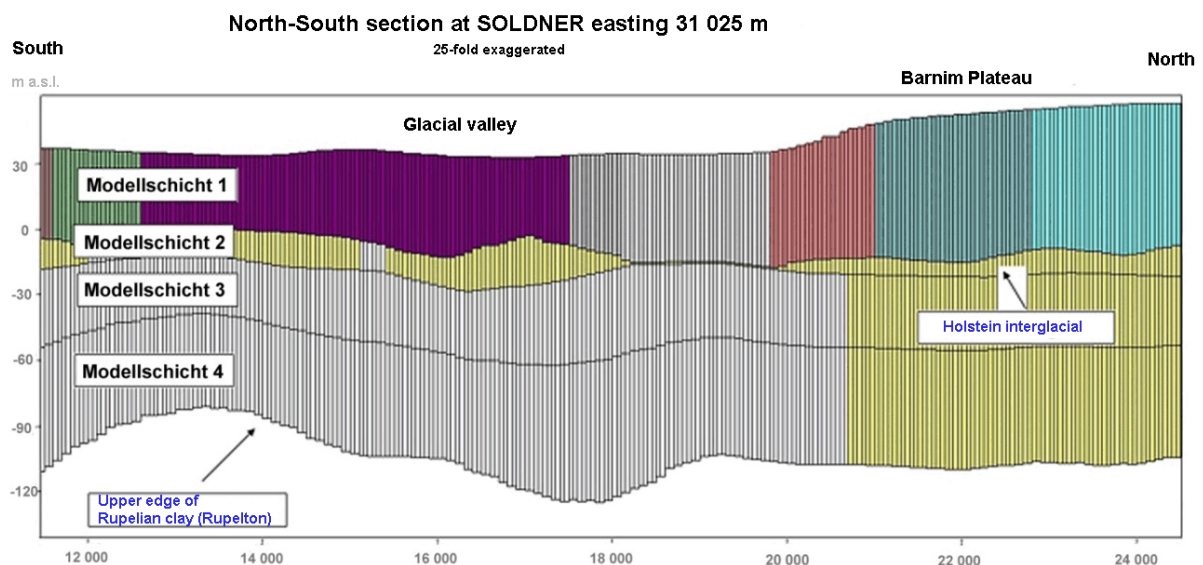

Figure 5: North-South section with vertical discretisation of the numerical groundwater flow model

5

Horizontally, the model is divided into rectangular cells. The cell size varies between 50 x 50 and 100 x 100 metres.

This flow model was calibrated and verified using hydraulically stationary calculations. The groundwater levels measured in 2004 (calibration) and 2001 (verification) were used for this purpose. The plausibility of the EHGL model based on this was checked very successfully by means of measured highest groundwater levels (cf. also description of the EHGL map).

For the computational simulation of the EMHGL, compared to that of the EHGL, the conditions new groundwater formation and water levels of the receiving waters (Spree, Havel and their tributaries) were changed. In accordance with the objective, mean highest water levels (MHWLs) were specified as water levels. The time series 1960 to 2009 was used for determining the MHWL. The long-term mean new groundwater formation and its local distribution in the Berlin city area with its strong urban character are not known down to the last detail despite many efforts to determine them. The only assertion that can be made about the new groundwater formation which, together with the recipient heights, gives rise to the mean highest groundwater level, is that it must be lower than in the case of the highest groundwater level. For this reason, calculations were carried out using different degrees of reduced new groundwater formation. The aim was the best possible adaptation to the mean highest groundwater levels calculated from observation well levels of groundwater measuring points that are preferably without influence from groundwater extractions or discharges.

In several steps, 103 suitable hydrographs were selected from more than several thousand, from existing and also no longer existing groundwater measuring points for which data was available until 2010 at the State Geological Service. The hydrographs fulfil the following criteria:

- filtration distance of the groundwater measuring points in the main aquifer;

- groundwater level measured at least during the ten years before 2010;

- no measurement gaps of more than half a year in the period for which the mean highest groundwater level is calculated;

- no discernible unnaturally large fluctuations in the period under consideration.

