Senate Department for Urban Development

02.13 Surface Runoff, Seepage, Total Runoff and Evaporation from Precipitation (Edition 2005)

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 seepage, 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 seepage capacity of the soils, since the transportation of substances from contaminated soils occurs largely via seepage water,
- It is important for conservation and landscape management to assess the water availability for vegetation from new groundwater formation and capillary water rise from the groundwater table.

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 sealed 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 sealed 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.

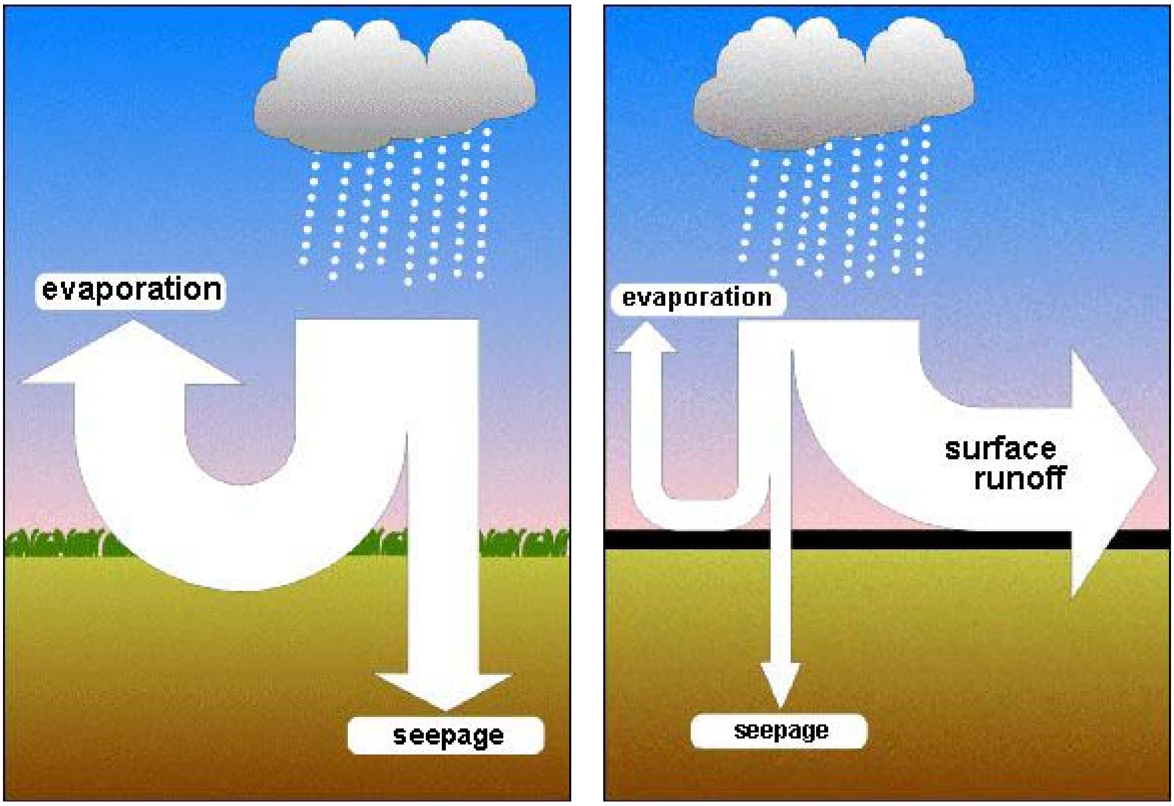


Fig.1: Water balance of vegetation areas and sealed areas

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 **sealed 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 sealed areas or within the partially sealed 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 seepage 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 seepage on unsealed soil surfaces is of special interest. On the one hand, the differing seepage capacity of soils can be derived from this value. On the other, the effect that any planned future sealing would have on the seepage 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 sealed and unsealed, and both sewer-system-connected and non-connected portions.

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

Statistical Base

The data for the calculation of the runoff quanta for the approx. 25,000 single areas of the ISU spatial reference system were provided by the Berlin City and Environment 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 2005a and Map 06.02, SenStadt 2005b). 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 of 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 sealing** determined for each block segment by evaluation of air and satellite photography, using the map of Berlin in a scale of 1: 4/5,000 and the city planning file at the beginning of the ‘90s, and continued in 2001 in the context of a key-area update. The data initially do **not** include the roadways (cf. Map 01.02, SenStadt 2004b). The data base distinguishes between the **built-up sealed** area (roof area) and the **non-built-up sealed** area (parking lots, walkways etc.). For the non-built-up sealed 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 sealing 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 sealing degree and surface-cover class distributions were assigned to all areas of each borough generally.

