

## 04.08 Long-term Precipitation Distribution and Runoff Formation (Edition 1994)

### Long-term Precipitation Distribution

#### Overview

##### Factors Affecting Precipitation

The intensity and distribution of precipitation determine the meteorological and climatic conditions of an area. They also directly affect **groundwater recharge** and the **water supply available to plants**. Precipitation also causes wash-outs from the atmosphere and, as “infiltration water” (cf. page), is the medium for **transport of pollutants** into the ground.

The average distribution of precipitation provides essential basic statements regarding precipitation phenomena in a given area. The distribution of precipitation in any given individual event, however, can deviate considerably from the average distribution. Strong rainfalls with unusual distribution of precipitation after the reactor accident at Chernobyl in May 1986 led to greater inputs of radioactive contamination in Europe (cf. Map 01.09, SenStadtUm 1992a).

Topography (**surface configuration of the earth**) is an important influence on the weather conditions of any given area. Mountain ranges, small groups of hill, and even low slopes influence precipitation quantities. This can be seen in the maps of average precipitation conditions of any given area. Other factors include forests, lakes, fields (cf. Flohn 1954). Residential areas of a certain size also influence quantities and distribution of precipitation.

One example is the increase of precipitation in the form of slope rains within a limited area. Slope rains are mainly due to the influence of bottom friction, the roughness parameter. Other influences in urban areas include increasing amounts of aerosols. The aerosols serve as nuclei for condensation, facilitating the formation of clouds and precipitation. Precipitation is also caused by the warmth of urban areas, in certain weather situations (convective precipitation).

An analysis of the **effects of urban landscapes** on precipitation quantities and distribution must distinguish between the influence of the urban landscape on any given precipitation process, and the role of the urban landscape as a catalyst for precipitation.

##### Effects of Precipitation

The effects of precipitation are also distinguished between those processes which purify the atmosphere and those processes resulting in pollutant contamination of the environment. Heavy precipitation does more than clean the air. High degrees of surface sealing and the extensive rain water and waste water disposal systems also result in the flushing of a range of pollutants in concentrated form into the storm sewer system and thus into bodies of water (cf. Map 02.09, SenStadtUm 1992b).

Berlin's separate sewer system has about 3,000 km of storm sewers. The storm sewers collect dust, air pollutants, street surfacing and tire abrasion, oil spills, and other materials. This highly polluted precipitation water is diverted directly into smaller and larger bodies of water at approximately 730 sites. The combined sewer system collects domestic, commercial, and industrial waste waters as well as rainwater. Heavy precipitation can cause short-term overloading of the disposal system, resulting in the diversion of all combined, unpurified waters into the receiving bodies of water.

A quantification of the effects of urban structures on precipitation requires the long-term operation of an extensive monitoring network. In contrast to surrounding rural areas, the vertical structure of the city (heights of buildings and vegetation) must be considered, in addition to the topographical form of the land.

## Regional Classification of Precipitation Conditions in Berlin

Precipitation conditions in Berlin are influenced at the regional scale by its location in a transitional area between continental and oceanic-influenced climate systems. Berlin is rather dry compared to other areas of Germany. The average annual quantity of precipitation is 568 mm per square meter. The "Brocken" mountain in southern Germany receives approximately 1,400 mm in an equal period of time. (cf. Fig. 1).

