

02.13 Surface Runoff, Percolation, Total Runoff and Evaporation from Precipitation (Edition 2007)

Overview

The prerequisite for a water-management planning process and a management system for water resources oriented toward the principles of sustainability is that the knowledge of surface runoff and percolation, and of new groundwater formation, be as precise as possible. For this, an accounting of the components of the water balance is of special importance, especially in the Berlin area, which has only limited water resources, compared with other urban areas, and where the number of its inhabitants and their drinking and industrial water needs, and the associated sewage output, result in a structural water-management deficit.

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 with it into those bodies of water;
- 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.

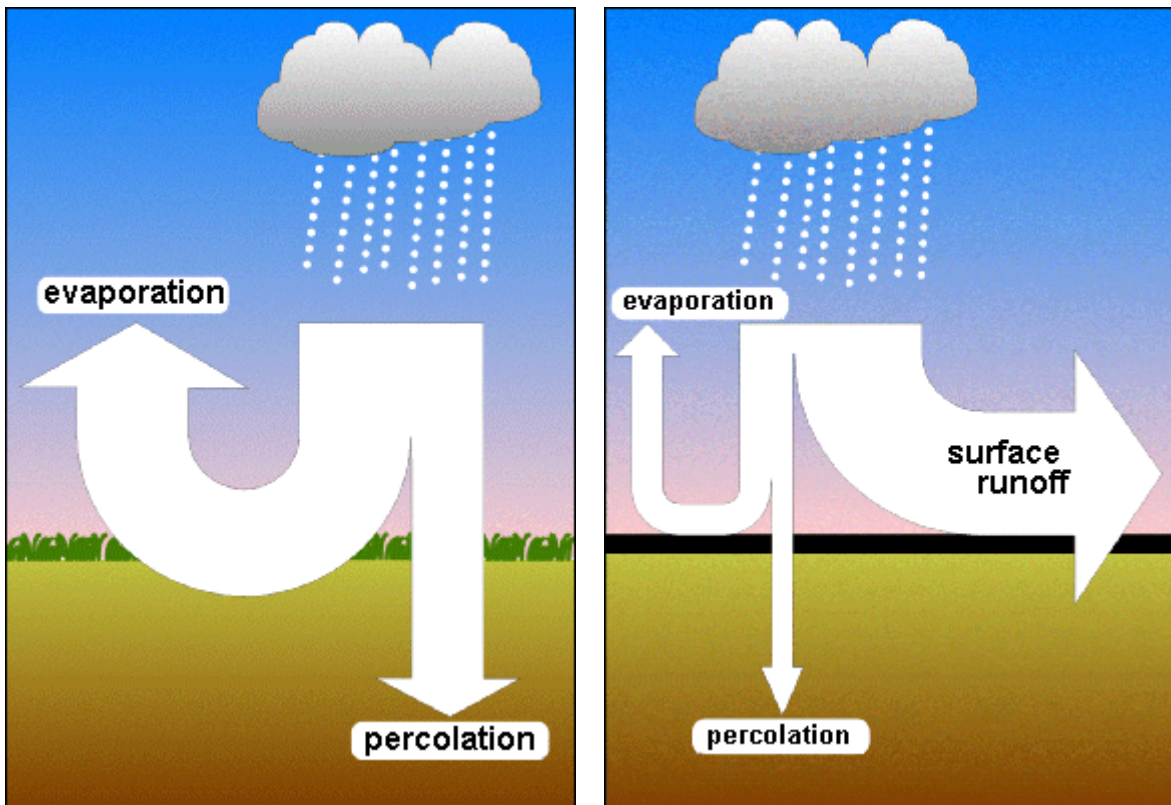


Fig. 1: Water balance in vegetation areas and impervious areas

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 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 rainwater sewage system, the percolation, or new groundwater formation, for these areas can therefore be ascertained by subtracting the entry of rainwater into the sewage 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 average 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).

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, SenStadt 2004c and Map 06.02, SenStadt 2004d). Some thirty types of use have been distinguished. With the exception of single supplements, they represent the state of utilization as of the end of 2001.

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, SenStadtUm 1994). The data from this model were calculated for the center-point coordinates of the block segments.

For the **potential evaporation**, long-term mean average 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/yr. and between 495 and 505 mm for the summer semester were assigned.

The **degree of impervious coverage** was determined at the beginning of the '90s for each block segment, by evaluation of air and satellite photography, with consultation of the map of Berlin in a scale of 1: 4/5000 and the city planning file, and continued in 2001 in the context of a key-area update. The data initially did **not** include roadways (cf. Map 01.02, SenStadt 2004b). 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 structural types on test areas in the terrain, and then referenced to all block segments of the same structural type. In some cases, the surface-cover-class break-down for certain segments was ascertained from aerial photography, and thus diverged from the overall evaluation.

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 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 derived from the Berlin Soil Association Map (cf. Map 01.01, SenStadt 2005a) in the context of an expert report (Aey 1993).

