MODELING AND RECONSTRACTION OF TIME SERIES ANNUAL FLOW UNDER ABSENCE OBSERVATION DATA (DANUBE REGION IN UKRAINE AND MOLDOVA)

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Abstract: The efficient approach for reconstructions of natural flow time-series of the Danube region (Ukraine and Moldova) have been developed and numerically realized. The following tasks have been solved: estimation of annual surface and groundwater runoff of rivers under absence or deficiency of observation data; definition of connection between the natural runoff parameters and climatic or laying surface ones; modeling time-series annual runoff.
Keywords: natural annual surface and groundwater runoff, empirical orthogonal functions, water-heat balance.

MODELLIERUNG UND ISTANDSETZUNG DER ZEITREIHEN DES JAHRESABFLUSSES (DONAU REGION IN UKRAINE UND MOLDAU)

Zusammensfassung: Die wirksamen Einstellungen zur Wiederaufbaus der Reihen des natürlichen Abflusses des donaueren Regiones sind entwickelt und sind numerisch verwirklicht. Die folgenden Aufgaben waren entschieden: die Rechnungen des jährlichen oberirdischen und unterirdischen Abflusses in die Bedingungen des Mangels der beobachteten Daten. Die Bestimmung der Verbindung zwischen den Parametern des natürlichen Abflusses, der klimatischen Faktoren und der unterlegenden Oberfläche, die Modellierung der Reihen des jährlichen Abflusses.
Der Wortschlüssel: natürlichen jährliche oberirdische und unterirdische Abfluß, natürlichen orthogonalen Funktionen, Die Wasser-Wärmibilanz

1. AREA DESCRIPTION, METHODS AND MATERIAL STADIED

We consider lower river of Prut (Moldova) and watershed of Danubian lakes (Ukraine). These water objects are found in arid zone (north-west of Black sea region) - (*Tabl.1*). The mean annual precipitation $\overline{X}$ has the magnitudes from 450 mm to 600 mm decreasing southeastward. The annual maximum possible evaporation $\overline{E}_m$ varies from 800 mm to 1000 mm increasing southeastward. The ratio of these two values $\beta_X = \overline{X}/\overline{E}_m$ changes from 0.8 to 0.5, and the runoff coefficient $\eta = \overline{Y}/\overline{X}$ is closely to 0.5. Data about a runoff in a natural condition is not available in part of studying region (Figure 1). Therefore, it is necessary to develop methods of its account and modeling on basis of meteorological information. Analysis of annual precipitation and maximally possible evaporation fields with the empirical orthogonal functions method are used for modelling of natural annual surface and groundwater runoff series. The data from the 27 meteorological and 26 hydrological stations for 1951-1980 years (one hydrological cycle) was used in this paper. The grid points were used to compare the characteristics of hydrological and meteorological fields.

Table 1 - Climatic and hydrological characteristics of arid and surplus moistening zones.

North-west Black sea region	Mean annual values of		
	Precipitation	Maximum possible evaporation	Annual runoff
	[mm]	[mm]	[mm]
	450-600	800-1000	10-50

