

02.12 Groundwater Levels and Catchment Areas for Waterworks (Edition 1993)

Groundwater Levels: Overview

Drinking water and large portions of water for other uses in Berlin are withdrawn from groundwater ("true" groundwater and bank-filtered water). This resource continually varies in quantity and quality. A well-functioning groundwater measuring network is necessary to secure and maintain water resources. Only constant control of both groundwater withdrawals and natural and artificial recharges can prevent excessive removals and overexploitation.

All construction activities intervene in the subsurface. The Berlin subsurface is characterized by strongly varying local ground and groundwater conditions. Local groundwater conditions must be known, especially for deeper construction works (traffic tunnels and deep foundations), in order to prevent irregular subsidence, lift dangers, and moisture damage. A knowledge of the deepest and highest groundwater levels is critical for planning and construction.

Development of Lowering of Groundwater

The first **lowering of groundwater tables** in the Berlin area (and the destruction of wetlands) occurred with the dewatering of swampy areas, such as the Hopfenbruch in Wilmersdorf in the 18th century. Additional areas were dewatered in the 19th and 20th century during the great expansion of canals. Groundwater levels sank due to increased demands for drinking and industrial water, by water retention at construction sites, and the restricting of groundwater recharge caused by (impervious) sealing of surface areas.

The industrial development of Berlin began in the mid-1880's and caused groundwater levels to sink to a low point in 1939. The economic collapse after the Second World War allowed groundwater levels to rise almost to pre-industrial levels.

Groundwater levels sank continually in large areas during the next era, from the beginning of the 50's till the beginning of the 80's, because of increasing withdrawals. Lowered groundwater was particularly noticeable in drinking water production areas. This was caused by a general increase of water consumption by households and construction, the post-war rebuilding of Berlin, subways and other large engineering projects. West Berlin's enlargement of water production plants in its borough waterworks was completed at the beginning of the 70's. An enlargement of the East Berlin Friedrichshagen waterworks was begun in the mid-70's to supply the new, large residential settlements in Hellersdorf, Marzahn and Hohenschönhausen.

Berlin's water needs are primarily satisfied by withdrawing water from aquifers located in ice age Pleistocene strata. Aquifers are porous and water-permeable subterranean layers of rock that hold and allow water to flow. The **upper aquifer** is extremely important. The aquifer base is formed by semi-permeable or impermeable silt, clay and boulder marl. Medium sands with fine and coarse pockets make up most of the groundwater conducting layer. Groundwater flows through layers of differing thickness depending on hydrogeological conditions.

Making of Groundwater Contour Maps

Although groundwater levels in Berlin have been measured for the last 100 years, groundwater contour maps for the entire city area have not been produced. The division of Berlin in 1948 caused geologic and hydrogeologic explorations to be done separately. All geologic and hydrogeologic data in the GDR (German Democratic Republic) was considered confidential material. That prevented a common effort.

Groundwater contour maps at a scale of 1:50,000 have been produced for West Berlin at the beginning and at the middle of the hydrographic year (November and May) since November, 1953. They were prepared

by the Department of Construction and Housing and are now prepared by the Berlin Department of Urban Development and Environmental Protection. They are published yearly in the "Gewässerkundlichen Jahresbericht des Landes Berlin (Hydrological Annual Report of Berlin). Groundwater contour maps for East Berlin appeared at irregular intervals as "Hydrogeologische Karten" (Hydrogeological Maps).

The fusion of the Oberflußmeisterei (Head River Master) and its groundwater measuring points with the West Berlin water authorities in 1991 allowed the preparation of a groundwater contour map for all Berlin for the first time.

Statistical Base

Statistical data for preparation of groundwater contour (watertable isohypse) maps were gathered from the Landesgrundwasserdienst (Berlin Groundwater Service) of the Berlin Department of Urban Development and Environmental Protection.

Regular recording of groundwater levels started in 1869, when 29 measuring points were established. In 1937 there were over 2,000 measuring points in Greater Berlin. In 1992 in West Berlin there were 1,581 **observation wells**. In East Berlin there were 2,380. The statistical basis for the map published here was selected from them.