For the determination of the **depths to water table**, a model of the terrain altitudes based on the digitalization and following interpolation of approx. 85,000 individual data on terrain altitude (cf. Map 01.08, SenStadt 2004b) was first developed. Parallel to that, a model of the height of the groundwater surface was compiled from measurements at observation pipes of the State Groundwater Service obtained in the measurement operation of May 2002. 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, SenStadt 2003).

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, available data on the area of roadways at the level of the statistical area were weighted for surface area and calculated for the segments.

The data on the **sewage system** were obtained from the Map Disposal of Rainwater and Sewage (cf. Map 02.09, SenStadt 2006), which shows the situation as of the end of 2005. The criterion was the existence of sewage lines for rainwater in the adjacent streets. The data is therefore initially independent of actual inflow of rainwater. The map only states whether the block is connected to the 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 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, special investigations have been necessary. For an estimate of the **actual degree of connection to the sewage system**, one new data source had become available since the first application of the model to Berlin (SenStadtUmTech 1999s). 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. Based on the consideration that the degree of connection is closely related to the age and structure of the buildings, general values were therefore determined arithmetically for each structural type from the BWB data and the map of building structures (cf. Map 06.07, SenStadt 2005b), which covers all areas, and assigned to all single blocks connected to the sewage system. The results are summarized in Tab. 1. A comparison of the values with those ascertained by Bach (1977) yielded good agreement. Only in one case, that of the Urban Structural Type P (green and open areas with little or no built-up component), does the degree of connection of the non-built-up impervious surfaces differ strongly from the value determined by Bach – 66%, as opposed to his 20. Since the analysis of the BWB database had shown that it was especially in these areas that the non-built-up impervious areas had been assessed insufficiently or not at all, Bach's value was used for this structural type. The actual degrees of sewage connection of roadway areas were also assigned as per Bach, since these areas had not been included in the BWB survey.

Tab. 1 :Effective Degree of Connection of Impervious Areas to the Sewage System (Sewage Service Level) for Berlin Urban Structural Types, calculated from data obtained from the Berlin waterworks						Apr. 6, 2005 Edition
			Degree of Connection to Sewage System (%)			
	Urban structure type	Section type	Built-up impervious areas	Non-built-up impervious areas	Impervious street areas (Bach 1997)	Number of data sets
A	Imperial-era block development with wings and rear buildings	1 - Closed courtyard 2 - Courtyard 5 - Preservation-oriented reconstruction	96	71	94	1256
B	Imperial-era block-edge development with few wings / rear buildings	3 - Decorative and garden court 6 - Shed court	83	56	91	633
C	Imperial-era block-edge development with major changes	4 - Reconstruction by decorating 7 - Post-war block edge	94	68	93	418
D	Twenties and thirties block-edge and row development	10 - Large court 72 - Row development (20's/30's)	89	57	87	748
E	Fifties and later row development	11 - Row development (>50's)	88	54	89	737
F	Post-war high-rise development	8 - Unplanned reconstruction 9 - Large settlement area	94	73	92	525
G	Eighties and nineties	71 - Settlement	95	76	90	83

	block-edge or row development	development				
R		73 - Residential areas of the nineties >= 4 floors	84	65	90 (estimated)	104
S		74 - Residential areas of the nineties < 4 floors	84	71	90 (estimated)	31
H	Low buildings with yards	21 - Villages 22 - Rowhouses w/ yard 23 - Yards 26 - Open residential development 59 - Weekend cottages	41	35	77	3171
I	Villa development with park-like gardens	24 - Park-like gardens	60	47	67	549
J	Development with yards and semi-private re-greening	25 - Yards and semi-private re-greening	62	40	70	313
L	Development with predominately commercial and service use	29 - Core areas 39 - Excursion restaurants	95	83	98	216
M	Low development with predominately small business and industrial use	30 - Industry / small business area A 32 - Utilities area 33 - Mixed area 2 (development <50%)	78	72	89	867
N	Dense development with predominately small business and industrial use	31 - Industry / small-business areas B 38 - Mixed area 2 (development >50%)	88	83	92	141
O	Development with predominately public facilities and special use	12 - Schools (old buildings) (<1940) 13/14 - Schools / new schools 41 - Law enforcement 42 - Postal 43 - Administrative 45 - Cultural	93	79	88	721
		44 - Universities and research 46 - Hospitals 47 - Day-care centers 49 - Churches 50 - Retirement home 51 - Youth centers 60 - Public facilities, misc.	85	74	89	456
P	Green and open spaces with little or no built-up component	15 - Water sports 27 - Cemeteries 28 - Sports facilities 34,35,37 - Allotment gardens 36 - Tree nurseries 53 - Green space / parks 54 - City squares / promenades 57 - Vacant areas 58 - Campgrounds	74	66	81	1116
Q	Non-street traffic areas with	92 - Railroad properties	82	72	-	10

little or no built-up component	99 - Railroad embankments	88	77	-	79
	91 - Parking lots	87	96	95	35
	93 - Airports	100	100		8
	94 - Other traffic areas	100	100	95	5