The location of the groundwater measuring points whose MHGL values were used as target values for the modelling is represented in Figure 6. According to both the EMHGL and the EHGL definitions, all model computations have in common that neither groundwater extractions nor discharges occur.
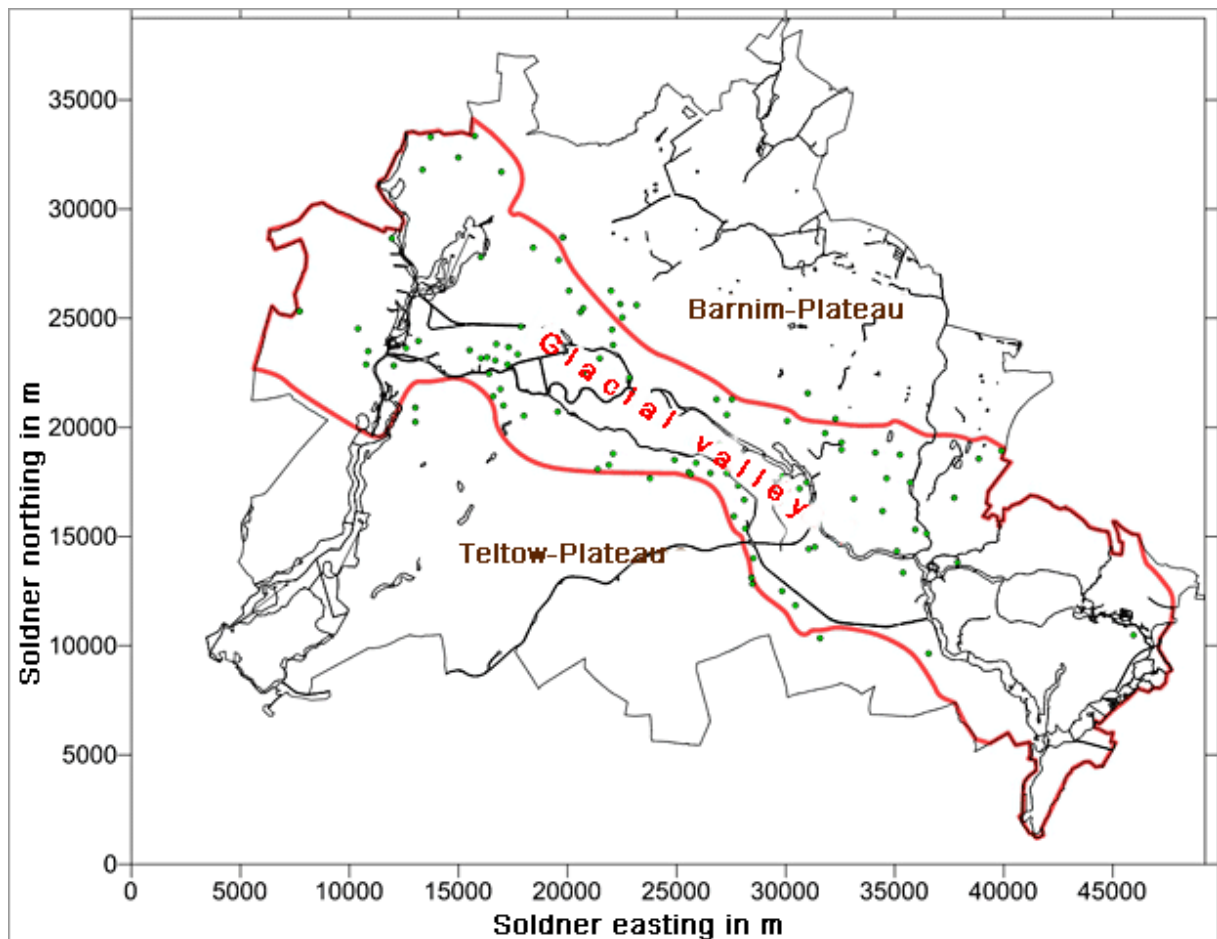
Fig. 6: Location of the 103 groundwater measuring points used for the EMHGL model adaptation

