

02.13 Surface Runoff, Percolation, and Total Runoff from Precipitation (Edition 1999)

Overview

Water management and water resource operation oriented to sustainability require precise knowledge about surface runoff, percolation, and groundwater recharge. The Berlin area has limited water resources and balancing the water economy is thus of particular importance. The size of water resources is in disparity to the number of inhabitants, their drinking and potable water needs (non-drinking uses), as well as the amounts of waste water produced.

It is important for the protection of

- bodies of water to be able to estimate the amounts of overland flow (surface runoff) that will be discharged into bodies of water (surface waters). Considerable loads of pollutants are transported by overland flow into bodies of water.
- groundwater to know the percolation capabilities of soils. The transport of materials out of contaminated soils occurs mainly through percolation.
- nature and the care of the landscape to be able to estimate the amount of water available to vegetation from groundwater recharge and from the capillary rise of water from groundwater.

Water introduced to an area by precipitation is classified into water supply parameters according to climatological conditions and other properties of the area. These water balance parameters include evaporation, overland flow (surface runoff), underground (subsurface) flow (percolation and groundwater recharge), and water supply modification. The first parameter to be determined is total runoff, as the sum of surface and subsurface flow.

The general water balance equation states that total runoff is equal to precipitation minus real evaporation. Evaporation is the critical parameter in this calculation. It is influenced under natural conditions primarily by vegetation, climate, and soil.

Real evaporation in an urban area is strongly modified compared to surrounding areas. Construction and sealing in the city clearly reduce evaporation compared to vegetation areas. Plants transpire through their leaves continuously, but the only evaporation from constructions and sealed surfaces comes from the slight amounts of water clinging to them after rainfall. Total runoff in urban areas is greater than in areas of strong vegetation.

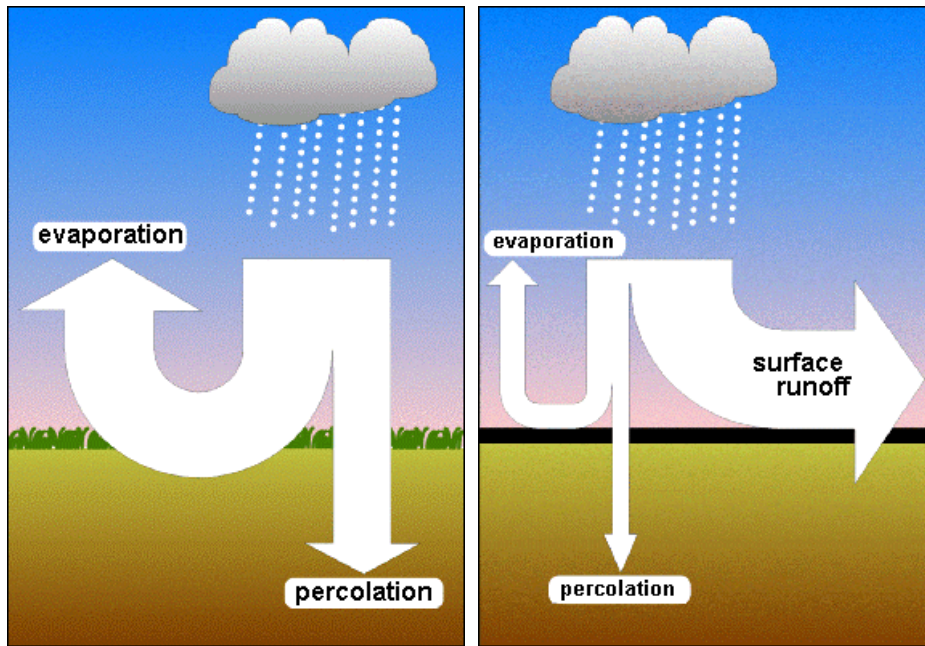


Fig. 1: Water Balance of Vegetation Areas and Sealed Areas

Total runoff best characterizes the hydrological conditions of area segments and catchment areas. The **water supplies** of closed catchment areas correspond to the sum of all area segment, total surface, and subsurface runoffs.

Depending on the degree of connection with the sewage system, urban areas with **sealed surfaces** discharge part of total runoff either directly to bodies of water, or indirectly by way of waste water treatment works. The remaining runoff infiltrates and percolates at the edge of sealed surfaces, or within partially sealed surfaces, into deeper soil layers below the zone influenced by evaporation, and eventually enters groundwater. Percolation and groundwater recharge for these areas can be derived from runoff formation minus rainwater diversion, given knowledge of the extent of the rainwater drainage system.

Statistical Base

The data bases for the calculation of runoff parameters were taken from the Berlin Environmental Information System (EIS), specifically from the 25,000 individual areas of the EIS spatial reference system. Only a few parameters were determined especially for this project. Most data bases came from long-term work for the Environmental Atlas and the EIS, and they were available for diverse evaluations and calculations.

Land use data are based on the evaluation of aerial photography, district land use maps, and other documents used by the Environmental Atlas (cf. Map 06.01, SenStadtUm 1995a, 1996c, and Map 06.02, SenStadtUm 1995b, 1996d). About 30 use types were differentiated, and they reflect the use situation in 1990, except for a few later entries.

The long-term **precipitation** means from 1961 to 1990, including the yearly mean and the May-to-October summer half-year mean, were calculated from measurements made by 97 monitoring stations maintained by the FU - Free University of Berlin and the German Weather Service (Deutscher Wetterdienst) (cf. Map 04.08, SenStadtUm 1994, 1996b). Data from this model were calculated for the midpoint coordinates of the block segments.

Potential evaporation used the longterm means of the 10% increased TURC-evaporation. This was calculated from observations made by climate stations in the Berlin area. Districts in the urban area were allocated 610 to 630 mm/a; and for the summer half-year they were allocated 495 to 505 mm.

Degree of sealing was determined by evaluating aerial and satellite photography, a map of Berlin at 1 : 4/5,000, and the urban planning data file for each block segment. Streets were **not** initially included (cf. Map 01.02, SenStadtUm 1993, 1996a). The data file differentiates between **built-up sealed surfaces** (including roofs) and **non-built-up sealed surfaces** (parking lots, pathways, etc.). The **type of sealing material** is an important initial parameter for non-built-up sealed surfaces. Surface sealing types are differentiated into four classes (cf. Tab. 2). These classes were determined at test areas in

terrain for specific individual building structure types; they were then referenced for all block segments of the same building structure type. The surface sealing classification for individual area segments in aerial photography sometimes deviated from general values.