There were considerable problems in preparing this first all-Berlin map. The East Berlin Oberflußmeisterei measuring network had many gaps and only 40% of them were even capable of functioning, according to studies conducted up to now. The hydrogeologic situation of individual measuring points is often either unknown, or else filters were set too shallowly in "floating tables". Information regarding groundwater developments can be given only with reservations, generally speaking, because the hydrogeological situations at most of the existing East Berlin measuring points remain relatively unclear, especially outside the Pleistocene watercourse. The East Berlin groundwater measuring network is being renovated with all urgency and available means. The renovation began in January 1992.

In the current transitional situation, Berlin groundwater can be measured at only 2,000 groundwater observation wells (daily, every 14 days or monthly).

In addition to the statistical basis given by the groundwater measuring network, **water table levels** near lakes and running waters were included as supplementary measuring values when a hydraulic connection with groundwater is probable. An average value for all observation periods was assumed because of the low range of variation. The structural situations of all **wells** of the Berlin Public Water Companies were also given consideration, for they are the largest continual groundwater consumers.

The state environmental agency made data available for approximately 50 groundwater measuring points bordering Berlin in the state of Brandenburg. The well galleries of the Stolpe, Erkner, and Eichwalde waterworks were included because of their probable influence on groundwater conditions in Berlin.

Methodology

Development of Depiction

Because the questions previously described remain unclear, the scale for the all-Berlin groundwater contour map was changed. Instead of the 1:50,000 scale used in the Gewässerkundlichen Jahresbericht (Hydrological Annual Report), groundwater contours are depicted at a scale of 1:125,000.

The contour maps of near-surface groundwater were produced with a computer-aided method for the spatial **interpolation** of point scattered initial data. The process for preparation of contour line-drop maps (**SCOP**) connected to the Berlin environmental information system served as methodological instrument. A linear function with a basic grid of 700 m was chosen as base function.

Observation wells for a sufficiently dense and regularly distributed data network were selected according to the following criteria:

- filtering in near-surface groundwater aquifers (as far as known)
- position of measuring points to each other
- an observation period as long as possible

A total of 950 observation wells in Berlin remained, depicted in Figure 1, and 50 observation wells in the surrounding areas.