The groundwater surface of the computational variant with the best adaptation to these target values corresponds to the EMHGL map. As an example, Figure 7 shows the hydrograph of a groundwater measuring point with the MHGL for the period 1998 to 2015 and the EMHGL calculated using the model. Here the EMHGL lies 0.13 m above the MHGL.
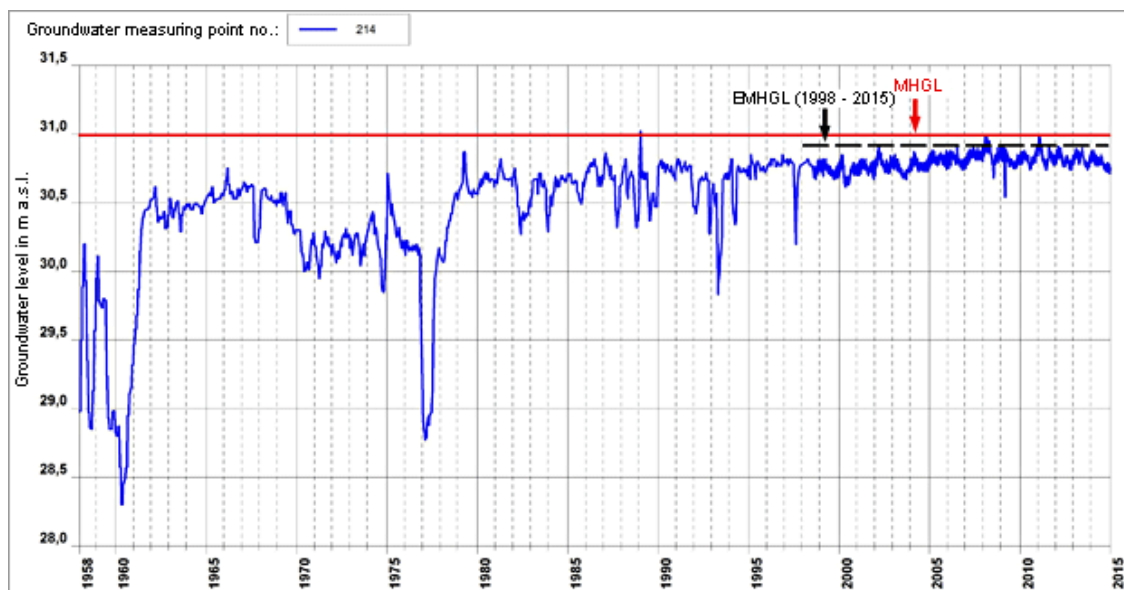

Fig. 7: Hydrograph of the groundwater measuring point 214 with recorded mean highest groundwater level (MHGL) for the period 1998 to 2005 and modelled expected mean highest groundwater level (EMHGL).

In 2014, the groundwater flow model was updated for the EMHGL since partial revisions were carried out in the eastern area of the EHGL model. Measurement series up to 2014 are thus also taken into account.

Panke valley

No EHGL map calculated with a suitable groundwater flow model was available as a basis for developing the map of the expected mean highest groundwater level (EMHGL) in the area of the Panke valley and its transition to the glacial valley. Here the EHGL map was calculated from augmented HGL values from a total of 105 groundwater measuring points that have measurement series until 2014, using the programme SURFER (cf. explanation of the EHGL map).

In order to prevent the EMHGL map from contradicting the EHGL map (by definition, the EMHGL must be below the EHGL everywhere), the map of the expected mean highest groundwater level was created analogously. The same groundwater measuring points as for the EHGL map served as sampling points.

Methodologically, the development of the EMHGL map is structured along the following steps:

- hydrograph analysis,

- statistical analyses of the groundwater levels,

- specification of the EMHGL values for 105 groundwater measuring points,

- calculation of the EMHGL distribution and map representation.

The hydrograph analysis showed that the artificial influence on groundwater levels before 1990 is for the most part too strong for an MHGL for whose calculation these data were also taken into account to be regarded as the expected mean highest groundwater level. Likewise, the data from before 1990 were not taken into account for the EHGL map because of the strong influence. Moreover, the hydrographs from the early 2000s on show a tendency towards higher groundwater levels than in the 1990s, which can also be verified statistically.

