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SOME DYNAMIC AND HYDROGRAPHIC PROPERTIES OF THE KAŠTELA BAY

NEKA DINAMIČKA I HIDROGRAFSKA SVOJSTVA KAŠTELANSKOG ZALIVA

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A large number of data on currents and hydrography of the Kaštela Bay was analyzed. The work demonstrated the influence of different factors affecting water circulation and annual variations of different properties of the bay.

INTRODUCTION

From the time of the early papers by Ercegović (1934, 1940), the Kaštela Bay (Kaštelanski zaliv) has been a kind of experimental basin for the Institute owing to the position of the Institute in the bay. Different biological phenomena have been carefully investigated, including the state of pollution in recent years. These investigations have also included the studies of the hydrographic and dynamic properties of this bay.

This paper is the result of the attempt to improve, as far as possible, the quantitative assessment of the influence of different factors on the movements of the sea water in the bay, which may be of use in the development of a dynamic model of the bay. Attempts have also been made to develop an appropriate empirical model of the system of circulation. The different factors on the current regime, as well as seasonal variability of the physical properties of the sea water and the relationship between horizontal and vertical circulation are separately examined.

All data collected from 1934 on have been utilized (see data sources in References). Even though not always systematically collected, the material used is abundant. In the 1953—1954 period the measurements of hydrographic properties and currents were made every 15 days at 13—20 stations. The measurements of somewhat smaller extent were carried out at 5 stations in 1972—1973.

FACTORS AFFECTING THE CIRCULATION OF THE WATER IN THE BAY

Several types of circulation occur in the surface layer, including cyclonic flow, anticyclonic flow and combinations of both. The occurrence of each type of circulation is dependent on a number of factors.

1. Wind direction is very of the factors of primary importance. The analyses of current meter and salinity data collected from a series of stations during a day, twice in a month's period in 1953—1954, show that anticyclonic circulation occurs with the scirocco (SE wind), and cyclonic circulation with the bora (NE wind) and maestral (NW wind, locally in the bay even of SW direction) (Figs. 1—4).

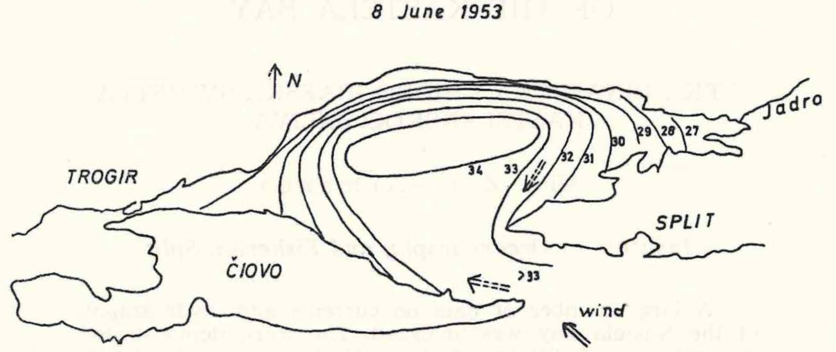


Fig. 1 Distribution of salinity (‰) in the Kaštela Bay during the scirocco (SE wind) with typical anticyclonic flow.

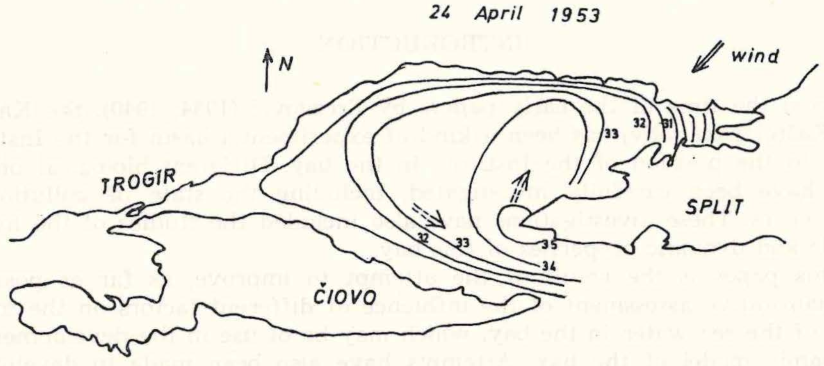


Fig. 2 Distribution of salinity (‰) in the Kaštela Bay during the bora (NE wind) with typical cyclonic flow.