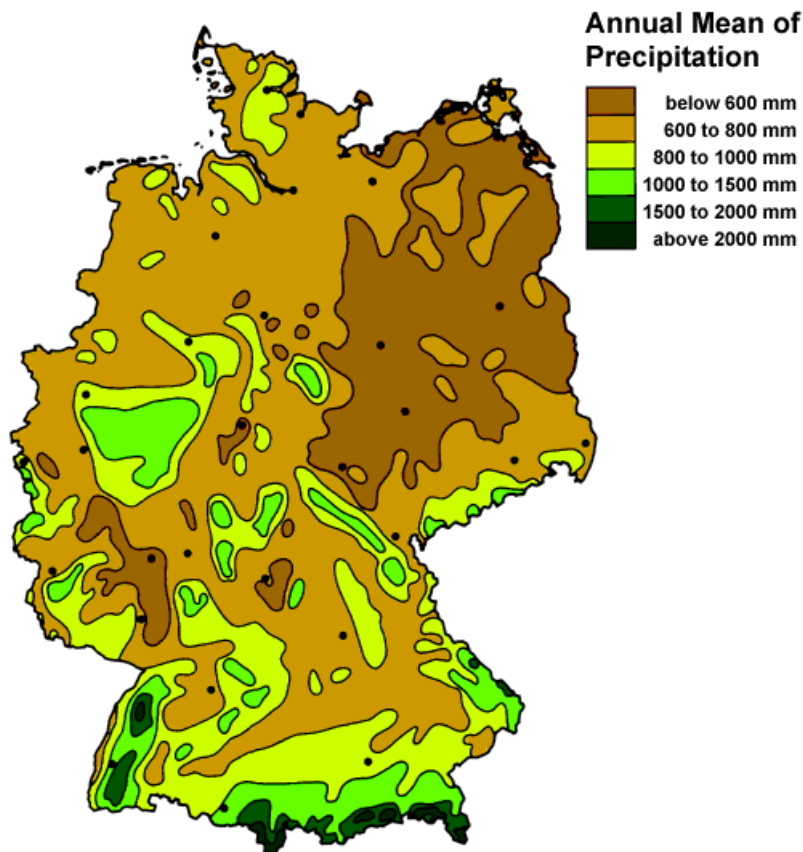


Fig. 1: Precipitation in Germany (from a Geo Magazine Special Issue 1982)

The global climate change will probably affect regional water supplies in the future. Climate changes in the past 10,000 years have clearly changed the geographic distribution of precipitation. Climate changes of equal orders of magnitude but considerably more quickly can be expected in the next 100 years. Their effects on the distribution and quantity of regional precipitation cannot yet be estimated (cf. Kleeberg et al. 1994).

## Statistical Base

A statistical base was provided by the results of **97 precipitation monitoring stations** for Berlin and the surrounding countryside, operated by the Freie Universität or the German Weather Service (cf. Schlaak 1991 and Deutscher Wetterdienst 1992 and cf. Fig. 2).

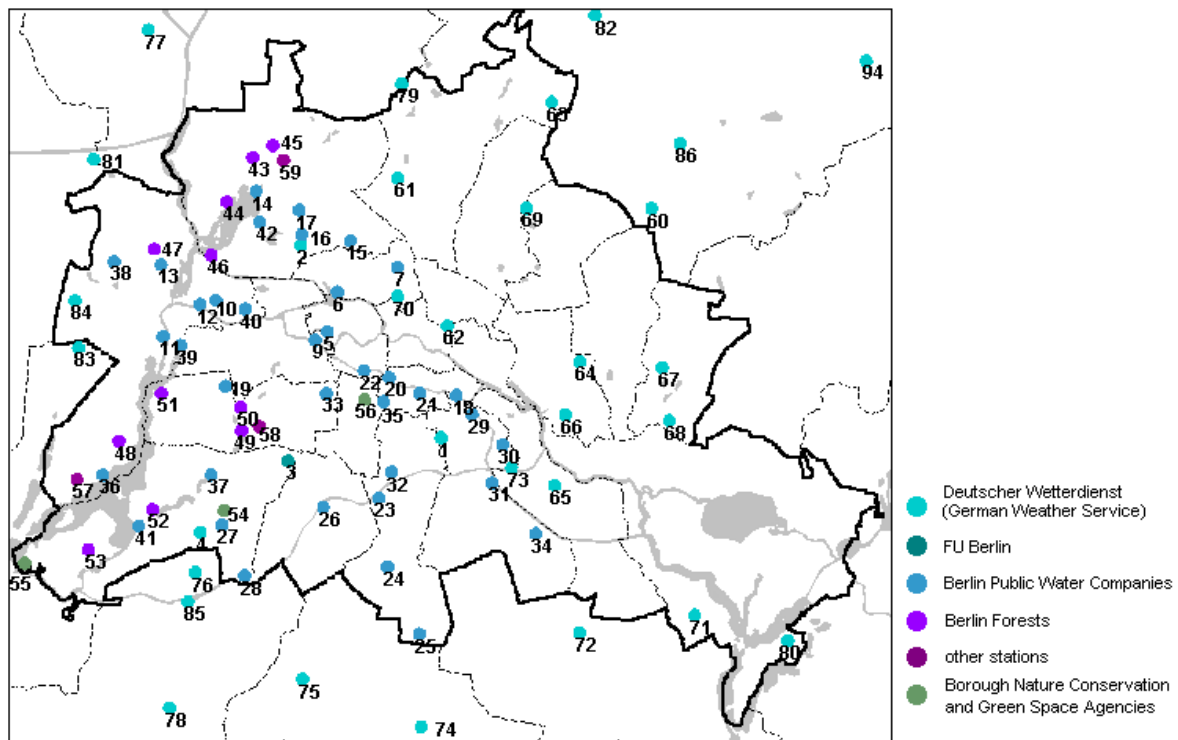


Fig. 2: Distribution of Precipitation Monitoring Stations for Calculating Precipitation Contour Lines

There are 59 monitoring stations in West Berlin; 14 monitoring stations in East Berlin; and 24 monitoring stations in the surrounding countryside.

