LONG-TERM FLUCTUATIONS OF THE BLACK SEA LEVEL AND STREAMFLOW

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The analysis of the Black Sea mean annual water level curve as observed by Odessa, Sevastopol, Kerch and Poti hydro-meteorological stations, testifies to the fact that apart from the secular sea level rise taking place everywhere alongside with the subsidence of the coast, the level fluctuates considerably enough from year to year at all the hydro-meteorological stations simultaneously. Thus the Black Sea proves to be some years deeper than others.

We assume that these level fluctuations are caused by the fluctuations of the sea water balance, and particularly by the difference in the amount of the streamflow into the Black Sea.

As early as 1895 Gnusin (2) determined that the seasonal fluctuations of the Black Sea and the Sea of Azov are the result of the difference in the amount of the streamflow into the sea. As 70 per cent of the continental flow comes into the north-west part of the Black Sea, the maximum values of the monthly sea level at the hydro-meteorological stations in other parts of the Black Sea is expected to somewhat lag as compared to that in north-west part of the sea. The further the station is from north-west, the larger is the time of this lagging. The maximum amount of the streamflow in the Danube mouth at Sulina falls on may (5), whereas the maximum levels at Odessa are in may-june, at Feodosia — in june and at Gagri — in july.

Figure 1 proves that the Danube annual runoff is in obvious concordance with the change of the sea level at the hydro-meteorological stations of Odessa, Sevastopol, Kerch and Poti. Though the Danube runoff considerably changes from year to year (approximately from 300 m^3 in 1915 to 1300 m^3 in 1921) it does not very much depart from its mean value. According to Dorin (7), the normal annual runoff of the Danube at Orshov, for 50 years (from 1876 to 1935) is 170 km^3, according to our calculations for 75 years (from 1876 to 1956) it being equal to 171 km^3. However, though the fluctuations of the Black Sea level come up to 20 cm for the two adjacent years (1921-1922 at the hydro-meteorological stations of Sevastopol, Poti, Odessa), they take place against the general background of the total relative rise of the sea level (i.e. against the background of the general coast subsiding in the Black Sea).

As the fluctuations of the streamflow influence the annual march of the Black Sea level, we have once again calculated the total continental runoff and it has proved to be 375 km^3. When making calculations we, unlike many other investigators, did not take into account the streamflow into the basin of the Sea of Azov, on the other hand we took into account the discharge of the Sea of Azov waters exceeding those of the Black Sea, which is the result of the exchange between waters through the Kerch strait. The calculated runoff to the Black Sea amounts to the total runoff value given by Bruevich (1) as 350 m^3.

The normal annual runoff into the north-west part of the Black Sea is 265 m^3 (70 per cent of the total runoff), the Danube alone giving annually the runoff average of 201 m^3 (6), i.e. 54 per cent of the total runoff into the Black Sea. The runoff at Orshov (955 km from the river mouth) makes up 84 per cent of the Danube runoff, or 45 per cent of the total continental runoff into the Black Sea. All the rivers pouring into the Black Sea, with the exception of the Danube and the Dnieper, are comparatively dry. These rivers are fed from various sources.

Considerable fluctuations of the continental runoff in the Black Sea are mainly due to the fluctuations of the Danube runoff its normal annual runoff is approximately fourfold as much as the corresponding Dnieper run off. Thus, the Danube mean annual runoff fluctuations, according to Orshovs discharge site, may be dealt with as an index of the fluctuations in the continental runoff into the Black Sea.

The Black Sea is the most isolated sea of the World Ocean, according to N.N. Zubov (4); its isolation (the ratio of the volume to the area of the minimum cross-section of the Bosporus strait) is expressed by the figure 16.10^6. Hence, the streamflow fluctuations influence not only

