Berlin

02.16 Dwell Time of Percolation Water in the Non-Saturated Zone (Edition 2004)

Overview

The protection of the groundwater as a natural resource is of the greatest importance, since groundwater forms the basis of the supply of the population with qualitatively good drinking water, and thus represents a key element of basic living conditions.

A primary prerequisite for good groundwater is the protection of the soil and the non-saturated zone, which together constitute the groundwater overburden, from contamination, because the percolation of pollutants from the surface into the soil and further into the groundwater represents the main source of contamination for groundwater resources.

The characterization of the pollution sensitivity of the groundwater to substance penetration from the surface is therefore an important basis for planning, as well as for measures aimed at providing groundwater protection, and also for prognostic statements about potential threats to groundwater deposits, as required, among others, for reporting under the European Water Framework Directive WRRL (EU 2000).

Fundamentally, groundwater everywhere is sensitive to pollutants entering from the surface. Spatial differences in pollution sensitivity arise, however, from the different times which substances introduced from the surface require to arrive at the groundwater table and possibly cause contaminations there. The pollution sensitivity of a groundwater deposit can therefore be described as the probability with which a certain amount of a pollutant may reach the groundwater table in a particular time.

Different approaches and methods exist for definition and assessment of groundwater pollution sensitivity. In addition to the concept "pollution sensitivity of the groundwater," the concept "protection function of the groundwater overburden" is used, where a high protection function of the groundwater overburden means low pollution sensitivity of the groundwater, and vice versa.

It is fundamental to distinguish between intrinsic and specific pollution sensitivity of the groundwater, or protection function of the groundwater overburden, respectively.

The **intrinsic ("location-inherent")** pollution sensitivity refers exclusively to the natural qualities of the groundwater overburden. It can be seen, with reference to Voigt et al. (2003), as a "worst-case scenario of pollutant entry into the non-saturated zone, in which no interaction of the pollutant with the media in the non-saturated zone take place". Intrinsic pollution sensitivity can be estimated on the basis of percolation water speed, or the dwell time of the percolation water in the groundwater overburden.

The **specific pollution sensitivity** refers to the entry of specific substances or pollutants at the surface. The specific pollution sensitivity thus always refers to a certain use, or a potential or real pollutant entry caused by such use, into the groundwater. Not only the geological-hydrological conditions are an important factor here, but primarily the specific behavior of the substances or pollutants or the substance or pollutant groups and their potentially or actually released quantities. At the same intrinsic pollution sensitivity, at the same location, the specific pollution sensitivity definitely can be very different, depending on the pollutant involved.

Factors which determine pollution sensitivity include:

- The thickness of the **groundwater overburden**, i.e. the depth at which the groundwater is located under the surface; the geological lithological and the geochemical qualities of the soils and rocks present, with their components which determine the water conductivity, the water-retention capacity (by cohesive binding to soil components), and the adsorption capacity for certain substances.

- The **quantity of percolation water** which penetrates the groundwater overburden, and the amount of the percolation water which ultimately flows to the groundwater (**new groundwater formation**), since substances are shifted through the percolation water into the groundwater in the non-saturated zone. The percolation water quantity and the amount of new groundwater formation are dependent on the climatic quanta precipitation and evaporation as well as on the geological structure of the non-saturated zone, the surface morphology, land use and surface sealing.

- The **structure of the aquiferous rock** below the groundwater surface (aquifers and aquitards), their dimension and thickness, their geological-lithological and geochemical (and in connection with that, their physical) qualities, such as usable porosity and water conductivity as well as, finally, the groundwater slope and groundwater flow direction. These parameters determine how water, and also dissolved substances which have entered the groundwater, can disseminate underground.

- In the case of the **specific pollution sensitivity, also the specific chemical/ physical qualities of pollutants**, such as their state of aggregation (solid, liquid, gaseous), their solubility in water, their degradability by chemical or bio-chemical processes, and their ecological/toxicological qualities.