Tab. 1: Effective degree of connection of impervious areas to the sewage system (sewage service level) for Berlin urban structural types

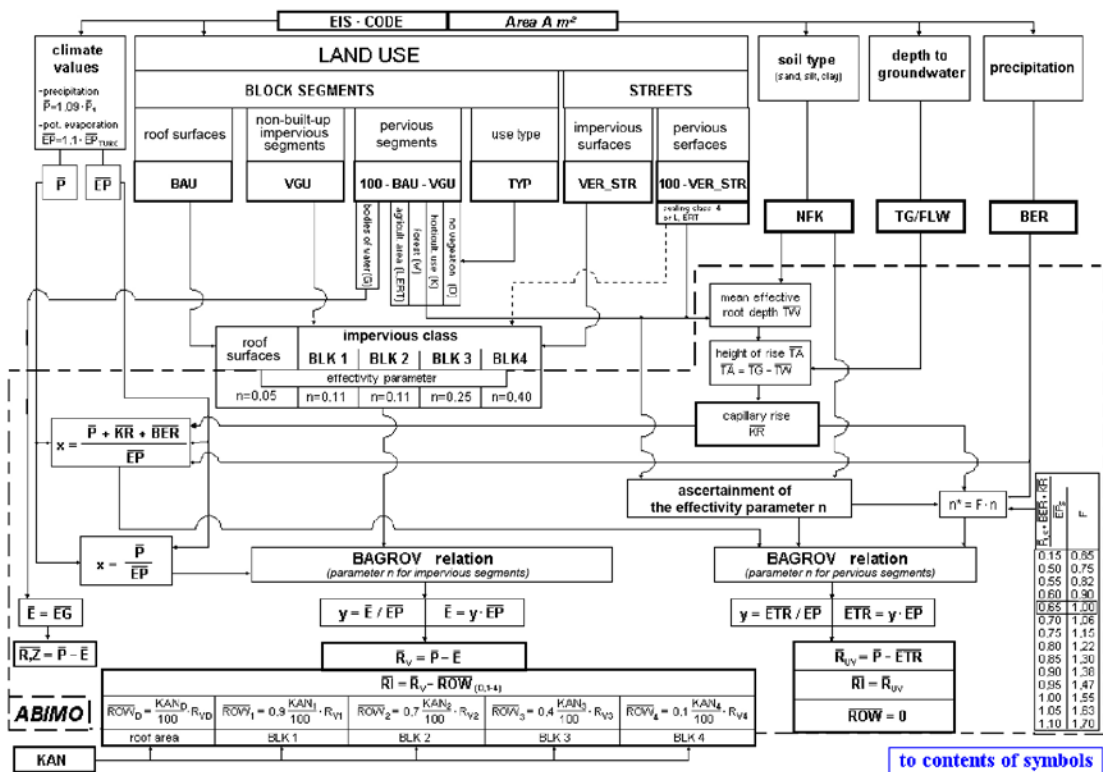
For the determination of percolation without consideration for impervious coverage (Map 02.13.4), the input data were changed by setting the impervious coverage level to zero for all sections, and hence effectively not considering it. The surface area of roadways was also set to zero, so that the resulting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

Methodology

Approx. ten years ago, 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 Hydrology Agency. The approximately 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) and applied again with updated data for the drainage of the rainwater via the sewage system.

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)

- \bar{P}_1 precipitation (1 m above the ground)
- \bar{P} precipitation at the soil surface
- \bar{KR} capillary rise from ground water near surface
- \bar{EP} potential evaporation ($EP = 1.1 \cdot EP_{TURC}$)
- \bar{ETR} real evapo-transpiration of vegetation covered land areas
- \bar{EG} evaporation from bodies of water
- \bar{E} real evaporation of impervious areas and areas without vegetation (and from the surfaces of bodies of water)
- \bar{BER} amount of precipitation water
- $\bar{Z} = \bar{P} - (\bar{E}, \bar{ETR}, \bar{EG})$ depletion of ground and surface water
 $(\bar{E}, \bar{ETR}, \bar{EG}) > \bar{P}$
- \bar{R}_v total runoff (impervious area)
- \bar{R}_{uv} total runoff (pervious area)
- \bar{ROW} rainwater and/or meltwater runoff from impervious area into the sewer system (or stream)
- \bar{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