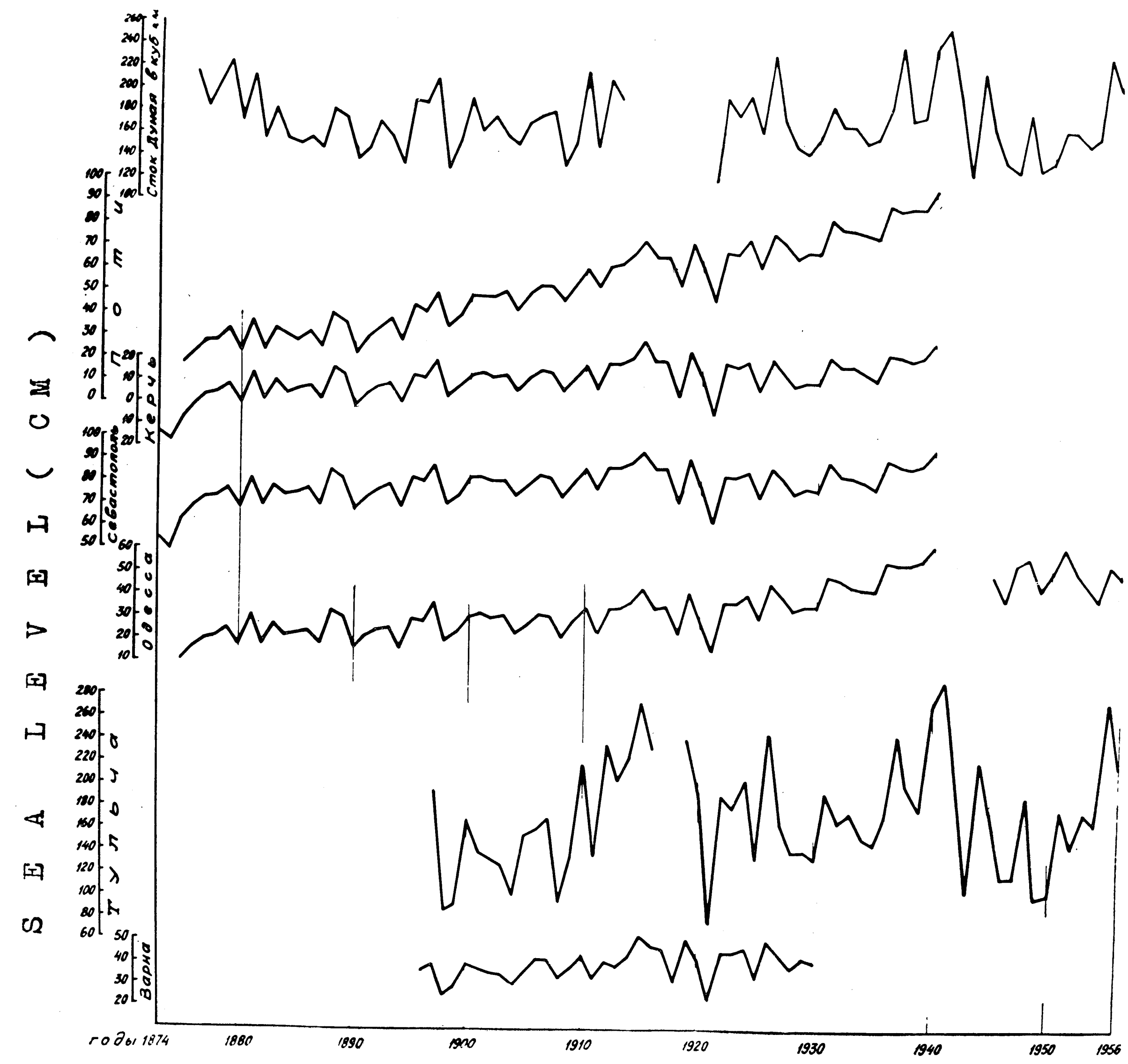

FIG. 1. — *The annual Danube dicharge at Orshova and yearly levels in Varna; Tulcha, Odessa, Sevastopol, Kerch and Poti in the period* 1874-1956.

the annual fluctuations of the water level, but also the annual march of the sea level, as is the case with the Caspian Sea, though to a lesser degree.

The dependence of the deviation in the annual march from its value for the previous year has been calculated for 50 years, according to Orshov's discharge site and to corresponding accretion of the mean annual level in the Black Sea, according to the data supplied by the Odessa hydro-meteorological stations.

We have succeeded in determining, in the similar way, the correlation factor and in calculating the equation showing the 41 year-long connection between the deviation in annual march, according to Orshov's discharge site, from its value for the previous year, and the corresponding accretions of the mean annual sea level as observed by the Sevastopol, Kerch and Poti hydro-meteorological stations.