All monitoring stations provided average monthly precipitation values over a 30-year period. West Berlin values are derived from monthly precipitation quantities from 1961 to 1990. Values in East Berlin and the surrounding countryside were calculated from the years 1951 to 1980. This difference had to be accepted, since a uniform data base could not be created. Several monitoring stations provided values for both time spans. Differences resulting from the varying length of observation periods proved to be negligible (cf. Methodology).

Only limited stationary time series were available from some stations in East Berlin and the surrounding countryside. Converted values for the observation period 1951 to 1980 were made available from the Deutscher Wetterdienst.

## Methodology

Individual depictions of the *isohyets* (contour-lines) of long-term precipitation distribution were prepared from individual values of the 97 monitoring stations in two partial steps, supplementing each other, in a computer-supported process:

- 1) A regular grid of precipitation values was generated out of the irregularly distributed basic data by using a geo-statistical process (**Kriging**). A basic grid scale of 1,000 m was selected (cf. Kannenberg 1991 and 1992);
- 2) A spatial interpolation of grid estimated values was performed with the help of a procedure for establishing contour-drop maps (**SCOP**) (cf. Map 01.09, SenStadtUm 1992a) integrated in the Environmental Information System (Umweltinformationssystem, UIS) Berlin.

West Berlin values (described above) were taken from the time series 1961 - 90, and values for East Berlin/surrounding countryside were taken from the years 1951 - 80. A total of seven stations in East Berlin/surrounding countryside had both time series. Deviations from the average values of the 30 year observation periods averaged 1.1 % and were thus negligible in comparison to the total difference of about 20% between the entire collected data. A dense and good data base could be assumed, compared with other urban study areas.

Time periods selected for representation were:

- long-term annual average 1961 - 1990
- long-term summer half-year average 1961 - 1990
- long-term winter half-year average 1961 - 1990.

The time-frames were divided into a summer half-year from May to October and a winter half-year from November to April, in order to be consistent with the water management runoff year (November - October).

Table 1 gives some elementary statistical parameters for these three time periods for all monitoring stations.

<b>Tab. 1: Distribution and Quantities of Long-term Precipitation for 97 Precipitation Monitoring Stations in Berlin and Surroundings</b>			
	<b>Year total</b>	<b>Summer</b>	<b>Winter</b>
Minimum (mm)	515	287	208
Maximum (mm)	664	356	282
Average (mm)	568	322	247
Variance (mm) 1)	745	287	241
Standard Deviation 2)	27.95	17	15,6
1) Variance as measure of distribution is the sum of the squared deviations of all measured values from their arithmetic average and then divided by the number of measurements. 2) The standard deviation is the root of the variance, also calculated as the average distribution of the individual measurements. (Kannenberg 1991 und 1992)			

**Tab. 1: Distribution and Quantities of Long-term Precipitation for 97 Precipitation Monitoring Stations in Berlin and Surroundings**

The variance of West Berlin values is clearly greater than those of East Berlin/surrounding countryside. This is possibly due to the interpolation of individual values in the data for East Berlin/surrounding countryside (cf. Statistical Base). The average value for the summer half-year in West Berlin is around 20 mm lower than in East Berlin/surrounding countryside, and the average value of the winter half-year is approximately 20 mm greater.

## Map Description

The distribution of precipitation depends basically on different prevailing wind directions in different seasons, (cf. Fig. 4 and Map 04.03, SenStadtUm 1994b) as well as natural and anthropogenic orographical conditions. The relatively low levels of precipitation in the Berlin area at all points in time is also meaningful. This initial condition worsens related situations, such as groundwater. Groundwater recharge is hindered. "Losses" of precipitation occur through evaporation and surface drainage before precipitation can percolate into the ground (cf. Map 04.08.4). Some precipitation values should clarify the Berlin situation (cf. Fig. 3).