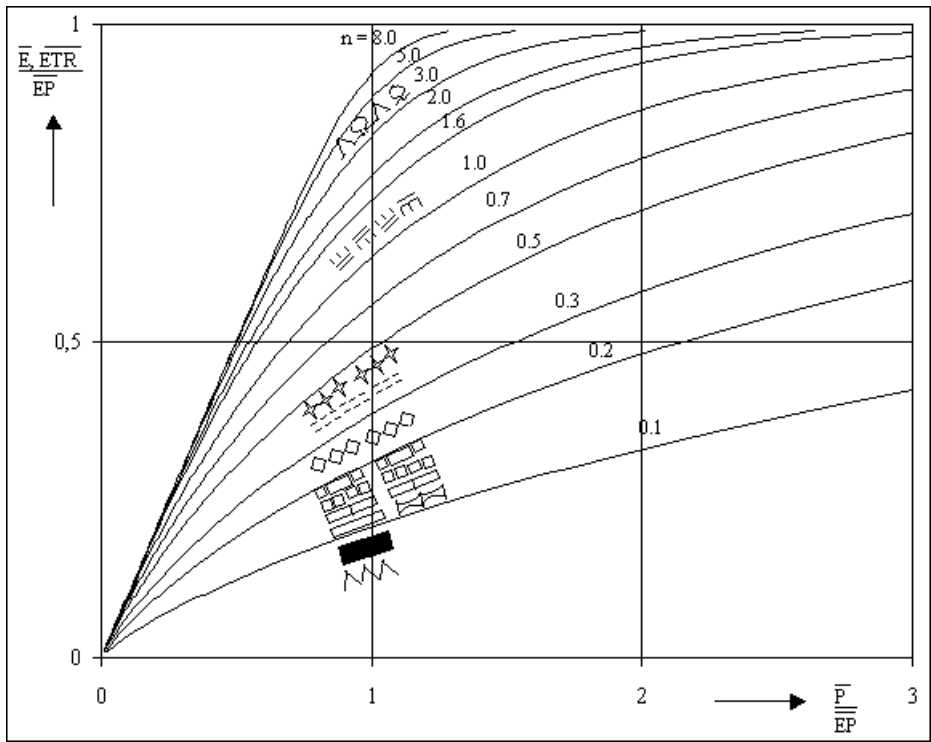
TG	depth to the water table (value in m – FLW) for the determination of KR
TA	height of rise (m), $TA = TG - TW$
TW	mean effective root depth (m)

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

Total Runoff

Total runoff is calculated from the difference between long-term annual mean precipitation values and real evaporation. **Real evaporation** as it is actually encountered, as a 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 higher 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 fulfills 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 lysimeter 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.



- sandy soil, forestry use
- sandy soil, agricultural use
- vegetation-free sandy soil
- grass pavers
- Bernburg 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:

- $\overline{E, ETR}$ 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

Fig.3: Representation of the Bagrov equation for select values of the parameter n, and dependence of this parameter upon land use and soil type (from Glugla et al. 1995)

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 effectiveness of pervious soil is the **usable field capacity** as a difference of 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 lysimeter stations and water-balance tests in river-catchment areas.

For sites and areas with surface-proximate 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) a uniform approximation value was added to the precipitation to take irrigation into account.

Surface Runoff

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 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-cover types). This Infiltration factor is dependent on the width, age and type of the seams. The non-percolating runoff is passed to the sewage system as surface runoff – depending on the degree of connection to the sewage system – or, if the sewage 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 sewage system also percolate into the soil (cf. Tab. 1). The difference between total runoff and surface runoff thus corresponds to **percolation** as a basic quantity for new groundwater formation.

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 lysimeter 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-cover types into surface-cover 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
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, gravel	0.4	0.9

Tab. 2: Effectivity Parameter n und 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 sewage system would affect the water balance, the ABIMO model was used for approx. 35 model sections with different input quantities; the results are shown in Table 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 sewage system.

Tab. 3 : Relationship between surface runoff, percolation and evaporation for areas of various types, imperviousness etc.														
Area description	degree of imperviousness in %	impervious areas, of which		Imperviousness class of non built-up areas (see Tab. 2): Surface cover -8in %)				connection to sewage system yes/no	sewage system connection, impervious areas, in %		soil (1)	sur-face runoff	perco-lation	evapo-ration
		built-up	non-built-up	1	2	3	4		built-up	non built-up				
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	10	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
Single-family homes with large garden areas	35	25	10	0	0	33	67	1	56	35	2	9	39	53
Single-family 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
Single-family homes with hollow drainage-trench systems	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 systems	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 areas	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 degree of imperviousness	87	47	40	21	38	27	14	1	94	68	52	43	26	31
Transportation areas/ 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 areas, 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)

A new version of the program ABIMO was used for the present 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 with the sewage system.