Table I shows the equation of the dependence and the correlation factors of the annual runoff deviation according to Orshov's discharge site, and the corresponding level fluctuations.

Locations of hydro-meteorolog. stations	II	Correlation Factor	Dependence Equation
Odessa	50	0.92	$\Delta h = 0.7 + 0.216\ \Delta Q$
Sevastopol	41	0.89	$\Delta h = 0.6 + 0.206\ \Delta Q$
Kerch	41	0.88	$\Delta h = 0.4 + 0.199\ \Delta Q$
Poti	41	0.99	$\Delta h = 1.2 + 0.207\ \Delta Q$

TABLE I

In the table Δ Q stands for the increase in the streamflow, according to Orshov's discharge site, as compared to its value for the previous year, Δ h stands for the corresponding increase in the annual water level.

Analysing the data of table I one can arrive at a conclusion that a big correlation factor between the Danube runoff fluctuations and the level proves that the relation determined by us is quite reasonable and can be used to make up the deficiencies in the mean annual water level data. Having solved the equation for Δ Q, one can determine the amount of the annual Danube runoff for the years when no observations were carried out at the Orshov's discharge site.

Bearing in mind that all the above equations differ but a little, it is possible, accurately to one tenth, to take the increase in the annual water level at all the Black Sea hydrometeorological stations as 0.2 of the accrement value of the annual runoff according to Orshov's discharge site.

One cannot but pay attention to the different value of the absolute term for various parts of the Black Sea coast. The presence of the absolute term in all these equations shows that the sea level rises even when no positive increase in the runoff has been observed, i.e. the absolute term indicates the subsiding of the coast. This term allows also to take into account the secular rise in the level of the World Ocean which lately has taken place due to the glacial melt water.

As it has been determined (3) the process of coast subsiding reaches its highest speed at Poti; the above equation determines, that it comes up to 1, 2 cm per year for this region. The least speed of coast subsiding, according to TSHIVAGO, is at Anapa (3); judging by the above data the lowest speed is at Kerch, near Anapa (there are no available data for Anapa itself) where it amounts to 0,4 cm per year.

Assuming approximately that the deviation of the mean annual level at the coastal stations corresponds to the deviations in the central parts of the sea, and knowing the sea area, it is possible to calculate the corresponding increase of the sea volume.

In « wet years » some part of river waters remains in the Black Sea and the balance between the Black Sea and the Sea of Marmara is registered with some delay. In « dry years » when the Danube runoff into the Black Sea is by far less than normal runoff, a considerable decrease in the mean annual sea level, as compared to that of the previous year, has been registered. The decrease in the level as compared to the previous year, when the runoff was close to the normal one, reaches 14 cm (1949, Odessa).

However, the considerable excess of the Black Sea level over that of the Sea of Marmara, which according to MAKAROV is 43 cm, prevents the inflow of water from the Sea of Marmara into the Blagk Sea, i.e. from « watering » the Black Sea.

The Black Sea currents in « dry years » must be much slower than in « wet years », according to the Bosporus observations. The amount of the Black Sea water runoff into the Sea of Marmora must be respectively less as compared to « average years ». It was a common practice to think of the intensity of the Bosporus currents as depending on winds only, without taking into consideration the streamflow into the Black Sea.

In connection with this, it should be of some interest that both MAKAROV's observations and MERZ's observations in the spring of 1918 were carried out in « dry years ». This is the reason why the normal annual curves of the Black Sea water balance usually contain the data on the Bosporus water exchange expressed by a lowered value which was calculated by LOTTA MILLER for the « wet year » of 1918.

The fluctuations of the Black Sea volume testify to the fact that a considerable part of north-west waters, after passing Bosporus, is probably the main cause of currents in the Black Sea; this is especially true of the spring and summer periods, characterized by the weaker atmospheric processes in the Black Sea basin, as well as by the maximum streamflow into the north-west part of the Sea. The winds may considerably influence the currents in winter time, when they get stronger and the streamflow gets less.

We can well assume, that the greater speeds of the main Black Sea current fall on the year marked by a larger streamflow into the Black Sea basin.

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