As an example, Figure 8 shows the hydrograph of the groundwater measuring point no. 293 with the MHGL values for the entire period under consideration from 1990 to 2014 (MHGL90-14), the one from 1990 to 2001 (MHGL90-01) and the one from 2002 to 2014 (MHGL02-14). It is typical that the MHGL for the period from 2002 to 2014 is considerably higher than the one for the period from 1990 to 2001 and, moreover, that the history of groundwater levels is better documented through mostly daily measurements. For these reasons, only the MHGL values of the period 2002 to 2014 were used for computing the EMHGL map.
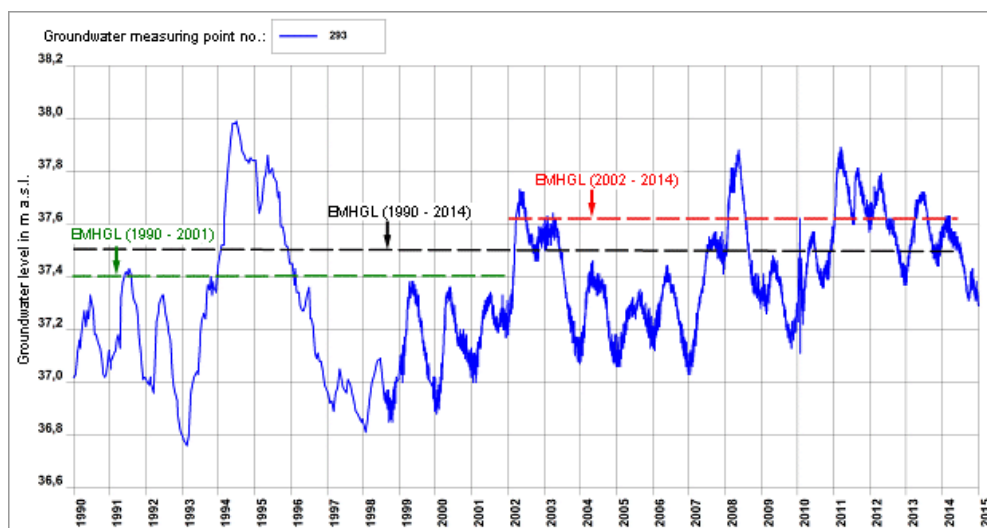

Fig. 8: Hydrograph of the groundwater measuring point no. 293 with the MHGL values for the periods 1990 to 2014 (black), 1990 to 2001 (green) and 2002 to 2014 (red)

Of the total of 105 groundwater measuring points on which the map of the expected highest groundwater level is based, 67 still existed in 2014. That is, for 38 measuring points, no or no sufficient groundwater level data are available for calculating the required MHGL for the period 2002 to 2014, but for the period 1990 until 2001 data are available, at least with some restrictions (e.g. lower measuring frequency). In order to obtain a grid of sampling points as dense as the one for the EHGL

map, the MHGLs of these 38 measuring points were estimated for the period 2002 to 2014. By means of correlation analyses between different quantities obtained from the hydrographs, a significant relationship between the EMHGL for the period 2002 to 2014 (EMHGL $_{02\text{-}14}$), the mean value of the measurements between 1990 and 2001 (MGL $_{90\text{-}01}$) and the standard deviation of the measurements between 1990 and 2001 (s $_{90\text{-}01}$) was found.

With an increment of 20 cm selected to account for the uncertainties inherent in this procedure, the following formula for calculating the desired EMHGL $_{02\text{-}14}$ is obtained:

$$\text{EMHGL}_{02\text{-}14} = 2.43 * \text{s}_{90\text{-}01} + 0.13 + \text{MGL}_{90\text{-}01}$$

with

EMHGL $_{02\text{-}14}$:   desired expected mean highest groundwater level

s $_{90\text{-}01}$:   standard deviation of the measurements between 1990 and 2001

MGL $_{90\text{-}01}$:   mean value of the measurements between 1990 and 2001

According to this method, the MHGL values for the 38 groundwater measuring points mentioned above were estimated by calculation. As desired, the MHGL values for 105 measuring points are thus available.

Based on these 105 MHGL values and on another 15 sampling points that were specified at the border to the EMHGL map for the glacial valley in order to ensure consistent continuity with that map, the distribution of the EMHGL was calculated (without taking the surface waters into account) by means of the software system SURFER and was represented in the form of EMHGL isolines. The calculation method is the same as the one used for the current map 'Groundwater Levels' (HANNAPPEL, HÖRMANN & LIMBERG 2007).