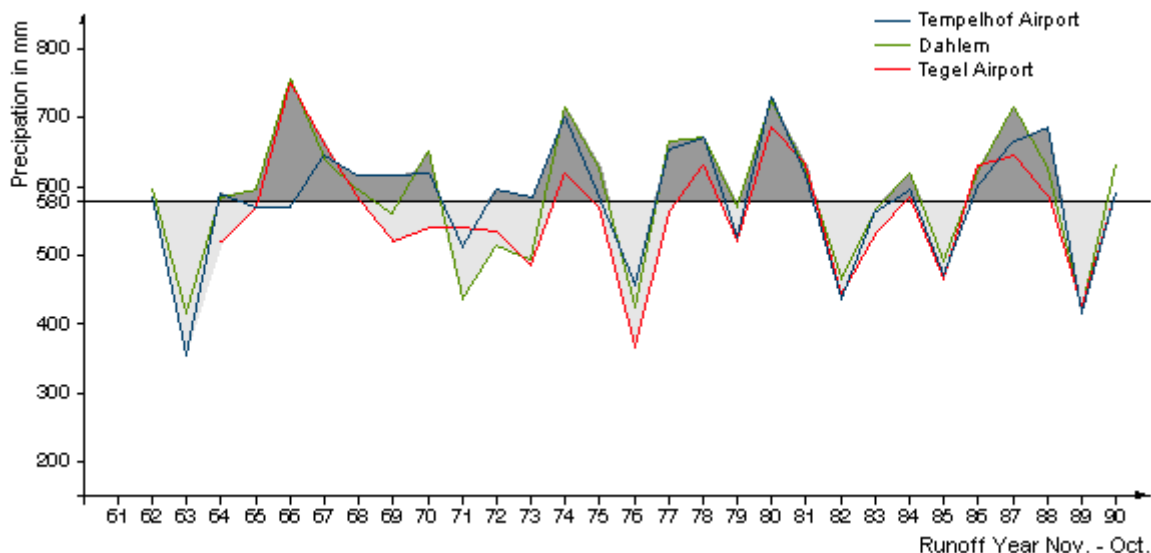


Fig. 3: Deviations in Annual Precipitation from Long-term Averages at the Stations Tegel Airport, Tempelhof Airport, and Dahlem between 1961 - 1990 (cf. Deutscher Wetterdienst 1994 and Schlaak 1991)

### Map 04.08.1: Long-term Distribution of Precipitation 1961 - 1990 / Winter Half-year

The distribution of winter snow and rain differ both from the total annual as well as from the summer half-year distribution. The variations are generally lesser than in the time periods of observation mentioned above. Areas with the largest precipitation quantities of 275 mm are concentrated within the Tegel and Grunewald forest areas only. Values fall under 240 mm in the eastern urban area and west of the areas of maximum quantities. This distribution pattern shows the influence in the winter half-year of mainly eastern continental prevailing winds carrying little precipitation. The influence of urban development shows its first effects west of the Neukölln, Schöneberg, Charlottenburg, Reinickendorf boroughs. Urban development effects then combine with the roughness effects of the forested chain of hills.

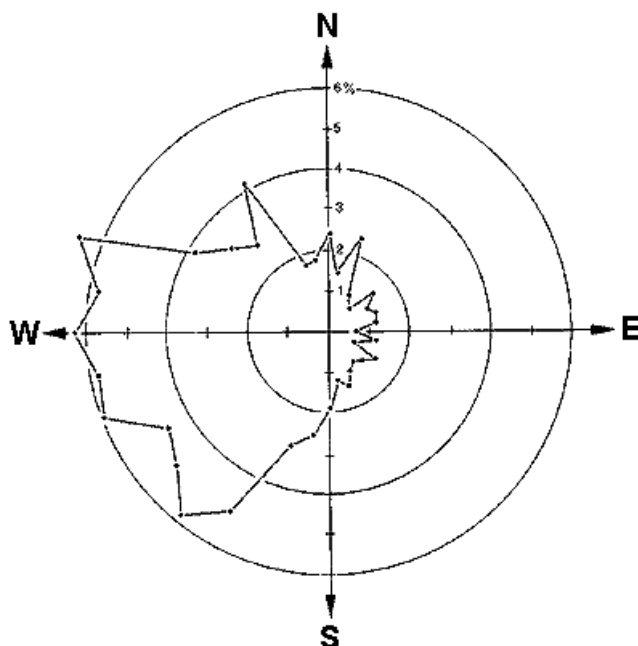


Fig. 4: Precipitation Quantities per 10° Sector of the Wind Rose in %, Reference Base: 597 mm per Year (Institute for Meteorology, FU Berlin 1973 - 1982, from: SenStadtUm 1991)

## Map 04.08.2: Long-term Distribution of Precipitation 1961 - 1990 / Summer Half-year

Precipitation distribution in the summer half-year (May to October) is very similar to the annual total distribution. The Grunewald forest range of hills and the effects of urban development both influence maximum precipitation here too. In contrast, areas with minimums under 300 mm can be recognized in adjacent eastern and southern areas. In comparison to the winter half-year, (Map 04.08.1) an average of 80 mm more precipitation falls in the summer months. This is due to the marked influence of maritime west wind weather conditions in these months.

