# 02.13 Surface Runoff, Percolation, Total Runoff and Evaporation from Precipitation (2019 Edition)

## Overview

Efficient water planning and water resource management based on the principles of sustainability requires knowledge of surface runoff and percolation, and of new groundwater formation that is as precise as possible. Budgeting the components of water balance is of particular importance, especially in the Berlin area, which has only limited water resources, compared with other urban centres. There is also a clear imbalance between these resources and the number of inhabitants, their drinking and non-potable water needs and the associated wastewater produced.

Moreover:

- It is important for the prevention of water pollution to be able to assess the amount of surface water flowing into the local bodies of water, since the precipitation water carries a considerable pollutant load into those bodies of water with it;

- It is important for the protection of groundwater to have knowledge of the percolation capacity of the soils, since the transportation of substances from contaminated soils occurs largely via percolation water;

- It is important for conservation and landscape management to assess the water availability for vegetation from new groundwater formation and capillary water rising from the groundwater surface.

The water supplied by precipitation to an area is broken down into the various components of the water balance, depending on climatological conditions and other local characteristics. These components are evaporation, surface runoff, sub-surface runoff (percolation or new groundwater formation) and water-inventory change. The parameter which must initially be ascertained is total runoff, the sum of surface and sub-surface runoff.

According to the general water-balance equation, total runoff equals the difference between precipitation and real evaporation. In this calculation, evaporation is the decisive quantum which, under natural conditions, is determined largely by vegetation, climatic conditions and soil conditions.

In urban areas however, real evaporation is considerably different from that of the surrounding countryside. Buildings and impervious areas in cities cause evaporation to be considerably lower than in areas covered with vegetation. While the plants continually perspire through their foliage, the only water to evaporate from the surfaces of buildings and impervious areas after rainfall is that small amount which has remained on their surfaces. Thus, total runoff is considerably higher in urban areas than in vegetation-rich areas.

In Berlin, for several years, roof planting has been increasingly used as an element of rainwater management. It reduces the runoff of rainwater and creates evaporation areas. In order to incorporate this effect in the water balance maps of the Environmental Atlas, since the 2019 issue the, green roofs of Berlin (cf. 06.11 Green Roofs) have been included in the calculations.
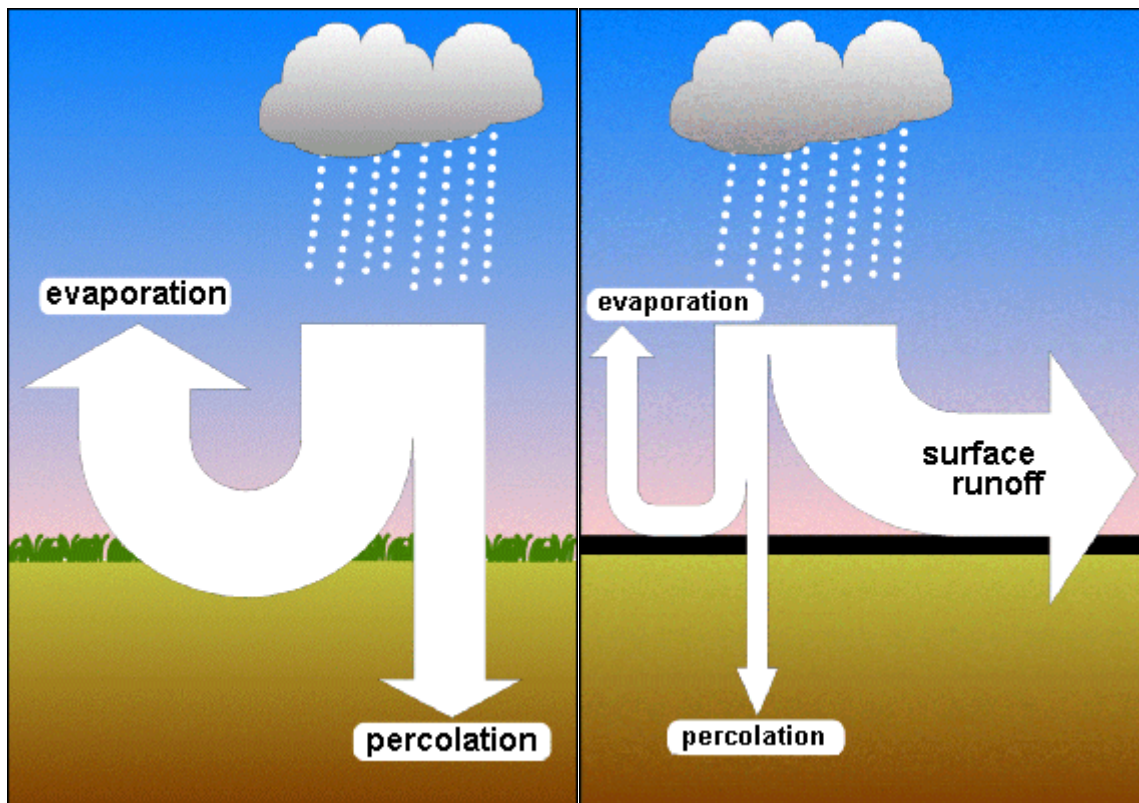
Fig.1: Water balance in vegetation areas and impervious coverage areas

Total runoff best characterizes the hydrologic conditions of catchment areas and segments. For closed catchment areas, the sum of the runoff of all segments equals the total surface and sub-surface runoff of the area, i.e., the **water supply**.

In urban areas with **impervious surfaces,** part of the total runoff flows directly into the watercourses via the appropriate inflow points, or indirectly via the sewage treatment plants – regardless of the degree of connection of these areas to the wastewater/sewage system. The rest of the runoff infiltrates the ground at the edge of the impervious areas or within the partially impervious areas, into the strata below the evaporation-affected zone, and thus recharges the groundwater. Given knowledge of the status of the expansion of the rain wastewater system, the percolation, or new groundwater formation, for these areas can therefore be ascertained by subtracting the entry of rainwater into the wastewater system from the total runoff amount.

The values on percolation and surface runoff thus ascertained are primarily of importance for water-management issues, and are also important characteristic quantities for the water balance of urban areas.

Moreover, in the context of the assessment of the efficiency of the soils for precautionary soil protection or for intervention assessment under the Conservation Law, the determination of percolation on pervious soil surfaces is of special interest. On the one hand, the differing percolation capacity of soils can be derived from this value. On the other, the effect that any planned future impervious coverage would have on the percolation capacity of a project area can be assessed in the context of the planning process.

These statements cannot be made on the basis of the values of Map 02.13.2, since the respective reference surfaces shown here are given with mean values of segments containing both impervious and pervious, and both sewer-system-connected and non-connected portions.

For these reasons, in addition to Map 02.13.2, the ascertainment and representation of percolation on pervious areas has been carried out for Map **02.13.4**. It shows **percolation of precipitation on pervious surfaces**. The values shown refer only to the pervious portions of the blocks or segments.

# Statistical Base

The data for the calculation of the runoff quanta for the approx. 25,000 single sections of the ISU spatial reference system were provided by the Berlin Urban and Environmental Information System (ISU). A detailed description of the data bases can be found in the extensive documentation (Gerstenberg and Goedecke, 2013).

The data on **land use** are based on the evaluation of aerial photography, borough land-use maps and additional documents for the Environmental Atlas (cf. Map 06.01 and Map 06.02, 2016 edition and Map 06.08, 2016 edition). Some 22 types of use and 52 area types have been distinguished. The area use data plays an important role in the water balance model. If site-specific data is not available for necessary input parameters, lump sum mean values per use type or area type are given at block or block segment level. In addition to the degree of connection to the sewage system (see below), above all, the evaporation parameters or a block or block segment are assigned globally via the vegetation properties or the structure of the vegetation to be expected on the area. The details of the area use and/or area type are used to determine this. This assignment, integrated in the program, was carried out as part of the program development at the end of the 1990s and has been adopted since then.

The long-term mean values of **precipitation** for the series of years 1961 through 1990, showing the annual mean temperatures and the means for the summer semesters (May through October), were calculated from the measurements from 97 measuring stations of the Free University of Berlin and the German Meteorological Service (cf. Map 04.08, 1994 edition). The data from this model were calculated for the center-point coordinates of the block segments.

For the **potential evaporation,** long-term mean values of the TURC evaporation, increased by 10 %, were used. These were calculated from observations by climate stations in the Berlin area. For the municipal area, borough-referenced values between 610 and 630 mm/a and between 495 and 505 mm for the summer semester were assigned.

The **degree of impervious coverage** was determined for the Environmental Atlas, among other things, by evaluating ALKIS data (Official Land Survey Register Information System) for the built-up impervious surfaces, and by analysis of high-resolution multi-spectral satellite image data for the non-built-up impervious surfaces. The method was developed in collaboration with the Technical University of Berlin, Humboldt University of Berlin and the company Digital Services for the 2007 edition of the sealing card and used again for the edition 2017 with current data. The data initially did **not** include roadways (cf. Map 01.02, 2017 issue). The data base distinguishes between the **built-up impervious** area (roof surfaces) and the **non-built-up impervious** area (parking lots, walkways etc.). For the non-built-up impervious area, the proportions of various **surface-cover types** was also an important factor. The surface-cover types were grouped into four surface-cover classes (cf. Tab. 2), and specifically ascertained for individual area types on test areas in the terrain, and then referenced to all block segments of the same area type.