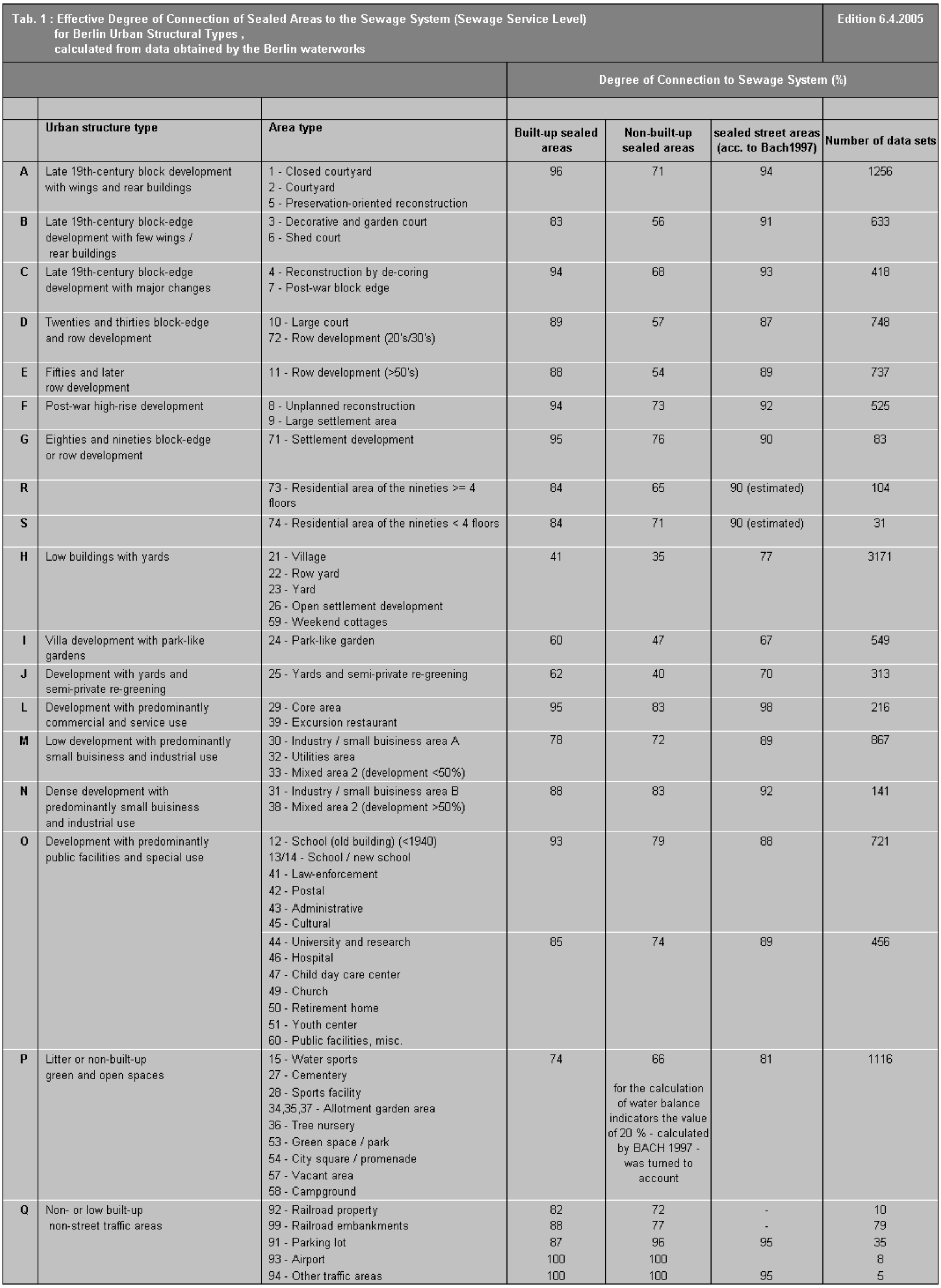
The **soil-scientific data** on the usable field capacity of the shallow-root zone (0-30 cm) and the usable field capacity of the deep-root zone (0-150 cm) were derived from the Berlin Soil Association Map (cf. Map 01.01) SenStadt 2005 in the context of an expert report (Aey 1993).

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 area altitude (cf. Map 01.08, SenStadt 1998c) 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-water-table data used for the calculation of the runoff were then calculated from the difference model between the altitude model and the groundwater height model (cf. Map 02.07, SenStadt 2003) for the center-point coordinates of the block segments.

The **area size** is used for the calculation of runoff volumes. The area size of each block segment (without roadway areas) is available from the ISU. In addition, the estimated area size 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 2004a, 2004b), which has in recent years been updated to the situation of ca. 2001 and digitalized. 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 area is connected to the sewage system at all. It is to be assumed that some highly sealed areas (mostly industrial and commercial areas) pass their rainwater on via the public sewage system or private pipes, but that no information is available on this.

However, the map does not yet state the extent to which the water derived from the built-up or sealed 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 sealed areas was carried out, which distinguished between connected and non-connected sealed 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 determining arithmetically for each structural type from the BWB data and the map of building structures (cf. Map 06.07, SenStadt 2005c), 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 (non- or little built-up green and open areas), does the degree of connection of the non-built-up sealed 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 sealed 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 Sealed Areas to the Sewage System (Sewage Service Level) for Berlin Urban Structural Types , calculated from data obtained by the Berlin waterworks

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			Degree of Connection to Sewage System (%)			
	Urban structure type	**Area type**	**Built-up sealed areas**	**Non-built-up sealed areas**	**sealed street areas (acc. to Bach1997)**	**Number of data sets**
A	Late 19th-century block development with wings and rear buildings	1 - Closed courtyard 2 - Courtyard 5 - Preservation-oriented reconstruction	96	71	94	1256
B	Late 19th-century block-edge development with few wings / rear buildings	3 - Decorative and garden court 6 - Shed court	83	56	91	633
C	Late 19th-century block-edge development with major changes	4 - Reconstruction by de-coring 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 block-edge or row development	71 - Settlement development	95	76	90	83
R		73 - Residential area of the nineties >= 4 floors	84	65	90 (estimated)	104
S		74 - Residential area of the nineties < 4 floors	84	71	90 (estimated)	31
H	Low buildings with yards	21 - Village 22 - Row yard 23 - Yard 26 - Open settlement development 59 - Weekend cottages	41	35	77	3171
I	Villa development with park-like gardens	24 - Park-like garden	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 predominantly commercial and service use	29 - Core area 39 - Excursion restaurant	95	83	98	216
M	Low development with predominantly small buisiness and industrial use	30 - Industry / small buisiness area A 32 - Utilities area 33 - Mixed area 2 (development <50%)	78	72	89	867
N	Dense development with predominantly small buisiness and industrial use	31 - Industry / small buisiness area B 38 - Mixed area 2 (development >50%)	88	83	92	141
O	Development with predominantly public facilities and special use	12 - School (old building) (<1940) 13/14 - School / new school 41 - Law-enforcement 42 - Postal 43 - Administrative 45 - Cultural	93	79	88	721
		44 - University and research 46 - Hospital 47 - Child day care center 49 - Church 50 - Retirement home 51 - Youth center 60 - Public facilities, misc.	85	74	89	456
P	Litter or non-built-up green and open spaces	15 - Water sports 27 - Cementery 28 - Sports facility 34,35,37 - Allotment garden area 36 - Tree nursery 53 - Green space / park 54 - City square / promenade 57 - Vacant area 58 - Campground	74	66 for the calculation of water balance indicators the value of 20 % - calculated by BACH 1997 - was turned to account	81	1116
Q	Non- or low built-up non-street traffic areas	92 - Railroad property	82	72	-	10
		99 - Railroad embankments	88	77	-	79
		91 - Parking lot	87	96	95	35
		93 - Airport	100	100		8
		94 - Other traffic areas	100	100	95	5