## Map 04.08.3: Long-term Distribution of Precipitation 1961 - 1990

The highest values (>600 mm) clearly appear in the western urban areas of the Grunewald and Tegel forests. This chain of hills, although only weakly formed, produce slope rains (orographic precipitation) from prevailing western currents. Lower precipitation quantities to under 540 mm are registered in the lee of the heights in the Spree river lowland area, and in the central municipal boroughs of Charlottenburg, Tiergarten, Wedding, Mitte, Kreuzberg and Schöneberg. These lee effects continue in the city's southern area and in the adjacent surrounding countryside, where values under 540 mm are again found in the Grossziethen/ Wassmannsdorf area. The influence of urban structures is clearly seen east of a line from Prenzlauer Berg, through Lichtenberg, the northern areas of Treptow, and Köpenick. The increased roughness effect of buildings causes an effect similar to that at the Grunewald hills. Rain levels here are also barely 600 mm. The urban heat island effect is visible in convective precipitation. Decreasing amounts of precipitation due to the lee effects of the city appear again in the eastern adjacent surrounding countryside.

# Runoff Formation

## Overview

### Definition

Water introduced into an area by precipitation enters various water balance processes, such as evaporation, surface and underground drainage, and changes in the water supplies. These processes and quantities depend upon the area's characteristics and climatological conditions. **Runoff formation** is derived as an average temporal value from the difference between precipitation and evaporation in area segments of a water catchment area. Changes in the water supplies, such as soil moisture, groundwater, and bodies of water, are neglected. Runoff formation best characterizes the hydrological conditions of area segments and catchment areas. Areas covered with vegetation have large amounts of evaporation, particularly areas with near-surface groundwater and/or bodies of water with their large surfaces. These surfaces do not produce much runoff. Sealed surfaces hinder evaporation and produce high quantities of runoff. Area segments are fed by surface or underground inflows from runoff formed by higher area segments, in addition to its own runoff. These water quantities formed by runoff and inflow then flow to areas located below. The **water supply** of a closed catchment area is thus the sum of runoff from all area segments and total surface and underground inflows. The quantity of exploitable water is generally much smaller and is determined in consideration of such factors as hydrology (temporal availability), hydrogeology (exploitability), hydrochemical (properties), and influences of use-structures (degree of development, nature preserves).

### Meaningfulness of Parameter

Knowledge of regional distribution of runoff are the basis for:

- evaluating the area's water resources as well as areas to be supplied and areas to be depleted;
- identification of water resources by comparing water supplies and water uses, and determination of measures to secure water supply sustainability;
- to issue resource-sparing water use permits;

- to determine optimal locations for water use facilities in regard to availability and allocation.

Runoff is a medium of material transport and thus of pollutant transport. The **maximum available amount of runoff** is the value required to calculate the transport of substances, and thus for estimating the degree of vulnerability of water resources to pollution.

## Area Description

Berlin-Brandenburg is part of the north German lowland, with relatively thick unconsolidated stone deposits. Among these deposits are the ground moraine flat upland areas formed during the ice ages. The groundwater aquifer is covered by a mantle of 10 to 30 m thick and poorly-permeable boulder marl complexes.

End moraine areas are to be considered as complex groundwater aquifers not covered by a mantle because of their heterogeneous geologic composition and the fracture zones created by glacial dynamics.

Individual groundwater storeys in ground and end moraines are recharged entirely by runoff. Hydrological investigations and observations of outflows into watercourses are required to clarify what quantities of alimentation (feed) amounts in the upper groundwater story can be used locally; and what quantities flow underground to watercourses in the flat upland areas, or flow through deeper groundwater layers into the "Urstromtal" glacial valley watercourse. These calculations require a knowledge of the underground catchment area (balance area).

The ice-age melt-water deposits of the outwash plains and glacial valleys, in contrast, form large areas of groundwater aquifers without a covering mantle, i.e. they are not covered by non-permeable strata. In the glacial valley and outwash plain areas infiltrated precipitation percolates to the groundwater table, after losses due to evaporation. The time required for groundwater recharge here corresponds to runoff formation (cf. Map 01.05, SenStadtUm, in preparation).

Particular hydrological problems occur in urban areas with **sealed surfaces** (building roofs, streets, squares, etc.). Runoff formation here is clearly increased due to reduced capabilities of water storage compared to unsealed areas. Some precipitation is discharged directly into watercourses, depending on the type of sewer system (cf. Map 02.09, SenStadtUm 1992b). The remainder of runoff infiltrates at the edge of sealed surfaces, or within partially sealed areas, reaches deeper layers underneath the evaporative zone, and recharges groundwater. Groundwater recharge for these areas can be determined by comparing runoff quantities with quantities led off by the rainwater drainage system, if the structural conditions of the rainwater drainage system are known. Such statements are relevant for the water and substance balances of inner city watercourses and groundwater.