Details on the impervious coverage degree of **roadway areas** were taken from statistics on roadways and their pavements from the Senate Building Department. The surface-cover types listed there were grouped into the above-mentioned surface-cover classes. Since these statistics only exist at the borough level, the impervious coverage degree and surface-cover class distributions were assigned generally to all road areas of each borough.

The **soil-scientific data** on the usable field capacity of the shallow-root zone (0-30 cm) and the usable field capacity of the deep-root zone (0-150 cm) were taken from the soil database of the soil association map of the "Berlin Soil Association Map – Usable Field Capacity" (cf. Map 01.06.02, 2018 edition).

For the determination of the **depths to water table**, a digital terrain model with a 5 m grid width was used (cf. Map 01.08, 2010 edition). Parallel to that, a model of the height of the groundwater surface was compiled from measurements at observation pipes of the State Groundwater Service and by the Berlin Water Utility obtained of May 2009. The depth-to-the-water-table data used for the calculation of the runoff were then calculated for the center-point coordinates of the block segments from the difference model between the altitude model and the groundwater height model (cf. Map 02.07, 2010 edition) for the block segments.

The **section size** is used for the calculation of runoff volumes. The size of each block segment (without roadway areas) is available from the ISU. In addition, the estimated surface area of the roadway surface, referenced to each single block segment, was indicated. For this purpose, the road areas of the ISU5

were distributed between the block segments proportional to the road frontage length of the block segments.

The data on the **wastewater/sewage system** were obtained from the "Management of Rain and Waste Water" map (cf. Map 02.09, 2018 issue), which shows the situation as of 2017. The criterion was the existence of sewage pipes for rainwater in the adjacent streets. The data is therefore initially independent of actual inflow of rainwater. The map only states whether the block area is connected to the wastewater/sewage system at all. It is to be assumed that some highly impervious areas (mostly industrial and commercial areas) pass their rainwater on via the public wastewater/sewage system or private pipes, but no information is available on this.

However, the map did not yet state the extent to which the water derived from the built-up or impervious areas is actually passed on. For this purpose, for the 2005 edition, special investigations were undertaken. Two data sources existed for an estimate of the **actual degree of connection to the wastewater/sewage system**. On the one hand, the lump sum values for the individual area types determined as part of a dissertation by Bach in 1997, which had been used in the 1999 edition. The second source of data was collected in the context of the restructuring of the sewage-fee schedule by the Berlin Waterworks (BWB). A property-specific survey of impervious areas was carried out, which distinguished between connected and non-connected impervious areas. Its purpose was to determine the costs of rainwater disposal, largely according to the principle of causality. These data were also recorded graphically and submitted to the Senate Department, aggregated to the data surfaces of the spatial reference system of the ISU. The evaluation of these data showed, however, that the BWB's graphic recording had not been carried out everywhere. For this reason, the original data could not be used directly for the water balance model of the Environmental Atlas. Based on the consideration that the degree of connection is closely related to the age and structure of the buildings, mean values were therefore determining arithmetically for the individual area types from the BWB data and the map extensive mapping of the urban structure types (cf. Map 06.07 and Map 06.08 as of 2015, 2016 edition), which covers all areas, and these were then assigned as lump sum values to all the individual areas of the corresponding area types connected to the wastewater/sewage system. The results are summarized in Tab. 1. A comparison of the values with those ascertained by Bach in 1997 yielded good agreement. Only in the case of green and open areas with little or no built-up component, the degrees of connection of the non-built-up impervious surfaces differ strongly from the values determined by Bach. As the analysis of the BWB data had shown that, especially in these areas, the undeveloped impervious areas had not been surveyed, or only inadequately, the Bach value was retained for this structure type. The actual degrees of connection to the sewage system of the road areas were also assigned from the Bach data, as the BWB had not surveyed the road areas. Tab. 1 shows the lump sum degrees of connection per area type, which were also input into the calculation of the water balance model, 2019 edition.

**Tab. 1: Effective degree of connection of impervious areas to the wastewater/sewage system (sewage service level) for the (differentiated) area types of Berlin (Evaluation as of 2012, area types as of 2010, degree of connection as of 1997, 2003)**

| | Section type | Degree of connection to sewage system built-up impervious areas | No. of data sets | Degree of connection to sewage system non-built-up impervious areas | No. of data sets | Degree of connection to sewage system impervious street areas (Bach1997) |
|---|---|---|---|---|---|---|
| 1 | Dense block development, closed rear courtyard (1870s - 1918), 5 - 6-storey | 98 | 174 | 75 | 174 | 94 |
| 2 | Closed block development, rear courtyard (1870s - 1918), 5-storey | 95 | 1052 | 70 | 1049 | 94 |
| 3 | Closed and semi-open block development, decorative and garden courtyard (1870s - 1918), 4-storey | 85 | 502 | 55 | 497 | 91 |
| 6 | Mixed development, semi-open and open shed courtyard, 2 - 4-storey | 75 | 110 | 54 | 109 | 91 |
| 7 | De-cored block-edge development, post-war gap closure | 94 | 421 | 65 | 421 | 93 |
| 8 | Heterogeneous inner-city mixed development, post-war gap closure | 94 | 49 | 75 | 49 | 92 |
| 9 | Large estate with tower high-rise buildings (1960s - 1980) 4 - 11-storey and more | 95 | 607 | 64 | 601 | 92 |
| 10 | Block-edge development with large quadrangles (1920s - 1940s), 2 - 5-storey | 93 | 579 | 46 | 569 | 87 |
| 11 | Free row development, landscaped residential greenery (1950s - 1970s), 2 - 6-storey | 86 | 796 | 50 | 782 | 89 |
| 12 | Old school (built before 1945) | 87 | 145 | 66 | 143 | 88 |
| 13 | New school (built after 1945) | 90 | 317 | 68 | 316 | 88 |
| 16 | Sport facility, covered | 68 | 305 | 51 | 319 | 81 |
| 17 | Sport facility, uncovered | 99 | 28 | 83 | 26 | 81 |
| 21 | Village-like mixed development | 49 | 85 | 46 | 84 | 77 |
| 22 | Row houses and duplex with yards | 49 | 563 | 41 | 543 | 77 |
| 23 | Detached single-family homes with yards | 38 | 3167 | 30 | 3052 | 77 |
| 24 | Villas and town villas with park-like gardens (mostly 1870s - 1945) | 56 | 583 | 45 | 571 | 67 |
| 25 | Densification in single-family home area, mixed development with yard and semi-private greening (1870s to present) | 60 | 323 | 38 | 323 | 70 |
| 27 | Cemetery | 63 | 131 | 56 | 114 | 81 |
| 29 | Core area | 94 | 223 | 84 | 207 | 98 |
| 30 | Commercial and industrial area, large-scale retail, sparse development | 76 | 743 | 70 | 746 | 89 |
| 31 | Commercial and industrial area, large-scale retail, dense development | 86 | 134 | 80 | 131 | 92 |
| 32 | Utility area | 82 | 75 | 78 | 71 | 89 |
| 33 | Non-residential mixed use area, sparse development | 73 | 132 | 62 | 132 | 89 |
| 36 | Tree nursery / horticulture | 55 | 41 | 59 | 38 | 81 |
| 37 | Allotment garden | 59 | 246 | 54 | 264 | 81 |
| 38 | Non-residential mixed use area, dense development | 86 | 16 | 82 | 16 | 92 |
| 41 | Security and order | 82 | 59 | 75 | 56 | 88 |
| 43 | Administrative | 88 | 134 | 77 | 130 | 88 |
| 44 | University and research | 82 | 80 | 66 | 76 | 89 |
| 45 | Culture | 89 | 59 | 70 | 61 | 88 |
| 46 | Hospital | 73 | 96 | 61 | 95 | 89 |
| 47 | Children's day care centre | 89 | 208 | 48 | 203 | 89 |
| 49 | Church | 76 | 101 | 57 | 93 | 89 |
| 51 | Other youth facility | 64 | 41 | 49 | 38 | 89 |
| 53 | Park / green space | 71 | 414 | 60 | 534 | 81 |
| 54 | City square / promenade | 84 | 38 | 72 | 45 | 81 |
| 55 | Forest | 0 | 170 | 0 | 203 | 0 |
| 56 | Agriculture | 0 | 31 | 0 | 35 | 0 |
| 57 | Fallow area | 71 | 171 | 67 | 202 | 81 |
| 58 | Camping ground | 99 | 4 | 52 | 2 | 81 |
| 59 | Weekend cottage and allotment-garden-type area | 70 | 62 | 67 | 54 | 77 |
| 60 | Other and miscellaneous public facility / special use area | 81 | 93 | 69 | 94 | 89 |
| 72 | Parallel row buildings with architectural green strips (1920 - 1930s), 2-5-storey | 80 | 355 | 46 | 344 | 87 |
| 73 | Rental-flat buildings of the 1990s and later | 76 | 183 | 55 | 158 | 90 |
| 91 | Parking area | 70 | 71 | 68 | 87 | 95 |
| 92 | Railway station and railway ground, without track area | 86 | 23 | 78 | 25 | 95 |
| 93 | Airport | 99 | 11 | 92 | 36 | 95 |
| 94 | Other traffic area | 84 | 65 | 66 | 99 | 95 |
| 99 | Track area | 73 | 91 | 70 | 106 | 95 |
| 100 | Body of water | 0 | 69 | 0 | 130 | 0 |

For the determination of percolation without consideration for impervious coverage (Map 02.13.4), the input data were changed by setting the impervious coverage level to zero for all sections, and hence effectively not considering it. The surface area of roadways was also set to zero, so that the resulting values refer only to the pervious surfaces of the blocks.