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

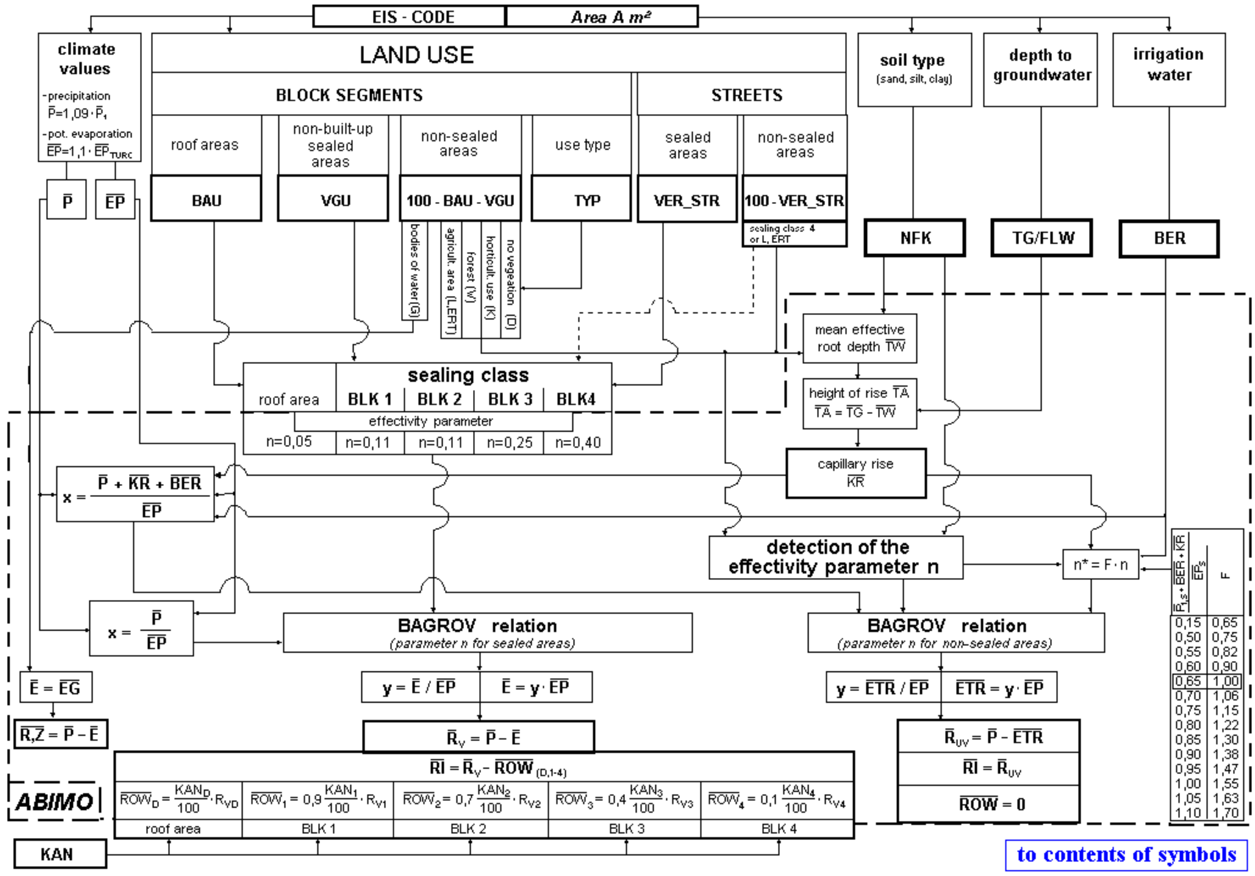
For the determination of seepage without consideration for sealing (Map 02.13.4), the input data were changed by setting the sealing level to zero for all areas, and hence effectively not considering it. The area size of roadways was also set to zero, so that the resulting values refer only to the unsealed surfaces of the block areas.

Methodology

Almost 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 City and Environment Information System (ISU) for each of the approx. 25,000 single areas. This model has now been used unchanged, albeit with updated data (cf. Data Base).

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 seepage. Fig.2. conveys an impression of the complexity of this procedure.