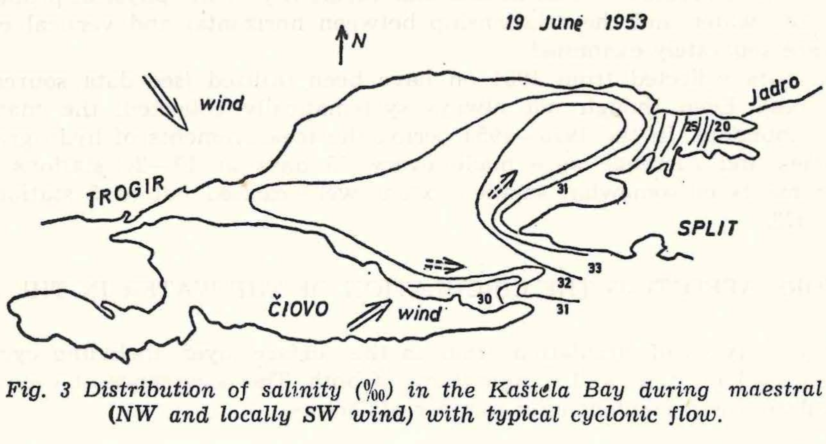


Fig. 3 Distribution of salinity (‰) in the Kaštela Bay during maestral (NW and locally SW wind) with typical cyclonic flow.

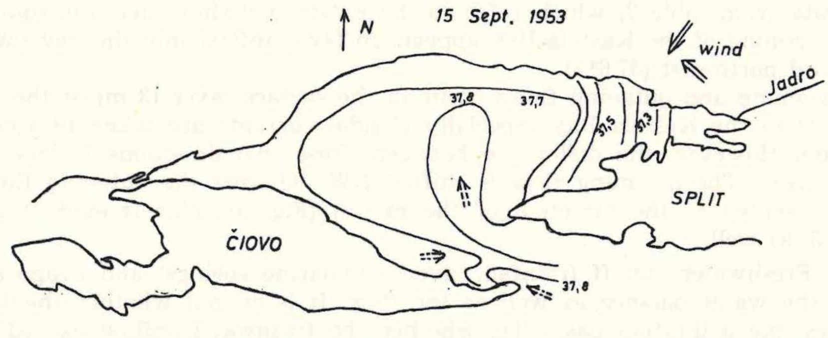


Fig. 4 Distribution of salinity (‰) in the Kaštela Bay while bora shifts to scirocco (SE wind).

In addition, in the surface layer the scirocco drives the water into the bay, and the bora, and to a smaller extent the maestral, drive the water out of the bay.

Close along the eastern coast the water flows out of the bay on the surface. At the Marjan Cape, along with wind observations the flow directions are visually determined from the shore every day at 7 a.m. and at 2 p.m. Here at the coast North direction represents incoming and South direction outgoing currents. Current flow direction data were analyzed to determine the relation of wind direction to current direction.

Table 1. Relation betpeen the incoming CN and outgoing CS currents on the surface at the Marjan Cape for different wind directions, expressed in percentages, according to the diurnal data for the 1961—1979 period (visual observations)

Wind	SE+S (SCIROCCO)		NE+N+E (BORA)		SW+NW+W (MAESTRAL)		Calm period	
Current	C_N	C_S	C_N	C_S	C_N	C_S	C_N	C_S
% of occurrence	36	64	12	88	16	84	13	87

The visual current and wind observations along the Marjan Coast are in agreement with the findings of the 1953—1954 current meter and salinity data; namely, that surface water is most strongly driven into Kaštela Bay during scirocco winds and flows out of the during bora and maestral winds.

2. The position of the mouth of the bay in relation to the dominant current and wind directions is of importance. The prevailing current direction along the eastern Adriatic coast is to the Northwest. The Kaštela Bay is open to this flow and thus it may occur in the bay in a high percentage of time.

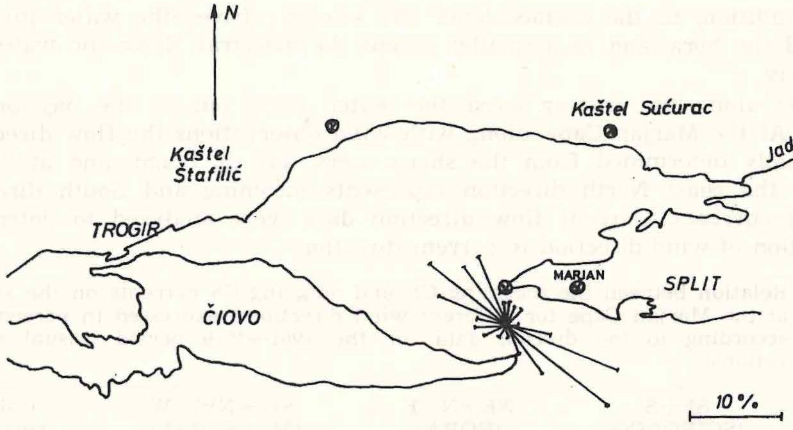
Table 2. Frequency of directions in the surface layer (3 m) of the Kaštela Bay according to the current meter data for 5 stations (measured at monthly intervals in 1972—1973). Frequencies are expressed in percentages calculated from diurnal resultants (tidal periods being filtered)