Statements on the degree of sealing of **streets** were taken from Berlin Building Administration statistics on streets and covering materials. Used sealing types were included into the sealing classes mentioned above. These statistics were only available for boroughs; the degree of sealing and sealing type were given a general value for all areas of each Berlin borough.

Soil science data on useful field capacity of the soil zone (shallow root zone from 0-30 cm, and deeper root zone from 0-150 cm) were derived from the Berlin Soil Associations Map (cf. Map 01.01, SenStadtUmTech 1998a, 1997) by an expert opinion of Dr. Aey (Aey 1993).

Depth to groundwater from the surface was initially developed in a model of terrain elevations based on digitalizing and interpolating about 85,000 individual data on terrain heights (cf. Map 01.08, SenStadtUmTech 1998a). Parallel to that, a model of depth of groundwater from the surface was constructed from values given by observation wells of the State Groundwater Service in May 1995. The depth to groundwater data used for calculating runoffs were themselves calculated from the difference model from the Terrain Elevations Model and the groundwater depth model (cf. Map 02.07, SenStadtUmTech 1998b, 1998d). These data were calculated for the midpoint coordinates of the block segments.

Area sizes were used to calculate flow volumes. The area size of block segments (without streets) is available in the EIS. Additionally, the estimated area of streets was given in relation to individual block segments. To that, existing statements on street area size at the level of statistical areas were transposed area-weighted into area segments.

Statements on the **sewage system** were taken from the map, "Disposal of Rain and Sewage Water" (cf. Map 02.09, SenStadtUmTech 1992), which has been transposed into digital form recently. The criteria was the existence of rainwater drainage in the adjoining street. The statement is thus initially independent on the actual diversion of rainwater. It can only be read from the map if the block is registered at all with the sewage system. The map was worked out at the beginning of the 90's. Individual changes and extensions have mainly to do with areas that do not discharge their water through water works networks. These changes and extensions are based on the knowledge and experience of Environmental Department employees. It can be assumed that some highly sealed areas (mostly industrial and commercial areas) discharge their rainwater by way of private pipelines or the public network, but no information about this exists.

The map does not indicate to what degree water on built-up or sealed areas is actually diverted. Special studies were required for this. The starting point was the consideration that the **actual degree of connection to the sewage system** depends greatly on the age and structure of construction. There is an all-area Map of Building Structures (cf. Map 06.07, SenStadtUm 1995c, 1996e). Of the roughly 11,000 blocks connected to the sewage system, 400 were chosen, and an estimate was made on-site of the actual degree of connection to the sewage system, e.g. the effective amount of sealed areas with runoff. The actual degree of connection to the sewage system was differentiated according to built-up sealed areas, non-built-up sealed areas, and streets. General values from this survey were derived for individual building structure types and allocated to the blocks. The data were determined in the course of a thesis for university (Bach 1997). The results are summarized in Tab. 1. Deviating from this, the actual degree of connection of streets was allocated according to Berlin boroughs.

Tab. 1: Effective Degree of Connection of Sealed Surfaces to the Sewage System (Degree of Connection to Sewage System) for Berlin Urban Structure Types (from Bach 1997, modified)					
	Urban structure type	Area type	Degree of Connection to Sewage System (%)		
			Built-up sealed areas (KAN_BEB)	Non-built-up sealed areas (KAN_VGU)	sealed street areas (KAN_STR)
A	Late 19th-century block development with wings and rear buildings	1 - Closed courtyard 2 - Courtyard 5 - Preservation-oriented reconstruction	99	81	94
B	Late 19th-century block-edge development with few wings / rear buildings	3 - Decorative and garden court 6 - Shed court	95	70	91
C	Late 19th-century block-edge development with major changes	4 - Reconstruction by de-coring 7 - Post-war block edge	100	76	93
D	Twenties and thirties block-edge and row development	10 - Large court 72 - Row development (20's/30's)	99	45	87
E	Fifties and later row development	11 - Row development (>50's)	98	53	89
F	Post-war high-rise development	8 - Unplanned reconstruction 9 - Large settlement area	100	66	92
G	Eighties and nineties block-edge or row development	71 - Settlement development	100	63	90
H	Low buildings with yards	21 - Village 22 - Row yard 23 - Yard 26 - Open settlement development 59 - Weekend cottages	46	29	77
I	Villa development with park-like gardens	24 - Park-like garden	68	42	67
J	Development with yards and semi-private re-greening	25 - Yards and semi-private re-greening	61	36	70
L	Development with predominantly commercial and service use	29 - Core area 39 - Excursion restaurant	100	88	98
M	Low development with predominantly small business and industrial use	30 - Industry / small business area A 32 - Utilities area 33 - Mixed area 2 (development <50%)	92	75	89
N	Dense development with predominantly small business and industrial use	31 - Industry / small business area B 38 - Mixed area 2 (development >50%)	99	78	92
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	100	77	88
		44 - University and research 46 - Hospital 47 - Child day care center 49 - Church 50 - Retirement home 51 - Youth center 60 - Public facilities, misc.	95	66	89
P	Litter or non-built-up green and open spaces	15 - Water sports 27 - Cemetery 28 - Sports facility 34,35,37 - Allotment garden area 53 - Green space / park 54 - City square / promenade 57 - Vacant area 58 - Campground	63	20	81
Q	Non- or low built-up non-street traffic areas	92 - Railroad property 99 - Railroad embankments 91 - Parking lot 94 - Other traffic areas	100 - 100 -	80 100 60 60	- - 95 95

Tab. 1: Effective Degree of Connection of Sealed Surfaces to the Sewage System (Degree of Connection to Sewage System) for Berlin Urban Structure Types (from Bach 1997, modified)