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yearly average values (mm/a)

$\overline{P_1}$	precipitation (1 m above the ground)
$\overline{P}$	precipitation (1 m above the ground)
$\overline{KR}$	capillary rise from ground water near surface
$\overline{EP}$	potential evaporation $\left(\overline{EP} = 1{,}1 * \overline{EP}_{TURC}\right)$
$\overline{ETR}$	real evapotranspiration of vegetation covered land areas
$\overline{EG}$	percolation above bodies of water
$\overline{E}$	real evaporation of sealed areas and areas without vegetation (and of surfacial water areas)

$\overline{BER}$	amount of irrigation 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 from ground and surface water
$\overline{R}_v$	total runoff (sealed area)
$\overline{R}_{uv}$	total runoff (unsealed area)
$\overline{ROW}$	rainwater and/or meltwater runoff of a sealed area into a sewer system (receiving stream)
$\overline{RI}$	infiltration into the soil (below the zone influenced by percolation)
sealed areas (in %)	
BAU	roof area
VGU	yard and parking area (non-built-up sealed area)
VER_STR	streets
BLK 1, ..., 4	sealing class of non-built-up sealed area
KAN	percentage of sealed areas connected to the rainwater drainage system
land use of unsealed areas	
L	agricultural land use (incl. pastures)
W	forest land use (assumption of an even distribution of inventories in respect of age)
K	horticultural land use (program intern: BER = 75 mm/a)
D	area without vegetation
G	area of surface water
soil type	
NFK	useable field-moisture capacity (volume moistness (Vol%) of field-moisture capacity minus Vol% of permanent wilt point)
S, U, L, T	indication to soil type (sands, silts, clays;
N, H	lower moor, upper moor) for the determination of capillary rise
depth to ground water and capillary rise	
TG	depth to ground water (value FLW in m) 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 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 real evaporation/potential evaporation quotient (ER/EP), and hence the real evaporation ER for sites and areas without groundwater influence can be ascertained, provided the climate quanta precipitation P and potential evaporation EP (quotient P/EP), and the effectivity parameter n of the quotient are known. The Bagrov method is also used in modified form to calculate the groundwater-influenced evaporation, adding the mean capillary water rise from the groundwater to the precipitation.

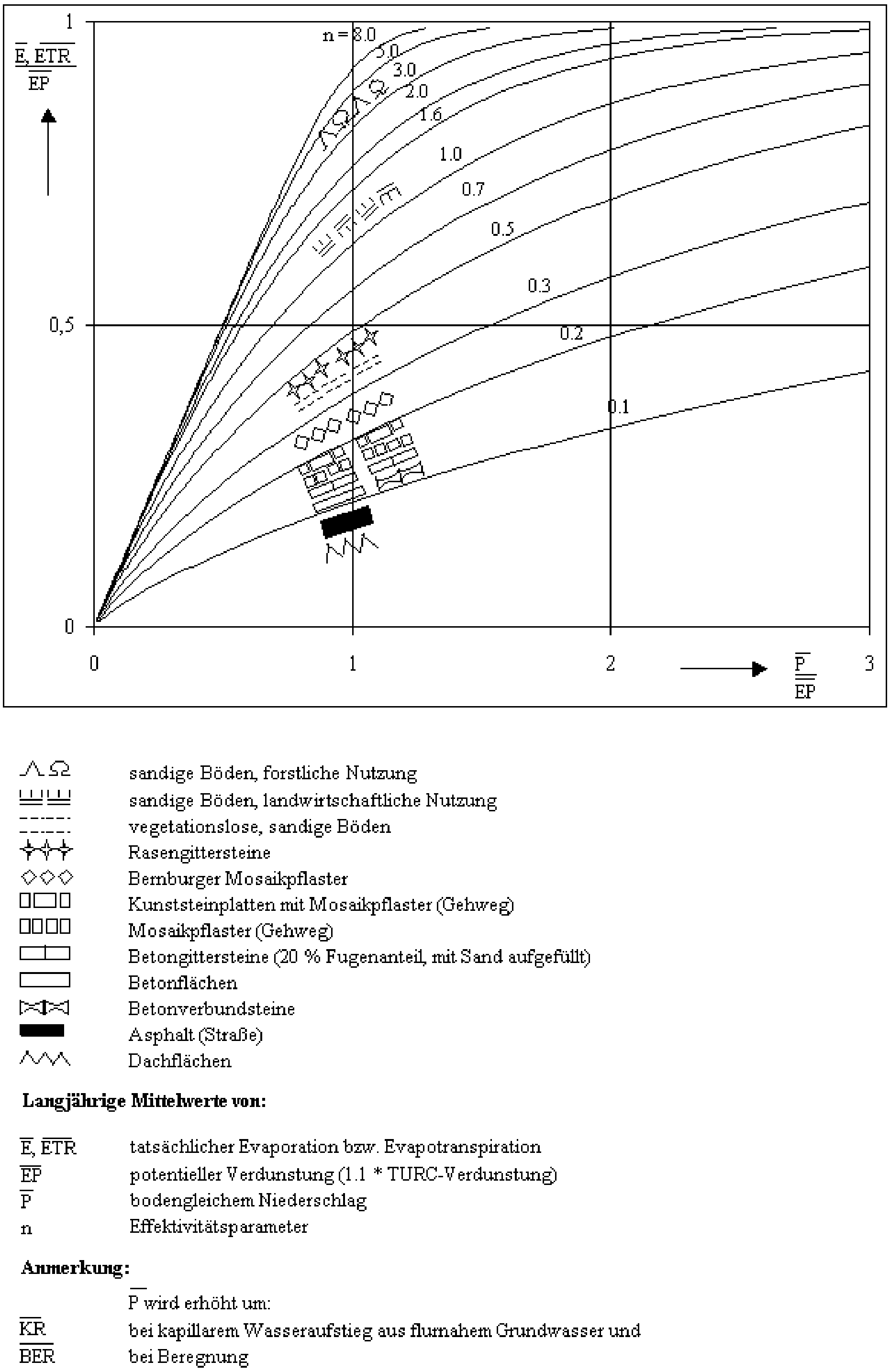


Fig.3: Representation of the Bagrov equation for select values of the parameter n, and dependence of this parameter upon land use and soil type (from Glugla et al. 1995)

With growing precipitation P, the value of real evaporation ER approaches that of potential evaporation EP i.e., the ER/EP quotient approaches the value of 1. At reduced precipitation P (P/EP approaches the value 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: sealed 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 unsealed soil is the **usable field capacity** as a difference of the humidity values of the soil for field capacity (beginning of water seepage 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.