Direction	N	NE	E	SE	S	SW	W	NW
Frequency (%)	15.6	12.5	9.4	12.5	6.2	6.2	18.8	18.8

Data from table 2, which refer to the entire bay show that the southeasterly opening of the Kaštela Bay appears to favor inflow into the bay toward west and northwest (37.6%).

Incoming and outgoing flows occur in the surface layer (3 m) at the very entrance to the Kaštela Bay especially if tidal currents are taken into consideration. However, the difference between these two directions is less than 180 degrees. The incoming flow is shifted NW, whereas the outgoing flow is freely adapted to the direction of the mouth (Fig. 5). This is evident from Table 3, as well.

3. Freshwater runoff (rainfall, river, submarine springs) and evaporation affect the water balance as well as the flow. It is crucial whether the basin behaves like a dilution basin, i.e. whether the freshwater inflow exceeds the evaporation, or if the opposite is true. The Kaštela Bay behaves like a dilution



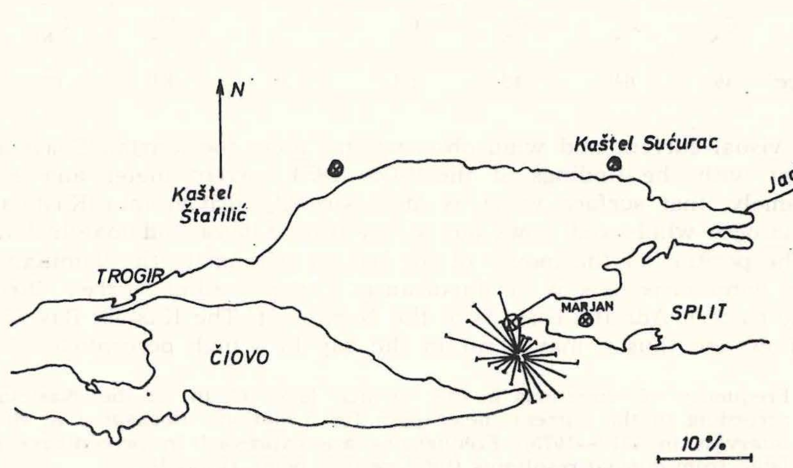


Fig. 5 Current roses constructed for the mouth of the Kaštela Bay according to the per cent of the frequency of occurrence of directions at 3 m depth (tops) and for 20 and 40 m together (bottom). Meteorological stations whose data were used in the work are marked by small circles.

Table 3. Frequencies of directions in percentages (according to all data) at the station in the middle of the mouth of the Kaštela Bay for 1972—1973, at 3 m depth and in deeper layers (20 and 40 m together)

Direction in ° of azimuth		5	20	35	50	65	80	95	110	125	140	155	170
Frequency %	3 m	3.2	2.7	2.7	0	2.7	0.8	5.2	13.3	14.2	7.0	3.2	1.0
	20+40 m	2.9	1.6	1.8	1.7	4.4	2.4	5.3	4.4	2.6	5.5	5.8	5.0
Direction in ° of azimuth		185	200	215	230	245	260	275	290	305	320	335	350
Frequency %	3 m	1.0	0	1.0	0	2.0	2.7	2.5	7.8	10.5	8.0	8.0	2.0
	20+40 m	0.7	3.0	2.3	2.9	3.4	5.1	7.1	5.6	7.0	5.3	8.2	3.8

basin for the major part of the year due to the Jadro River influx and submarine springs. If compared to the adjacent region the salinity data clearly indicate the effects of dilution in the bay. This is quite evident from the mean salinity data from outside and inside of the bay for the entire water column and for the surface alone.

Table 4. Data on salinity inside and outside the Kaštela Bay

Station	Mean annual salinity for 1972—73 in ‰ entire column	sea surface
In front of the Split town port (3 Nm eastward from the bay)	37.42	36.55
Mouth	37.33	36.47
Middle of the bay	37.32	36.48
Eastern part of the bay (K. Sućurac)	36.81	35.15

It is evident from Table 1 as well that a very high percentage of the flow of water out of the bay in the surface layer. Directions are more variable in deeper layers. However, as evident from Table 3 and Fig. 5 the flow aut of the bay ni the surface layer is balanced by the flow into the bay at deeper layers.