Map Description

The EMHGL map for the Berlin glacial valley and the Panke valley (2015) covers slightly more than half of the area of the State of Berlin. The expected mean highest groundwater level is represented by lines of equal height in metres above sea level. The difference in height between groundwater isolines is 0.1 m. Thus the map shows the groundwater surface for the EMHGL of the main aquifer, which is predominantly unconfined in this area, and its piezometric surface where it is confined. In the glacial valley, this is GWL (Grundwasserleiter, aquifer) 1.3 and GWL 2, in the Panke valley it is GWL 1.2 according to the aquifer nomenclature following LIMBERG & THIERBACH (2002).

It is evident from the course of the contour lines that the Spree and the Havel and their tributaries form the receiving waters for the groundwater close to the surface. The groundwater flow direction lies perpendicular to the contour lines from the higher to the lower level. The EMHGL varies between about 58.0 m above sea level in the northern Panke valley on the state border and 30.5 m above sea level near the canalised Lower Havel in Spandau. The closer clustering of the contour lines in the Panke valley shows that the height gradient of the groundwater is larger here than in the glacial valley, as expected. Thus the course of the EMHGL isolines shows a plausible picture for the case that neither groundwater extractions nor artificial groundwater replenishments occur.

On the digital map, the EMHGL value for a certain location can be displayed on screen by a mouse click.

Thus the user receives an EMHGL value for his question in a simple manner.

The following should be noted:

The map value applies to the groundwater level of the uppermost aquifer. In the represented area of the glacial and Panke valley, the groundwater in the uppermost aquifer is predominantly unconfined. Thus, as a rule the map value indicates the height of the groundwater surface. However, in some places overlying layers with low water conductivity, such as boulder clay and boulder marl, clay, silt and organic soils, cause the groundwater to be confined (e.g. in the area of a boulder marl "island" in Charlottenburg designated on the map). In these cases, the map does not specify the height of the groundwater surface, but rather that of the piezometric surface of the confined groundwater.

Due to the scale and the rather heterogeneous individual sedimentation conditions, the two possible deviations from the usual hydrogeological configuration that were mentioned are not, or not completely, representable in the Geological Outline provided. However, they can be recognised in the framework of a subsoil expertise, which is principally required for construction activity. In addition, in concrete cases advice may be sought from the State Geological Service regarding the geological

substructure of the subsoil, and the strata-log sheets from the digital drilling map can be consulted online.

It should also be noted that the EMHGL may lie above ground level. In this case, the formation of groundwater ponds cannot be excluded.

Near surface waters, in addition to high groundwater levels, short-term local flooding may occur, which cannot be inferred from the map of the expected mean highest groundwater level. Information on this is available at https://www.berlin.de/sen/uvk/umwelt/wasser-und-geologie/hochwasser/ [in German].

In the Panke valley, in particular in its northern part, the groundwater measuring points are sometimes relatively far apart in view of the heterogeneity of the aquifer and the mostly large natural groundwater gradient. As a result, the EMHGL map is more fraught with uncertainty here than in the area of the glacial valley. This also applies to areas in the immediate vicinity of surface waters (the Panke and its small tributaries). If new investigations (drillings, groundwater level measurements) yield results in such areas that clearly contradict the EMHGL value of the map (e.g. current groundwater level within metres above the map value), the EMHGL should be locally modified by an expert. In such cases, the Berlin Groundwater Service (*Landesgrundwasserdienst*) kindly requests to be notified.

Regulation for planning percolation facilities in the water conservation areas

When planning percolation facilities for precipitation water outside of the water conservation areas, the EMGHL is to be taken as the design groundwater level in large parts of Berlin. Within the individual conservation zones of a water conservation area, however, the following provisions apply:

- outer conservation zone III B
  In order to guarantee a higher protection of the groundwater within the outer conservation zone III B, the harmless percolation of runoff or collected precipitation water is possible here without permission under the conditions of the precipitation water exemption ordinance (*Niederschlagswasserfreistellungsverordnung*). However, instead of the EMHGL, the EHGL, which is usually a few decimetres higher, has to be taken as the basis.

- outer conservation zone III A
  Percolating precipitation water without permission is not possible here. A permission under water law must be obtained from the water authority.

- outer conservation zone III
  Percolating precipitation water without permission is not possible here. A permission under water law must be obtained from the water authority.

- inner conservation zone II
  Construction is generally prohibited here, which also applies to percolation facilities for precipitation water.

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