While the general connections between climatic, pedological, geological and hydrogeological conditions and the groundwater pollution sensitivity seems quite simple, the quantification of the processes which specifically determine groundwater pollution sensitivity is quite complicated, and as a rule requires a very comprehensive database and often very complex methods.

As a reference point for the pollution sensitivity of the groundwater, the dwell time of percolation water has been derived from the characteristic quanta for the thickness and qualities of the groundwater overburden as well as the new groundwater formation rate, as a measure for the protection function of the groundwater overburden, and has been represented in the present map.

Statistical Base

A variety of very different data enter into the calculation of the dwell time of percolation water: on the one hand, geological pedological data (spatial distribution of soil and rock types, characteristic values of soil and rock), and on the other hydrological/ hydrogeological data (spatial distribution of percolation water quantities, new groundwater formation quantities, depth to groundwater from the surface).

The following specific sources have been taken into account:

- General Geological Map of Berlin and Surroundings of 1:100,000 GÜK 100, (LGRB and SenStadt 1995)

- Hydrogeological Segments from the Berlin Geological Atlas (SenStadt 2002),

- Berlin Environmental Atlas, Updated and Enlarged Edition, (SenStadt)

    - Map 01.01 Soil Associations, 1:50,000 (1998),

    - Map 01.06.1 Types of Soil, 1:50,000 (2002),

    - Map 02.07 Depth to Groundwater, 1:50,000 (new edition 2003),

    - Map 02.13.5 New Groundwater Formation, 1:50,000 (new edition 2003),

- Soil database of the City and Environment Information System (SenStadt),

- Data of approx. 33,000 drillings from the Berlin State Geological Archives,

- Map for the Characterization of the Overburden Layers, according to WRRL 1:100,000 (SenStadt 2002).

Methodology

In the map, the dwell time of the percolation water in the non-saturated zone is represented as a measure for the **intrinsic pollution sensitivity** of the groundwater. The certification of specific pollution sensitivity requires the consideration of concrete pollutants, pollutant quantities and uses, which is more significant for concrete and detailed location investigations than for extensive representations.

The mean dwell times of the percolation water in the non-saturated zone - i.e. the period which the percolation water requires to move from the surface to the groundwater table under the force of gravity - were calculated. A method which allows the estimate of this dwell time on the basis of available climatic hydrologic and geological pedological data was developed at the Brandenburg Technical University of Cottbus (BTU method) (Heinkele et al. 2000, Voigt et al. 2003). The calculation of the percolation water speed and the dwell time of the percolation water in the non-saturated zone are carried out by reference to DIN 19732 "Determination of the Site-Shift Potential of Non-Absorbable Substances." This procedure as per DIN 19732 was originally designed for the assessment of local locations, but with modification (see below), it is also suitable for larger-scale observations.

The following parameters affect the determination of the dwell time of percolation water in the groundwater overburden:

new groundwater formation

capillary capacity of the groundwater overburden

thickness of the groundwater overburden.

New groundwater formation is derived from the percolation water rate and represents the water quantity which arrives at the groundwater table and replenishes the groundwater stocks (see Map 02.13.5).

Capillary capacity means the quantity of water which is adsorbed in the non-saturated soil zone due to cohesion and capillary forces and can be retained against the force of gravity (i.e., it does not percolate immediately). This is primarily water in pore-centered radii <50 μm. This water quantity can be described as soil moisture in per cent by volume of the soil. This capillary capacity is dependent on soil type. The assignment of capillary capacities to soil types is carried out according to the geological mapping guideline Ka 4 (Soil Ad-Hoc Working Group 1994). Fine-grained soils have a high capillary capacity (e.g. clay between 40 % and 54 %), while coarse-grained soils have low capillary capacity (e.g., coarse to medium-grain sand between <10 % and 13 %). A large quantity can therefore be adsorbed into percolation water and stored in fine-grained soils. A shift of percolation water due to gravity occurs only at water contents above capillary capacity.