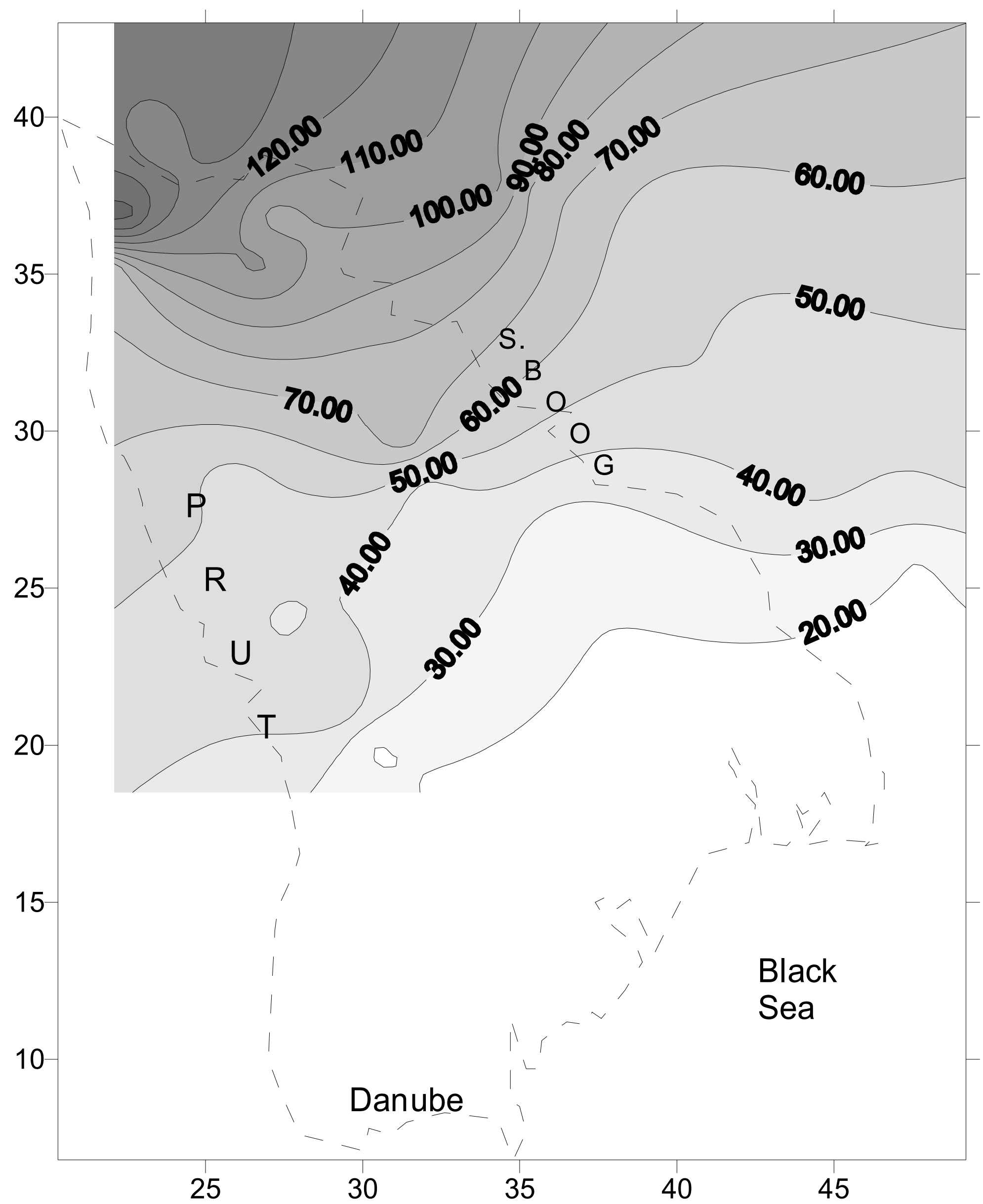

Figure 1 – Isolines of long-time average (norm) annual life-conditioned runoff (mm) for the north-west Black Sea region

1.1. Method of main components

A general idea of using the empirical orthogonal functions (EOF) is to make a linear transformation of the original data and produce a new orthogonal set of function.This approach is known as the method of main components (e.g. Obied and Creuten, 1986). As consistent with this method, any matrix entry of initial variable φ_{ij} (the latter means the *i*-th objects at the *j*-th time point) can be calculated if the eigenvectors problem is solved

$$\varphi_{ij} = \sum_{k=1}^{m} U_{ki} Z_{kj} \quad \text{as} \quad i = 1,m;\ j = 1,n. \tag{1}$$

The magnitudes of U_{ki} vary spatially under the change of object but is time-independent. In Eq. (1), φ_{ij} are the components of *j*-th random vector (field) for the centralized and normalized initial data; U_{ki} are the weighting coefficients reflected the contribution of *i*-th object into each *k*-th component or, in other words, the components of eigenvector for correlation matrix; Z_{kj} are the components of *k*-th decomposition component; *m* and *n* are the number of objects and the initial series length respectively.