To make easier the assessment of the effects of these different factors, seasonal aspect of their influence was evaluated. Good series of data on salinity and water temperature, as well as on the rainfall, humidity, wind and River Jadro runoff were available. Even though no quantitative data on the activity of submarine springs were available it was assumed that their intensity variability coincided with that of rainfall. It was also assumed that the water exchange took place only through the main mouth of the Kaštela Bay. The narrow mouth near Trogir was neglected due to its depth of only few metres.

SEASONAL CHANGES OF SALINITY AND CIRCULATION

Annual variations in salinity were observed in order to assess the factors affecting it and thus to determine the relationship between the local factors and the influence of the open sea, i.e. advection.

Mean monthly values of salinity for the station in the middle of the bay are well indicative of the seasonal changes of salinity.

Table 5. Mean monthly values of salinity for the station in the middle of the Kaštela Bay for 1932—1971

	0 m	10 m	20 m	30 m	35 m
Jan.	35.07	36.69	37.43	37.74	37.94
Feb.	35.55	36.69	37.29	37.65	37.75
March	35.16	36.17	36.92	37.45	37.59
April	33.78	36.38	37.14	37.47	37.59
May	34.20	36.56	37.34	37.63	37.70
June	34.58	36.74	37.56	37.84	37.94
July	36.22	37.39	37.74	37.94	38.01
Aug.	36.62	37.52	37.95	38.12	38.19
Sept.	36.78	37.63	38.01	38.21	38.22
Oct.	36.96	37.63	37.92	38.06	38.15
Nov.	35.73	37.41	37.72	37.86	37.92
Dec.	35.10	36.82	37.61	37.86	38.03

Minimum salinity occurs at the surface in April and maximum in October. However, already at 10 metres and down to the bottom minimum occurs in March and maximum in September.

Surface salinity is influenced by the E-P factor, vertical mixing and advection. Of those the first two could be understood as local influences and the third as an external influence. E-P factor does not affect the deeper layers leaving only vertical mixing and advection of importance below the surface.

Surface salinity will be considered first (Fig. 6). The influence of vertical mixing may be approximately given as the difference in density between the surface layer and the bottom one. This difference is minimum in October, coinciding with maximum surface salinity due to the intensive vertical mixing. Mixing top to bottom or complete overturn is rather rare and observed in autumn months only.

The greatest difference in density between the surface and 30 m is recorded in June, but is also large in April. Yet, the April minimum of surface salinity may be attributed to the influence of E-P factor (including Jadro). A secondary minimum occurs in December owing to the intensive rainfall in November and December. The secondary maximum in February is connected with strong vertical mixing and evaporation. The increase of salinity in June—July if of particular interest. It may be due to the upwelling, vhich is indicated for that period by the sea temperature climatic data (Fig. 7). In this period SE scirocco wind occurs infrequently. Since scirocco winds suppress upwelling by driving surface water into the bay, the absence of these winds allows free development of upwelling.

To get a better insight into the mutual relationship of these different factors a multiple correlation was calculated. Mean monthly values of evaporation were first determined. Data on humidity were used from two coastal stations of the bay (Marjan Cape and Kaštel Štafilić), the sea surface temperature data at Marjan Cape (1952—1978) and wind data from Marjan (meteorological first order station). The data from the shore station at Marjan Cape (1951—1978) were used as representative of the rainfall. The data on

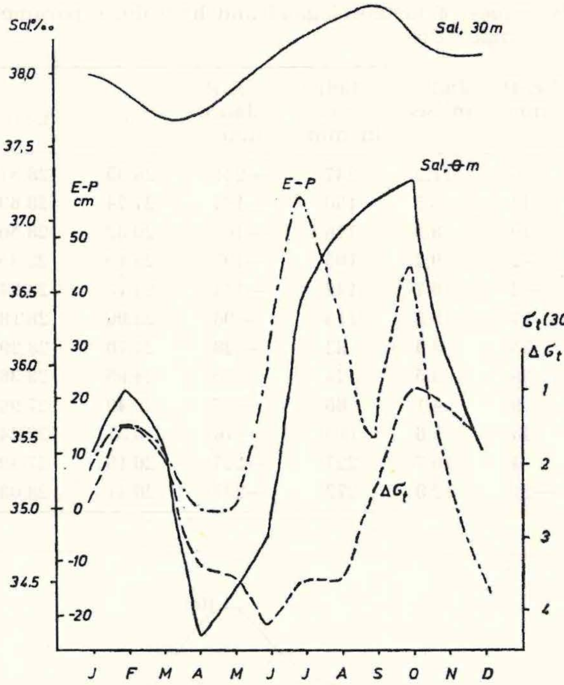


Fig. 6 Annual fluctuations of salinity on the surface and at 30 m depth at the station in the central part of the Kaštela Bay. Difference in density (σ_t) between the surface and 30 m throughout the year is given as well as the difference between evaporation and precipitation (E—P) calculated from the meteorological data at the shore stations.