## Statistical Base

The Map of Total Runoff is the edition updated for Berlin from Map 2.03 (Runoff formation from precipitation and mean annual precipitation) from the "Ecological Resource Planning for Berlin and surrounding countryside" of 1991/92. The map scale was enlarged from 1:200,000 (grid area: 2.5 x 2.5 km) to 1:125,000 (grid area 1 x 1 km). Area information and calculations refer to it. Surface waters and lowland areas with near-surface groundwater were proportionately registered for the grid area and runoff calculations correspondingly taken into consideration. The runoff calculations refer to the precipitation values mentioned above, 1961 - 1990.

Data entered for:

### Total Berlin

- **long-term distribution of precipitation** 1961 - 1990 (cf. Maps 04.08.1 - 3, SenStadtUm 1994a);
- values of **potential evaporation**, taken from a Map 1:1,000,000 (reduced overview in: Dyck et al. 1978, Image 3.26). It was prepared following Budyko, from climate station data of the GDR regarding the radiation balance of an area with continually high moisture.
- **Evaporation from bodies of water** from a Map of Evaporation Areas (650, 700, 750 and 800 mm/a) (cf. Richter 1979);
- areas of forest use (excepting reforested areas of former sewage farms) were assigned an average age. Tree type and age were not specially considered.

## East Berlin

- Information for **land use** from the Topographical Maps (National Economy Edition) at a scale of 1:25,000 (status 1975/81) and 1:10,000 (status 1980/85) with specifications regarding
- classifications of agricultural yields from statements in Agricultural Cooperatives *Schlagkartei* (area cadastre) and from estimates;
- tree type and age for reforested areas at former sewage farms in northern Berlin;
- **degree of sealing** from procentual estimates of built-up (sealed) areas within the grid area, such as buildings, streets, squares, courtyard areas, etc., by means of a grid pattern with an estimated deviation of about  $\pm 5$  to  $\pm 10$  % from actual value.

The non-sealed area was classified according to the dominance principle into one of the main use categories; agricultural, forest exploited areas, gardening use, bodies of water.

- Statements about **soil type** were from Soil Estimate Maps at a scale of 1:10,000 or 1:25,000 (status 1934/51) and from soilgeological maps;
- Statements about **groundwater depth from the surface** from the difference of statements giving geodetic altitudes (Topographical Map 1:10,000 or 1:25,000) and the groundwater level of the upper groundwater storey (Hydrogeologic Map at a scale of 1:50,000, Map 2.2).

## West Berlin

Information for **land use**:

- agricultural or forest exploited areas, garden areas or bodies of water categorized according to the dominance principle, from the Environmental Atlas - Map 06.02 Inventory of Green and Open Spaces (SenStadtUm 1987) and the Satellite Map of Berlin (SenBauWohn 1989);
- **degree of sealing** of built-up areas as in the Environmental Atlas - Map 01.02 Sealing of Soil Surfaces (SenStadtUm 1993, work status 1988);
- statements about **soil type** according to the Environmental Atlas - Map 01.01 Soil Societies (SenStadtUm 1985a);
- statements about **groundwater depth from the surface** from the Environmental Atlas - Map 02.07 Depth of Groundwater (SenStadtUm 1985b).



Tab. 2: Overview of Factors	
Factor	Parameter
<b>Climatic Factors</b>	Precipitation Potential evaporation
<b>Main Form of Use</b>	Agricultural use – Class of agricultural harvests Forest use – Tree type – Tree age for reforested areas of former sewage farms Gardening/ horticulture Urban areas – Degree of sealing Areas without vegetation Bodies of water
<b>Soil Type</b>	Differentiated as sand, loam-like sand, loamy sand, very loamy sand sandy loam, loam (clay loam, clay)
<b>Depth of Groundwater from Surface</b>	Class of groundwater depth from surface Value of groundwater depth from surface, especially for areas with near surface groundwater

**Tab. 2: Overview of Factors**

# Methodology

## Evaporation

Runoff is calculated from the difference between long-term annual mean precipitation and actual evaporation. **Actual evaporation**, as it actually averages at specific locations and general areas, is calculated from the most important factors of precipitation, heat supply (radiation balance), and the average storage properties of evaporative areas. **Potential evaporation** is a calculation where the heat supply is replaced by quantities of evaporated water corresponding to the amounts of heat. Sufficient inputs of moisture to evaporating areas allow actual evaporation values to approach potential evaporation values. Actual evaporation is modified additionally by the storage properties of the evaporating area. Greater storage effectiveness, such as a greater cohesive capacity of the soil and greater root depth, causes greater evaporation.