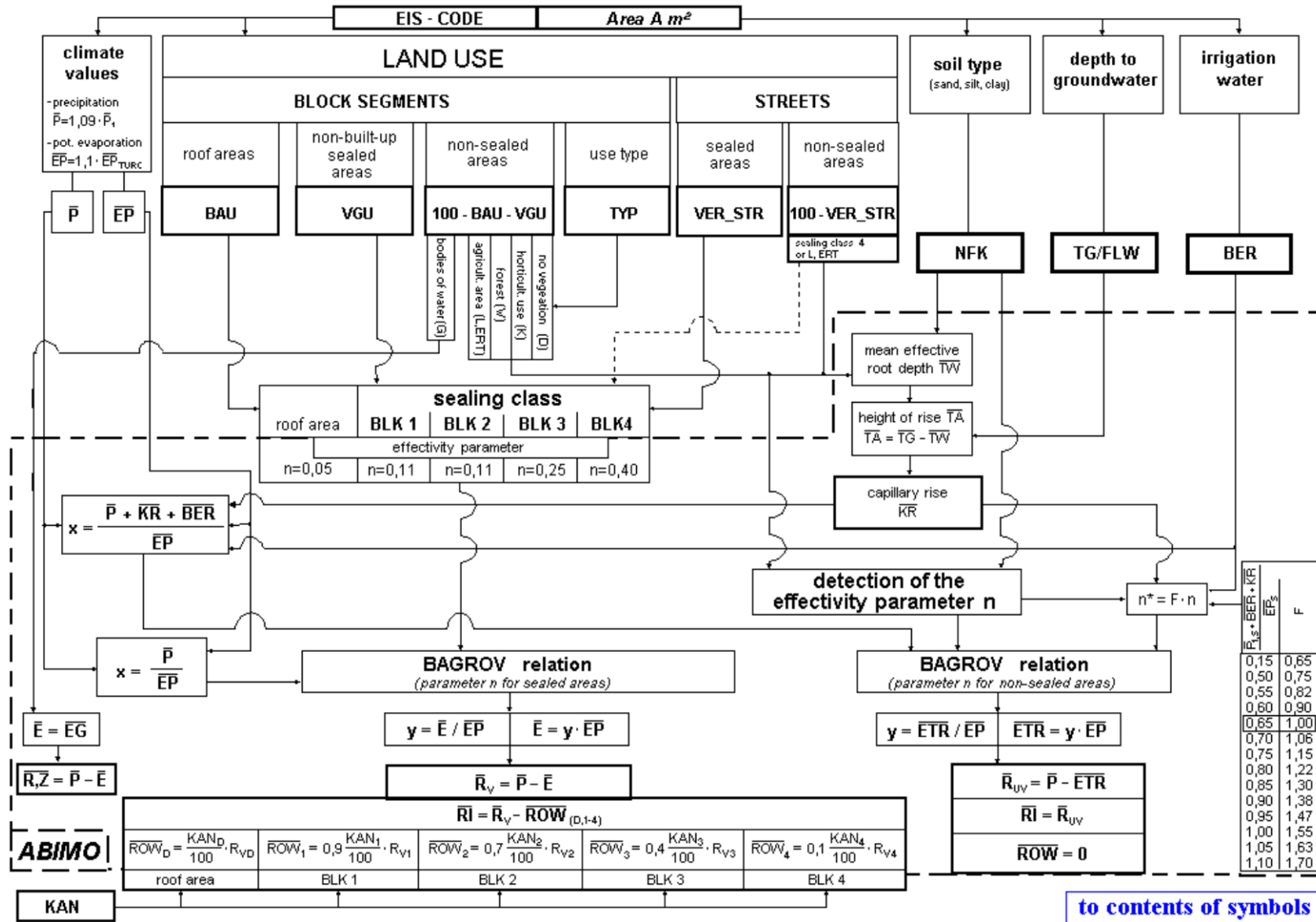
Methodology

A model for the most important parameters of water management has been developed, programmed and applied in recent years. This model was developed in cooperation with the Federal Institute of Hydrology (Bundesanstalt für Gewässerkunde). The approximately 25 basic data and initial parameters

required for each of the 25,000 areas were furnished by the Environmental Information System EIS.

The runoff formation model ABIMO developed by Glugla originated on the basis of models developed since the 70's for the calculation of groundwater supplies. This model was extended with components that consider the special situation in urban areas. This extension was made through expert opinions from the Institute for Ecology (Soil Science) of the TU -Technical University of Berlin, and it was supported by a thesis in geography at the FU - Free University of Berlin. A computer realisation performed by an external software office fitted it to the special data situation in Berlin.

The calculation procedure initially determined actual evaporation in order to calculate total runoff (precipitation minus evaporation). A second step determined surface runoff as part of total runoff. The difference between total runoff and surface runoff gives percolation. Fig. 2 gives an impression of the complexity of the procedure.



yearly average values (mm/a)

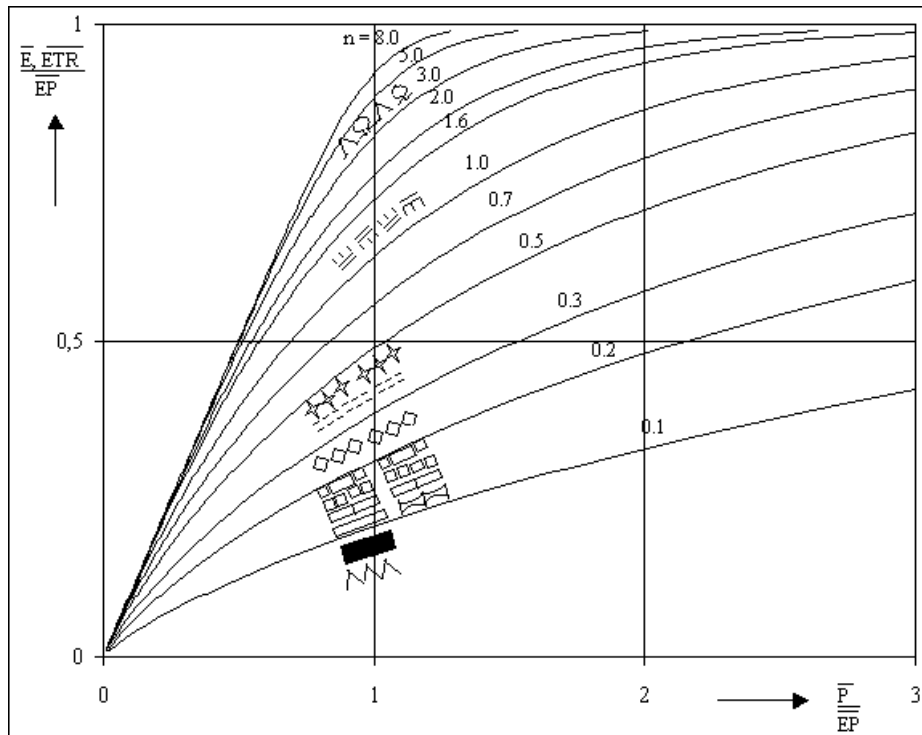
\overline{P}_1	precipitation (1 m above the ground)
\overline{P}	precipitation (1 m above the ground)
\overline{KR}	capillary rise from ground water near surface
\overline{EP}	potential evaporation ($\overline{EP} = 1,1 * \overline{EP}_{TURC}$)
\overline{ETR}	real evapotranspiration of vegetation covered 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
$\overline{Z} = \overline{P} - (\overline{E}, \overline{ETR}, \overline{EG})$	depletion from ground and surface water
$(\overline{E}, \overline{ETR}, \overline{EG}) > \overline{P}$	
\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 Diagram of the ABIMO Model (from Bach 1997, modified)

Total runoff is calculated from the difference between long-term annual mean precipitation and real evaporation. **Real evaporation**, as it actually occurs in means at specific locations and areas, is calculated from the most important influence parameters of precipitation and **potential evaporation**, as well as the mean storage characteristics of the evaporative areas. With sufficient introduction of moisture to the evaporative zone, real evaporation approaches potential. Real evaporation is additionally modified by the storage properties of the evaporative zones. High storage capacity (such as greater binding quality of soil and greater rooting depth) causes greater evaporation.