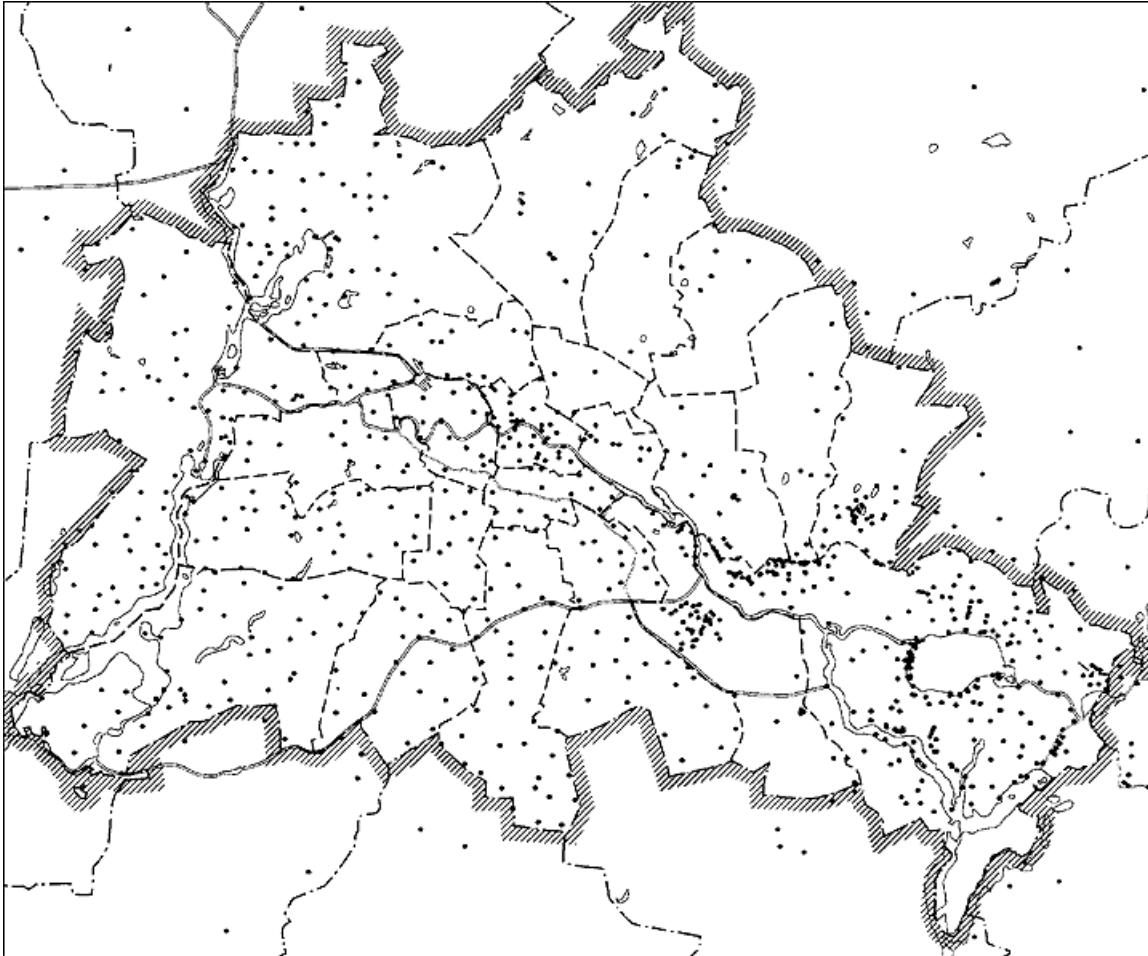


Fig. 1: Distribution of Groundwater Observation Wells Used for the Calculation of Groundwater Levels

The course of average deviation of groundwater levels from the long-term average helped select representative time periods of relatively higher and lower groundwater levels (cf. Map 02.07).

The following time periods were selected for depiction:

- May 1976 as period of **relatively low** groundwater levels
- May 1988 as period of **relatively high** groundwater levels
- May 1990.

The month of May (end of winter) gives the time period of comparatively higher groundwater levels in the course of the water management hydrographic year (November-October).

Confined Groundwater Conditions

There were problems in determining the first groundwater aquifer, especially in the Barnim flat upland area, as well as in other areas with **confined** groundwater conditions. The determination was made more difficult by sandy-gravelly interstratifications in the marl strata of the flat upland area where - independent of the groundwater aquifer - **perched** groundwater can form. Misinterpretations can be expected here due to complicated geological conditions. This could lead to water levels deviating in meter range from those depicted on this map, especially in the Barnim flat upland area, according to available knowledge.

The depiction of **observation well levels** of groundwater can be misinterpreted very easily in areas where groundwater may be confined under and pressing against a thick, impermeable or semi-permeable marl mantle. Groundwater may climb through the drilled mantle, up the pipes of the groundwater measuring station, up to the **measured gauge level**. These areas were therefore separately classified on the basis of available knowledge.

Map Description

Groundwater tables in the Berlin area can generally be determined in their hydrogeological conditions in spite of the massive influences exerted on them today. Groundwater flows from the Barnim and Teltow **flat upland areas** into the Warsaw-Berlin Pleistocene watercourse, with the Spree river as receiving body of water, and from the Nauen Platte into the **Haveltal**. The extent of **changes** in this natural flow behavior as well as groundwater table levels depend upon precipitation conditions, but even more upon the influence of groundwater withdrawals and returns.

Map 02.12.1: Groundwater Levels in May 1976 (relatively higher groundwater level)

The water management year 1976 was characterized by **low amounts of precipitation** (70% of the 60-year average), and by **comprehensive interventions** in the groundwater economy.

Groundwater withdrawals reached a new record due to public water supply plants and diverse civil-engineering construction projects (cf. Tab. 1). **West Berlin** especially showed wide cones of depression resulting from subway construction (Line 7, Fehrbelliner Platz-Spandau) and the city freeway (Innsbrucker Platz). Lowering of groundwater levels in the southern areas of the Wedding borough is due to a private sector construction project. The high(est) values of public groundwater withdrawals in West Berlin are reflected in wide cones of depression under the Jungfernheide and Beelitzhof waterworks. All waterworks operated in their present size, except for the Kuhlake gallery of the Spandau waterworks. 315 larger private sector water supply plants also affected groundwater level gradients noticeably.