The system of function U_{ki} is often represented as the function of coordinates (x_i, y_i) for *i*-th objects as follows

$$U_{ki} = f(x_i, y_i) = U_k(x_i, y_i) \tag{2}$$

The components of row-vector for the matrix **Z [** $z_{k1} \quad z_{k2} \quad \cdot \cdot \quad z_{kp} \quad \cdot \cdot \cdot \quad z_{kn}$ **]** can be represented as the function of time (amplitude function) and are common for all objects

$$z_{kj} = f(t) = z_k(t) \tag{3}$$

In this connection, Eq. (1) can be rewritten by

$$\varphi(x, y, t) = \sum_{k=1}^{m} U_k(x, y) z_k(t)\,, \tag{4}$$

Using the firsts eigen vectors and components vectors system, which discribe main part of dispersion of initial data, it is fulfilled an inverse transition from components to observed values excepting an influence of the poorly informative processes. The filtered values of initial variable $\tilde{x}_{ij}$ can be obtained from the following equations (Krasovskaia I., Gottshalk L. (1987):

$$\tilde{x}_{ij} = \bar{x}_i + \sigma_i \sum_{k=1}^{p} u_{ki} z_{kj} \tag{5}$$

$$\tilde{x}_{ij} = \bar{x}_i + \sum_{k=1}^{p} w_{ki} z_{kj}\ , \tag{6}$$

Here $\bar{x}_i, \sigma_i$ are the average arithmetical value and average quadratic deviation of an initial number. Values of w_{ki}, u_{ki} are the weight coefficients of main components, which are the elements of the eigen vectors of the covariance or correlation matrix (eigen vectors of matrix of a covariance or correlation); z_{ij} is a value of the *k-th* component (amplitude functions) in *j-th* instant. The values $\bar{x}_i, \sigma_i, w_{ki}, u_{ki}$ are deterministic functions in a space. They are dependent upon the coordinates in point (x,y); z_{kj} are set of functions common to all series; p - number of main first components.

1.2. Water – heat balance method

For an evaluation natural (not infringed the economic activity) runoff in conditions of defect of the hydrological observations data it has been developed a modification of the water-heat balance method, which includes a direct using the meteorological data (Loboda N.S. 1998). A basis of water-heat balance method is joint solving the equations of water and heat balances of the earthly surface, which contain a common component - total evaporation. A quantitative parameter of moistening resources is an annual precipitation (X), and a parameter for heat resources is a maximum possible evaporation (E_m). A heat resource or maximum possible evaporation E_m is a layer of water (mm), which could evaporate provided that all positive components of heat balance of a surface are spent on this process. The master equation is following:

$$Y_C = X + w_1 - w_2 - E_m\left[1+\left(\frac{X + w_1 - w_2}{E_m}\right)^{-n}\right]^{-\frac{1}{n}}, \tag{7}$$

Here Y_C - calculated values of runoff (mm); X – precipitation; $w_1 - w_2$ - change of humidity of soil; E_m - maximum possible evaporation. For long-time year, when $w_1 - w_2 = 0$, one can write as follows:

$$\overline{Y}_C = \overline{X} - \overline{E_m}\left[1+\left(\frac{\overline{X}}{\overline{E_m}}\right)^{-n}\right]^{-\frac{1}{n}}, \tag{8}$$

Here $\overline{Y}_C$ is an averaged value of annual runoff for long-time period (norm), which is dependent upon the climatic factors (mm); $\overline{X}$ is the annual precipitation norm (mm); *n* is a parameter which accounts for an influence of physically geographical conditions for runoff formation; $\overline{E}_m$ is the norm of maximum possible evaporation or thermal energetic equivalent (mm).

The runoff, calculated by the water-heat balance method, is called as climatic one and it is designated as Y_C (mm). The initial data for calculation are as follows: the positive component of radiation balance, precipitation for various time intervals, temperatures and deficiencies of the air humidity, water-physical characteristics of soil. A comparison of norms for annual climatic flow with natural ones has shown satisfactory results. The climatic runoff is identified as natural one. A climatic runoff, while it reflects influences of climatic factors, does not include effects of intra-catchment natural factors (azonal, intra-zonal) that shape the annual runoff. For evaluation of small river's resources, where influence of local factors is great, the special procedures have been developed to modify climatic flow into natural one. Figure 2 illustrates spatial distribution of main climatic factors and climatic flow.