The demonstrated connection between long-term mean values of real evaporation, on the one hand, and precipitation, potential evaporation, and evaporative effectivity of the location, on the other hand, satisfies the relation according to Bagrov (cf. Gluga et al. 1971, Gluga et al. 1976, Bamberg et al. 1981, and Fig. 3). The Bagrov relation is based on the evaluation of long-term lysimeter studies. It describes the non-linear relation between precipitation and evaporation in dependence on local properties. With knowledge of the climate parameters precipitation P, and potential evaporation EP (the quotient of P/EP), and the effectivity parameter n, the Bagrov relation can determine the quotient real evaporation / potential evaporation (ER/EP), and thus the real evaporation ER for locations and regions without

groundwater influence. The Bagrov procedure is also used in modified form for the calculation of groundwater-influenced evaporation by allocating the mean capillary water inflow from groundwater to precipitation.



-  sandy soils, forest land use
-  sandy soils, agricultural land use
-  no vegetation, sandy soils
-  lawn lattice stone
-  Bernburger mosaic stone
-  Artificial stone plates with mosaic stone (walkways)
-  Mosaic stone (walkways)
-  Concrete lattice stone (20 % open space, filled with sand)
-  Poured concrete
-  Mixed concrete
-  Asphalt
-  Roofs

Longterm mean values of:

- $\overline{E, ETR}$ Actual evaporation / evapotranspiration
- \overline{EP} Potential evaporation (1.1 * TURC Evaporation)
- \overline{P} Precipitation (measured at ground surface level)
- n Effectivity parameter

Notes:

- \overline{P} is increased by:
- \overline{KR} By capillary rise of water from near-surface groundwater and
- \overline{BER} By irrigation water

Fig. 3: Portrayal of the Bagrov Equation for Selected Values of the Parameters n and the Dependency of these Parameters on Land Use and Soil Type (after Glugla et al. 1995)

With increasing precipitation P , real evaporation ER approaches potential evaporation EP , e.g. the quotient ER/EP approaches a value of 1. With decreasing precipitation P , (P/EP approaches a value of 0), real evaporation ER approaches precipitation P . The intensity with which these frame conditions are achieved, is modified by the storage properties of the evaporative zone (effectivity parameter n).

Storage properties of a location are particularly influenced by the type of land use (increasing storage effectivity in the order of: sealed surfaces, soils without vegetation, agricultural, horticultural, and forest use) as well as soil type (increased storage effectivity with greater binding capacity of the soil).

A measure for the storage effectivity of unsealed surfaces is **usable field-moisture capacity**. It is defined as the difference between the moisture values of the soil for field capacity (water begins to

infiltrate the soil) and for the wilting point (permanent damage to plants). Other land use factors modify the parameter value n . These factors include yield per hectare, and tree type and age. The parameter n is quantified by the evaluation of observations of numerous domestic and foreign lysimeter stations, and from water management studies in river catchment areas.

Locations and regions with near-surface groundwater have increased evaporation in comparison with conditions uninfluenced by groundwater. This is due to the capillary rise of groundwater into the evaporative soil zone, influenced by groundwater depth and soil properties. The formation of surface runoff flow is reduced. If real evaporation exceeds precipitation, there is water depletion. Values for surface runoff become negative, such as in river and lake lowlands.

Bodies of water show increased potential evaporation, in comparison to land areas. This is due to greater heat (lower reflective capacity for incoming radiation). Actual evaporation from bodies of water was equated with this increased potential evaporation, as an approach.

Percolation at specific points, such as at groundwater recharge plants of the water works, was not considered. Horticultural land uses (allotment gardens) were given a set value and added to precipitation, in order to give an approximate value for plant watering.

Mean total surface flow was calculated as the difference between precipitation and real evaporation. A second step then determined **surface runoff**. Surface runoff corresponds to total runoff for roof areas that discharge into the sewage system. Areas not connected to the sewage system do not produce overland flow. Non-built-up sealed surfaces infiltrate some of the discharge flow into the ground, depending on the type of covering material (surface sealing type). This infiltration factor depends on the type, size, and age of the joints. Depending on the degree of connection to the sewage system, surface flow which does not infiltrate is discharged as surface runoff by way of the sewage system, or infiltrates at the edge of the sealed surfaces. This is also true for roof areas not connected to the sewage system (cf. Tab. 1). The difference between total runoff and surface runoff thus corresponds to **percolation** as a parameter for groundwater recharge.

The application of this procedure for urban regions requires the determination of the parameters n and the infiltration factors of various sealing materials. Evaluations were made of lysimeter studies on various sealing materials, and of calculations for loss from wetting (cf. Wessolek/Facklam 1997). Selected dimensions for these parameters are listed in Tab. 2. Changes in these parameters related to the aging process, the thickening and the muddying of the joints were also considered. Insufficient basic scientific data cause the statements to contain some uncertainties. Beyond that, a different classification of sealing types into sealing classes would be desirable for hydrological questions.

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, gravel	0.4	0.9

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

The calculations provided long-term mean values for total runoff, surface runoff, and percolation for 25,000 individual areas. The values were classified into mm/a and are depicted in this map. Total amounts in m³/a were also calculated and balanced. It must be taken into consideration that the depicted values are mean values for blocks depicted as uniform surfaces; but in reality blocks are not

homogeneous structures. Flows of sealed and unsealed surfaces are given here as average values per block. Also, runoff from streets was allocated to the adjacent blocks. It cannot, for example, be seen in the map how much percolation takes place in a square meter of unsealed soil. Special evaluations, both all-area and block-related, had been made in the framework of the Environmental Information System.

