

METHOD FOR EVALUATION WATER BUDGET IN SMALL RIVER CATCHMENTS

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Abstract. The atmospheric water infiltrating the underground predetermines the water storage of large and small rivers, groundwater and inter-stratum water supplies and base-flow. Climate fluctuation cycles affect the natural fluctuations of water-table horizon. Groundwater exploitation, usually responsible for reduction of groundwater supplies, is another important factor of groundwater dynamics. Water-table phreatic zones are replenished by infiltration water which never is of good quality. These negative trends became especially evident in the 21st century. The goal of the present research is to evaluate the groundwater storage formation ingredients in small river catchments based on analysis of precipitation water, relief dissection, surface deposits and types of land use. This method allows evaluating effective precipitation, infiltration condition of sediments, land use structure and relief dissection. The evaluation based on thematic large-scale maps and digital data bases.

Keywords: river catchment, precipitation, infiltration, retention, interception, relief dissection.

1. Introduction

The atmospheric water entering the underground predetermines the water budget of large and small rivers, groundwater and laminated water supplies and groundwater safe yield. Climate fluctuation cycles affect the natural fluctuations of groundwater horizon. Groundwater exploitation, usually responsible for reduction of groundwater supplies, is another important factor of groundwater dynamics in a horizon (Arustienė and Kadūnas 2007; Giedraitienė 2009, Šmitienė and Gaigalis 2010, Vaikasas and Bastienė 2000). Groundwater horizons are replenished by infiltration water which never is of good quality. These negative trends became especially evident in the 21st century as a result of imprudent groundwater exploitation and salting of roads and streets in winter (Baltrėnas and Kazlauskienė 2009; Baubinas and Taminskas 1998; Kadūnas 2007).

Preservation of groundwater supplies and improvement of its quality are the main environmental problems in Vilnius and its expansion zone. Due to increasing rates of pollution, surface bodies of water are unable to satisfy the recreational and aesthetic demands of the population. Moreover, processes deteriorating the groundwater quality are taking place in small river catchments. Their groundwater and interstitial water represent the potable and technological water supplies.

Erosion activity of rainfall waters is another important aspect in the context of deteriorating

groundwater quality. Blocks of flats and individual houses often are built in the wrong places: slopes of hills and valleys. Steep and long slopes are responsible for concentration of surface water flows during rainfalls and development of linear erosion forms (Česnulevičius 1998, 2005; Morkūnaitė and Česnulevičius 2005).

The goal of the present study is to systematize the methods for preliminary evaluation of water supplies based on analysis of atmospheric water amounts, surface deposits and distribution patterns of land use types and landscape elements.

2. Evaluation of water inflow

Evaluation of groundwater quantity in the small river catchments is based on evaluation of three components: precipitation, evaporation and discharge (Fig 1).

For evaluation of water resources in river catchments, it is expedient to use blocks of empirical formulae defining the quantitative values of precipitation, evaporation, infiltration and surface runoff. It is important that the calculations were based on the coefficients reflecting the local or regional conditions (Fig 2).

3. Evaluation of precipitation

Precipitation in river basins is evaluated in a few aspects: amount, duration, intensity and frequency. Lack of local observation data is the major problem in this

context. Interpolation-extrapolation of the data from a few closest meteorological stations is one of the possible solutions. The intensity of rainfalls is one of the major indices (Jaworowska *et al.* 2003; Bajkiewicz-Grabowska and Mikulski 2007) (Fig 3). Yet the data on the intensity of rainfalls are provided only by meteorological stations. The interpolation-extrapolation method for evaluation of rainfall intensity is not ultimately reliable whereas establishment of additional observation posts (rain gauges) is time-consuming and expensive. Besides, when the observation time is short (one year), the network of rain gauges in a catchment must be rather dense (Sokolov and Chapman 1976).