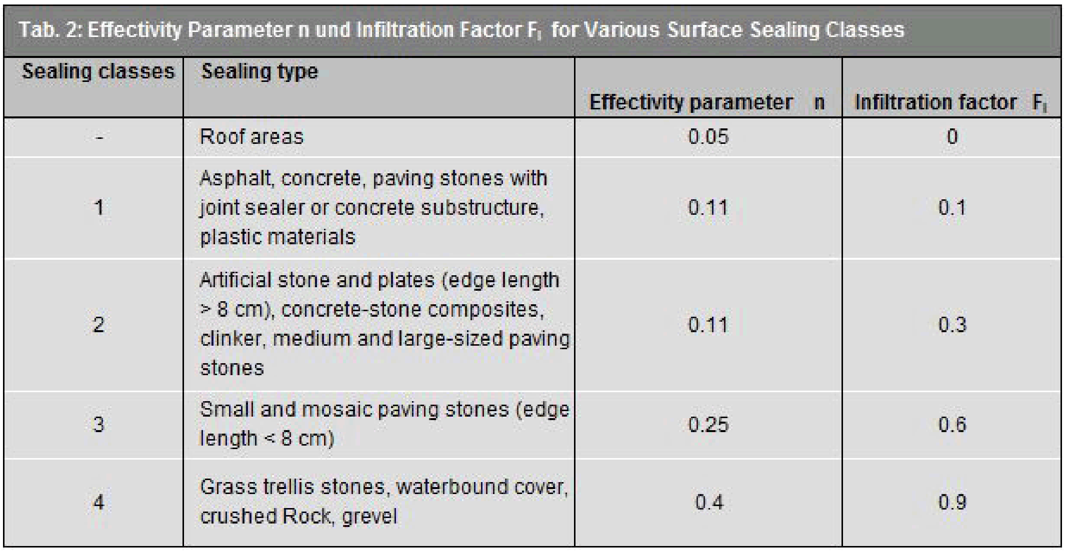
For sites and areas in surface-near groundwater, increased evaporation compared with non-groundwater-uninfluenced conditions occurs in the evaporation-influenced soil zone due to capillary rise of groundwater, depending on the depth to water table and soil qualities. Runoff is reduced. If real evaporation 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 seepage, 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.

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 sealed 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-seeping 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, seeps away at the edge of the sealed areas. Those portions of the precipitation onto roof areas not connected to the sewage system also seep away (cf. Tab. 1). The difference between total runoff and surface runoff thus corresponds to **seepage** 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 sealing materials. Both lysimeter tests were evaluated with different sealing 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.