Map Description

Map 02.13.3 **Total Runoff** was only published in the digital edition of the Environmental Atlas. It shows total runoff values in the range of 350-450 mm/a for the highly sealed inner city area (S-Bahn-Ring - City Rail Circle). There were higher values for extremely high sealed areas in the city center and for some industrial areas. Only about 150 mm/a evaporates here, related to precipitation observations (measured in 1 m above the ground) that are about 10 - 15% under the precipitation measured at the soil surface. Loosely built-up outer districts show runoffs of 250-300 mm/a. Berlin had values of only about 150 mm/a. Compared to the runoffs of unsealed outer areas and surrounding areas, Berlin can be viewed as an island of strongly increased runoffs. The reduction of evaporation by sealing and lack of vegetation lead to runoffs 2 or 3 times greater than would occur under natural conditions.

Groundwater depletion, the negative values of runoff formation, only appear in a few regions of low precipitation and lesser depths to groundwater, for vegetation evaporates more water from groundwater than can be conducted to groundwater by precipitation.

The 02.13.1 Map **Surface Runoff** shows that about 250 mm/a is discharged to the sewage system in inner city areas connected to the sewage system. Peak values are above 350 mm/a. Outer areas in regions connected to the sewage system have about 100 mm/a.

The 02.13.2 Map of **Percolation** gives an initially surprising picture. It shows that about 120 mm/a percolates in the inner city. This is almost as much as in forests. Clearly higher percolation rates of 200 mm/a are shown in the loosely built-up settlements of outer districts. Regions with a low degree of connection to the sewage system have higher rates of about 300 mm/a. Settlements not connected to the sewage system show percolation of total runoff of about 300-350 mm/a, with maximum values over 400 mm/a.

It may be determined that:

- reduced permeability caused by high degrees of sealing in the inner city is compensated for by infiltration of precipitation. Inner city percolation rates are higher than initially assumed and almost correspond to "natural" conditions.
- the amount of sealing is a secondary factor for percolation. The primary factor is determined by the actual degree of connection to the sewage system. The type of sealing material, i.e. the different infiltration capacities of various sealing types is also an important factor.
- the reduction of evaporation caused by sealed surfaces in loosely built-up areas having low degrees of connection to the sewage system give these areas the highest percolation; about double that of "natural" percolation.

The glacial valley watercourse is marked by permeable sands overlaying groundwater. Percolation to groundwater is direct and complete. Percolation corresponds to **groundwater recharge**. The ground moraine flat uplands in the Barnim and Teltow areas however, are overlaid with clayey layers of low permeability; these are usually over confined groundwater. The deeply-cut flows here are mainly fed by confined groundwater and/or by way of sandy and thus permeable layers in the ground moraine. Only the (calculated) percolation not discharged through receiving streams could be seen as true feeding of the main water aquifer under the ground moraine. This water reaches the glacial valley watercourse as underground flow. The division is dependent on the specific hydrogeological conditions. A comparison of measured and calculated flows shows, for example, that in the catchment area of the Neuenhagen Mühlenfließ about 35 % of calculated percolation discharges underground into the glacial valley watercourse. The Tegeler Fließ discharges to the surface almost all runoff formed by the percolation of its catchment area.

Evaporation of **bodies of water** not depicted in the map are about 160 mm/a greater than precipitation. Evaporation removes a total of about 9 million cubic meters of water a year from bodies of water in Berlin.

There is no information to indicate if some highly sealed areas discharge precipitation by way of the sewage system. This is the reason that total runoff in these areas is given as percolation in the map. The degree of sealing and the size of runoff make it seem improbable in some cases that the water actually percolates. It would seem that surface runoff tends to be underestimated and percolation to be

overestimated.

The aid of area parameters of the reference areas enabled **runoff volumes** to be calculated and balanced (cf. Tab. 3).

Tab. 3: Longterm Mean Values of Runoff Formation			
	area [km ²]	mm/a *)	million m ³ /a
Total Berlin (without bodies of water)	846		
Precipitation (measured values, uncorrected)	846	570	481
Evaporation (Precipitation – Total Runoff)	846	300	277
Total Runoff	846	270	204
Surface Runoff thereof	846	78	54
Combined sewage system	79	192	19
Separate sewage system	246	129	35
Percolation	846	192	150
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 12 km² larger than the true area size.

Tab. 3: Long-term Mean Values of Runoff Formation

Calculations show that about 60 % of precipitation evaporates, leaving about 200 million m³/a available as total runoff. Three-quarters of this percolate into the ground; one-quarter is diverted by the sewage system. The combined sewage system (waste water and rainwater) only takes up about one-quarter of the total area connected to the sewage system, but more than one-third of surface runoff is formed in it. If one compares the percolation of 150 million m³ (which does not entirely reach groundwater) with the drinking water use of about 250 million m³/a, then there is clearly a considerable deficit. This deficit is compensated for by surface flows such as the Spree and Havel rivers, and the removal of groundwater from surrounding areas. Water works use surface water in the form of bank filtrate groundwater removals (well galleries in the vicinity of bodies of water remove water that has been filtered through the banks of the body of water) and groundwater recharge plants.

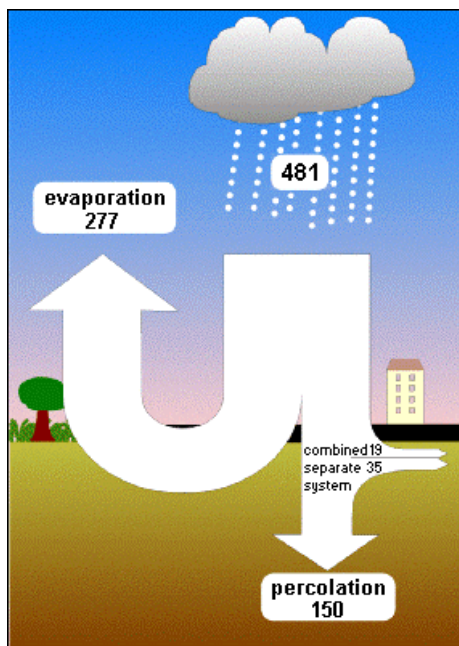


Fig. 4: Berlin Water Balance (Long-term Mean Values in million m³, without Bodies of Water)

The Environmental Information System has statements for each area of the separate sewage system: into which receiving stream, body of water, or body of water section it discharges. This enables balances

to be made of what average amounts the bodies of water receive. This concerns about 150 bodies of water or body of water sections. Table 4 shows the collected discharged amounts in sections into bodies of water in Berlin. Surface runoffs in the combined sewage system area are allocated to the waste water treatment plants, with the exception of water diverted directly into bodies of water during strong rains by emergency diversions of the pump works and the rainwater overflow conduits of the sewage network. The waste water treatment plants perform a waste water treatment and, together with true waste water, are discharged into bodies of water.