The **capillary capacity of the groundwater overburden** is the water that can be adsorbed and retained in the entire non-saturated zone in this manner. It can be determined expansively from the data on the distribution of types of soil and rocks in soil maps, geological maps and the results of drillings, with consideration for the thickness of the groundwater overburden.

The **thickness of the groundwater overburden** corresponds to the depth to groundwater and is immediately derivable from the appropriate maps, with consideration for the unusual features of unconfined and confined groundwater conditions. The thickness of the groundwater overburden has been taken from Map 02.07 Depth to Groundwater of the Environmental Atlas, and refers in each case to the nearest-to-surface aquifer (GWL) which permanently carries water. In most cases, this is the main aquifer (GWL 2, according to the categorization of Limberg and Thierbach 2002), which is used for the drinking-water supply of Berlin, and is open in the glacial spillway, but covered in the area of the plateaus. In some areas, the evaluation was carried out on the basis of the GWL 1 (e.g. in the area of the Panke Valley) or the GWL 4 (tertiary formations).

The dwell time ts of the percolation water in the groundwater overburden, i.e., the time period during which the water moves from the surface to the groundwater can be derived from the new groundwater formation, and from the thickness and the capillary capacity of the groundwater overburden, according to the following equation (Voigt et al. 2003):

$$t_s = \Sigma\, M_i * FK_i\ /\ GWNB = (\,M_1 * FK_1 + M_2 * FK_2 + \ldots + M_n * FK_n)\ /\ GWNB$$

where:

t_s	Dwell time of the percolation water in the non-saturated zone
GWNB	new groundwater formation rate in mm/yr.
FK	Capillary capacity of the entire groundwater overburden in % or mm/dm
FK_1, FK_2 ... FK_n	Capillary capacity of the 1st ,2nd... nth layer of soil, or the deeper groundwater overburden in mm/dm
M	Thickness of the entire groundwater overburden in dm
M_1, M_2 ... M_n	Thickness of the 1st ,2nd... nth layer of soil or the deeper groundwater overburden in dm.