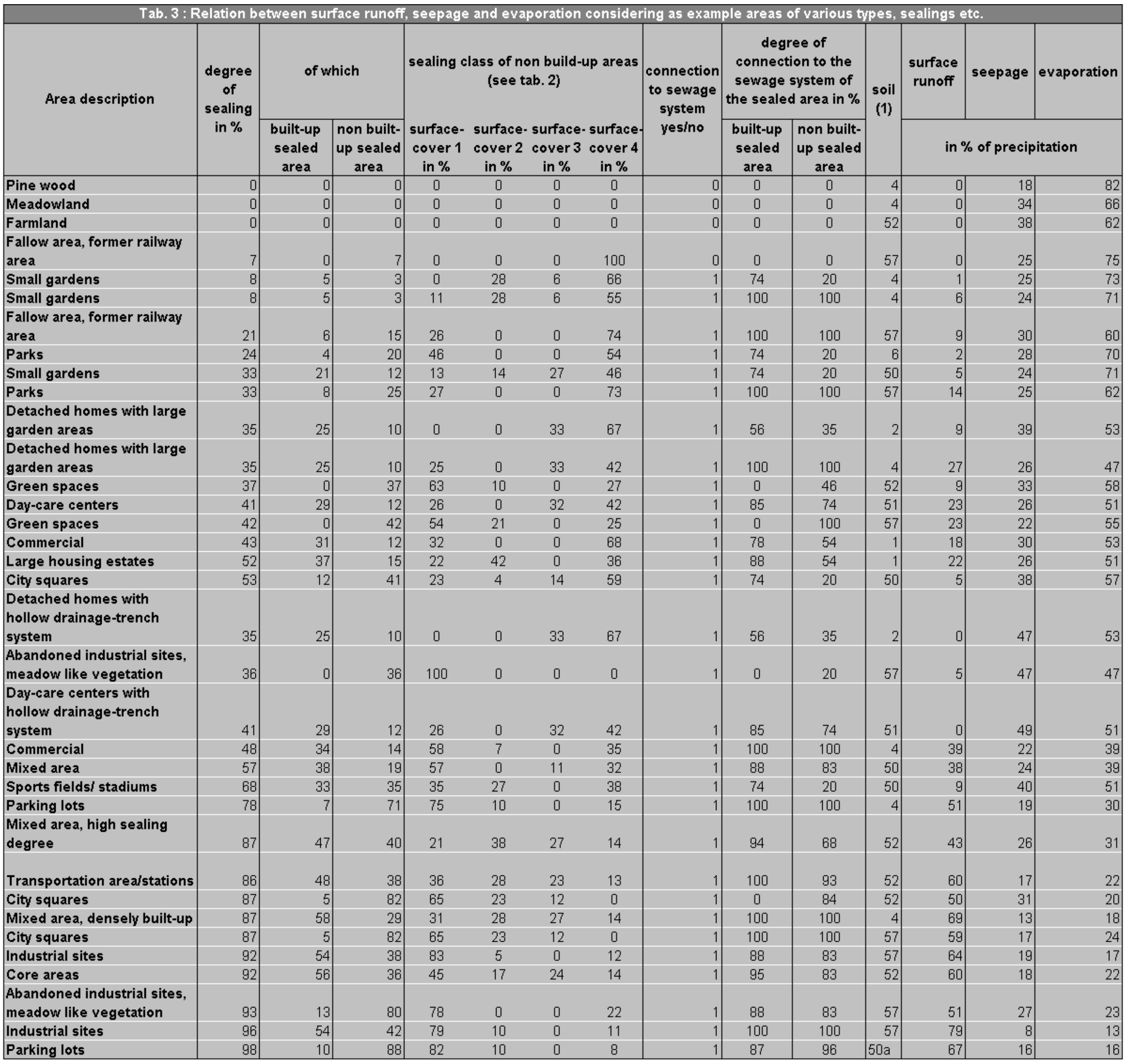


Tab. 2: Effectivity Parameter n und Infiltration Factor F_i for Various Surface Sealing Classes

Sealing classes	Sealing type	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, grevel	0.4	0.9

Tab. 2: Effectivity parameter n and Infiltration factor F_i for different surface-cover classes

In order to provide an impression as to how the various area uses, sealing parameters and conditions of the sewage system would affect the water balance, the ABIMO model was used for approx. 35 model surfaces with different input quantities; the results are shown in Table 3. The relationship between surface runoff, sealing and evaporation is decisively dependent of the extent of sealing and the passage of rainwater to the sewage 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	evaporation
		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, seepage and evaporation for sample surfaces of different uses, sealing types, etc. (Köppel/Deiwick 2004)

As a result of these calculations, updated long-term mean values for total runoff, surface runoff and seepage are available for each of the 25,000 separate areas. 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 blocks represented as uniform areas; in fact, however, they have non-homogeneous structures. The runoffs of sealed and unsealed 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 seepage capacity of a square meter of unsealed ground is. For this purpose, another full-coverage and block-referenced calculation has therefore been carried out with changed marginal parameters, i.e., assuming completely unsealed 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 sealed 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 02.13.6) 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 unsealed 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 by sealing and lack of vegetation – as can be seen in the map **Evaporation** (Map 02.13.6) – leads to runoff double or triple the natural run-off.

Groundwater net consumption occurs only in few areas, caused by low precipitations with simultaneously low depths to water table, which produces negative runoff formation values, since here, the vegetation, which withdraws groundwater, can evaporate more water 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 **Seepage** map (02.13.2) shows a picture that is at first surprising. According to this, the inner city shows precipitation seepage of about 120 mm/yr. – roughly as much as the woodlands. The non-densely built-up residential areas on the outskirts show considerably higher seepage 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 seeps away, averaging about 300-350 mm/yr. and reaching maximum values of over 400 mm/yr.

In conclusion, the following can be stated:

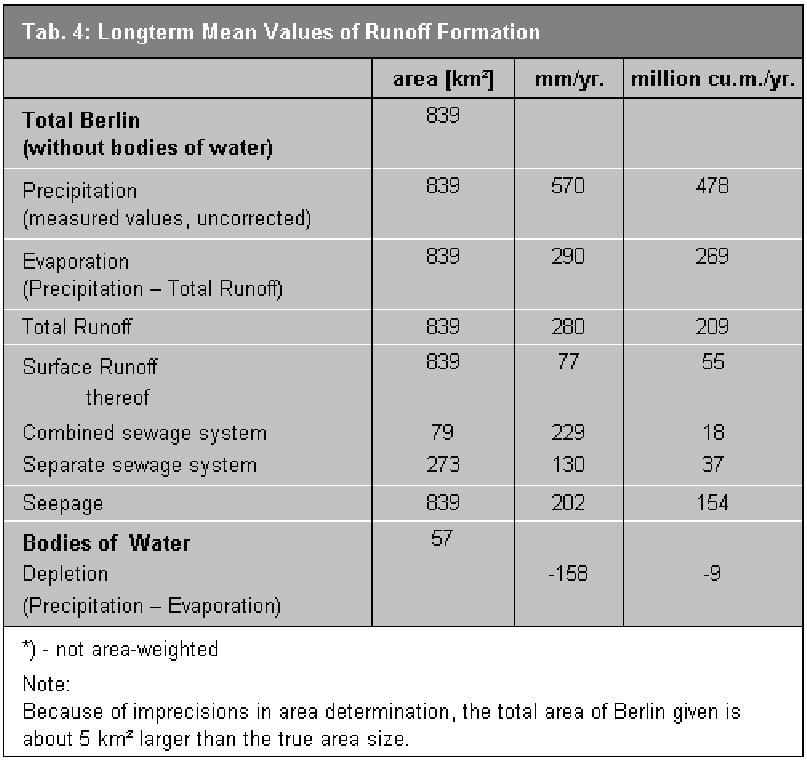
- The effect of the reduced permeability of the soil caused by the high degree of sealing in the inner city is to a large extent counteracted by the effect of reduced evaporation, so that the inner-city seepage capacities are higher than initially assumed, and almost reach “natural” levels.
- The extent of sealing is only secondarily important for seepage capacity; of primary importance is the actual degree of connection to the sewage system. The type of sealing, i.e. the differing seepage capacity of the various surface-cover types, also plays an important role.
- The reduction of evaporation due to sealing in low-density areas with simultaneously low degrees of connection to the sewage system causes the seepage capacities in these areas to be the highest, and approximately double those of “natural” seepage.