Tab.1: Groundwater Withdrawals, Returns and Recharges in West Berlin in 1976, 1988 and 1990

Operator	Hydrographic Year						Change 1988 compared to 1976		Change 1990 compared to 1988	
	1976		1988		1990		million m ³	%	million m ³	%
	million m ³	%	million m ³	%	million m ³	%				
Groundwater withdrawals of Berlin Public Water Companies										
Tegel	61,2	31,7	66,5	34,9	69,4	37,4	+ 5,3	+ 8,7	+ 2,9	+ 4,4
Beelitzhof	46,7	24,2	41,3	21,7	40,3	21,7	- 5,4	- 11,6	- 1,0	- 2,4
Jungfernheide	31,9	16,5	22,9	12	19,8	10,7	- 9,0	- 28,2	- 3,1	- 13,5
Tiefwerder	21,6	11,2	17,9	9,4	17,1	9,2	- 3,7	- 17,1	- 0,8	- 4,5
Spandau	19,6	10,2	32,9	17,3	30,4	16,4	+ 13,3	+ 67,9	- 2,5	- 7,6
Kladow	6,9	3,6	6,9	3,6	6,7	3,6	0	0	- 0,2	- 2,9
Riemeisterfenn	4,9	2,5	1,9	1	1,9	1	- 3,0	- 61,2	0	0
Total	192,8	100	190,3	100	185,6	100	- 2,5	- 1,3	- 4,7	- 2,5
Withdrawals by private sector water supply plants										
Total	42	100	24,3	100	23,4	100	- 17,7	- 42,1	- 0,9	- 3,7
Withdrawals for groundwater retention reservoirs										
Subway construction	29,6	45,1	0,3	5,3	1	7,6	- 29,3	- 99,0	+ 0,7	+ 233,3
Freeway construction	19,2	29,3	–	–	–	–	- 19,2	- 100,0	–	–
Other public construction projects of Berlin	3,1	4,7	0,4	7	8,1	61,4	- 2,7	- 87,1	+ 7,7	+ 1925,0
Construction projects of dewatering works	4,6	7	0,7	12,3	0,2	1,5	- 3,9	- 84,8	- 0,5	- 71,4
Private sector construction projects	9,1	13,9	2,3	40,4	3,5	26,5	- 6,8	- 74,7	+ 1,2	+ 52,2
Restoration	–	–	2	35,1	0,4	3	+ 2,0	x	- 1,6	- 80,0
Total	65,6	100	5,7	100	13,2	100	- 59,9	- 91,3	+ 7,5	+ 131,6
Total Sum	300,4	100	220,3	100	222,2	100	- 80,1	- 26,7	+ 1,9	+ 0,9
Groundwater returns / recharges										
Private sector water supply plants	4,3	9,5	2,2	4,5	1,8	3,5	- 2,1	- 48,8	- 0,4	- 18,2
Construction projects	17,2	38,1	2	4,1	3,9	7,6	- 15,2	- 88,4	+ 1,9	+ 95,0
Berlin Public Water Companies	23,6	52,3	44,3	91,3	45,8	88,9	+ 20,7	+ 87,7	+ 1,5	+ 3,4
Total	45,1	100	48,5	100	51,5	100	+ 3,4	+ 7,5	+ 3,0	+ 6,2
– no existing x statement not meaningful The hydrographic year is from 1 November - 31 October.										

Tab.1: Groundwater Withdrawals, Returns and Recharges in West Berlin in 1976, 1988 and 1990

No depiction of the entire East Berlin area is possible due to insufficient data bases. The low degree of expansion of the largest waterworks in Friedrichshagen is remarkable. In 1976 only the A-D galleries north of Müggelsee (see = lake) existed (cf. Map 01.22). The large plants south of the lake were put into operation between 1982 and 1984, with increased demands exerted by construction of the new residential areas of Marzahn, Hellersdorf and Hohenschönhausen as well as reduced surface water withdrawals from Müggelsee. The galleries which existed in 1976 withdrew about 14.6 million m³ raw water in May 1976, a record for this month. There are correspondingly large cones of depression around the waterworks.