Tab. 4: Surface Runoff from the Separate Sewage System into Bodies of Water in Berlin, as Longterm Mean Values					
No.	Surface Water Segment ('see' = lake)	Area (ha)	Mean (mm/a)	Total (m³/sec)	Total (million m³/a)
Flow area of the Spree River					
067	Müggelsee / Spree	393	130	0.02	0.6
030	Langer See, Dahme, Große Krampe	367	113	0.01	0.4
061	Urban Spree to Britzer Zweigkanal	731	169	0.05	1.5
065	Wuhle	1,852	111	0.07	2.2
062	Urban Spree to Landwehrkanal	479	151	0.02	0.8
069	Ruschegraben	638	189	0.04	1.3
064	Marzahn-Hohenschönhausener Grenzgraben	1,646	163	0.10	3.2
063	Urban Spree to Berlin-Spandau Shipping Canal	510	179	0.03	0.9
071	Urban Spree to mouth	675	169	0.04	1.3
080	Canals north of the Spree	747	144	0.05	1.7
081	Panke from Verteilerbauwerk to Nordhafen	1,492	132	0.06	2.0
090	Canals south of the Spree	680	216	0.05	1.7
Flow area of the Havel River					
111	Oberhavel to mouth Tegeler See	95	87	< 0.01	0.1
120	Tegeler See	199	155	0.01	0.4
121	Tegeler Fließ	431	89	0.01	0.4
122	Nordgraben	772	109	0.03	1.0
123	Panke north of Verteilerbauwerk	379	91	0.01	0.3
112	Oberhavel to Spandau Locks	391	157	0.02	0.7
130	Unterhavel (Spree mouth to Jungfernsee)	1,070	128	0.04	1.4
140	Großer Wannsee	194	81	< 0.01	0.1
141	Kleine Wannseekette (chain of lakes)	133	69	< 0.01	< 0.1
Flow area of the Teltow canal					
104	Rudower Arm	1,734	100	0.06	1.8
105	Britzer Zweigkanal	255	147	0.01	0.4
101	Teltowkanal	5,596	117	0.23	7.3
Lakes, ponds, etc.					
160	Biesdorfer Baggersee	243	121	0.01	0.3
170	Fauler See / Obersee	129	130	< 0.01	0.2
180	Schäfersee	224	173	0.01	0.4
150	Flughafensee	524	147	0.03	0.9
142	Grunewaldseenkette (chain of lakes)	863	141	0.04	1.2
000	Other small bodies of water (ponds, ...)	1,172	84	0.03	1.0
All sections		24,616	129	1.12	35.3

Tab. 4: Surface Runoff from the Separate Sewage System into Bodies of Water in Berlin, as Long-term Mean Values

The ABIMO model/program is an instrument enabling simulations with variable initial conditions. The estimation of changes to be expected in the water balance because of construction projects is especially important. Other applications include the estimation of effects of de-sealing measures and disconnection measures. Differentiated initial data enables ABIMO to be applied to individual plans at the micro level of property lots. Changes of model parameters are possible at any time by using the results of current studies.

02.13.4 Percolation from Precipitation without consideration of surface sealing

Overview

For water-economic questions and in context with the calculation of percolation the influence of sealing

and the sewage system has to be considered as a crucial influence on the water supply of urbane areas. (Cf. text to maps 02.13.1-3) However, the investigation of the percolation is of particular interest for the evaluation of the capability of soils for soil protection programs or for the evaluation of interventions following the nature conservation law. On the one hand it is possible to derive the different capability of soils from this figure. On the other hand it can be appraised in the context of plannings which influence a planned future seal would have on the rate of percolation for a planned area. These statements cannot be met with the values of the map 02.13.2, because here median values for the respective reference areas from sealed and unsealed as well as from canalized and not canalized areas are portrayed.

For these reasons, the investigation and depiction of the percolation of unsealed surfaces is shown on map **02.13.4**. This map portrays the **percolation by precipitations on unsealed surfaces**. The given values refer only to the unsealed part of the blocks and block segments. The percolation and seepage measurements from unsealed soils is also a basis for the calculation of the exchange frequency of ground water.

Statistical Base

Details can be found in the text to map 02.13. For this investigation of percolation, the initial data was used under the assumption that all surfaces were unsealed, ie. the value was set as zero that means that surface sealing was not considered. The surface area of the streets was also not considered and taken to be zero. Thus the results apply only to unsealed soils of block areas.

Methodology

The calculations were made (as with map 02.13) using the complex drain model "ABIMO" developed at the Federal Institution for Hydrography in Berlin. The procedure assesses data from the Information System City and Environment. Calculations for approximately 25,000 different areas were made with the assumption that all surfaces were unsealed. Again, street surface areas were not considered. The percentage of percolation resulting from precipitation is above all dependent on the vegetation, the soil and the depth to groundwater. A detailed description of the method is located in the text to map 02.13.

Map Description

With a yearly percolation of **200-250 mm**, the high anthropogenic altered soils of the inner city and industrial areas reach the highest percolation rate in the Berlin, followed by the predominantly sandy pleistocene valleys/watercourses and sand plateaus with levels of **150-200 mm**. When this sandy soils are living forest areas then the average percolation sinks to **100-150 mm**, as the depth of the rootsystems allows an increase in evaporation. Due to the high water holding ability of the clay soils in Teltow and Barnim, the vegetation here can increase the evaporation, leading to a percolation as low as **50-100 mm**. Areas with a high ground water level are susceptible to additional water loss due to the capillary effect which pushes ground water up into a higher evaporation zone. This can give a yearly average of less than **50 mm**.

If actual evaporation is higher than precipitation this leads to water depletion and the calculated percolation becomes negative. Some areas are capable of a percolation of more than **300 mm**. ie. individual areas with extremely low (or no) vegetation foliage. In these cases only an extremely low amount of precipitation is due to evaporation and the predominant part is simply due to drain off.

When data for the estimation of the consequences of additional sealed surfaces in the context of **planning processes** are used, the following is to be noted :

The percolation rate portrayed in the map will be reduced to zero by planned seal only if the planned seal is truly unpermeable and waterproof (roofs, asphalt) and if the precipitation water drains complete into the sewage system. If partly permeable surfaces are planned or the runoff from precipitation water drains only partly into the sewage system, corresponding reductions are to be performed regarding the reduction of the percolation rate. For more **exact calculations**, the application of the drain model ABIMO is recommended; with the input of simulated data for planned surface structures it is possible to compare the contemporary situation with the planned situation.