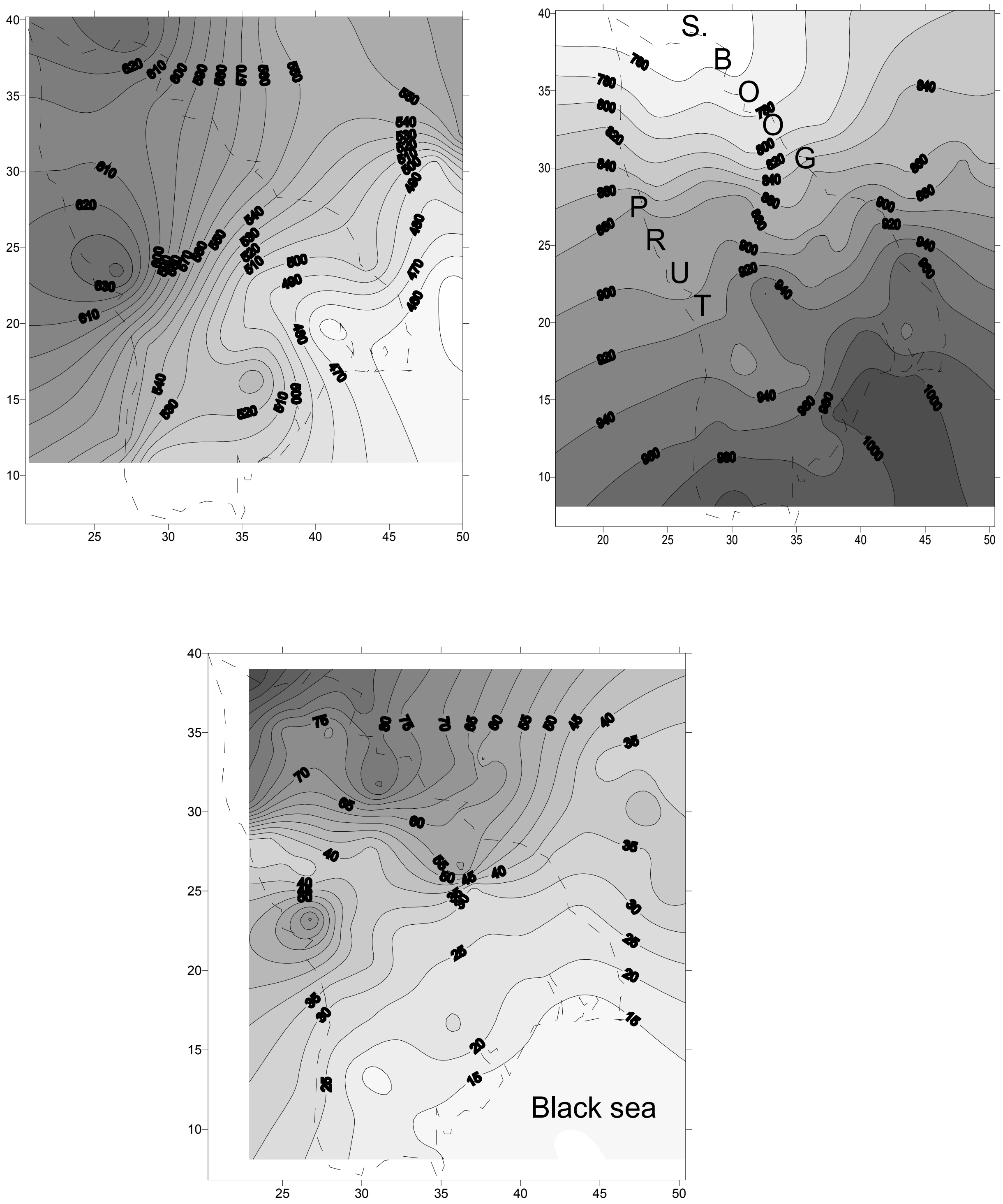

Figure 2 - Isolines of norms (mm) for the north-west Black Sea region
1 – annual precipitation; 2 – maximum possible evaporation; 3 – climatic runoff

For an evaluation natural (not infringed the economic activity) groundwater runoff in conditions of defect of the hydrological observations data there have been used conception about norm of infiltration of precipitation in aquifer U_0. Value of U_0 is function of quantity of annual precipitation and hydrogeological factor. Norms of surface and groundwater runoff were used as $\bar{x}_i$ in Eq. (6) for modelling of natural runoff rows.