the Jadro River discharge (1957—1978) were kindly made available by the Hydrometeorological Service. Evaporation was calculated by a formula taken from Sverdrup (1942); the E-P factor was then calculated. Thus evaporation and rainfall were taken into account as well as the River Jadro inflow recalculated for height in mm for the whole area of the bay. The Jadro inflow was divided by two since the correlation was computed for the salinity from the station in the middle of the bay. All of these data cover a long period of observations.

A coefficient of correlation between the mean monthly values of surface salinity and E-P — Jadro is 0.56. This coefficient between the same salinities and the difference in density between the surface and 30 metres is —0.37. It may be of interest that the coefficient of correlation between two factors, the relationship of which was not studied, i.e. E-P — Jadro and the difference in density between the surface and above the bottom is 0.41. This indicates that these parameters are also interdependent.

Coefficient of multiple correlation between the mean monthly values of surface salinity, E-P and difference in density between the surface and 30 m depth is 0.85. It would probably be even higher if the E-P factor and vertical mixing were more carefully determined. However, it is held to be quite suf-

Table 6. Mean monthly values of meteorological and hydrologic parameters used for the correlation computation

	Evap. mm	Rainf. mm	E-P mm	Jadro m³/sec	Jadro rec. in mm	E-P-Jadro mm	$\sigma_{t,\,0\,m}$	$\sigma_{t,\,30\,m}$	$\sigma_{t,\,0\,m}$ to $\sigma_{t,\,30\,m}$
Jan.	95	89	6	11.2	237	—231	26.85	28.37	2.52
Feb.	83	70	13	8.5	180	—167	27.24	28.63	1.39
Marc	73	63	10	8.3	176	—166	26.82	28.50	1.68
April	63	65	—2	9.2	195	—197	25.19	28.35	3.36
May	56	58	—2	6.7	142	—144	24.73	28.24	3.51
June	68	51	—17	5.3	113	—96	23.96	28.18	4.22
Jbly	85	30	55	3.9	83	—28	24.78	28.29	3.51
Aug.	84	45	39	3.5	74	—35	24.85	28.36	3.51
Sept.	73	64	9	4.1	86	—77	25.49	27.96	2.47
Ocrt.	115	72	43	5.6	119	—76	26.31	27.24	0.93
Nov.	123	119	4	10.7	227	—227	26.19	27.43	1.24
Dec.	98	119	—21	12.8	272	—293	26.41	28.03	1.62