Large construction projects in East Berlin with groundwater retention reservoirs were mainly in the Mitte borough, at the construction site for the Palace of the Republic, the Charité hospital, various hotels, and the expansion of the Friedrichstraße boulevard. No information is available for amounts withdrawn by private sector water supply plants.

Measures for groundwater recharge and return at construction projects for the stabilization of the groundwater economy were performed in the entire city. This amounted to about 45 million m³ in West Berlin, 52% of it around the Jungfernheide waterworks, which fed lakes Kuhlake and Saatwinkel. Another

38% were returned at construction projects (cf. Tab. 1). A groundwater recharge by means of an earth basin was performed in East Berlin around the Johannistal waterworks between 1972 and 1976. Infiltrated amounts in 1973 were 1.5 million m³. Groundwater has been recharged by the Stolpe waterworks into the bordering Havelwiese since 1974. The amounts flow to recharge by natural slope and amount to about 6 million m³/year.

Map 02.12.2: Groundwater Levels in May 1988 (relatively higher groundwater level)

In comparison to the strongly lowered groundwater levels in May 1976, the picture changed for large portions of Berlin, differing in both parts of the city.

Groundwater levels in West Berlin have risen again since the mid-80's. That is mainly due to smaller groundwater withdrawals by private sector water supply plants, and lessened withdrawals by groundwater retention ponds and restoration/redevelopment projects. Compared to 1976, 78 million m³ less groundwater was withdrawn in 1988 (cf. Tab. 1). The considerable increase of 88% in groundwater recharge by the Berlin Public Water Companies compared to 1976 also contributed to relief of the groundwater economy. Withdrawal amounts of the Berlin Public Water Companies remained mostly unchanged compared to 1976; proportional amounts of individual waterworks have shifted.

This favorable development was supported climatically by mild months in winter and spring with high amounts of precipitation.

Changes in East Berlin in comparison to 1976 are especially noticeable in the Köpenick forest area. The expansion of the south gallery of the Friedrichshagen waterworks at the beginning of the 80's led to cones of depression. In later years this also led to a deterioration of vegetation in individual wetlands.

There is no information for private sector water supply plants or groundwater withdrawals at construction sites in East Berlin in 1976. Withdrawal amounts in 1988 by private sector water supply plants obligated to payment (excluding hospitals, sports facilities, zoos and similar public facilities) were 12.9 million m³. About 12.7 million m³ were pumped out by construction projects. Extensive construction projects in the Mitte borough led to lowering of groundwater levels similar to 1976. The new residential areas of Marzahn and Hellersdorf, on the other hand, are located on the Barnim flat upland. No lowering of groundwater was required because there were greater groundwater depths from the surface.

Groundwater recharges in East Berlin around the Stolpe waterworks were about 5.6 million m³ in 1988.

Map 02.12.3: Groundwater Levels in May 1990

Groundwater levels in **West Berlin** changed only slightly in May 1990 compared to 1988. The hydrographical year 1990 was average climatically, with 628 mm of precipitation (measuring point Dahlem). Withdrawal amounts of public and private sector wells and groundwater recharges are at comparable levels (cf. Tab. 1). There were no important changes in groundwater tables.

East Berlin, including the Stolpe waterworks, showed a different development. East Berlin waterworks withdrew 31.3 million m³ less in 1990 than in 1989. This was a result of the economic effects of German reunification and the reduced commercial/industrial activity associated with it. The consequences of this reduction were smaller cones of depression around the galleries, and a more balanced situation with smaller gradients in the rest of East Berlin. Groundwater recharge in the Havel lowlands at the Stolpe waterworks remained unchanged at 6.2 million m³ compared to 1988.

The "transition situation" of this current time period will lead to a rise in demand due to new industrial parks and residential construction projects, especially in the east. Water consumption of the public water supply in West Berlin in 1990, including all groups of consumers, was 233 liters per inhabitant per day; in East Berlin 318 liters per inhabitant per day. The long-term goal is 240 liters per inhabitant per day.