Literature

- [1] **Aey, W. 1993:**
Zuordnung von Bodenkenngrößen zu Bodengesellschaften und Nutzungen, Gutachten im

Auftrag der Senatsverwaltung für Stadtentwicklung und Umweltschutz, Berlin.

- [2] **Bach, M. 1997:**
Erfassung des Kanalisierungsgrades versiegelter Flächen für ein urbanes Niederschlags-Abfluß-Modell am Beispiel Berlin, Diplomarbeit am FB Geowissenschaften der FU Berlin, Berlin.
- [3] **Bamberg, H.-F., Busse, W., Ginzel, G., Glugla, G., Schlinker, K., Ziegler, G. 1981:**
KdT-Empfehlung zur Ermittlung der Grundwasserneubildung. Zentrales Geologisches Institut. Gedruckt als WTL-Sonderheft 5, Berlin.
- [4] **Berlekamp, L.-R., Pranzas, N 1992:**
Erfassung und Bewertung von Bodenversiegelung unter hydrologisch-stadtplanerischen Aspekten am Beispiel eines Teilraums von Hamburg. - Dissertation, Hamburg.
- [5] **Glugla, G., Tiemer, K. 1971:**
Ein verbessertes Verfahren zur Berechnung der Grundwasserneubildung. Wasserwirtschaft-Wassertechnik, 21 (10): S. 349 – 353, Berlin.
- [6] **Glugla, G., Enderlein, R., Eyrich, A. 1976:**
Das Programm RASTER – ein effektives Verfahren zur Berechnung der Grundwasserneubildung im Lockergestein, Wasserwirtschaft-Wassertechnik, 26 (11): S. 377 – 382, Berlin.
- [7] **Glugla, G., König, B. 1989:**
Der mikrorechnergestützte Arbeitsplatz Grundwasserdargebot. Wasserwirtschaft-Wassertechnik, 39 (8): S. 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. Kolloquium Hydrogeologie 10/93 Erfurt, 22 - 26.
- [9] **Glugla, G., Krahe, P. 1995:**
Abflußbildung in urbanen Gebieten. Schriftenreihe Hydrologie/Wasserwirtschaft 14, Ruhr-Universität Bochum, S.140-160.
- [10] **Glugla G. & Fürtig, G. 1997:**
Dokumentation zur Anwendung des Rechenprogramms ABIMO. Bundesanstalt für Gewässerkunde, Außenstelle Berlin.
- [11] **Glugla, G. & Müller, E. 1997:**
Grundwasserneubildung als Komponente der Abflussbildung. in: C. Leibundgut & S. Demuth (Hrsg.): Grundwasserneubildung. Freiburger Schriften zur Hydrologie. Band 5, S. 23 -35.
- [12] **Glugla, G., Goedecke, M., Wessolek, G., Fürtig, G. 1999:**
Langjährige Abflußbildung und Wasserhaushalt im urbanen Gebiet Berlin. Wasserwirtschaft, in preparation.
- [13] **Graf, H.-F. 1979:**
Der Einfluß von Großstädten auf das Niederschlagsregime am Beispiel von Berlin. Dissertation A, Humboldt-Universität Berlin, Berlin.
- [14] **Kleeberg, H.-B., Niekamp, O., 1994:**
Klimaänderung und Wasserwirtschaft. Vortrag auf der 3. Deutschen Klimatagung, Tagungsband S. 136 – 140, Potsdam.
- [15] **Rachimov, C. (pro data consulting) 1996:**
ABIMO 2.1, Abflußbildungsmodell, Algorithmus zum BAGROV-GLUGLA-Verfahren für die Berechnung langjähriger Mittelwerte des Wasserhaushalts, Programmbeschreibung; im Auftrag der Bundesanstalt für Gewässerkunde, Außenstelle Berlin, not published.
- [16] **Richter, D. 1979:**
Informationsspeicher für die einheitliche Bestimmung der Verdunstungshöhe von freien Wasserflächen. Forschungsinstitut für Hydrometeorologie des Meteorologischen Dienstes der DDR, not published.
- [17] **Wessolek, G. 1994:**
Auswertung von Versuchen zur Ermittlung der Abflußverhältnisse unterschiedlich versiegelter und kanalisierter Flächen Berlins; im Auftrag der Bundesanstalt für Gewässerkunde, Außenstelle Berlin, not published.

- [18] **Wessolek, G., Facklam, M. 1997:**
Standorteigenschaften und Wasserhaushalt von versiegelten Flächen. Zeitschrift für Pflanzenernährung und Bodenkunde, 160,S. 41-46.

Analogous Maps

- [19] **Dyck, S. et al. 1978:**
Karte der potentiellen Verdunstung, in: Angewandte Hydrologie, Bd. 2, 1:1 000 000, Verlag für Bauwesen, Berlin.
- [20] **SenStadtUm (Senatsverwaltung für Stadtentwicklung und Umweltschutz Berlin) (Hrsg.) 1992:**
Umweltatlas Berlin, Karte 02.09 Entsorgung von Regen und Abwasser, 1:50 000, Berlin.
- [21] **SenStadtUm (Senatsverwaltung für Stadtentwicklung und Umweltschutz Berlin) (Hrsg.) 1993:**
Umweltatlas Berlin, Karte 01.02 Versiegelung, 1:50 000, Berlin.
- [22] **SenStadtUm (Senatsverwaltung für Stadtentwicklung und Umweltschutz Berlin) (Hrsg.) 1994:**
Umweltatlas Berlin, Ausgabe 1994, Karte 04.08.1–3 Langjährige Niederschlagsverteilung, Karte 04.08.4 Abflußbildung aus Niederschlägen 1:125 000, Berlin.
- [23] **SenStadtUm (Senatsverwaltung für Stadtentwicklung und Umweltschutz Berlin) (Hrsg.) 1995a:**
Umweltatlas Berlin, Karte 06.01 Reale Nutzung der bebauten Flächen, 1:50 000, Berlin.
- [24] **SenStadtUm (Senatsverwaltung für Stadtentwicklung und Umweltschutz Berlin) (Hrsg.) 1995b:**
Umweltatlas Berlin, Karte 06.02 Grün- und Freiflächenbestand, 1:50 000, Berlin.
- [25] **SenStadtUm (Senatsverwaltung für Stadtentwicklung und Umweltschutz Berlin) (Hrsg.) 1995c:**
Umweltatlas Berlin, Karte 06.07 Stadtstruktur, 1:50 000, Berlin.
- [26] **SenStadtUmTech (Senatsverwaltung für Stadtentwicklung Umweltschutz und Technologie Berlin) (Hrsg.) 1998a:**
Umweltatlas Berlin, Karte 01.01 Bodengesellschaften, 1:50 000, Berlin, in print.
- [27] **SenStadtUmTech (Senatsverwaltung für Stadtentwicklung Umweltschutz und Technologie Berlin) (Hrsg.) 1998b:**
Umweltatlas Berlin, Karte 02.07 Flurabstand des Grundwassers, 1:50 000, Berlin, in print.