To include the roof planting, the approx. 400 ha of extensively and intensively planted roof areas from the existing Environmental Atlas Map 06.11 Green Roofs (edition 2017) were used.

# Methodology

In the middle of the '90s', a model for calculating the most important quanta of the water balance was developed, programmed and used in cooperation with the Berlin office of the Federal Institute of Hydrology. The approx. 25 required basic data or input parameters could be provided by the Urban and Environmental Information System (ISU) for each of the approx. 25,000 single sections. This model has been improved (ABIMO 3.2) and applied again with updated data.

The runoff model ABIMO developed by Glugla has been created on the basis of models developed as early as the '70s for the calculation of groundwater supply, and been expanded to include modules which take into account the special situation of urban areas. This expansion was supported by an expert report by the Institute for Ecology (soil science) of the Berlin University of Technology, and a master's thesis at the Department of Geography at the Free University of Berlin. The arithmetic implementation carried out by an external software company in addition adapted it to the specific data situation of Berlin.

The calculation method first of all ascertains the actual evaporation, in order to calculate total runoff (precipitation minus evaporation). In the second work stage, the surface runoff is determined as a share of total runoff. The difference between total runoff and surface runoff then constitutes the percolation. Fig. 2 conveys an impression of the complexity of this procedure.
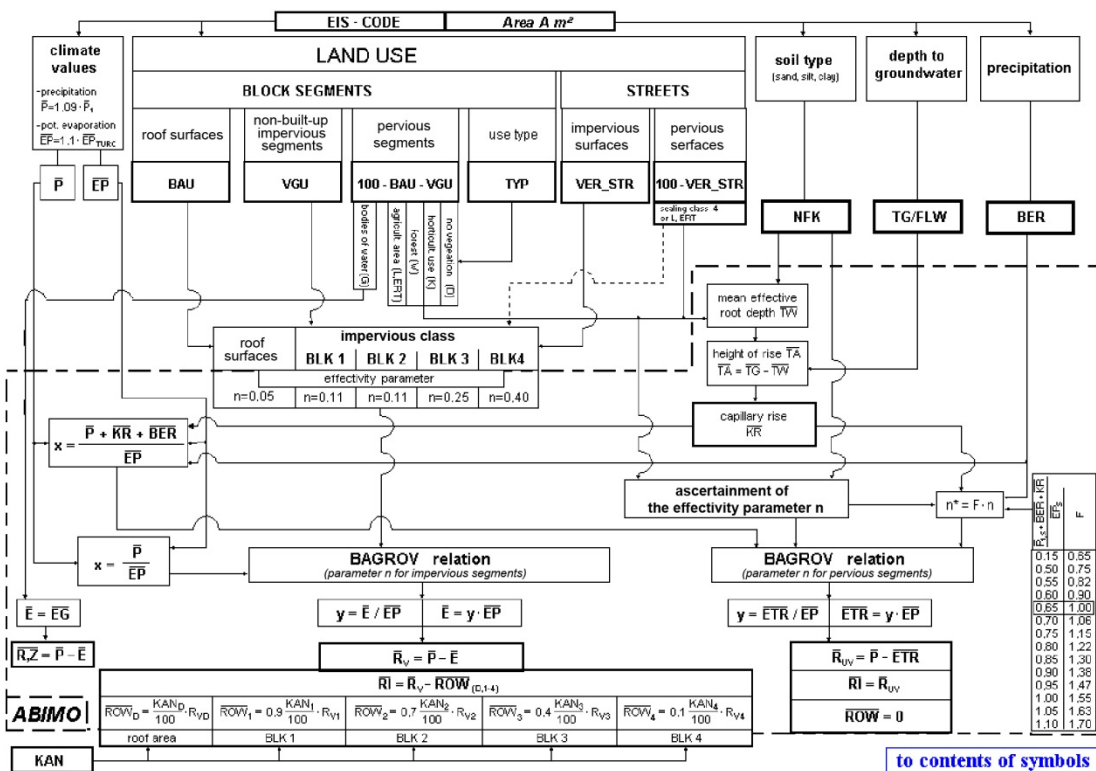


**Mean annual values (mm/a)**

| | |
|---|---|
| $\overline{P_1}$ | precipitation (1 m above the ground) |
| $\overline{P}$ | precipitation at the soil surface |
| $\overline{KR}$ | capillary rise from ground water near surface |
| $\overline{EP}$ | potential evaporation *(EP = 1.1\*EP$_{TURC}$)* |
| $\overline{ETR}$ | real evapotranspiration of vegetation covered land areas |
| $\overline{EG}$ | evaporation from bodies of water |
| $\overline{E}$ | real evaporation of impervious areas and areas without vegetation (and from the surfaces of bodies of water) |
| $\overline{BER}$ | amount of precipitation water |
| $\overline{Z} = \overline{P} - \left(\overline{E}, \overline{ETR}, \overline{EG}\right)$ $\left(\overline{E}, \overline{ETR}, \overline{EG}\right) \succ \overline{P}$ | depletion of ground and surface water |
| $\overline{R_v}$ | total runoff (impervious area) |
| $\overline{R_{uv}}$ | total runoff (pervious area) |
| $\overline{ROW}$ | rainwater and/or meltwater runoff from impervious area into the sewer system (or stream) |
| $\overline{RI}$ | infiltration into the soil (below the zone influenced by evaporation) |

**Impervious areas (in %)**

| | |
|---|---|
| BAU | roof surface |
| VGU | courtyard and parking areas (non-built-up impervious areas) |
| VER_STR | streets |
| BLK 1, ..., 4 | Impervious-coverage class of non-built-up impervious area |
| KAN | percentage of impervious areas connected to the rainwater drainage system |

**Land use of pervious areas**

| | |
|---|---|
| L | agricultural land use (incl. pastures) |
| W | forest land use (assuming of an even distribution of stocks with respect of age) |
| K | horticultural land use (program intern: BER = 75 mm/a) |
| D | area without vegetation |
| G | area of surface waters |

**Soil type**

| | |
|---|---|
| NFK | useable field-moisture capacity (moisture by volume [vol%] of field-moisture capacity minus vol% of permanent wilting point) |
| S, U, L, T | indication of soil type (sands, silts, clays; |
| N, H | low bog, high bog) for the determination of capillary rise |

**Depth to groundwater and capillary rise**

| | |
|---|---|
| TG | depth to the water table (value in m – FLW) for the determination of KR |
| TA | height of rise (m), TA = TG - TW |
| TW | mean effective root depth (m) |

*Fig.2: Flow chart of the ABIMO model (from Bach 1997, modified)*

# Total Runoff

**Total runoff** s calculated from the difference between long-term annual mean precipitation values and real evaporation. **Real evaporation** as it is actually encountered, as an mean, at sites and in areas, is calculated from the most important quanta precipitation and **potential evaporation**, and the mean storage qualities of the evaporating areas. Given sufficient moisture input into the evaporation area, the real evaporation value will approach that of the potential evaporation. The real evaporation is additionally modified by the storage qualities of the evaporation area. A higher storage effect (e.g. greater binding capacity of the soil and greater perracination depth) causes greater evaporation.