As a result of these calculations, updated long-term mean values for total runoff, surface runoff and percolation are available for each of the 25,000 separate sections. These values have been shown classified in mm/year in these maps; the totals in cu.m./year have also been calculated and averaged. It must be taken into account that the values shown are mean values covering the sections represented as uniform areas; in fact, however, they have non-homogeneous structures. The runoffs of impervious and pervious areas have been standardized to average 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 (Urban-Rail Ring Line) is in the range of 350-450 mm/yr.; the values are even higher in the very dense center-city area and in some industrial areas. Here, only about 150 mm/yr. (Map 02.13.5) evaporate, referenced to the precipitation measurements (at 1 m height), which are about 10-15% less than the ground-level precipitation. The less densely built-up areas in the outskirts of the city show runoffs of 250-350 mm/yr. Compared with the runoffs of the pervious areas on the outskirts, or in the areas surrounding Berlin, where the values are approximately 150 mm/yr., 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 run-off.

Groundwater net consumption 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 sewage system, an average of about 250 mm/yr. is fed to the sewage system. Peaks values are more than 350 mm/yr. In outlying areas connected to the sewage system, the values are around 100 mm/yr.

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/yr. – roughly the same as for woodlands. The non-densely built-up residential areas on the outskirts show considerably higher percolation capacities of 200 mm/yr.; the values for the areas with low degrees of connection to the sewage system in fact climb to 300 mm/yr. In the residential areas with no connection to the sewage system, all the runoff percolates into the soil, averaging about 300-350 mm/yr. and reaching maximum values of over 400 mm/yr.

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 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 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 ground-moraine highlands of Barnim and Teltow 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 2007).

The evaporation from **bodies of waters surfaces**, which are not shown on the map, is approx. 160 mm/yr. more than the precipitation which falls on them, so that Berlin’s bodies of water lose a total of approx. 9 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 sewage 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 percolation to be overestimated.

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

Tab. 4: Long-term Mean Values of Runoff Formation (determined with ABIMO3)			
	area [km²]	mm/yr.	million cu.m./yr.
Total Berlin (without bodies of water)	840		
Precipitation (measured values, uncorrected)	840	570	478
Evaporation (Precipitation – Total Runoff)	840	312	262
Total Runoff	840	258	216.8

Surface Runoff thereof	840	80	67.7
Combined sewage system	81	256	20.7
Separate sewage system	310	151	46.9
Percolation	840	177	149.1
New groundwater formation	840	149	125.5
Bodies of Water	54		
Depletion (Precipitation – Evaporation)		-158	-9
*) area-weighted			
Note: Because of imprecisions in area determination, the total area of Berlin given is about 2 km ² larger than the true area size.			

Tab. 4: Long-term mean runoff formation values (determined with ABIMO3)

The calculations show that about 60% of the precipitation evaporates, and thus about 200 million cu.m./year are available as total runoff. Three quarters of this percolates into the soil to the sub-surface, while one quarter is passed through the sewage system. Although the mixed-sewage system covers only about one quarter of the total area served by the sewage systems, it accounts for a third of total surface runoff. Comparing the annual percolation quantity of approx. 150 million cu.m., which, as stated above, is not entirely fed into the groundwater, with drinking water consumption of approx. 250 million cu.m. per year, 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 2001 figures, the most noticeable fact is that the long-term mean of surface drainage, which has hitherto been 54.8 cu.m./year, has now risen to 67.7 cu.m./year. In addition, a slight rise in overall runoff and a slight reduction in percolation can be observed.

Two circumstances can be identified as the primary reasons for these changes:

- Thanks to the incorporation of more current and generally improved documentation on the rainwater sewage system, considerably more areas than at the last evaluation are today recognized as being served by the rainwater system. This primarily affects the increase in surface drainage, since only a part of the precipitation of the impervious areas reaches the sewage system.
- A change in the parameter control for the degree of connection of roof surfaces with the sewage system is an essential reason for the major increase in surface drainage. In the new program ABIMO 3, higher values for the connection degree of surfaces on buildings are considered than in the old program, which results in greater drainage.

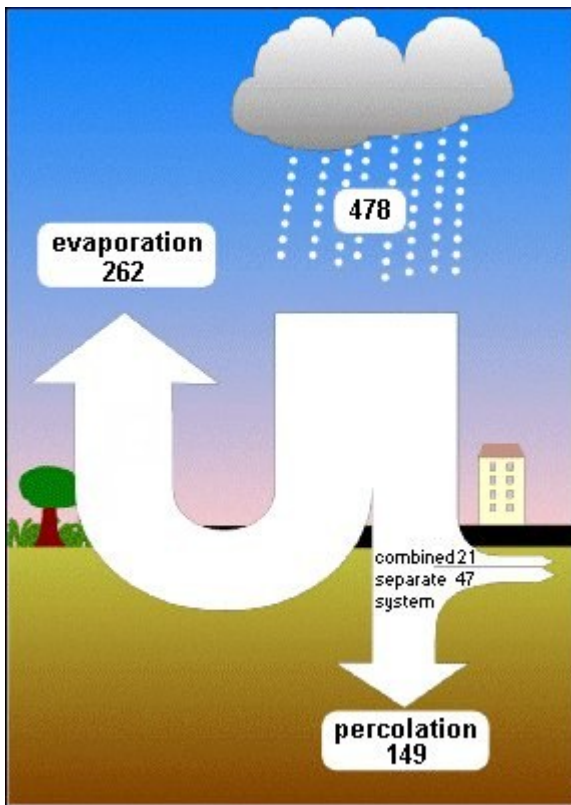


Fig.4: The Berlin water balance (long-term mean values in million cu.m., without bodies of water)

For each section served by the separate-sewage 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.) 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 180 bodies of water or body-of-water segments are involved.