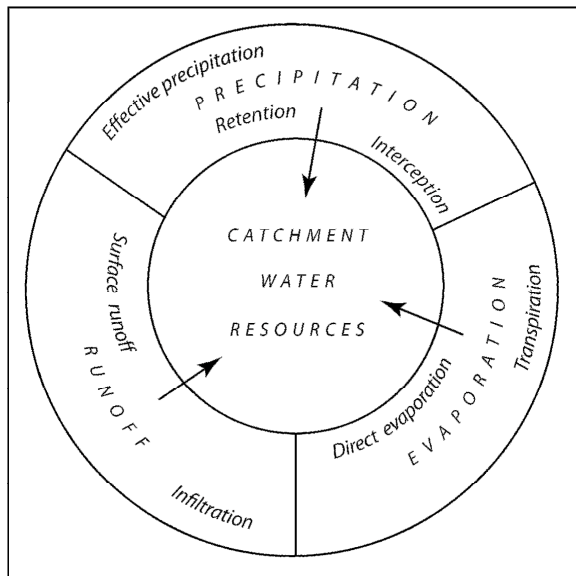


Fig 1. Water resources of river catchment

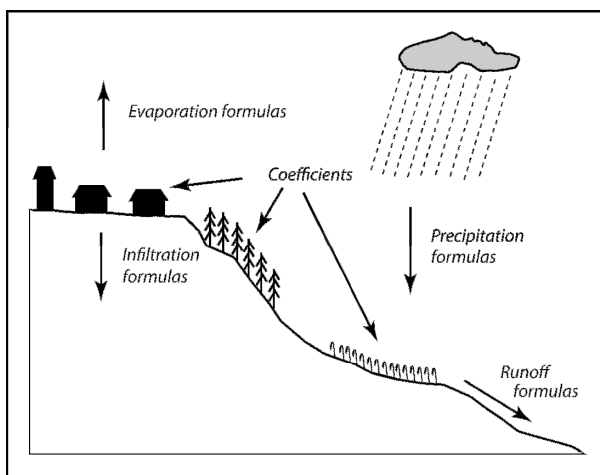


Fig 2. Water resources empiric evaluation blocs in river catchment

Effective precipitation represents one more important index for evaluation of water balance in river catchments. Effective precipitation is the amount of precipitation that is actually added and stored in the surface deposits. Less than 5 mm of rainfall is not considered effective as this amount of precipitation actually would not soak into the ground. It would likely

evaporate or be transpired by vegetation. Moreover, only 75 % of slightly more than 5 mm of rainfall are considered effective. The effectiveness coefficient of monthly effective rainfalls is even lower (Fig 4) (Table 1).

$$I_{max} = \frac{a}{(t+b)^n} + c \text{ (mm/min)}$$

where $t = \text{rain time (in min)}$,
 $a, b, c, n = \text{coefficients}$.

For Lithuania territory it's value are:
 $a = 17,164$
 $b = 3,5$
 $c = - 1,44$
 $n = 0,39$

$$I_{max} = \frac{17,164}{(t+3,5)^{0,39}} - 1,44 \text{ (mm/min)}$$

Fig 3. Evaluation of rain intensity

$$P_a = P - S_a - S_p - I$$

where $P_a = \text{effective precipitation}$
 $P = \text{precipitation}$
 $S_a = \text{interception}$
 $S_p = \text{retention}$
 $I = \text{infiltration}$

Evaluation of effective precipitation in warm period:
 $P_a = (P - 5 \text{ mm}) \times 0,75$

Fig 4. Effective precipitation

Table 1. Quantitative correlation between month precipitation (P) and month effective precipitation (Pe) (by Brouwer and Heibloem 1986)

P (mm/mth)	Pe (mm/mth)	Coefficient
0	0	0
10	0	0
20	2	0.11
30	8	0.26
40	14	0.35
50	20	0.40
60	26	0.43
70	32	0.46
80	39	0.49
90	47	0.52

Retention is one of decisive factors of slow distribution of rainfall water on the ground. Vegetation is a sort of barrier for precipitation to reach the ground directly. The amount of precipitation retained by plants depend the type of vegetation: the multi-storey vegetation (forests) act as a "leaky umbrella". It retains rainfall water for some time and then lets it concentrate. The higher plants especially strongly modify the intensity and

distribution of precipitation depending on: their leaf type (coniferous or deciduous), leaf parameters and their distribution (Monson *et al.* 1992). Besides, in the middle latitudes, large amounts of precipitation are preserved as snow in cold season.