The connection shown between the mean value of real evaporation over several years on the one hand and precipitation, and potential evaporation and evaporation effectivity of the site on the other fulfils the

Bagrov relation (cf. Glugla et al. 1971, Glugla et al. 1976, Bamberg et al. 1981 and Fig. 3). The Bagrov relation is based on the evaluation of long-term lysimetre tests, and describes the nonlinear relationship between precipitation and evaporation in dependence on site characteristics. With the Bagrov relation, the climate quanta precipitation P and potential evaporation EP (P/EP ratio), and the effectivity parameter n, and hence the real-evaporation/ potential-evaporation ratio (ER/EP) and the real evaporation ER for sites and areas without groundwater influence can be ascertained. The Bagrov method is also used in modified form to calculate the groundwater-influenced evaporation, by adding the mean capillary water rise from the groundwater to the precipitation.
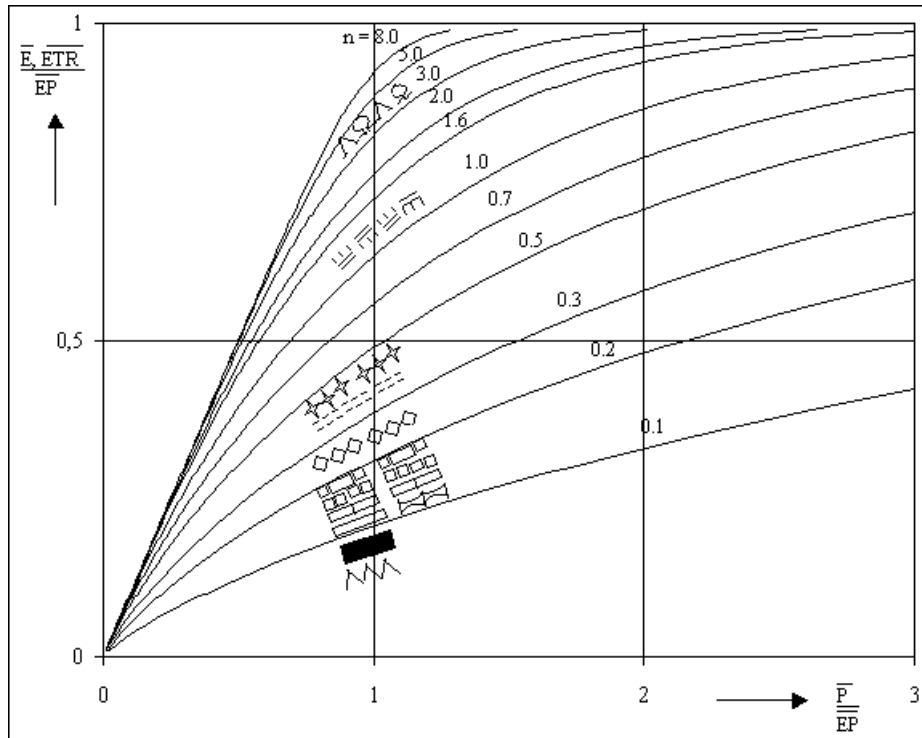


| Symbol | Description |
|---|---|
| ∧ Ω | sandy soil, forestry use |
| ⊔ ⊔ | sandy soil, agricultural use |
| - - - - - | vegetation-free sandy soil |
| ✦✦✦ | grass pavers |
| ◇◇◇ | Bemburg mosaic paving |
| □□□ | artificial stone plates with mosaic paving (sidewalk) |
| □□□□ | mosaic paving (sidewalk) |
| ▭▭ | concrete grass pavers (20% of area is joints, filled with sand) |
| ▭ | concrete surface |
| ⋈⋈ | concrete interlocking pavement |
| ▬ | asphalt (roadway) |
| ∧∧∧ | roof areas |

**Long-term mean average values of:**

| | |
|---|---|
| $\overline{E}, \overline{ETR}$ | actual evaporation or evapotranspiration |
| $\overline{EP}$ | potential evaporation (1.1 * TURC evaporation) |
| $\overline{P}$ | on-grade precipitation ground |
| n | effectiveness parameter |

**Note:**

$\overline{P}$ is increased by:

| | |
|---|---|
| $\overline{KR}$ | with capillary water rise from surface-proximate groundwater, and |
| $\overline{BER}$ | with rainfall |

With increased precipitation P, the value of real evaporation ER approaches that of potential evaporation EP i.e., the ER/EP ratio approaches the value of 1. With reduced precipitation P (P/EP approaches the value of 0), the real evaporation value approaches that of precipitation P. The intensity with which these boundary conditions are reached is determined by the storage qualities of the evaporating area (effectivity parameter n).

The storage qualities of the site are particularly determined by the use form (increasing storage effectivity in the following order: impervious area, vegetation-free surface, agricultural, horticultural/ silvicultural use) as well as soil type (increasing storage effectivity with higher binding capacity of the soil).

The measure for the storage effectivity of pervious soil is the **usable field capacity** the difference between the humidity values of the soil for field capacity (beginning of water percolation into the ground), and for the permanent wilting point (permanent drought damage to plants). Other land-use factors, such as hectare yield and types and ages of trees, modify the parameter value n. The parameter n has been quantified by evaluation of observation results from numerous domestic and foreign lysimetre stations, and water-balance investigations in river-catchment areas.

For sites and areas with near-surface groundwater, increased evaporation compared with non-groundwater-influenced conditions occurs in the evaporation-influenced soil zone, due to the capillary rise of the groundwater, depending on the depth to the water table and soil qualities. Runoff is reduced. If real evaporation exceeds precipitation, water consumption occurs and the values for runoff become negative (e.g. river and lake lowlands).

Water areas have a higher potential evaporation than land areas, because of higher heat supply (lower reflectivity of the irradiation). For the sake of approximation, the actual water evaporation is stated as equal to this increased potential evaporation.

Selective percolation, e.g. via groundwater charging facilities by the waterworks, has not been taken into account. For gardening use (allotment gardens, weekend cottages, parks, cemeteries, tree nurseries/ horticulture and partly in residential use or public facilities/special use), a uniform approximation value was added to the precipitation to take irrigation into account (50-100 mm/a).

After the mean total runoff has been calculated as a difference between precipitation and real evaporation, **surface runoff** is determined in a second work step. Surface runoff corresponds to the total runoff on roof areas which drains into the wastewater/sewage system. Areas not connected to the sewage system thus produce no surface runoff. Non-built-up impervious areas infiltrate a part of their drainage into the sub-surface, depending on the type of surface (surface-coverage types). This Infiltration factor is dependent on the width, age and type of the seams. The non-percolating runoff is passed to the wastewater system as surface runoff - depending on the degree of connection to the system - or, if the system does not receive it, percolates into the soil at the edge of the impervious areas. Those portions of the precipitation onto roof areas not connected to the wastewater system also percolate into the soil (cf. Tab. 1). The difference between total runoff and surface runoff thus corresponds to **percolation** as a basic quantum for new groundwater formation. The evaporation of the blocks and block segments is then calculated from the difference between the corrected precipitation (corrected precipitation = precipitation multiplied by the global factor 1.09 for Berlin) and the total runoff.

For the application of the method for urban areas, the parameters n and the infiltration factors had to be determined for the various impervious paving materials. Both lysimetre tests were evaluated with different impervious-paving materials and calculations for wetting loss (cf. Wessolek/Facklam 1997). The quanta selected for the stated parameters are listed in Tab. 2. The change of these parameters due to compression and silting of the joints associated with the ageing process has been taken into account. However, due to still insufficient scientific bases, this information still involves certain uncertainties. Moreover, a different grouping of surface coverage types into surface coverage classes would be desirable from a hydrological point of view.

| Imperviousness class | Type of imperviousness | Effectivity parameter n | Infiltration factor $F_i$ |
|---|---|---|---|
| - | Roof areas | 0.05 | 0 |
| 1 | Asphalt, concrete, paving stones with joint sealer or concrete substructure, plastic materials | 0.11 | 0.1 |

| | | n | $F_i$ |
|---|---|---|---|
| 2 | Artificial stone and plates (edge length > 8 cm), concrete-stone composites, clinker, medium and large-sized paving stones | 0.11 | 0.3 |
| 3 | Small and mosaic paving stones (edge length < 8 cm) | 0.25 | 0.6 |
| 4 | Grass trellis stones, waterbound cover, crushed rock, grevel | 0.4 | 0.9 |

**Tab. 2: Effectivity parameter n and infiltration factor $F_i$ for various surface imperviousness classes**

In order to provide an impression as to how the various area uses, imperviousness parameters and conditions of the wastewater/sewage system would affect the water balance, the ABIMO model was used for approx. 35 model sections typical uses and their different typical properties; the results are shown in Tab. 3. The relationship between surface runoff, imperviousness and evaporation is decisively dependent of the extent of impervious coverage and the passage of rainwater to the wastewater system.

Tab. 3 : Relation between surface runoff, seepage and evaporation considering as example areas of various types, sealings etc.