In the glacial spillway area, the seepage water can percolate directly and completely to the groundwater table, due to the permeable sands which overlay the groundwater. Here, the calculated seepage 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 flows are largely fed by confined groundwater or from sandy and thus permeable layers in the ground moraine. Only that part of the seepage water (calculated seepage) not passed on by the tributaries can be considered a true recharging of the main aquifer underneath 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 seepage percolates sub-surface to the glacial spillway area, while the Tegel Creek passes on at the surface virtually all of the runoff it receives from the seepage of its catchment area. On the basis of the seepage water rates determined during the ‘90s with the ABIMO model, a map of new groundwater formation has also been developed (Environmental Atlas Map 02.17).

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 sealed 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 seepage. However, the degree of sealing and the amount of runoff makes it seem improbable in some cases that the water actually seeps away. As a result, it is likely that the share of surface runoff tends to be underestimated, and that that of seepage 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: Longterm Mean Values of Runoff Formation

	area [km²]	mm/yr.	million cu.m./yr.
Total Berlin (without bodies of water)	839		
Precipitation (measured values, uncorrected)	839	570	478
Evaporation (Precipitation – Total Runoff)	839	290	269
Total Runoff	839	280	209
Surface Runoff	839	77	55
thereof			
Combined sewage system	79	229	18
Separate sewage system	273	130	37
Seepage	839	202	154
Bodies of Water	57		
Depletion (Precipitation – Evaporation)		-158	-9

*) - not area-weighted

Note:
Because of imprecisions in area determination, the total area of Berlin given is about 5 km² larger than the true area size.

Tab. 4: Long-term mean runoff formation values

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 seep away to the sub-surface, a quarter is passed through the sewage system. Although the mixed-sewage system covers only about one quarter of the total area served by sewage systems, it accounts for more than a third of total surface runoff. If annual seepage quantity of approx. 150 million cu.m., which as stated above, is not entirely fed into the groundwater, is juxtaposed to the drinking water consumption of approx. 250 million cu.m. per year, it is obvious that there is a considerable deficit. This deficit is compensated for by surface influxes (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 facilities.

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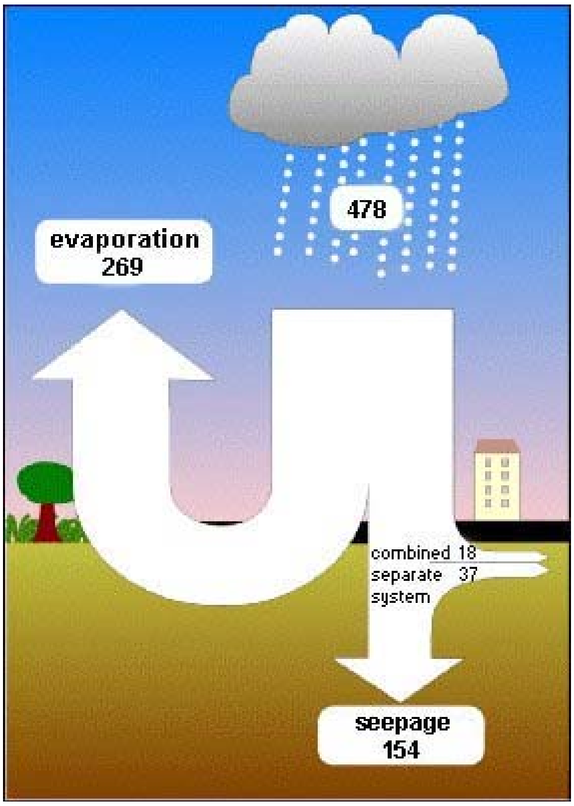
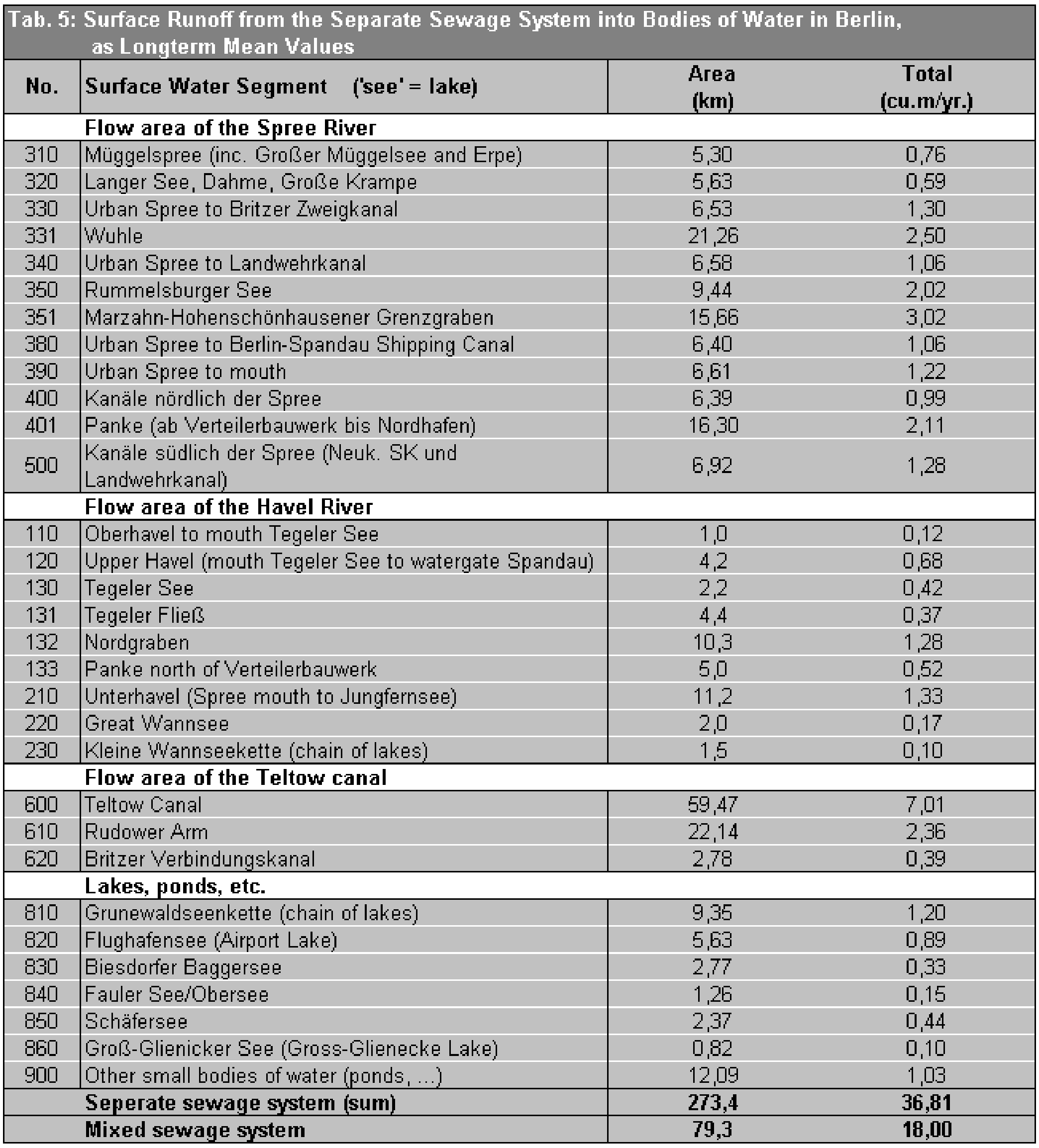