Table 5 shows the amounts of introduction into the Berlin bodies of water, 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 sewage 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.

Tab. 5: Surface Runoff from the Separate Sewage System into Bodies of Water in Berlin, as Long-term Mean Values (data 12/2005; interpretation 01/2007)			
No.	Surface Water Segment ('see' = lake)	Area (km)	Total (cu.m/yr.)
Flow area of the Havel River			
110	Upper Havel to mouth of Tegel Lake	1.6	0.17
120	Upper Havel (mouth of Tegel Lake to Spandau watergate)	4.2	0.78
130	Tegeler See (Tegel Lake)	2.5	0.51
131	Tegeler Fließ (Tegel Creek)	5.8	0.52
132	Nordgraben ("North Ditch")	11.0	1.55
133	Panke north of Verteilerbauwerk	5.7	0.69
210	Lower Havel (Spree mouth to Jungfernsee)	12.6	1.74
220	Great Wannsee	2.4	0.21
230	Kleine Wannseekette (little chain of lakes)	1.5	0.12
Flow area of the Spree River			
310	Müggel-Spree (incl. Great Müggel Lake and Erpe)	8.6	1.17
320	Langer See (Long Lake), Dahme, Große Krampe (lake)	7.5	0.82
330	City Spree to Britz er Zweigkanal (canal)	7.5	1.55
331	Wuhle (creek)	23.2	3.11
340	City Spree to Landwehrkanal	7.3	1.31
350	Rummelsburg Lake	9.6	2.32

351	Marzahn-Hohenschönhausener Grenzgraben (border ditch)	16.8	3.38
380	City Spree to Berlin-Spandau Shipping Canal	6.5	1.22
390	City Spree to mouth	7.4	1.40
400	Canals north of the Spree	7.8	1.70
401	Panke (Verteilerbauwerk to Nordhafen port)	19.1	2.93
500	Canals south of the Spree (Neuk. SK and Landwehrkanal)	6.8	1.79
Flow area of the Teltow Canal			
600	Teltow Canal	64.6	8.90
610	Rudow Arm	24.5	2.96
620	Britz Verbindungskanal	2.7	0.49
Lakes, ponds, etc.			
810	Grunewaldseenkette (chain of lakes)	10.4	1.53
820	Flughafensee (Airport Lake)	6.2	1.08
830	Biesdorfer Baggersee (Artificial Lake)	4.1	0.53
840	Fauler See/Obersee (lakes)	1.4	0.18
850	Schäfersee (lake)	2.3	0.51
860	Gross-Glienecker See (lake)	1.0	0.11
900	Other small bodies of water (ponds, ...)	17.8	1.67
Seperate sewage system (sum)		310.4	46,9
Mixed sewage system		81.0	20.7

Tab. 5: Surface Runoff from the Separate Sewage System into Bodies of Water in Berlin, as Long-term Mean Values (data 12/2005; interpretation 01/2007)

The ABIMO model or program 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 urban development projects, or of measures for the restoration of perviousness, including the disconnection of areas from the sewage system, to permit percolation of precipitation there. With appropriately differentiated data, the program 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.

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 highlands, 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 highland areas of Teltow and Barnim, 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 surface-near 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 are 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 sewage system. If partially water-permeable impervious coverage is planned, or if the precipitation water runoff is to be only partially passed into the sewage 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.