| Area description | degree of sealing in % | of which | | sealing class of non build-up areas (see tab. 2) | | | | connection to sewage system yes/no | degree of connection to the sewage system of the sealed area in % | | soil (1) | surface runoff | seepage | evapo-ration |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | built-up sealed area | non built-up sealed area | surface-cover 1 in % | surface-cover 2 in % | surface-cover 3 in % | surface-cover 4 in % | | built-up sealed area | non built-up sealed area | | in % of precipitation | | |
| Pine wood | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 18 | 82 |
| Meadowland | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 34 | 66 |
| Farmland | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 52 | 0 | 38 | 62 |
| Fallow area, former railway area | 7 | 0 | 7 | 0 | 0 | 0 | 100 | 0 | 0 | 0 | 57 | 0 | 25 | 75 |
| Small gardens | 8 | 5 | 3 | 0 | 28 | 6 | 66 | 1 | 74 | 20 | 4 | 1 | 25 | 73 |
| Small gardens | 8 | 5 | 3 | 11 | 28 | 6 | 55 | 1 | 100 | 100 | 4 | 6 | 24 | 71 |
| Fallow area, former railway area | 21 | 6 | 15 | 26 | 0 | 0 | 74 | 1 | 100 | 100 | 57 | 9 | 30 | 60 |
| Parks | 24 | 4 | 20 | 46 | 0 | 0 | 54 | 1 | 74 | 20 | 6 | 2 | 28 | 70 |
| Small gardens | 33 | 21 | 12 | 13 | 14 | 27 | 46 | 1 | 74 | 20 | 50 | 5 | 24 | 71 |
| Parks | 33 | 8 | 25 | 27 | 0 | 0 | 73 | 1 | 100 | 100 | 57 | 14 | 25 | 62 |
| Detached homes with large garden areas | 35 | 25 | 10 | 0 | 0 | 33 | 67 | 1 | 56 | 35 | 2 | 9 | 39 | 53 |
| Detached homes with large garden areas | 35 | 25 | 10 | 25 | 0 | 33 | 42 | 1 | 100 | 100 | 4 | 27 | 26 | 47 |
| Green spaces | 37 | 0 | 37 | 63 | 10 | 0 | 27 | 1 | 0 | 46 | 52 | 9 | 33 | 58 |
| Day-care centers | 41 | 29 | 12 | 26 | 0 | 32 | 42 | 1 | 85 | 74 | 51 | 23 | 26 | 51 |
| Green spaces | 42 | 0 | 42 | 54 | 21 | 0 | 25 | 1 | 0 | 100 | 57 | 23 | 22 | 55 |
| Commercial | 43 | 31 | 12 | 32 | 0 | 0 | 68 | 1 | 78 | 54 | 1 | 18 | 30 | 53 |
| Large housing estates | 52 | 37 | 15 | 22 | 42 | 0 | 36 | 1 | 88 | 54 | 1 | 22 | 26 | 51 |
| City squares | 53 | 12 | 41 | 23 | 4 | 14 | 59 | 1 | 74 | 20 | 50 | 5 | 38 | 57 |
| Detached homes with hollow drainage-trench system | 35 | 25 | 10 | 0 | 0 | 33 | 67 | 1 | 56 | 35 | 2 | 0 | 47 | 53 |
| Abandoned industrial sites, meadow like vegetation | 36 | 0 | 36 | 100 | 0 | 0 | 0 | 1 | 0 | 20 | 57 | 5 | 47 | 47 |
| Day-care centers with hollow drainage-trench system | 41 | 29 | 12 | 26 | 0 | 32 | 42 | 1 | 85 | 74 | 51 | 0 | 49 | 51 |
| Commercial | 48 | 34 | 14 | 58 | 7 | 0 | 35 | 1 | 100 | 100 | 4 | 39 | 22 | 39 |
| Mixed area | 57 | 38 | 19 | 57 | 0 | 11 | 32 | 1 | 88 | 83 | 50 | 38 | 24 | 39 |
| Sports fields/ stadiums | 68 | 33 | 35 | 35 | 27 | 0 | 38 | 1 | 74 | 20 | 50 | 9 | 40 | 51 |
| Parking lots | 78 | 7 | 71 | 75 | 10 | 0 | 15 | 1 | 100 | 100 | 4 | 51 | 19 | 30 |
| Mixed area, high sealing degree | 87 | 47 | 40 | 21 | 38 | 27 | 14 | 1 | 94 | 68 | 52 | 43 | 26 | 31 |
| Transportation area/stations | 86 | 48 | 38 | 36 | 28 | 23 | 13 | 1 | 100 | 93 | 52 | 60 | 17 | 22 |
| City squares | 87 | 5 | 82 | 65 | 23 | 12 | 0 | 1 | 0 | 84 | 52 | 50 | 31 | 20 |
| Mixed area, densely built-up | 87 | 58 | 29 | 31 | 28 | 27 | 14 | 1 | 100 | 100 | 4 | 69 | 13 | 18 |
| City squares | 87 | 5 | 82 | 65 | 23 | 12 | 0 | 1 | 100 | 100 | 57 | 59 | 17 | 24 |
| Industrial sites | 92 | 54 | 38 | 83 | 5 | 0 | 12 | 1 | 88 | 83 | 57 | 64 | 19 | 17 |
| Core areas | 92 | 56 | 36 | 45 | 17 | 24 | 14 | 1 | 95 | 83 | 52 | 60 | 18 | 22 |
| Abandoned industrial sites, meadow like vegetation | 93 | 13 | 80 | 78 | 0 | 0 | 22 | 1 | 88 | 83 | 57 | 51 | 27 | 23 |
| Industrial sites | 96 | 54 | 42 | 79 | 10 | 0 | 11 | 1 | 100 | 100 | 57 | 79 | 8 | 13 |
| Parking lots | 98 | 10 | 88 | 82 | 10 | 0 | 8 | 1 | 87 | 96 | 50a | 67 | 16 | 16 |

**Tab. 3: Relationship between surface runoff, percolation and evaporation for areas of various types, imperviousness etc. (Köppel/Deiwick 2004)**

Since the 2012 edition, version 3.2 of the ABIMO program has been used for the current calculation. This version differs from the old one primarily in its improved parameter control in the assignment of values for the degree of connection of roof surfaces to the wastewater system.

## Consideration of the influence of planted roofs on the water balance data

Thanks to the extensive spatial data on planted roof areas available for the first time with the Environmental Atlas Map 06.11 Green Roofs (edition 2017), it was possible to calculate the effects of the green roofs on the water balance for the first time in this current edition. As the original model does not provide for the consideration of green roofs, a method had to be developed, which allows these effects to be budgeted nonetheless. To do this, it was first necessary to determine reliable values on evaporation behaviour from the literature. The literature search identified different annual runoff coefficients for intensively and extensively planted roofs (cf. for example, Rüngeler 1998, SenStadtWohn 2017). In the method selected for the database used (Environmental Atlas Map Green Roofs 06.11), based on the spectral reflection properties of the remote sensing data. a differentiation is only made between extensively and intensively planted roofs. Other important properties, for example, the height of the vegetation or the substrate build-up cannot be collected in this way and are therefore also not available for the evaluation with regard to the water balance.

Therefore, for the further calculation, a uniform annual runoff coefficient of 0.5 was assumed for all green roofs, that is to say, 50 % of the precipitation falling on them evaporates.

A small part of the precipitation falling on normal, unplanted roofs also evaporates. This evaporation is calculated for blocks and block segments using ABIMO 3.2. Accordingly, unplanted building roofs produce between 75.5 mm/a and 83.6 mm/a evaporation, regardless of the degree of connection to the sewage system and the type of impervious surface. This corresponds to 12.3 % and 13.4 % of the corrected precipitation. The additional evaporation of a planted roof was first calculated using the following formula:

$Evaporation_{GreenRoofAdditional} = Evaporation_{GreenRoof} - Evaporation_{NormalRoof}$

The total additional evaporation of all planted roofs of a block or block segment was then calculaed and deducted from the total runoff, surface runoff and percolation parameters. The evaporation with green roof is calculated from the evaporation and the additional evaporation. These calculations were performed subsequently, outside the ABIMO 3.2 program (cf. Goedecke/Gerstenberg 2019).

## Final Result

As a result of these calculations, updated long-term mean values for total runoff, evaporation, surface runoff and percolation incl. consideration of the green roofs are available for each of the approx. 25,000 separate areas. These values have been shown classified in mm/a in these maps; the totals in cu. m./a have also been calculated and budgeted. It must be taken into account that the values shown are mean values covering the blocks represented as uniform areas; in fact, however, they have non-homogeneous structures. The runoffs of impervious and pervious areas have been standardized to mean values per block. In addition, the runoff of roadways has been attributed to the adjacent blocks. The maps do not show, for instance, how great the percolation capacity of a square meter of pervious soil is. For this purpose, another full-coverage and block-referenced calculation has therefore been carried out with changed marginal parameters, i.e., assuming completely pervious conditions. The results of this calculation are shown in Map 02.13.4.

# Map Description

The map of **Total Runoff** (Map 02.13.3) shows that the total runoff for the highly impervious inner-city areas (inside the Urban-Rail Ring Line) is in the range of 350-450 mm/a; the values are even higher in the very dense centre-city area and in some industrial areas. Here, only about 150 mm/a (Map 02.13.5) evaporate, referenced to the precipitation measurements (at 1 m height), which are about 10-15 % less than ground-level precipitation. The less densely built-up areas in the outskirts of the city show runoffs of 250-350 mm/a. Compared with the runoffs of the pervious areas on the outskirts, or in the areas surrounding Berlin, where the values are approx. 150 mm/a, Berlin can be considered an island of greatly increased runoff. The reduction of the evaporation due to imperviousness and lack of vegetation - as shown in the map **Evaporation** (Map 02.13.5) - leads to runoff double or triple the natural runoff.

**Groundwater net consumption (depletion)** occurs only in a few areas characterized by low precipitation and simultaneously low depth to the water table, which produces negative runoff formation

values, since here, the vegetation is fed by groundwater, and can evaporate more of it than can subsequently be supplied by precipitation.

The map of **Surface Runoff** (02.13.1) shows that in the inner-city areas connected to the wastewater/sewage system, an average of about 250 mm/a is fed to the wastewater system. The peak values are higher than 400 mm/a. In outlying areas connected to the wastewater/sewage system, the values are around 100 mm/a.

The **Percolation** map (02.13.2) shows a picture that is surprising at first glance: It shows inner-city percolation from precipitation of about 120 mm/a - roughly the same as for woodlands. The non-densely built-up residential areas on the outskirts show considerably higher percolation capacities of 200 mm/a; the values for the areas with low degrees of connection to the wastewater/sewage system in fact climb to 300 mm/a. In the residential areas with no connection to the sewage system, all the runoff percolates into the soil, averaging about 300-350 mm/a and reaching maximum values of over 400 mm/a.