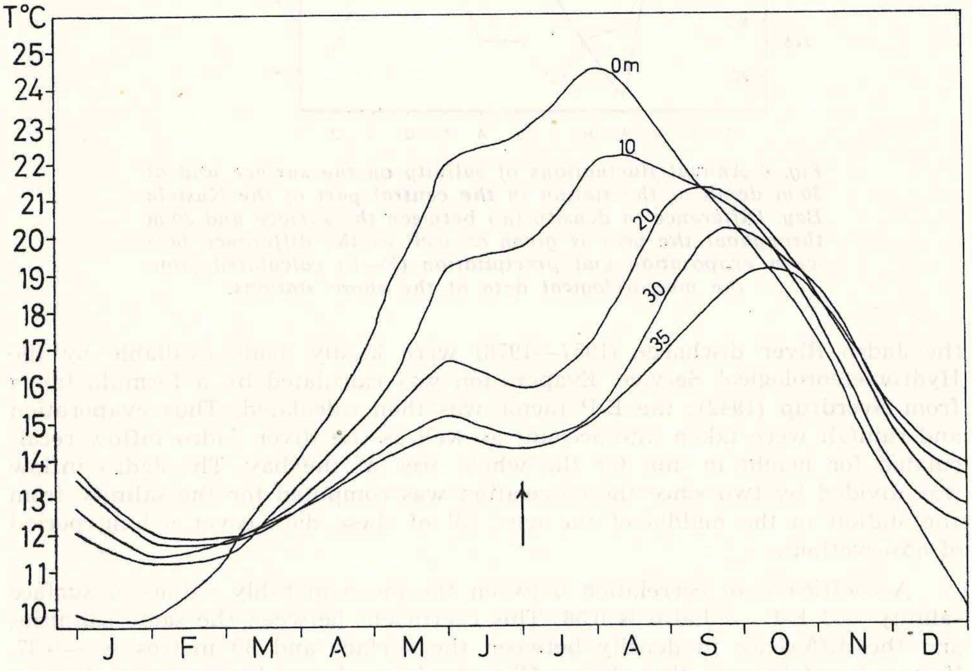


Fig. 7 Annual variation in the sea temperature at the station in the central part of the Kaštela Bay.

ficient for the present level of these studies. Significance of this coefficient was examined taking into account the magnitude of the coefficient and the number of input data. Significance is about 50 percent. This means that up to 50 per cent of the influence on salinity changes is due to local factors, and therefrom it appears that the intensity by which the local and external factors affect the bay is almost equal. Therefore, it is also assumed that the E-P relationship, wind and external advection influence the bay's circulation by almost equal intensity.

At 5 metres already both the salinity minimum and maximum occur a month earlier (March, September). The same situation is recorded in all the layers down to the bottom. Advection and mixing are likely to be the factors which affect these annual variations. In the cold period salinity is decreased. This may be accounted for by the influence of sinking of surface water which cools. In addition, in winter, the advection of external water into the bay takes place in the surface layer, while the bottom layer water flows out of the bay. The March minimum occurs prior to stratification, which hinders the water from sinking. From April to September salinity is increased in the bottom layer. This is due to the inflow of water predominantly in deeper layers, and outflow of surface layer water, with the reduced vertical mixing. Temperature data (Fig. 7) are indicative of the fact that the upwelling is best marked in June. In June—July period salinity increases sharply in the surface layer. This also may be partly due to the upwelling. Maximum salinity in the surface layer in October coincides with the fall of salinity in the bottom layer. Both are the result of intensified vertical mixing. Therefore the bottom layer salinity maximum occurs in September, prior to the surface cooling and vertical mixing.

So the salinity data show that in vertical circulation it is essential that the inflow of water in the surface layer and sinking and outflow of water in the bottom layer prevail in winter. In summer, however, the outflow occurs in the surface layer connected to the upwelling and inflow in the bottom layer.

The factors affecting the inflow and outflow of water in surface layer will now be considered by seasons.

The inflow of water in the surface layer is influenced by the following factors (they are given sign +):

i) scirocco (SE wind) (W_{SE})
ii) advection by the NW incoming Adriatic current (A)
iii) evaporation (E)

The outflow of water in the surface layer is influenced by the following factors (given sign —):

i) bora (W_{NE})
ii) maestral (in the open area NW wind, in the bay shifted to SW) (W_{SW})
iii) freshwater influx (Jadro River, submarine springs, rainfall) (P).

All these factors were determined by seasons and the occurrences of minima, maxima and mean values recorded. The maximum of any factor was given a value of 1, the minimum O. For the other two seasons the given value was 1/2. The agreement of these approximate estimations with the current meter data indicate that the relative relations between the observed factors have been well assessed. Seasons were taken as is common in oceanography, thus that spring covers April, May and June, sumer July, August, September, etc.

Table 7. Seasonal values of factors affecting water circulation in the Kaštela Bay

	Wind NE			Wind SE			Wind SW						
	freq. %	int. B	wind index	freq. %	int. B	wind index	freq. %	int. B	windi index	E mm	Rain mm	Jadro m³/sek	Advection NW flow cm/sec
Spring	23	3.2	73,6	17	7,7	62,9	19	2.2	41,8	62	58	7,1	3
Summer	26	2,9	75,4	11	3,2	35,2	22	2,3	50,6	81	46	3,8	7
Autumm	38	3,2	121,6	19	4,4	83,6	6	2,2	13,2	112	103	9,7	—
Winter	39	3,7	144,3	19	4,1	77,9	7	1,8	12,6	84	74	8,8	11

The product of intensity and frequency was used as the index for wind; NW current speed at the mouth of the bay as the index for advection. The values from Table 7 agree well with the earlier findings of the generally greatest intensity of NW current in winter along the east Adriatic coast. Absceance of this current in autumn is connected with the flow from the eastern coast towards the open sea which prevails in that season (Zore--Armanda, 1968).