The constituent of interception is important in the precipitation balance. The term interception is applied to precipitation temporarily retained by trees, shrubs or grasses before reaching the ground. In coniferous forests, interception accounts for 25–35 % of the annual precipitation, in deciduous forests and shrubberies for 15–25 % and in meadows and cornfields for 11–19 % (Fig 5, Table 2).

$$S_a = a + bP^n$$

where S_a = interception
 a, b, n = coefficients

Fig 5. Evaluation of interception

Table 2. Coefficient of interception in different land using areas

Type of vegetation	Coefficients		
	a	b	n
Deciduous forest	0.5	0.15	1.0
	1.0	0.23	
Deciduous scrubs	0.5	0.4	1.0
Coniferous forest	0.3	1.0	0.5
	1.3		
Vegetable gardens	1.67 h	0.49 h	1.0
Grassland	0.42 h	0.26 h	1.0
Corn fields	0.42 h	0.16 h	1.0

h – average plants height in meter.

Evaporation rates from the small river catchments require individual field investigations. Using the data from meteorological stations, the long-term evaporation values can be taken as a constant and eliminated from calculations.

4. Evaluation of surface deposit

Infiltration properties of surface deposits represent one of the major indices predetermining water resources in river catchments. The actual infiltration properties of surface deposits in river catchments are evaluated during field investigations by determining the filtration rates. This is an expensive and complicated way to obtain information. For this reason, evaluation of infiltration is evaluated using approximated formulae. The infiltration rates are predetermined by a few factors: strength of capillary suction, amount of precipitation (column of

precipitation) and permeability coefficient of deposits (Juodkazis 1992; Juodkazis and Marcinonis 2008). The estimations of infiltration rates are separate for one rainfall and for long-term precipitation (Fig 6, Table 3).

The horizons of surface deposits are evaluated using large-scale (1:5 000 and 1:10 000) soil and 1:50 000 lithological maps. Lithological types of deposits with identical water filtration properties are plotted.

For single rainfall:

$$V_i = s \times t \times k$$

For long-term rainfall:

$$V_i = K + \frac{KH}{s}$$

V_i - sinking velocity (mm / sec)
 K - infiltration coefficient (mm / sec)
 H - height of capillary rising (mm)
 s - height of percolation water (mm)
 t - time of rainfall (min)

Fig 6. Sinking velocity

Table 3. Infiltration coefficient of surface sediments

Surface sediments	Infiltration coefficients	
	m / day	mm / sec
Loam	0.05	0.0005
Sandy loam	0.1 – 5	0.0011 – 0.0578
Fine-grained sand	1 - 5	0.0115 – 0.0578
Medium-grained sand	5 – 20	0.0578 – 0.2314
Coarse-grained sand	20 – 50	0.2314 – 0.5787
Gravel	50 – 120	0.5787 – 1.3888
Pebble	100 – 500	1.1574 – 5.7870
Boulders	500 - 1000	5.7870 – 11.5740

5. Land use structure

Land use structure is evaluated using topographic maps at a scale 1:10 000 and digital data bases at a scale 1:50 000 (Cartographic Data Base ..., 2009; Colorful Raster Data Bases..., 2009). Based on them, natural and anthropogenic types of land use are distinguished: ploughed fields, meadows and pastures, forests, homestead plots of lands, compact plots of land of individual houses and collective gardens, quarters of the blocks of flats, industrial buildings, roads and other artificial water-impermeable surfaces. These types of land use are distinguished by different infiltration conditions (Table 4).