In conclusion, the following can be stated:

- The effect of the reduced permeability of the soil caused by the high degree of impervious coverage in the inner city is to a large extent counteracted by the effect of reduced evaporation, so that inner-city percolation capacities are higher than initially assumed, and reach almost "natural" levels.

- The extent of impervious coverage is only secondarily important for percolation capacity; of primary importance is the actual degree of connection to the wastewater/sewage system. The type of impervious coverage, i.e. the differing percolation capacity of the various surface-cover types, also plays an important role.

- The reduction of evaporation due to impervious coverage in low-density areas with simultaneously low degrees of connection to the wastewater/sewage system causes the percolation capacities in these areas to be the highest, and approximately double those of "natural" percolation.

In the Glacial Spillway area, the percolation water can percolate directly and completely to the groundwater surface, due to the permeable sands which overlay the groundwater. Here, the calculated percolation is equal to **new groundwater formation**. On the Barnim and Teltow ground-moraine plateaus however, loamy and thus poorly water-permeable layers overlay the mostly confined groundwater. Here, the deeply cut streams are fed largely by confined groundwater or via sandy and hence permeable layers in the ground moraine. Only that part of the percolation water (calculated percolation) not passed on by the tributaries can be considered true recharging of the main aquifer beneath the ground moraine. These water quantities reach the glacial spillway area as sub-surface runoff. The break-down is respectively dependent on the concrete hydrogeological conditions. A comparison of the runoffs measured and calculated shows that e.g. in the catchment area of the Neuenhagen Mill Stream, some 35 % the calculated percolation percolates sub-surface to the glacial spillway area, while the Tegel Creek passes virtually all of the runoff it receives from the percolation of its catchment area on at the surface. A map of new groundwater formation has also been developed on the basis of the percolation-water rates determined by means of the ABIMO model ([Map 02.17](#) as of 2019).

The evaporation from **bodies of waters surfaces,** which are not shown on the map, is approx. 152 mm/a more than the precipitation which falls on them, so that Berlin's bodies of water lose a total of approx. 8 million cu. m. of water per year due to evaporation.

For some very highly impervious areas, no information was available as to whether the rainwater from them is passed on via the wastewater system. For this reason, runoff for these areas has been certified in the maps as percolation. However, the degree of impervious coverage and the amount of runoff makes it seem in some cases improbable that the water actually percolates into the soil. As a result, it is likely that the share of surface runoff tends to be underestimated, and that that of percolations overestimated.

With the aid of the area sizes of the reference surfaces, the **runoff volumes** could also be calculated and then totalled (cf. Tab. 4).

| Tab. 4: Long-term mean values of runoff formation (determined using ABIMO 3.2) | | without green roofs | | with green roofs | |
|---|---|---|---|---|---|
| | area [km²] | mm/a. *) | million cu. m./a. | mm/a. *) | million cu. m./a. |
| **Berlin total** **(without bodies of water)** | 837 | | | | |
| Precipitation (measured values, corrected) | 837 | 622 | 521 | 622 | 521 |
| Evaporation (Precipitation – Total Runoff) | 837 | 367 | 307 | 368 | 308 |
| Total Runoff | 837 | 256 | 214 | 255 | 213 |
| Surface Runoff thereof | 837 | 87 | 73 | 86 | 72 |
|    Combined sewage system | 85 | 260 | 22 | 256 | 22 |
|    Separate sewage system | 327 | 155 | 50 | 153 | 50 |
| Percolation | 837 | 169 | 142 | 169 | 142 |
| New Groundwater Formation | 837 | 141 | 118 | 141 | 118 |
| **Bodies of Water** | 54 | | | | |
| Depletion (Precipitation – Evaporation) | | -152 | -8 | -152 | -8 |
| *) area-weighted | | | | | |

*Tab. 4: Long-term mean runoff formation values, with and without consideration of the planted roofs (determined with ABIMO3.2), as of 2017*

The calculations show that about 60 % of the precipitation evaporates, and thus about 200 million cu. m./a are available as total runoff. Two thirds of the total runoff percolates into the soil, while one third is removed by the wastewater system. Although the combined sewage system covers only about one quarter of the total area served by the wastewater/sewage systems, it accounts for a third of total surface runoff. Comparing the annual percolation quantity of approx. 140 million cu. m., which, as stated above, is not entirely fed into the groundwater, with drinking water consumption of approx. 200 million cu. m./a (AfS 2016), obviously yields a considerable deficit. This deficit is compensated for by surface seepage (from the Spree and Havel rivers) as well as sub-surface influx of groundwater from the surrounding countryside. The surface water is used as shore filtrate at near-shore groundwater withdrawal facilities, and for groundwater charging at the waterworks.

Considering the changes compared with the 2013 edition figures, the most noticeable fact is that the long-term mean of total runoff and surface drainage has continued to rise, and that evaporation has reduced. These changes can be attributed to the further increase in impervious coverage of the soil and the expansion of the wastewater network for the removal of rainwater.

Tab. 4 also shows the still small influence of the approx. 400 ha planted roof area on the total area of Berlin. However, large differences exist locally. Taking into account the green roofs throughout the state, the evaporation increases by 1 mm/a in total. The table shows that the effects of the roof planting is particularly significant in the area of combined sewers with high degrees of connection to the sewage system. In this area there are approx. 160 ha green roofs (approx. 40 %). It can be assumed that the number of green roofs has increased since 2016 (year of the green roof survey), which means that the green roofs have a greater influence in reality.

The hypothetical potential of the roof planting with regard to the water balance can be determined by calculating the water balance variables, assuming that all roofs in Berlin are planted (approx. 10,800 ha instead of the current 400 ha). The evaporation would then increase by a further 8 % and surface runoff would reduce by a further 22 %.
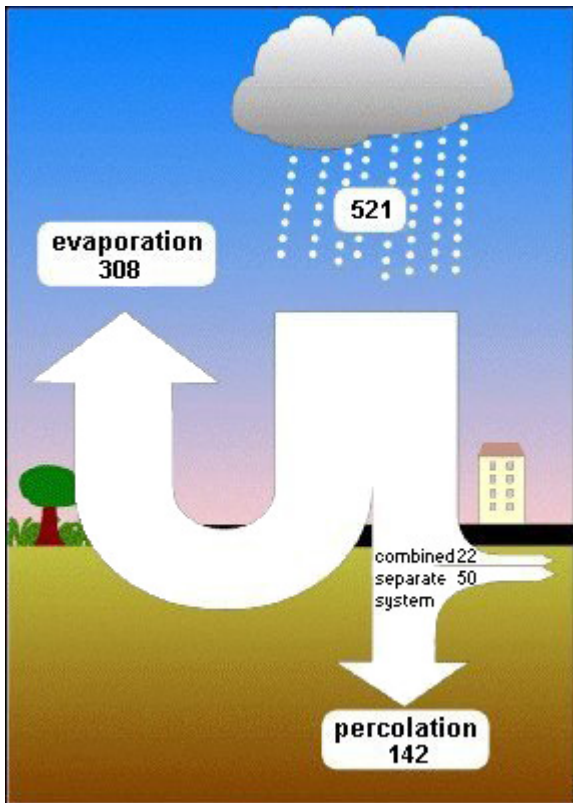
Fig.4: The Berlin water balance (long-term mean values in million cu. m., without bodies of water)

For each a served by the separate-wastewater system, the Information System provides data as to the tributary, body of water or body-of-water segment into which that section is drained (cf. Map 02.09.2, 2018 edition). As a result, it is possible to generate balance sheets stating the amount of rainwater which each body of water has to receive, on average. About 200 bodies of water or body-of-water segments are involved. Table 5 shows the amounts of introduction into the Berlin waters, summarized by segments. Except for those quantities which at heavy rainfall flow through the emergency outlets of the pumping stations and through the rain overflows of the wastewater network, and then also flow directly into the bodies of water, the surface runoff in the area of the mixed system is passed to the sewage treatment plants, from where they are fed into the bodies of waters after appropriate sewage-treatment, together with the treated sewage.