Literature

- [1] **Aey, W. 1993:**
Zuordnung von Bodenkenngrößen zu Bodengesellschaften und Nutzungen, [*Assignment of soil characteristic quantities to soil associations and uses*], expert report commissioned by the Senate Department for Urban Development and Environmental Protection, Berlin.
- [2] **Bach, M. 1997:**
Erfassung des Kanalisierungsgrades versiegelter Flächen für ein urbanes Niederschlags-Abfluß-Modell am Beispiel Berlin [*Ascertainment of degrees of sewage-system connection of impervious areas for an urban precipitation runoff model, using the example of Berlin*], thesis at the Earth Sciences Department of the Free University of Berlin.
- [3] **Bamberg, H. F., Busse, W., Ginzel, G., Glugla, G., Schlinker, K., Ziegler, G. 1981:**
KdT-Empfehlung zur Ermittlung der Grundwasserneubildung [*KdT Recommendation for ascertaining new groundwater formation*]. Central Geological Institute. As special WTL 5, Berlin.
- [4] **Berlekamp, L.-R., Pranzas, N. 1992:**
Erfassung und Bewertung von Bodenversiegelung unter hydrologisch-stadtplanerischen Aspekten am Beispiel eines Teilraums von Hamburg [*Ascertainment and assessment of soil impervious coverage, considering hydrological city-planning aspects, using the example of a part of Hamburg*]. Dissertation, Hamburg.
- [5] **Glugla, G., Tiemer, K. 1971:**
"Ein verbessertes Verfahren zur Berechnung der Grundwasserneubildung" [*An improved method for the calculation of new groundwater formation*]. Wasserwirtschaft-Wassertechnik, 21 (10):pp. 349 -353, Berlin.
- [6] **Glugla, G., Enderlein, R., Eyrich, A. 1976:**
"Das Programm RASTER – ein effektives Verfahren zur Berechnung der Grundwasserneubildung im Lockergestein" [*RASTER Program – a more effective procedure for the calculation of the new groundwater formation in loose roc*], Wasserwirtschaft-Wassertechnik, 26 (11): pp. 377 -382, Berlin.
- [7] **Glugla, G., König, B. 1989:**
"Der mikrorechnergestützte Arbeitsplatz Grundwasserangebot" [*The microcomputer-aided workplace for groundwater supply*]. Wasserwirtschaft-Wassertechnik, 39 (8): pp. 178 -181, Berlin.
- [8] **Glugla, G., Eyrich, A. 1993:**
"Ergebnisse und Erfahrungen bei der Anwendung des BAGROV-GLUGLA-Verfahrens zur Berechnung von Grundwasserhaushalt und Grundwasserneubildung im Lockergestein Norddeutschlands" [*Results and experiences in the application of the Bagrov-Glugla method to the calculation of basic water balance and new groundwater formation in the loose rock of Northern Germany*]. Kolloquium Hydrogeologie 10/93 Erfurt, pp. 22 -26.
- [9] **Glugla, G., Krahe, P. 1995:**
Abflußbildung in urbanen Gebieten [*Runoff formation in urban areas*]. Document series, *Hydrologie/Wasserwirtschaft* 14, Ruhr University of Bochum, pp.140 160.
- [10] **Glugla G., Fürtig, G. 1997:**
Dokumentation zur Anwendung des Rechenprogramms ABIMO [*Documentation on the application of the computer program ABIMO*] Federal Institute of Hydrology, Berlin office.
- [11] **Glugla, G., Müller, E. 1997:**
"Grundwasserneubildung als Komponente der Abflussbildung" [*New groundwater formation as a component of runoff formation*]. in: C. Leibundgut & S. Demuth (eds.): Grundwasserneubildung (New groundwater formation). Freiburger Schriften zur Hydrologie. Vol. 5, pp. 23-35.
- [12] **Glugla, G., Goedecke, M, Wessolek, G., Fürtig, G. 1999:**
"Langjährige Abflußbildung und Wasserhaushalt im urbanen Gebiet Berlin" [*Long-term runoff formation and water balance in the Berlin area*]. Wasserwirtschaft, Vol. 89 No.1 1999 pp. 34 -42.
- [13] **Glugla, G., et.al. 2003:**

BAGLUVA Wasserhaushaltsverfahren zur Berechnung vieljähriger Mittelwerte der tatsächlichen Verdunstung und des Gesamtabflusses, BfG - 1342, Bundesanstalt für Gewässerkunde, Koblenz.

- [14] **Graf, H. F. 1979:**
Der Einfluß von Großstädten auf das Niederschlagsregime am Beispiel von Berlin [*Effect of cities on the precipitation system, the example of Berlin*]. Diss. A, Humboldt University of Berlin.
- [15] **Kleeberg, H.-B., Niekamp, O. 1994:**
"Klimaänderung und Wasserwirtschaft" [*Climate change and water management*]. Lecture at the 3rd German climate conference, Conference Book pp. 136 -140, Potsdam.
- [16] **Köppel, J., Deiwick, B. (TU Berlin) 2004:**
Verfahren zur Bewertung und Bilanzierung von Eingriffen im Land Berlin [*Procedure for the assessment and calculation of interventions in the state of Berlin*]. Expert report commissioned for Senate Department of Urban Affairs, not published.
- [17] **Rachimov, C. (pro data consulting) 1996:**
ABIMO 2.1, Abflußbildungsmodell, Algorithmus zum BAGROV-GLUGLA-Verfahren für die Berechnung langjähriger Mittelwerte des Wasserhaushalts [*ABIMO 2.1, runoff formation model, algorithm on the Bagrov-Glugla method for calculating long-term mean average water-balance values, program description*]; for the Federal Institute of Hydrology, Berlin, not published.
- [18] **Rachimov, C., Rachimov, M. (pro data consulting) 2006:**
ABIMO 3, Abflussbildungsmodell, Algorithmus zum BAGROV-GLUGLA-Verfahren für die Berechnung langjähriger Mittelwerte des Wasserhaushalts, Programmbeschreibung; im Auftrag der Senatsverwaltung für Stadtentwicklung, not published.
- [19] **Richter, D. 1979:**
Informationsspeicher für die einheitliche Bestimmung der Verdunstungshöhe von freien Wasserflächen. [*Information bank for the uniform regulation of the evaporation height of free water areas*]. Research Institute for Hydrometeorology of the Meteorological Service of the GDR [East German meteorological office], not published.
- [20] **Wessolek, G. 1994:**
Auswertung von Versuchen zur Ermittlung der Abflußverhältnisse unterschiedlich versiegelter und kanalisierter Flächen Berlins [*Evaluation of tests for the ascertainment of the runoff conditions of variously impervious and sewage-served areas of Berlin*], under commission for the Federal Institute of Hydrology, Berlin office, not published.
- [21] **Wessolek, G., Facklam, M. 1997:**
"Standorteigenschaften und Wasserhaushalt von versiegelten Flächen" Zeitschrift für Pflanzenernährung und Bodenkunde, 160. pp. 41-46. [*Site qualities and water balances of impervious areas*]