Spring: Evaporation is minimum, bora is minimum; no factor is of maximum intensity. Accordingly

$$W_{SE}\ (1/2) + A\ (1/2) + E\ (O) - W_{NE}\ (0) - W_{SW}\ (1/2) - P\ (1/2).$$

Total is zero and therefore neither the inflow nor the outflow prevail in the surface layer.

Summer: Maestral is maximum, scirocco is minimum, fresh water inflow (rainfall and Jadro River) is minimum. Accordingly

$$W_{SE}\ (0) + A\ (1/2) + E\ (1/2) - W_{NE}\ (1/2) - W_{SW}\ (1) - P\ (0)$$

Total is — 1/2 and the outflow of water prevails in the surface layer. This is in agreement with the occurrence of upwelling and increased salinity in the bottom layer.

Autumn: Scirocco is maximum, evaporation maximum, precipitations (and Jadro inflow) maximum, and advection minimum. Accordingly

$$W_{SE}\ (1) + A\ (0) + E\ (1) - W_{NE}\ (1/2) - W_{SW}\ (1/2) - P\ (1)$$

Total is zero and neither the inflow nor the outflow prevail in the surface layer.

Winter: Advection is maximum, bora maximum, and maestral minimum. Accordingly

$$W_{SE}\ (1/2) + A\ (1) + E\ (1/2) - W_{NE}\ (1) - W_{SW}\ (0) - P\ (1/2)$$

Total is +1/2 what means that the water inflow exceeds the outflow in the surface layer. This is in agreement with the annual variations in salinity which is reduced in the bottom layer in winter due to the sinking of the less saline surface water, which in the bottom layer flows out of the bay.

Besides being supported by the annual salinity variations, these findings have also been proven by the current meter data. On the basis of measurements taken in the 1972—1973 period at 5 stations of the bay, surface (3 m) current roses were constructed by seasons (Fig. 8). Furthermore, the incoming (C_{NW} and outgoing (C_{SE}) flow components were determined for each season.

Spring	C_{NW}	= 5,2 cm/sec	C_{SE}	= 3,5 cm/sec
Summer	C_{NW}	= 19,8 cm/sec	C_{SE}	= 31,2 cm/sec
Autumn	C_{NW}	= 14,1 cm/sec	C_{SE}	= 17,6 cm/sec
Winter	C_{NW}	= 18,8 cm/sec	C_{SE}	= 9,0 cm/sec

In spring and autumn the inflow and outflow components differ only slightly. The previous estimations of the factors affecting the flow show that neither of the two components should prevail.

In summer, the outflow component exceeds the inflow for about 10 cm/sec. In winter, the inflow component exceeds the outflow one for about 10 cm/sec. This gives good support to the previous estimations.

Thus the assumption that the observed factors-wind direction, evaporation, precipitation, river runoff and prevailing curents-exert approximately the same influence is sufficiently accurate for a general understanding of the circulation of Kaštela Bay.

This analysis, as well as current roses indicate another fact of interest. In spring when the forcing factors are lowest, the flow is most sluggish. In autumn when the forcing factors are best marked, the flow is most rapid. Therefore, the situation in the bay is most stagnant in spring. Even though the flow is most intensive in autumn the directions are dispersed. Vertical mixing is also most intensive in autumn. Closed vertical circulation is developed in winter (downwelling) and summer (upwelling), even though in the opposite directions.

CIRCULATION SCHEME

Observations from the preceeding part enabled us to make a schematization of the circulation patterns in different seasons and under different conditions of characteristic winds. Current flow with bora and scirocco are given in Figs. 9, 10, and 11, as well as the spring flow without wind forcing, the sumer one with maestral, and the autumn one with scirocco and calm period.

Upon entering the bay the surface layer water takes the direction along either of the coasts. An earlier statistical analysis (Gačić and Smirčić, 1973) also showed that the stations at the mouth of the bay coincided better with stations close to either of the coast, than with any of the stations in the central part of the bay.

Closed vertical circulation is developed in summer and winter. As it has been seen, in these seasons the respective inflow or outflow component exceeds the opposite one for about 10 cm/sec. This incoming and or outgoing transport respectively should be compensated in deeper layers. Further, mean annual arithmetical flow speeds for 5 stations of the bay (after the of data from 1972—1973) are given in Fig. 12. At the entrance of the bay surface flow is more rapid. However, as one proceeds from the mouth towards the central part of the bay the flow speeds on the surface and in the deeper layers become more and more uniform. This means that in communication

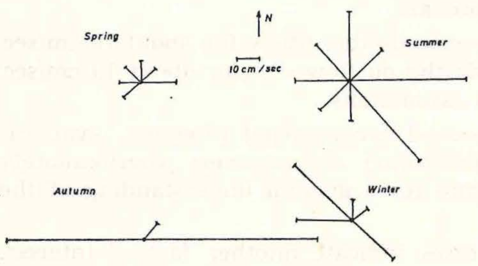


Fig. 8 Surface current roses for the Kaštela Bay for 4 seasons. Roses were constructed on the basis of mean diurnal vectors (resultants) for 5 stations of the bay.