2. Results

The parameterization of annual surface runoff in form of the weighting coefficients U_{ki} allows to ascertain the regression equations depicting the relationships between U_{ki} and various runoff-generative factors both climatic and surface ones (Loboda, 1999). The EOF-analysis of annual precipitation, maximum possible evaporation and runoff data shows that more then 80% of variation is already explained by the first three components. A detailed comparison of spatial distribution of the weight coefficients for the first components and amplitude functions allows make the following conclusions. For the first three components of the decomposition of hydrometeorological variables on the empirical orthogonal functions a spatial distribution of the weighting contributions has the general similar feature. It can be explained by a resulting influence of the large-scale atmospheric processes on a forming the climate and water resources. First component of expansion is stipulated by the planetary scale processes, which take influence on the climatic background of precipitation, air temperatures (maximum possibility evaporation), and runoff. The weighting coefficients of first component for annual runoff data of South – West Ukraine vary smoothly over the studied region. Hence they can be considered by functions of spatial coordinates (*x*, *y*) or climatic factors ($\bar{X}$, $\bar{E}_m$), which are functions of the spatial coordinates, too. One can write as follows:

$$w_{1i} = 0{,}0115y - 0{,}00510x - 0{,}0365\,; \;\; R = 0{,}815 \tag{10}$$

$$w_{1i} = -0{,}000884\bar{E}_{mi} + 0{,}000361\bar{X}_i + 0{,}660\,; \quad R = 0{,}884 \tag{11}$$

Here $\bar{X}$ and $\bar{E}_m$ are the magnitudes for the norm of annual precipitation and for the norm of annual maximum possible evaporation respectively; *R* is the coefficient of multiple correlation.

The second component contains an information about synoptic scale processes. For cold half-year (October - March) the warm and humid air masses move on the quasi-meridian trajectories through territory of Ukraine. In the converse case, for warm half-year (April – September) the anticyclone weather predominates without precipitation with a high temperature background in Ukraine. Thus, the processes of synoptic scale ensure an existence of two climatic factors (equal on effect!) generating the annual runoff: annual precipitation and maximum possible evaporation. Weighting coefficients (elements of the eigenvectors for matrixes of correlation or covariance) for second component of precipitation and maximum possible evaporation change a sign in accordance with promoting west-to-east. In absolute values the second coefficient gives dominant influence. Weighting coefficients of second component depends on the geographical longitude (*x*)

$$w_{2i} = 0{,}0172x - 0{,}519\,; \;\; r = 0{,}740 \tag{12}$$

The distribution of weighting coefficients for third component of annual runoff field changes with promoting north to south and depends on the geographical latitude (*y*) as follows:

$$w_{3i} = 0{,}0190y - 0{,}667\,;\ r = 0{,}726\,, \tag{13}$$

where r is the correlation coefficient.
For flat regions of Ukraine a value of U_3 can be represented in dependence on values of the norms of maximally possible evaporation $\bar{E}_m$. Correspondingly, for mountain regions this is in dependence on distributing the annual precipitation norms $\bar{X}$. Thus first three weighting coefficients are the deterministic function in a space (Figure 3). This important result reflects the meso-scale features in distribution of climatic factors. For example, we may say about dependence of precipitation distribution upon the mountain hills exposition or dependence of evaporation temperature upon an influence of the breeze circulation. Fourth and fifth components of decomposition are concerned with the sub-lying surface factors. Weighting coefficients of fourth component depend on the intra-catchment natural factors (azonal, intra-zonal). The maximal values of the fifth component weighting coefficients are established for the river basin runoff under the water-management reconstruction.

So, using the first three or four (for small rivers) components gives possibility to get natural series for the annual runoff. Water management influence is excluded by fulfilling the filtration of numbers of a runoff on the basis of the first three components (amplitude functions), which reflect a temporal trend of a runoff stipulated only by the climatic factors. Such procedure in the method of main components is named the "filtration" of initial data.