Table 4. Infiltration characteristics of artificial surfaces and natural land using areas

Surface type	Infiltration coefficients, K
Concrete	0.01
Asphalt	0.02
Pavement	0.03
Grassland	0.1
Coniferous forest	0.2
Deciduous scrubs	0.25
Deciduous forest	0.3
Arable land	1.0

6. Relief dissection

Relief dissection is evaluated using large-scale (1:10 000) topographic maps or digital data bases (Baubiniene *et al.*, 2002; Cartographic Data Base ..., 2009; Colorful Raster Data Bases., 2009). Surface inclination is one of the main indices of relief dissection affecting infiltration rates. Even a small slope angle conditions a rapid flow of precipitation water down the slope (Table 5). Especially large losses of precipitation water occur in the areas with an artificial surface (concrete, asphalt). The rainfall water may accumulate at the bottoms of slopes what are the cases during intensive rainfalls and spring thaws. There is a high probability that the larger part of the down-slope rainfall water flows will be carried away by a direct surface runoff and only some of it will soak the surface deposits and enter the groundwater discharge. This runoff models is characteristic of the small river catchments with glaciolacustrine and basal till deposits of Middle and West Lithuanian plains. Meanwhile, in the Žemaičiai Upland, Baltija Upland and North-East and South-East Plains, distinguished for coarser deposits, infiltration of rainfall water is more intensive. In these territories, the rainfall water is carried away by direct surface runoff only in very rare cases (intensive summer rainfalls).

Table 5. Reduction of water amount (P_r) in different slope inclination cases

Inclination of slope, degrees	Reduction of water amount, %
1	3
2	5
3	7
4	10
5	13
6	17
7	20
8	23
9	27
10	30
15	50
20	70
25	90

The quantitative evaluation of water budget in the small river catchments is based on estimation of three

components: precipitation, evaporation and runoff. Analysis showed that for preliminary evaluation of infiltration rates the formula given in Fig 7 can be used which encompasses the major water balance elements: amount of precipitation, interception and retention by plants, surface deposits and morphometric indices of relief.

$$I = (P - P_r - S_a - S_p) \times I_c$$

where P = precipitation
 P_r = reduction of precipitation
 S_a = interception
 S_p = retention
 I = infiltration
 I_c = coefficient of infiltration

Fig 7. Evaluation of infiltrated water amount in small river catchment

The main advantage of this formula is that the included parameters do not require long-term complex field observations. The available maps and digital data bases can be used.

7. Conclusions

It is difficult to evaluate the actual amount of precipitation in the small river catchments. Organization of local observations becomes quite a problem. Interpolation-extrapolation of the data from the closest meteorological stations can be chosen as the best solution. This method allows evaluating the effective precipitation which is actually added and stored in the soil. The part of effective precipitation is reduced by retention and interception. In coniferous forests, interception accounts for 25–35 % of the annual precipitation, in deciduous forests and shrubberies for 15–25 % and in meadows and cornfields for 11–19 %.

Infiltration properties of surface deposits represent one of the major indices predetermining water resources in river catchments. Based on thematic large-scale lithological soil maps (1:50 000), lithological areas of the same type of soils can be distinguished. The highest infiltration capacity is characteristic of gravel and pebbles and the lowest of clay and loam. Their infiltration capacity can be estimated using approximated types distinguished for identical water filtration.

The land use structure is evaluated using topographic maps at a scale 1:10 000 and digital data bases. The distinguished areas of natural and anthropogenic types of land use are marked by different filtration capacity. The least permeable and impermeable are artificial covers (concrete and asphalt). The most permeable are areas of ploughed fields.

The relief dissection is evaluated using topographic maps at a scale 1:10 000 and digital data bases. Surface inclination is the main index of relief dissection

predetermining the rainfall water infiltration rates. At small slope angles (1–5 °), the part of infiltrated rainfall water is reduced by 3–13 % and at slope angles (10 – 15°) by 30 – 50 %.

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