The long-term assurance of a balanced groundwater economy requires such measures as:

- a more sparing use of drinking and industrial water
- increased groundwater recharge
- use of rainwater for industrial water purposes
- the de-sealing of surfaces.

Tab. 2: Groundwater Withdrawals in East Berlin in 1976, 1988 and 1990

Waterwork	Calendar Year						Change in 1988 compared to 1976		Change in 1990 compared to 1988	
	1976		1988		1990		million m ³	%	million m ³	%
	million m ³	%	million m ³	%	million m ³	%				
Alt-Glienicke	2,8	2,1	2,3	1,5	0,8	0,6	- 0,5	- 17,9	- 1,5	- 0,7
Buch	2,2	1,7	2,2	1,4	2,4	1,8	0	0	+ 0,2	+ 9,1
Friedrichsfelde	1,0	0,8	2,6	1,7	3,1	2,3	+ 1,6	+ 160,0	+ 0,5	+ 19,2
Friedrichshagen	43,1	32,7	72,6	47,3	64,2	48,5	+ 29,5	+ 68,4	- 8,4	- 11,6
Johannisthal	23,7	18,0	21,2	13,8	19,4	14,7	- 2,5	- 10,5	- 1,8	- 8,5
Kaulsdorf	10,5	8,0	10,6	6,9	6,0	4,5	+ 0,1	+ 1,0	- 4,6	- 43,4
Köpenick	1,8	1,4	0,8	0,5	0,7	0,5	- 1,0	- 55,6	- 0,1	- 12,5
Stolpe	18,5	14,0	18,6	12,1	18,0	13,6	+ 0,1	+ 0,5	- 0,6	- 3,2
Wuhlheide	28,1	21,3	22,7	14,8	17,8	13,4	- 5,4	- 19,2	- 4,9	- 21,6
Total	131,7	100	153,6	100	132,4	100	+ 21,9	+ 16,6	- 21,2	- 13,8

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Catchment Areas for Waterworks: Overview

Water catchment areas are understood as a watershed areas which discharge into a receiving body of water. They are differentiated, depending on the origin of the waters, into **above ground** (surface waters) and **subterranean** (groundwater) collecting areas. Their borders are formed by water divides, where water is directed to flow above or below, in different directions, perpendicular to morphological contours or groundwater contours. Water divides of surface catchment areas thus run along the highest morphological levels between two receiving bodies of water.

Overland flows formed by precipitation reach surface bodies of water after a certain time depending on the surface gradient and the storage capabilities of the soil. The water divides of subterranean collecting areas can be recognized from the lines of highest groundwater levels. Groundwater also flows towards bodies of water. The time required depends on the gradient and the geological structure of the groundwater aquifer. The surface and subterranean water divides of a receiving body of water do not usually coincide.

Groundwater withdrawals by waterworks and other consumers effect changes in the groundwater direction of flow, and thus the course and gradients of natural water divides. They form their own groundwater collection areas within a catchment area, and reduce groundwater amounts flowing in the natural watershed.

The total inflow of a receiving body of water corresponds to the amount of precipitation in its collecting area, minus evaporation. The portion which becomes overland flow depends on the lithological structure of near-surface strata, vegetal covering, relief intensity, and the degree of sealing and other anthropogenic influences. The remaining portion of precipitation infiltrates the soil and percolates into the groundwater table. The time required depends on the structure and thickness of the covering strata. This process is called **groundwater recharge** and is the critical factor in managing a water economy. Within a collecting area, only recharge amounts of water are available for waterworks and other consumers. Groundwater withdrawals larger than recharge amounts lead to the lowering of groundwater tables over a wide area, as well as ecological damages resulting from lowered water tables. Water economical considerations must be observed to avoid negative consequences. The determination that groundwater removals within a collection area exceed the amounts of groundwater recharge requires either the reduction of removals, or the increase of groundwater recharges by other measures. Recharge can be performed by the percolation of surface waters from infiltration basins made for that purpose. Increased removals of bank-filtered water by well galleries in the shore vicinity of surface waters also spare groundwater and thus aid the recharge process.

Statistical Base

The data base for the derivation of groundwater collection area borders of Berlin waterworks was given by the groundwater contour map drawn from groundwater levels in **May 1988** (cf. Map 01.12.2).