The following procedural plan (Fig. 1) explains the ascertainment of the dwell time on the basis of the above-named data bases.
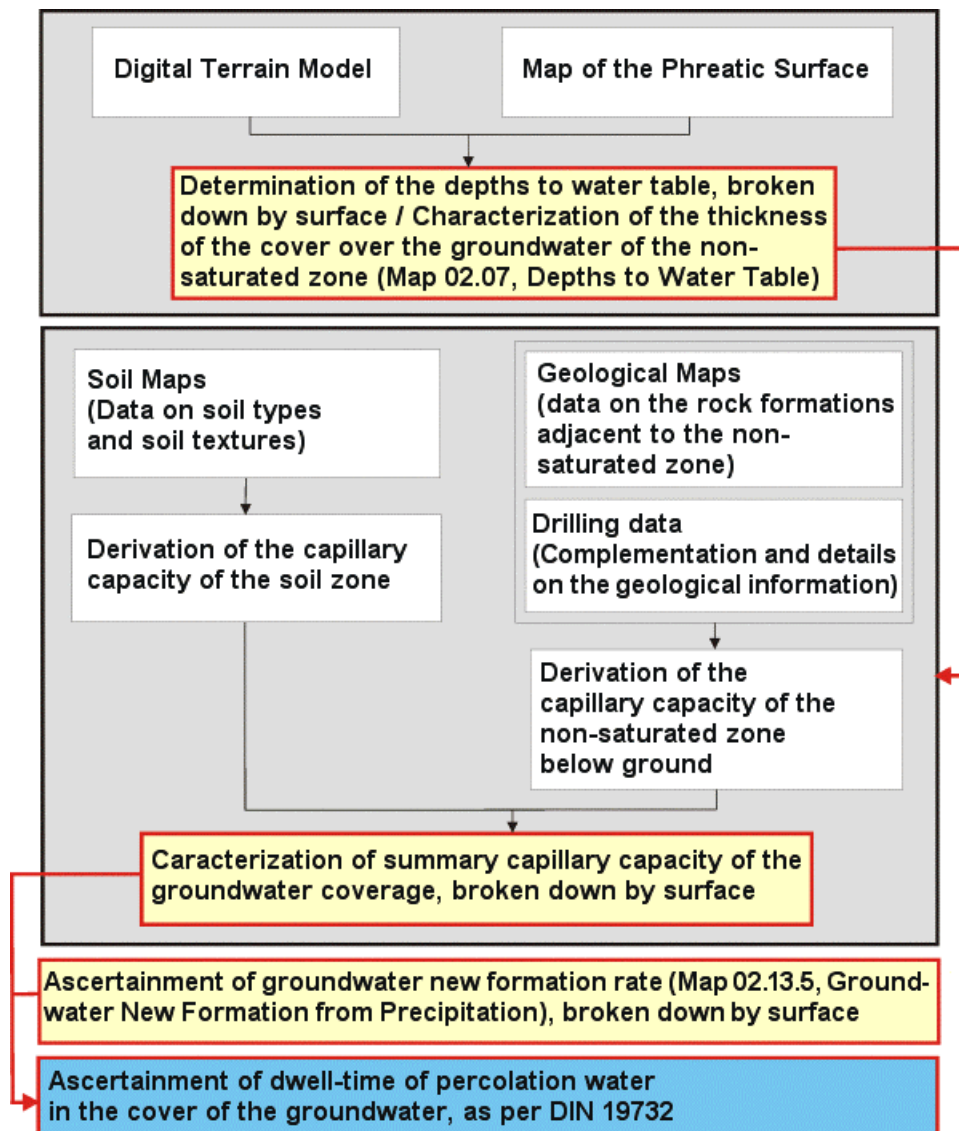
Fig. 1: Flow chart for the determination of the dwell time of the percolation water

The following restrictions for the applicability of the dwell times calculated on the basis of the above-mentioned DIN 19732 must be observed (modified according to DIN 19732):

• The calculated mean shift speed describes the center of gravity of a shift front. The leading and/ or trailing material flow caused by hydrodynamic dispersion cannot be calculated.

• The calculations apply to largely homogeneous subterranean structures. The effect of greater heterogeneity of the sub-soil, such as extremely variegated layer structures and particularly preferential flow paths (processes of macro-pore flow and of preferential flow) cannot be taken into account.

Map Description

The present map shows the dwell time of the percolation water in the groundwater overburden derived according to the represented method for the nearest-to-surface water-carrying aquifer from the factors depth to groundwater, structure of the surface overburden, and the new groundwater formation, and can be seen as a measure of intrinsic pollution sensitivity. It should be noted here that, due to the scale of the data bases of 1:50,000 (see above), this map is primarily suitable for large-scale spatial observations. For a precise assessment of specific sections, detailed investigations are necessary.

Below, a general description of the rock structures occurring in the groundwater overburden in the Berlin area, which are predominantly Pleistocene, i.e. Ice-Age formations, are described, followed by a description of the pollution sensitivity of the groundwater for the geomorphological units of Berlin.

General Description of the Pleistocene Formations

During the last epoch of the Tertiary (the Pliocene), a strong cooling of the area around the North Pole marked the transition to the Ice Age (Pleistocene). Heavy precipitation in Scandinavia led to the formation of glacial flows, which moved southward, eroding the existing surface and carrying large quantities of rock material with them. In Northern Europe, three great glacial advances, separated by warmer periods, can be identified - the Elster, Saale and Vistula glaciations. The retreat of the ice was made possible by melt-offs caused by climate warming. The following landscape elements were shaped by the phases of advance and retreat of the ice:

Ground moraine: Rock material remolded at the base of the glacier; an unsorted mixture of clay, silt and sand (glacial till, debris loam) and non-remolded boulders (bed-load in the glacial till mass). The fine-grained portion (silt, clay) generally reaches weight proportions of from 20 % to more than 60 %. The deposit of the material occurred at the melt-off of the glaciers.