Maps

- [22] **Dyck, S. et al. 1978:**
Map of the potential evaporation, in: Angewandte Hydrologie, vol. 2, Verlag für Bauwesen, 1:1,000,000, Berlin.
- [23] **SenStadtUm (Senate Department for Urban Development and Environmental Protection, Berlin) (ed.) 1994:**
Berlin Environmental Atlas, 1994 version, Map 04.08.1-3 Long-Term Precipitation Distribution, Map 04.08.4 Runoff Formation from Precipitation, 1:125,000, Berlin.
- [24] **SenStadtUmTech (Senate Department for Urban Development, Environmental Protection and Technology, Berlin) (ed.) 1996 B:**
Berlin Environmental Atlas, digital version, Map 04.08.1-3 Long-Term Precipitation Distribution, Map 04.08.4 Runoff Formation from Precipitation, 1:125,000, Berlin.
- [25] **SenStadt (Senate Department for Urban Development, Berlin) (ed.) 2003:**

- Berlin Environmental Atlas, Map 02.07 Depths to Groundwater, 1:50,000, Berlin.
Internet:
<http://www.stadtentwicklung.berlin.de/umwelt/umweltatlas/eib207.htm>
- [26] **SenStadt (Senate Department for Urban Development, Berlin) (ed.) 2004a:**
Berlin Environmental Atlas, Map 01.02 Sealing of Soil Surface, 1:50,000, Berlin.
.Internet:
<http://www.stadtentwicklung.berlin.de/umwelt/umweltatlas/eia102.htm>
- [27] **SenStadt (Senate Department for Urban Development, Berlin) (ed.) 2004b:**
Berlin Environmental Atlas, digital version, Map 01.08 Area Heights, 1:50,000, Berlin.
Internet:
<http://www.stadtentwicklung.berlin.de/umwelt/umweltatlas/ei108.htm>
- [28] **SenStadt (Senate Department for Urban Development, Berlin) (ed.) 2004c:**
Berlin Environmental Atlas, Map 06.01 Actual Use of Built-Up Areas, 1:50,000, Berlin.
Internet:
<http://www.stadtentwicklung.berlin.de/umwelt/umweltatlas/eib601.htm>
- [29] **SenStadt (Senate Department for Urban Development, Berlin) (ed.) 2005 B:**
Berlin Environmental Atlas, Map 06.02 Inventory of Green and Open Areas, 1:50,000, Berlin.
Internet:
<http://www.stadtentwicklung.berlin.de/umwelt/umweltatlas/eib601.htm>
- [30] **SenStadt (Senate Department for Urban Development, Berlin) (ed.) 2005a:**
Berlin Environmental Atlas, Map 01.01 Soil Associations, 1:50,000, Berlin.
Internet:
<http://www.stadtentwicklung.berlin.de/umwelt/umweltatlas/eia101.htm>
- [31] **SenStadt (Senate Department for Urban Development, Berlin) (ed.) 2005b:**
Berlin Environmental Atlas, Map 06.07 Urban Structure, 1:50,000, Berlin.
Internet:
<http://www.stadtentwicklung.berlin.de/umwelt/umweltatlas/eib607.htm>
- [32] **SenStadt (Senate Department for Urban Development, Berlin) (ed.) 2006:**
Berlin Environmental Atlas, Map 02.09 Disposal of Rain and Sewage, 1:50,000, Berlin.
Internet:
<http://www.stadtentwicklung.berlin.de/umwelt/umweltatlas/eia209.htm>
- [33] **SenStadt (Senate Department for Urban Development, Berlin) (ed.) 2007:**
Berlin Environmental Atlas, Map 02.17 New Groundwater Formation, 1:50,000, Berlin.
Internet:
<http://www.stadtentwicklung.berlin.de/umwelt/umweltatlas/eia217.htm>