Resalts of investigation of groundwater fields discern from one's, obtained for surface annual runoff. First two main components discribe more 80% of unitial data dispersion, first component contains 70%. Weight coefficients of first component depends on norms of infiltration U_0 and average elevation of basin H_{CP}

$$w_{1i} = 0.0068U_0 + 0.000298H_{CP} - 0.0529\,,\ R = 0.91\,, \tag{14}$$

Weight coefficients of second component connect with swampiness f_S

$$w_{2i} = 0.0567f_S - 0.0463\,,\ r = 0.65\,, \tag{15}$$

3. Conclusion

Solving tasks of restoring magnitudes of time rows of runoff can be realized by using amplitude function (common for all territory) and weight coefficients of first components, deteminated for the point in space (center of watershed). Main equation of modelling is (6). A validity of our results is confirmed by comparing the observed annual runoff and reconstructed natural (undisturbed by the economical activity) one by means of the method of main components (Loboda, 2001). The adequacy of reconstruction lies in the limits ±10-15%. We used only first component for restiring groudwater rows. The adequacy of reconstruction lies in the limits ±15-20% (Loboda N.S., Shamenkova O.I., 2001). Under conditions of absence of observation data such approach to modelling is very efficacious. Comparision of observed and calculated data shown on figure 4 for ground water runoff.

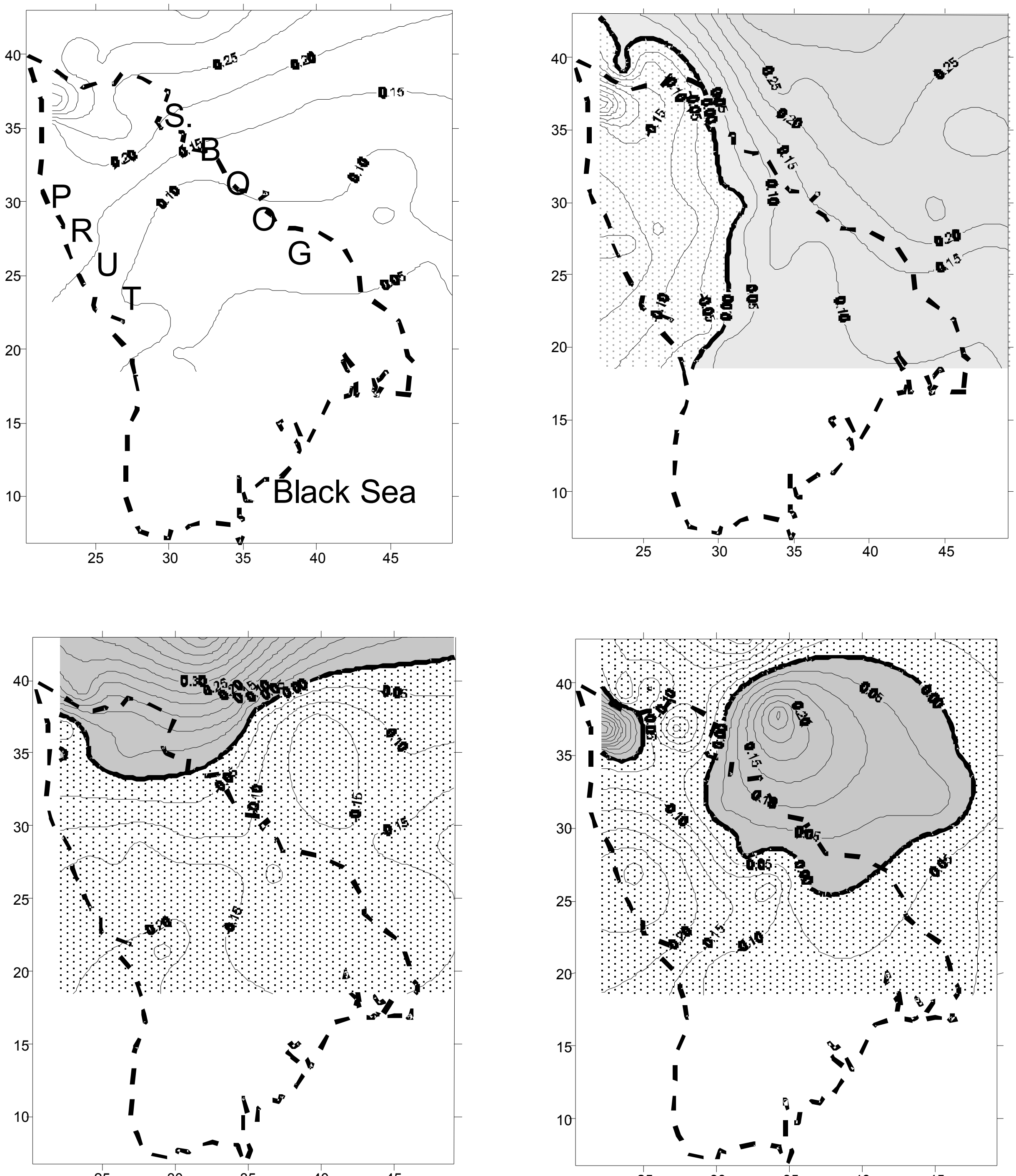

Figure 3 - Spatial distribution of weight coefficients of first four components
(annual flow fields)