End moraine: Formed by coarse rock material (boulders) transported in front of the ice; when the re-supply and the melt-off of the ice reaches a balance (standstill of the inland ice periphery), the deposit of frequently coarse block packets of Nordic rock material, and also of gravel and sand and to some extent also of clayey material occurred. The deposit occurred at the front edges and the peripheries of the glaciers.

Outwash: Gravelly and primarily coarse and medium-sandy material which was deposited in front of the glacier and washed out of end moraines by melt-off water (it originates from the ice edge, and also from the glacial surface).

Glacial spillway: Runoff area of the melt-off water. Sands of different granulations are generally common; generally finer-grained than in outwash areas. During the warmer postglacial periods, materials with high organic contents were frequently deposited in the valleys (gyttja and peat).

During each of the three great glacial advances, several phases of advance and retreat occurred (e.g. during the Vistula glaciation, three major phases are distinguished: the Brandenburg, Frankfurt and Pomeranian phases), with the above-described glacial sequence. This has resulted in several overlapping glacial sequences, with the corresponding landscape elements.

The splitting of the glacier into many glacial flows with corresponding sequences caused an additional nesting of glacial forms, so that in areas with small-scale glacial landscape elements, it is often difficult to assign the formations with genetic certainty.

Especially the ground-moraine landscape is subdivided even more strongly. The melt-off activity of the water resulted on the one hand in lakes of various forms, and on the other in various deposits of rock material contained in the ice. The runoff of melted water in the ice crevices of the glacier created deep, narrow finger lakes (e.g. the Grunewald lakes, the Havel lakes); long-drawn, often broad and deep, tongue-basin lakes originated from the erosion activity of former ice tongues of the inland ice. Melting dead ice floes (blocks of ice detached from the melt-off inland ice) created water-filled depressions (kettle-holes, pools) with no runoff. Rocky material (sand, gravel, boulders) from intraglacial streams and pothole structures, which remained on the ground moraine at the melt-off of the ice, formed eskers and kames (stratified sand and gravel deposits in ice crevices and rubble hills). The moving ice passed over older, already mature sediments, thus creating drumlins (elliptical rubble hills with a core of glacial till).

These different geological formations have different grain sizes and compositions. Very different capillary capacities and water conductivities result. On the one hand, these affect the capillary capacity (and hence the storage capacity) of the groundwater overburden, and also the new groundwater formation (see Map 02.13.5) and the depth to groundwater (unconfined predominantly sandy valley areas, confined glacial till plateaus). The dwell time of the percolation water is closely connected with the distribution of these formations.

Mean Dwell Time of the Percolation Water in the Non-Saturated Zone

The dwell times calculated according to the BTU method range from more than 200 years to less than one year, and vary considerably by location.