Digital Maps

- [28] **SenStadtUmTech (Senatsverwaltung für Stadtentwicklung, Umweltschutz und Technologie Berlin) (Hrsg.) 1996a:**
Umweltatlas Berlin, digitale Ausgabe, Karte 01.02 Versiegelung, 1 : 50 000, Berlin.
Internet: [http:// www.sensut.berlin.de/sensut/umwelt/uisonline/dua96/html/ei102.htm](http://www.sensut.berlin.de/sensut/umwelt/uisonline/dua96/html/ei102.htm)
- [29] **SenStadtUmTech (Senatsverwaltung für Stadtentwicklung, Umweltschutz und Technologie Berlin) (Hrsg.) 1996b:**
Umweltatlas Berlin, digitale Ausgabe, Karte 04.08.1–3 Langjährige Niederschlagsverteilung, Karte 04.08.4 Abflußbildung aus Niederschlägen, 1 : 125 000, Berlin.
Internet: [http:// www.sensut.berlin.de/sensut/umwelt/uisonline/dua96/html/ei408.htm](http://www.sensut.berlin.de/sensut/umwelt/uisonline/dua96/html/ei408.htm)
- [30] **SenStadtUmTech (Senatsverwaltung für Stadtentwicklung, Umweltschutz und Technologie Berlin) (Hrsg.) 1996c:**
Umweltatlas Berlin, digitale Ausgabe, Karte 06.01 Reale Nutzung der bebauten Flächen, 1 : 50 000, Berlin.
Internet: [http:// www.sensut.berlin.de/sensut/umwelt/uisonline/dua96/html/ei601.htm](http://www.sensut.berlin.de/sensut/umwelt/uisonline/dua96/html/ei601.htm)
- [31] **SenStadtUmTech (Senatsverwaltung für Stadtentwicklung, Umweltschutz und Technologie Berlin) (Hrsg.) 1996d:**
Umweltatlas Berlin, digitale Ausgabe, Karte 06.02 Grün- und Freiflächenbestand, 1 : 50 000, Berlin.
Internet: [http:// www.sensut.berlin.de/sensut/umwelt/uisonline/dua96/html/ei601.htm](http://www.sensut.berlin.de/sensut/umwelt/uisonline/dua96/html/ei601.htm)

- [32] **SenStadtUmTech (Senatsverwaltung für Stadtentwicklung, Umweltschutz und Technologie Berlin) (Hrsg.) 1996e:**
Umweltatlas Berlin, digitale Ausgabe, Karte 06.07 Stadtstruktur, 1 : 50 000, Berlin.
Internet: [http:// www.sensut.berlin.de/sensut/umwelt/uisonline/dua96/html/ei607.htm](http://www.sensut.berlin.de/sensut/umwelt/uisonline/dua96/html/ei607.htm)
- [33] **SenStadtUmTech (Senatsverwaltung für Stadtentwicklung, Umweltschutz und Technologie Berlin) (Hrsg.) 1997:**
Umweltatlas Berlin, digitale Ausgabe, Karte 01.01 Bodengesellschaften, 1 : 50 000, Berlin.
Internet: [http:// www.sensut.berlin.de/sensut/umwelt/uisonline/dua96/html/ei101.htm](http://www.sensut.berlin.de/sensut/umwelt/uisonline/dua96/html/ei101.htm)
- [34] **SenStadtUmTech (Senatsverwaltung für Stadtentwicklung, Umweltschutz und Technologie Berlin) (Hrsg.) 1998c:**
Umweltatlas Berlin, digitale Ausgabe, Karte 01.08 Geländehöhen, 1 : 50 000, Berlin.
Internet: [http:// www.sensut.berlin.de/sensut/umwelt/uisonline/dua96/html/ei108.htm](http://www.sensut.berlin.de/sensut/umwelt/uisonline/dua96/html/ei108.htm)
- [35] **SenStadtUmTech (Senatsverwaltung für Stadtentwicklung, Umweltschutz und Technologie Berlin) (Hrsg.) 1998d:**
Umweltatlas Berlin, digitale Ausgabe, Karte 02.07 Flurabstand des Grundwassers, 1 : 50 000, Berlin.
Internet: [http:// www.sensut.berlin.de/sensut/umwelt/uisonline/dua96/html/ei207.htm](http://www.sensut.berlin.de/sensut/umwelt/uisonline/dua96/html/ei207.htm)
- [36] **SenStadtUmTech (Senatsverwaltung für Stadtentwicklung, Umweltschutz und Technologie Berlin) (Hrsg.) 1999a:**
Umweltatlas Berlin, digitale Ausgabe Karte 02.13.2 Versickerung aus Niederschlägen, Karte 02.13.3 Abflussbildung, 1 : 50 000, Berlin.
Internet: [http:// www.sensut.berlin.de/sensut/umwelt/uisonline/dua96/html/ei213.htm](http://www.sensut.berlin.de/sensut/umwelt/uisonline/dua96/html/ei213.htm)
- [37] **SenStadt (Senatsverwaltung für Stadtentwicklung Berlin) (Hrsg.) 2002:**
Karte zur Charakterisierung der Deckschichten nach WRRL (digitale Karte im arcview- shape-Format).
- [38] **SenStadt (Senatsverwaltung für Stadtentwicklung Berlin) (Hrsg.) 2003:**
Flächen der oberflächlichen Einzugsgebiete im Stadtgebiet Berlin, digitale Karten arcview- shape-Format : "Obere_havel_sol", "Untere_havel_sol", "Spree_berlin", „Dahme_sol"
- [39] **SenStadt (Senatsverwaltung für Stadtentwicklung Berlin) (Hrsg.) 2003:**
Umweltatlas Berlin, Karte 02.07 Flurabstand des Grundwassers, 1:50 000, Berlin.
Internet: [http:// www.sensut.berlin.de/sensut/umwelt/uisonline/dua96/html/eia207.htm](http://www.sensut.berlin.de/sensut/umwelt/uisonline/dua96/html/eia207.htm)