The demonstrated connection between actual evaporation to precipitation, potential evaporation and the evaporation effectiveness of the location is satisfied by the relationship according to Bagrov (cf. Glugla et al. 1971, Glugla et al. 1976, Bamberg et al. 1981 and cf. Fig. 5). The actual evaporation ER for locations and areas not influenced by groundwater can be determined by the Bagrov relationship with knowledge of the climate factors precipitation (P), potential evaporation (EP) (quotient P/EP), the effectivity parameter (n), and the quotient actual evaporation/potential evaporation (ER/EP). The Bagrov process is also used in modified form for calculations where groundwater influences evaporation; the average capillary water inflow from the groundwater is added to precipitation.

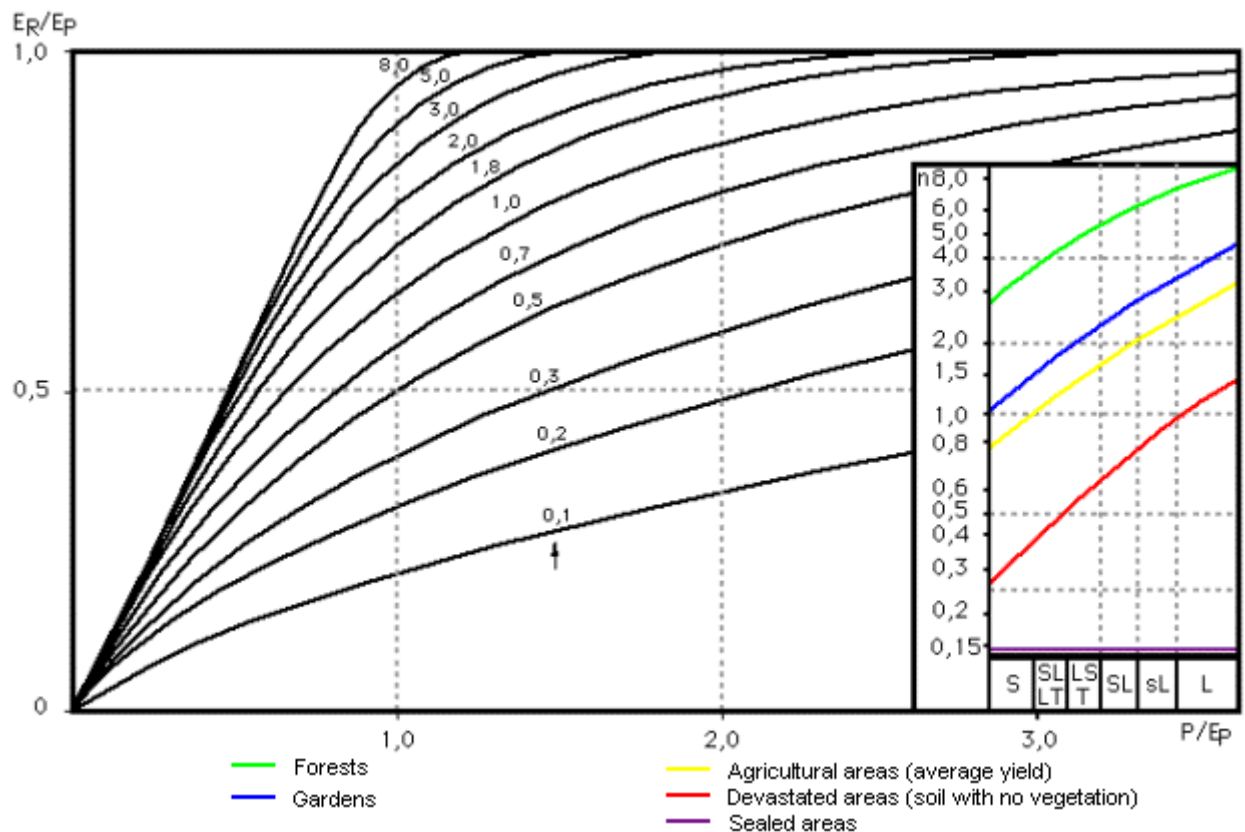


Fig. 5: Depiction of Bagrov Equation for Selected Parameter  $n$  and Dependency of Parameter  $n$  on Land Use and Soil Type (cf. Glugla 1994)

Increasing precipitation ( $P$ ) causes actual evaporation ( $ER$ ) to approach potential evaporation ( $EP$ ); i.e. the quotient  $ER/EP$  approaches the value 1. Decreasing precipitation ( $P$ ) ( $P/EP$  inclines to value 0) causes actual evaporation ( $ER$ ) to approach precipitation ( $P$ ). The intensity with which these boundary conditions are reached is changed by the storage properties of the evaporating areas (effectivity parameter  $n$ ).