Methodology

The groundwater catchment area for Berlin waterworks are given directly by groundwater contours; the borders of the groundwater catchment areas run perpendicular to the watertable isohypse lines.

The previously described deficiencies in the groundwater contour maps used are reflected in some areas in the Map of Catchment Areas too. These deficiencies were somewhat balanced out by including original values; taking the waterworks in Brandenburg into consideration; and by the approximate calculation of the areal extent of individual groundwater catchment areas required for those amounts of groundwater withdrawals. The estimated groundwater recharge amounts of the catchment areas (method after Schlinker, KdT 1980) were compared with the groundwater improvement programs of waterworks, taking into consideration the proportions of bank-filtered water and groundwater recharge. The Gatow/Tiefwerder area was also supplemented by the contents of a hydrogeological expert analysis of the Berlin Public Water Companies (Leibenath 1990).

A main problem in the delineation of catchment areas was the uncertain connection of surface water to groundwater; it may be mostly sealed off by sewer systems and thick waste sludge layers. It must also be considered that the map only portrays conditions in the first groundwater level. Well galleries which withdraw from other levels have different, sometimes much larger catchment areas whose borders are not yet known.

Map Description

The map gives the approximate course of the groundwater catchment area borders for individual waterworks. It was sometimes possible to define the catchment area for individual galleries of a waterworks, such as the Friedrichshagen waterworks. Galleries of several waterworks were sometimes included in a single area, such as Beelitzhof and Tiefwerder.

The areas present only the catchment area of groundwater formed by percolation of precipitation. Water brought in by running waters originates in other catchment areas and is not observed here. Estimated bank-filtered water and groundwater recharge proportions in the total operations of waterworks are found in Table 3.

Tab. 3: Proportion of Bank-filtered Water and Groundwater Recharge in Berlin Waterworks in 1990 (according to AG Wasser 1991)

Waterwork	of it		
	Groundwater withdrawals 1990	Bank-filtered water amounts (estimated)	Groundwater recharge measures
	m ³ in thousands/day	%	%
Friedrichshagen	175,9	82	–
Wuhlheide	48,7	58	–
Johannisthal	53,2	62	–
Kaulsdorf	16,4	–	–
Friedrichsfelde	8,6	–	–
Altglienicke	2,0	–	–
Buch	6,6	–	–
Köpenick	1,9	74	–
Tegel	186,0	54	27
Beelitzhof	101,1	66	7
Spandau	83,7	30	48
Jungfernheide	54,9	52	43
Tiefwerder	48,9	61	–
Kladow	18,9	68	–
Riemeisterfenn	5,0	17	–
– none existing			

Tab. 3: Proportion of Bank-filtered Water and Groundwater Recharge in Berlin Waterworks in 1990 (according to AG Wasser (Work Group Water) 1991)

Unused groundwater may be fed into surface waters. Unused groundwater from the Barnim and Teltow flat uplands flows into the Berlin Pleistocene watercourse. It flows as groundwater parallel to the Spree, and as surface water in the Spree, in the direction of the Havel. It may also be used as bank-filtered water, or for groundwater recharge at the Jungfernheide waterworks.

The strong effect of groundwater withdrawals on groundwater divides is reflected especially by the groundwater catchment area of the Rupenhorn and Schildhorn galleries, as well as the catchment area of the north and south galleries of the Tiefwerder waterworks. The catchment areas extend not only to the east (where the galleries are), but also to the west of the Havel. The galleries withdraw groundwater that was percolated through the sewage farms of Karolinenhöhe. The groundwater dynamic shows an undercurrent of the Havel in the areas of these galleries (Leibenath 1990). The groundwater from both sides of the Havel would flow into this area under natural conditions.

A reversal of natural flow directions because of anthropogenic intervention has also occurred around other galleries which withdraw groundwater as bank-filtered water (the galleries at Müggelsee, Langen See, both sides of Tegel lake, and the Havel). Groundwater does not flow towards the surface waters, but rather away from them. It flows towards the galleries.

The map shows on the whole that the **entire city** can be seen as a catchment area for the Berlin waterworks. Most of the catchment areas extend beyond the city limits into the state of Brandenburg.

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