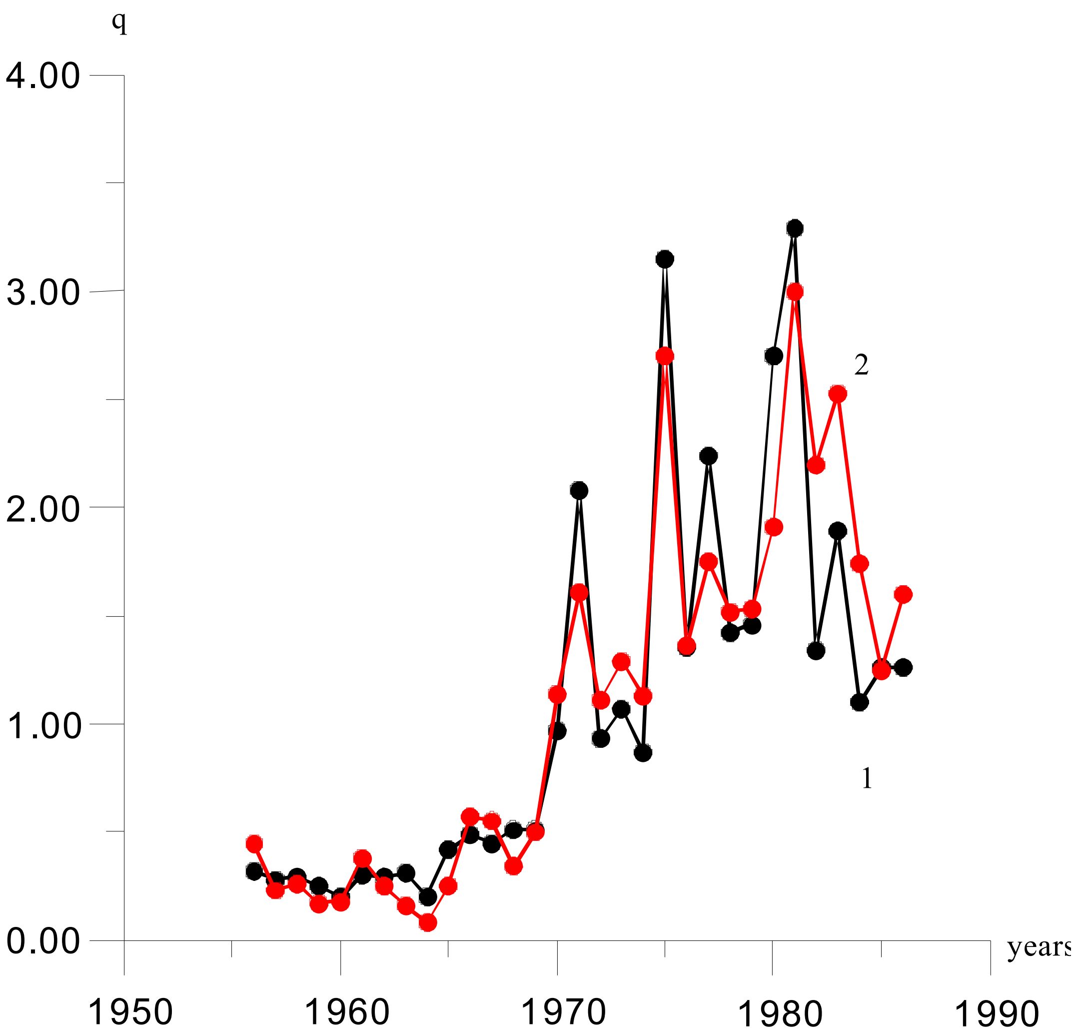

Figure 4 – Comparison calculated (2) and initial (1) data of growndwater annual runoff (restoriing on base of first componenet)

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