## Useful Field Capacity

Local storage properties are especially influenced by forms of use. Use forms classified in order of increasing storage effectiveness are: sealed areas; soil with no vegetation; agricultural areas; gardens or forests. Soil type is also an influence (greater soil cohesiveness increases storage effectiveness).

**Useful field capacity** is a measure of the storage effectiveness of unsealed soil. It is the difference between soil moisture values for field capacity (beginning of infiltration into the soil) and for the permanent wilting point (lasting dessication injury to plants). Other land use factors modify the parameter value  $n$ , such as crop production per hectare, tree type and age. The parameter  $n$  was quantified by evaluating observation results of numerous domestic and foreign lysimeter stations and by water balance studies in river catchment areas.

Capillary uptake of groundwater into the evaporation-influenced soil zone increases evaporation rates in locations and areas with near-surface groundwater according to the depth of groundwater from the surface and soil properties. The formation of runoff declines. Water depletion occurs if actual evaporation exceeds precipitation. Runoff values then become negative, such as at lowlands of rivers and lakes.

An increased potential evaporation appears at water surfaces in comparison with land areas, because of the greater heat supply (lesser reflective capacity of incoming radiation). Actual groundwater evaporation, as an approximation, is assumed to be equal to increased potential evaporation.

## Estimation of the Method of Calculation

The meaningfulness and precision of the calculation method was tested by comparing calculated total runoff with observed runoff values of closed river catchment areas. The mean deviation of calculated runoff from observed runoff was then determined. The deviation was approximately  $\pm 15$  to  $\pm 10$  % for areas

with a size between 25 and 50 km<sup>2</sup>; approximately  $\pm 10$  to  $\pm 5$  % for areas between 50 to 1,000 km<sup>2</sup>; and under  $\pm 5$  % for areas larger than 1,000 km<sup>2</sup>. An average deviation of about  $\pm 25$  % is estimated for the individual grid areas (1 km<sup>2</sup>) presented here. The calculated values for outflow were rounded off at 5 mm/a. Runoff calculations were performed with the calculation program GRID - RASTER (cf. Glugla et al. 1989).

Certain types of local percolation were not taken into consideration, such as groundwater recharge for waterworks. Garden watering was added to precipitation in the form of a uniform approximate value.

## Map Description

### Spatial Description

Runoff values determined for the by 1 x 1 km grid area show considerable regional differences. They meet expectations based on the essential factors of:

High runoff values occur at inner city areas with a high degree of sealing. A large portion of runoff water in the Berlin urban area is directly discharged into watercourses (mainly the Spree river and canals) by the storm sewer system. Groundwater recharge is thus lost. Statements about groundwater recharge in urban areas are possible only with detailed knowledge of local distribution by the rain water drainage system.

Water depletion (negative values) or minimal runoff are found where larger lakes and wetlands are connected. Runoff quantities in non-urban areas correspond to the groundwater recharge of the upper groundwater storey. The upper groundwater storeys discharge horizontally into the flat upland surface waters, and vertically into lower groundwater storeys. Runoff quantities in the glacial valley area are to be considered equal to groundwater recharge of the main groundwater aquifer.

### Application Examples

Two examples will demonstrate how the Map of Runoff can be applied in the determination of water resources.

- To determine an average subterranean runoff: The average subterranean runoff from the Barnim ground moraine area to the glacial valley for a closed underground balance area. (It is a watershed with areas on the flat upland area as well as in the glacial valley):

The first calculation is the water supply quantity (total runoff) of the area segment on the flat upland area. It is the sum runoff of all grid areas (including areas beyond the state border, if necessary). Throughflow into watercourses leaving the upland/glacial valley area border zone is subtracted from the water stocks of the upland area. Removals from groundwater or surface waters in the upland area are subtracted from the water stocks, in as far as these removals do not remain in the upland area as sewage. The difference is the approximate average underground outflow of the upland area.

- To determine the bank-filtration portion of groundwater removals for the area just described. It is affected in the glacial valley area by a surface water:

Water stocks are calculated from the total runoff of all grid areas in the glacial valley area, plus the projected underground runoff from the flat upland area. If the available water stocks described above are subtracted from groundwater removals, the approximate quantity of water filtered through banks will be derived. Detailed investigations also require those watercourses which flow through the glacial valley area to be taken into consideration. Areas with high degrees of surface sealing cause water quantities to be diverted directly into surface waters by the storm sewer system. These quantities are subtracted from calculated water stocks.

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