| Body of Water Number | Catchment Areas by Bodies of Water | Catchment area (km) | Rain runoff (cu.m./a.) |
|---|---|---|---|
| 110 | Upper Havel to mouth of Tegel Lake | 3,4 | 0,3 |
| 120 | Upper Havel (mouth Tegel Lake to Spandau watergate) | 4,5 | 0,82 |
| 130 | Tegeler See (Tegel Lake) | 2,6 | 0,51 |
| 131 | Tegeler Fließ (Tegel Stream) | 6,6 | 0,70 |
| 132 | Nordgraben (North Ditch) | 12,5 | 1,81 |
| 133 | Panke north of distribution structure | 8,2 | 0,89 |
| 210 | Lower Havel (Spree mouth to Jungfernsee Lake) | 17,4 | 2,60 |
| 220 | Great Wannsee Lake | 3,0 | 0,25 |
| 230 | Kleine Wannseekette (little chain of lakes) | 1,8 | 0,18 |
| 310 | Müggelspree (incl. Great Müggel Lake and Erpe) | 8,6 | 1,19 |
| 320 | Langer See (Long Lake), Dahme, Große Krampe (lake) | 6,3 | 0,72 |
| 330 | City Spree to Britzer Zweigkanal (canal) | 7,1 | 1,37 |
| 331 | Wuhle (stream) | 23,3 | 3,28 |
| 340 | City Spree to Landwehr Canal | 6,8 | 1,11 |
| 350 | Rummelsburg Lake | 10,5 | 2,25 |
| 351 | Marzahn-Hohenschönhausener Boundary Ditch | 15,8 | 2,77 |
| 380 | City Spree to Berlin-Spandau Shipping Canal | 6,7 | 1,27 |
| 390 | City Spree to mouth | 7,1 | 1,42 |
| 400 | Canals north of the Spree | 7,0 | 1,42 |
| 401 | Panke (Distribution structure to Nordhafen port) | 18,3 | 3,12 |
| 500 | Canals south of the Spree (Neuk. SK and Landwehrkanal) | 6,5 | 1,49 |
| 600 | Teltow Canal | 66,6 | 10,04 |
| 610 | Rudower Arm | 25,9 | 3,44 |
| 620 | Britzer connecting canal | 3,0 | 0,58 |
| 810 | Grunewaldseenkette (chain of lakes) | 11,5 | 1,75 |
| 820 | Flughafensee (Airport Lake) | 6,1 | 1,21 |
| 830 | Biesdorfer Baggersee (lake) | 4,7 | 0,56 |
| 840 | Fauler See/Obersee (lakes) | 1,4 | 0,21 |
| 850 | Schäfersee (lake) | 2,4 | 0,54 |
| 860 | Groß-Glienicker See (Gross-Glienecke Lake) | 0,9 | 0,11 |
| 900 | Other small bodies of water (ponds, ...) | 19,9 | 2,14 |
| | **Separate sewage system (total)** | **326,6** | **50,08** |
| | **Combined sewage system** | **84,7** | **21,72** |

**Tab. 5:** *Rainwater discharge into the sewage system – catchment areas and runoffs (long-term mean, as of 2017)*

The ABIMO 3.2 model or programme is an instrument with which simulations can also be carried out under modified circumstances. In particular, this could include an assessment of the likely changes in the water balance to be expected due to climate changes (Löschner 2008) or urban development projects, or of measures for the restoration of pervious situations, including the disconnection of areas from the wastewater system, to permit percolation of precipitation there. With appropriately differentiated data, the programme can also be applied on a small scale for projects at the single-lot level. Changes of the model parameters by incorporation of current findings are possible at any time. It must be emphasised that the ABIMO 3.2 can only be used to model annual mean values. It is not possible, for example, to simulate heavy rainfall events.

## Percolation without consideration of impervious cover

The map **Percolation without Consideration for Impervious Coverage** (02.13.4) shows conditions which are in some cases considerably different from those shown in the Percolation map, for which impervious coverage was taken into account.

With **200-250 mm** of annual percolation, the greatly anthropogenically transformed, yet pervious, surfaces of the inner city and the industrial areas achieve the highest percolation capacities in the municipal area, followed by the predominantly sandy areas of the Glacial Spillway and the sandy parts of the plateaus, with approx. **150-200 mm**. If the sandy soils are woodlands, the average annual percolation drops to **100-150 mm**, since the trees, due to their root depth, allow considerably more water to evaporate. Due to the higher retention capacity of the loamy soils of the Teltow and Barnim plateau areas, considerably more water can also be evaporated by the vegetation there, so that only approx. **50-100 mm** percolates into the soil. In areas with near-surface groundwater, increased evaporation is caused by the capillary rise of groundwater into the evaporation-influenced soil zone, so that only an annual average of less than **50 mm** percolates into the soil. If real evaporation is higher than precipitation, net water consumption occurs, i.e. the calculated values are negative.

Certain areas have percolation capacities of more than **300 mm**; these are areas with little or no vegetation covering. Therefore only small amounts of precipitation can evaporate there; the greater share percolates into the soil.

If the data of the Map 02.13.4 are used to estimate the results of additional impervious coverage in the context of **Planning Procedures**, the following should be considered:

The percolation capacity indicated in the map is only reduced to zero by impervious coverage if the planned coverage is actually completely impervious to water (roof surfaces, asphalt) and the precipitation water of these sections is passed entirely to the wastewater system. If partially water-permeable impervious coverage is planned, or if the precipitation water runoff is to be only partially passed into the wastewater system, corresponding modification must be incorporated into the calculations with regard to the reduction of imperviousness. For **more exact calculations**, application of the ABIMO runoff model is recommended, in which simulated data for planned surface structures can be entered as input data, so that the actual state and the plan can be compared.

# Excursus – INKA BB

## Calculation of the percolation water rates on an annual and monthly basis, and forecast changes due to climate change

Water balance data calculated with the ABIMO model provide a 30 year long-term mean value. However, in reality, the values fluctuate considerably on an annual basis, depending on the precipitation levels, and are also subject to fluctuations over the course of a   year. In the present research project, percolation water rates were calculated with a considerably higher temporal resolution.

### Project

The results presented below were developed in the context of the Inka BB research project of the German Federal Ministry for Education and Research (Subsidy Code 01LR0803C), Subproject 23. INKA BB is the acronym for the Berlin-Brandenburg Climate Adaptation Innovation Network (http://www.inka-bb.de/). In this research project, which was broken down into 24 subprojects, subproject 23 addressed technologies for climate adapted water management in urban areas in the context of climate change. For this purpose, the climate scenarios developed by the project partner Potsdam Institute for Climate Impact Research (PIK) were incorporated into the various models in order to make statements on issues relevant for water management.

### Statistical Base

The input data adopted comprised the land-use categories (cf. Maps 06.01 and 06.02, 2008 edition), the classified degree of impervious coverage (cf. Map 01.02, 2007 edition), the classified depth to groundwater (cf. Map 02.07, 2010 edition), and such soil parameters as usable field capacity and Kf values from the data base of the Berlin Environmental Atlas (cf. Map 01.06, 2009 edition), for approx. 25,000 polygons. Additional soil parameters, such as porosity, were substantiated by reference to the soil associations in the Environmental Atlas (cf. Map 01.01, 2009 edition), using values from the Soil Scientific Mapping Guideline (BGR, 2005). In case of incomplete data sets, plausible assumptions were

made, or data was taken from already completed DHI-WASY projects. The result was that 78 different soil types, 156 soil textures, 12 depth-to-groundwater classes and 775 land-use classes were obtained.

The climate data used were the daily data for precipitation and potential evaporation from 11 precipitation stations in Berlin and the surrounding area. The climate data was gathered by the DWD and made available by the PIK in the context of the INKA BB research project. In order to be able to correctly represent the spatially differentiated distribution of precipitation in Berlin and the surrounding areas (cf. Map 04.08, 1994 edition), the climate data were extracted by means of inverse distance weighting (a geostatistical procedure) for 19 precipitation zones. The spatial distribution of the precipitation zones is shown in Figure 5.
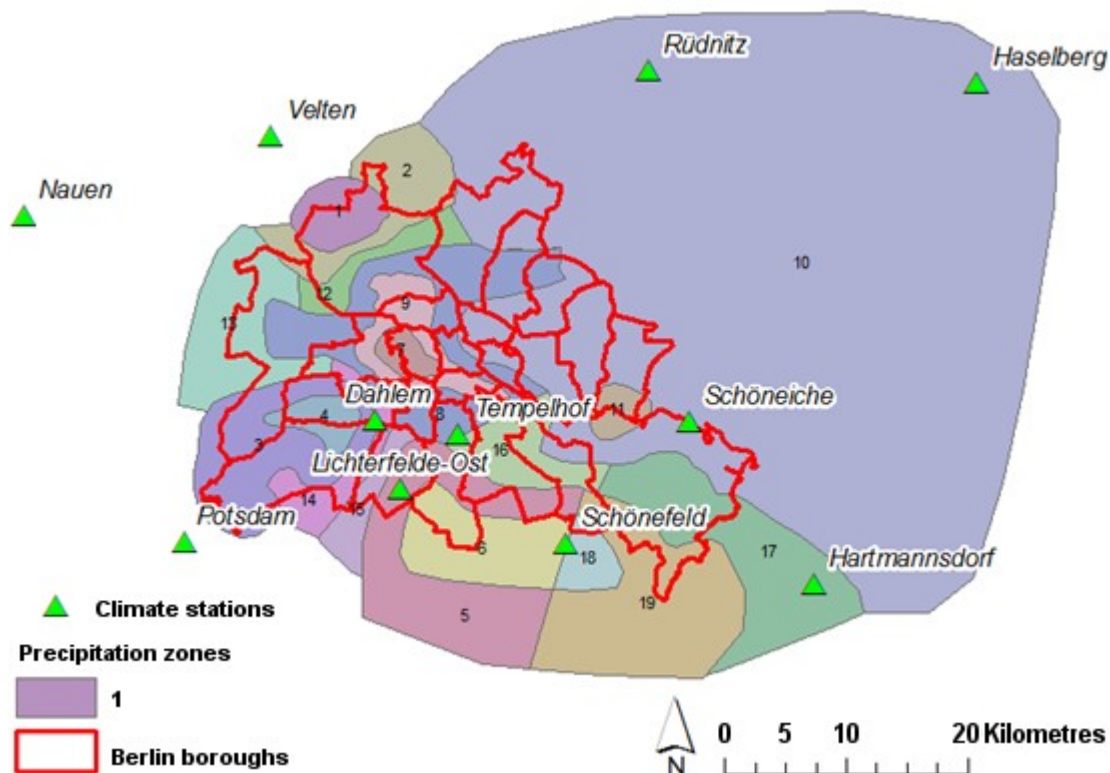