Fig. 2 shows the area shares of the different dwell-time categories. According to the different area shares, two maximums can be distinguished, one in areas with dwell times between 3 and 10 years, with a generally high pollution sensitivity of the groundwater; and the other in areas with dwell times of more than 25 to 100 years, which have less pollution sensitivity of the groundwater. These represent the two main geological morphological structures in the Berlin area: the valleys and lowlands (the Berlin glacial spillway and its side valleys, like the Panke valley); and the plateaus (the Barnim and Teltow ground moraine areas, the kames formations of the Havel Hills).
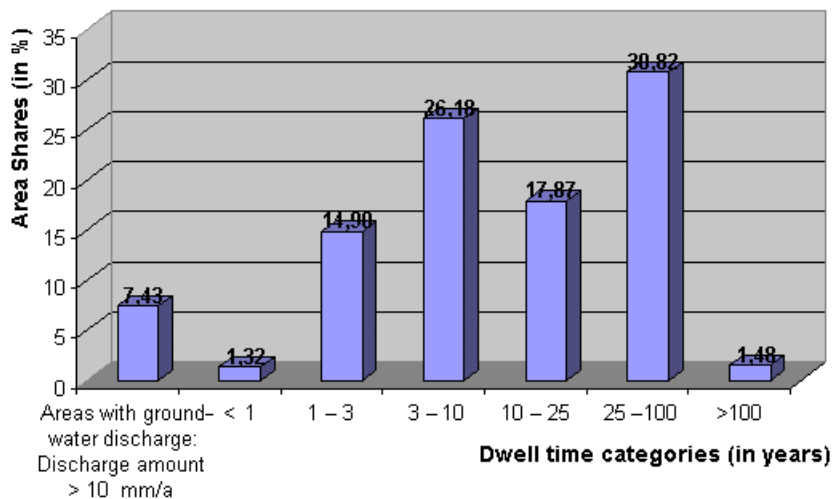
Fig. 2: Area shares of the dwell time categories for the State of Berlin

Dwell times of from <1 year to 5 years are predominantly reached in the valley areas (e.g. of Warsaw-Berlin glacial spillway, the valley of the Panke). These short dwell times can be explained by the predominantly shallow depth to groundwater. The protection function of the groundwater overburden can be classified as low and the pollution sensitivity of the groundwater as predominantly high, since substance entry into the groundwater may occur within a few years. In other valley structures carved into the plateaus, like the Wuhle valley, a glacial stream on the Barnim plateau, small-scale areas with high pollution sensitivity are also found.

In the lowlands, in areas of particularly low depth to groundwater (<1,5 m), the annual water balance yields groundwater discharge in many cases, i.e. in the summer months more water is withdrawn from the groundwater by plants and evaporation than flows into it in the entire year through percolation to form new groundwater. These areas must be classed as very sensitive areas, due to their shallow depth to groundwater. Moreover, some ecologically significant wetlands are found here.

Dwell times of between >20 years to 100 years were calculated for the Barnim and the Teltow plateaus, and the Havel Hills. Here, the protection function of the groundwater overburden must be considered generally high. In sections of the Teltow plateau, immediately east of the Teufel Lake - Pech Lake - Bars Lake glacial stream running northeast to southwest, shorter dwell times of between 5 and 15 years occur, which mean greater pollution sensitivity.

Dwell times of > 25 years have been ascertained for the areas with cohesive, silty-clayey material structures in the Barnim and the Teltow plateaus, but also for the areas of the Havel Hills and the Nauen plate, which, according to the geological map, are largely covered with sands. The long dwell times in the sandy areas are on the one hand caused by the very great thicknesses of the groundwater overburden. The results, despite high sand contents of the groundwater overburden, are high to very high (overall) capillary capacities. On the other hand, the soil category of sands can overburden a broad range of capillary capacities, depending on granulation (11 % to 24 %). Mean capillary capacities of in general more than 20 % were ascertained for these areas of the plateau sands by means of evaluation of the stratification from drillings. This indicates a dominance of fine sands and fine-grained medium sands. The dwell times in these areas are therefore easy to explain, due to the high depth to groundwater and the actual lithological conditions.

The calculation of the dwell time of the percolation water in the non-saturated zone was carried out with consideration for new groundwater formation at current surface sealing (see Map 02.13.5). The determined values represent mean average values for individual block sections. The calculation of the dwell times without sealing was carried out analogously, using data on new groundwater formation without sealing. These data are also available from the Senate Department, but have not been published in the Environmental Atlas. The basic tendency exists for the dwell time of the percolation water to be reduced, primarily in highly sealed areas of the inner city, due to the increase of the percolation water quantity in those areas which are unsealed. In less sealed zones in outlying areas, a contrary trend can in many cases be observed. With de-sealing, the percolation water quantities are reduced (due to changed drainage conditions and increased evapotranspiration), and the dwell times increased.

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