Fig.4: The Berlin water balance (long-term mean values in million cu.m., without bodies of water)

The Information System registers for every area served by the separate-sewage system an indication as to which tributary or which body of water or body-of-water segment that area is drained to (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 runoffs in the area of the mixed system are passed to the sewage treatment plants, of the channel net, from where they are fed into the bodies of waters after an appropriate sewage-treatment process, together with the treated sewage.



Tab. 5: Surface Runoff from the Separate Sewage System into Bodies of Water in Berlin, as Longterm Mean Values

No.	Surface Water Segment ('see' = lake)	Area (km)	Total (cu.m/yr.)
	Flow area of the Spree River		
310	Müggelspree (inc. Großer Müggelsee and Erpe)	5,30	0,76
320	Langer See, Dahme, Große Krampe	5,63	0,59
330	Urban Spree to Britzer Zweigkanal	6,53	1,30
331	Wuhle	21,26	2,50
340	Urban Spree to Landwehrkanal	6,58	1,06
350	Rummelsburger See	9,44	2,02
351	Marzahn-Hohenschönhausener Grenzgraben	15,66	3,02
380	Urban Spree to Berlin-Spandau Shipping Canal	6,40	1,06
390	Urban Spree to mouth	6,61	1,22
400	Kanäle nördlich der Spree	6,39	0,99
401	Panke (ab Verteilerbauwerk bis Nordhafen)	16,30	2,11
500	Kanäle südlich der Spree (Neuk. SK und Landwehrkanal)	6,92	1,28
	Flow area of the Havel River		
110	Oberhavel to mouth Tegeler See	1,0	0,12
120	Upper Havel (mouth Tegeler See to watergate Spandau)	4,2	0,68
130	Tegeler See	2,2	0,42
131	Tegeler Fließ	4,4	0,37
132	Nordgraben	10,3	1,28
133	Panke north of Verteilerbauwerk	5,0	0,52
210	Unterhavel (Spree mouth to Jungfernsee)	11,2	1,33
220	Great Wannsee	2,0	0,17
230	Kleine Wannseekette (chain of lakes)	1,5	0,10
	Flow area of the Teltow canal		
600	Teltow Canal	59,47	7,01
610	Rudower Arm	22,14	2,36
620	Britzer Verbindungskanal	2,78	0,39
	Lakes, ponds, etc.		
810	Grunewaldseenkette (chain of lakes)	9,35	1,20
820	Flughafensee (Airport Lake)	5,63	0,89
830	Biesdorfer Baggersee	2,77	0,33
840	Fauler See/Obersee	1,26	0,15
850	Schäfersee	2,37	0,44
860	Groß-Glienicker See (Gross-Glienecke Lake)	0,82	0,10
900	Other small bodies of water (ponds, ...)	12,09	1,03
	Seperate sewage system (sum)	**273,4**	**36,81**
	Mixed sewage system	**79,3**	**18,00**

Tab. 5: Rainwater fed into the sewage system: catchment areas and runoff (long-term mean values, as of 2001)

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 de-sealing measures, including the disconnection of areas from the sewage system, to permit seepage 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 **Seepage without Consideration for Sealing** (02.13.4) shows conditions which are in some cases greatly different from those shown in the Seepage map for which sealing was taken into account.

With **200 -250 mm** of annual seepage, the greatly anthropogenically transformed, yet unsealed, surfaces of the inner city and the industrial areas achieve the highest seepage 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 seepage 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** seep away. 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** seeps into the soil. If real evaporation is higher than precipitation, net water consumption occurs, i.e. the calculated values are negative.

Certain areas have seepage capacities of more than **300 mm**; these are areas with low vegetation covering, or without vegetation. Therefore only small portions of the precipitation are able to evaporate there; the greater share seeps away.

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

The seepage capacity indicated in the map are only reduced to zero by sealing if the planned sealing is actually completely impervious to water (roof areas, asphalt) and the precipitation water of these areas is passed entirely to the sewage system. If partially water-permeable sealing 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 sealing performance. 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.

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