Figure 5 Distribution of the precipitation zones used in ArcSIWA

## Model Description

The results presented below are based on an ArcSIWA model designed for the entire area of the state of Berlin, including the boundaries of the intake area of the Tegel waterworks. The ArcSIWA model (Monninkhoff, 2001) is a reduced precipitation-runoff model for a one-dimensional description of runoff formation and of the soil-water balance for quasi-homogeneous area segments, with a temporal resolution of one day. The ArcSIWA accounts for interception, trench storage, infiltration and vertical dampness flow to groundwater, including new formation of groundwater and capillary rise. Thepercolation water rates calculated by the ArcSIWA correspond to the quantity of water exiting vertically from the approx. 2 m thick soil zone. A detailed representation of the ArcSIWA model built is to be presented in Sklorz & Monninkhoff (2013) sometime in 2013.

## Results

Figure 6 shows the annual percolation water rates between 1961 and 1990 calculated by means of the ArcSIWA. It shows that the annual values often vary strongly, between 49 and 239 mm/a. The mean value for the 30 year period is 142 mm/a, and the median value, 156 mm/a. A significant trend, e.g. due to climate, cannot be ascertained during this time period. The results are generally quite comparable with the long-term mean of the percolation water rate (160 mm/a) from the ABIMO model (SenStadt, 2009c). By contrast with the values in Table 4, the stated values were ascertained by incorporating bodies of water into the mean at a percolation water rate of zero. Spatial differences in the model results were particularly evident in the central part of the city, where the ArcSIWA calculated significantly lower

percolation water rates. This difference is essentially due to the different approaches for impervious coverage upon which the two models are based.
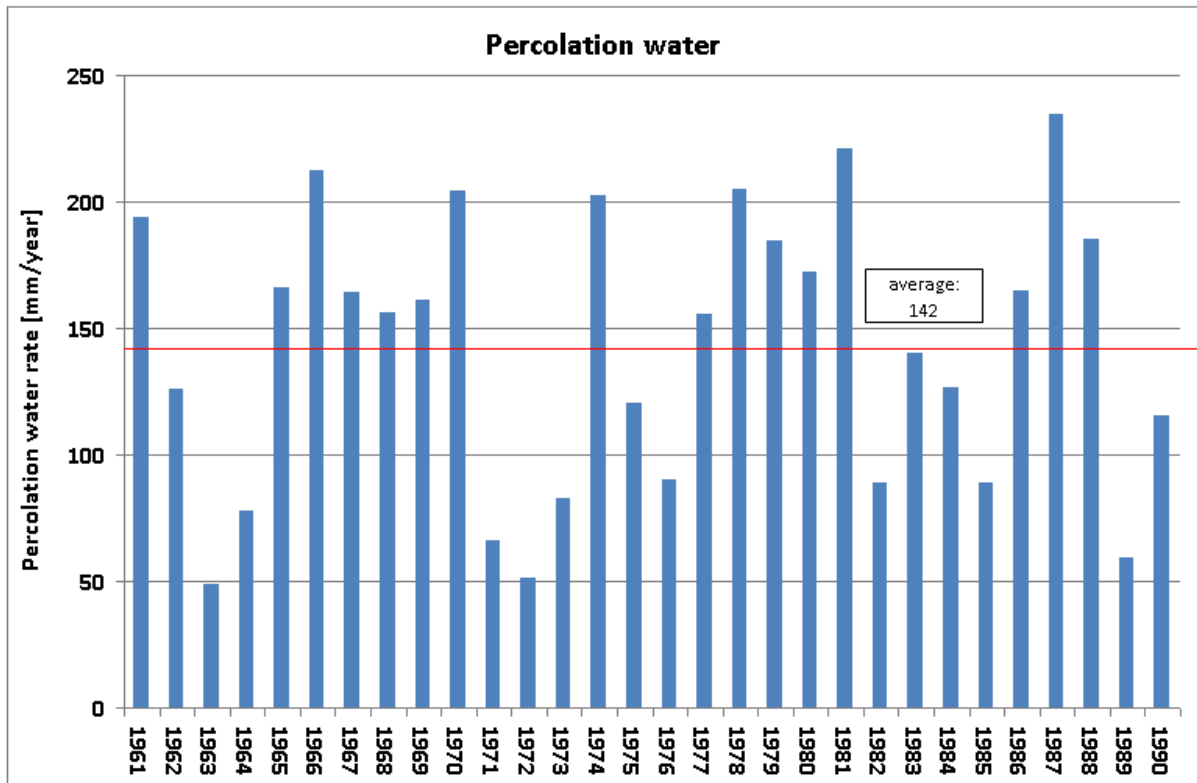


*Figure 6 Annual values of percolation water rates in Berlin for the period 1961 to 1990*

Figure 7 shows the long-term monthly percolation water rates for the period 1961 to 1990. It shows that the percolation water rate could vary between 1.2 and 24.5 mm per month during the course of the year. The winter months show the highest percolation water rates, while in summer, the lowest percolation water rates occur.
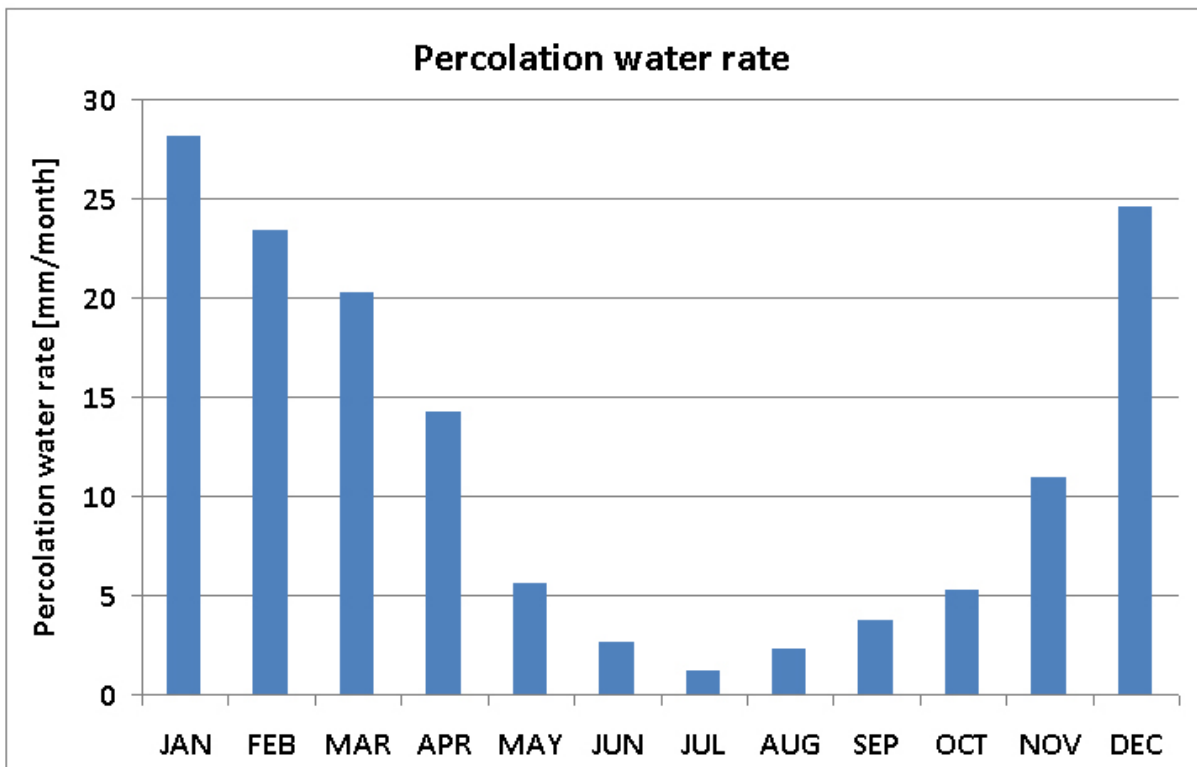


*Figure 7 Long-term monthly percolation water rates for the period 1961 to 1990*

The period 1961 - 1990 was used for the model calibration of the INKA BB research project, subproject 23. Subsequently, changes of percolation water and groundwater new formation were calculated with the model based on the climate scenarios developed by the PIK. A comparison was then undertaken between the T-0 scenario (the reference scenario assuming no climate change) and the T-2 scenario (assuming a temperature increase of 2°C). The calculations show a clear reduction of groundwater new formation for the future, attributable to climate change (DHI, 2012).

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