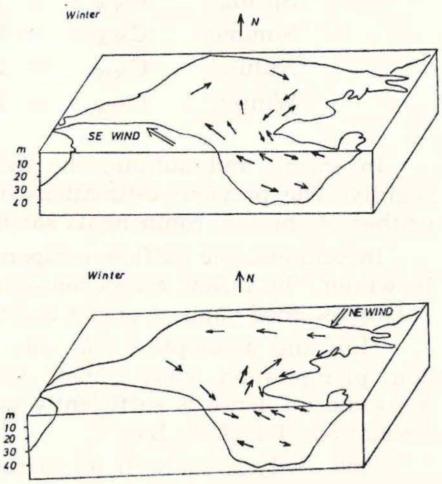


Fig. 9 Scheme of circulations in the Kaštela Bay in winter during scirocco (SE wind) and bora (NE wind). During scirocco the incoming flow dominates with the anticyclonic circulation in the surface layer. The cyclonic circulation is typical during bora, but, due to the influence of Jadro River the outflow occurs adjacent to the eastern coast.

of a semi-closed basin with the adjacent sea, a part of the flow energy from the surface is transferred to the deeper layers. This assumes the vertical circulation in the bay. The fact that surface speeds are gradually reduced going towards the centre of the bay indicates that the water is downwelled (or upwelled) in the most part of the bay. In winter situation for example the water flows in the surface and out in the intermediate and bottom layers.

Table 8. Calculation of water transport at the mouth of the bay

Layer	Layer's depth m	Mean flow speed cm/sec	Mouth's cross setion cm^2	water transport cm^3/sec
Surface	15	16	2x10^8	32x10^8
Intermediate	20	11	2x10^8	22x10^8
Bottom	10	10	1x10^8	10x10^8

As seen from Table 8 the incoming (surface layer) and outgoing transport (intermediate and bottom layers) are in equilibrium. If it is assumed that all the water which entered the bay sinks for about 20 m over only a half of the total area of the bay (61 square kilometres), the water sinking

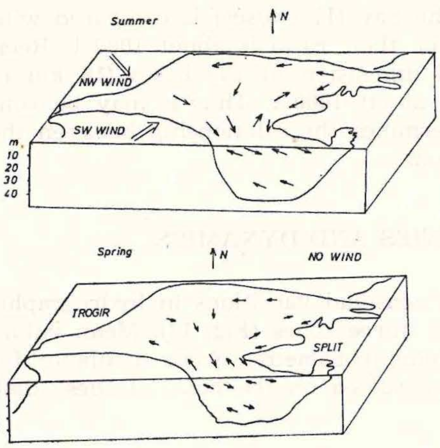


Fig. 10 Scheme of circulation in the Kaštela Bay in summer during maestral (locally SW wind) and in spring during calm period. In summer the water outflow prevails in the surface layer. Cyclonic flow dominates on the surface. However, the water flows out adjacent to the eastern coast of the bay also. Water flows into the bay in the lower layers. In spring the speeds are smaller, and flow directions variate.

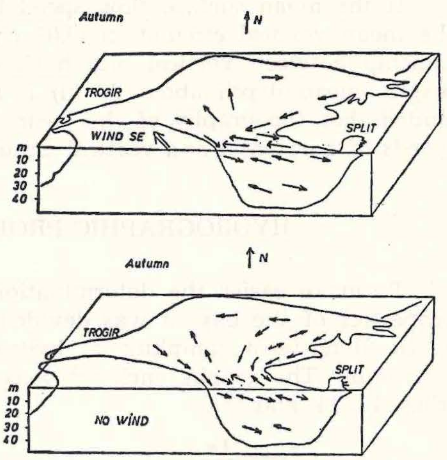


Fig. 11 Scheme of circulation in the Kaštela Bay in autumn during scirocco (SE wind) and in the calm period, Flow is intensive. During scirocco water flows into the bay in the surface layer through the middle of the mouth, and flows out along either of the coasts (influences of the Jadro River in the eastern part and of submarine springs in the western part). During calm period the directions variate.

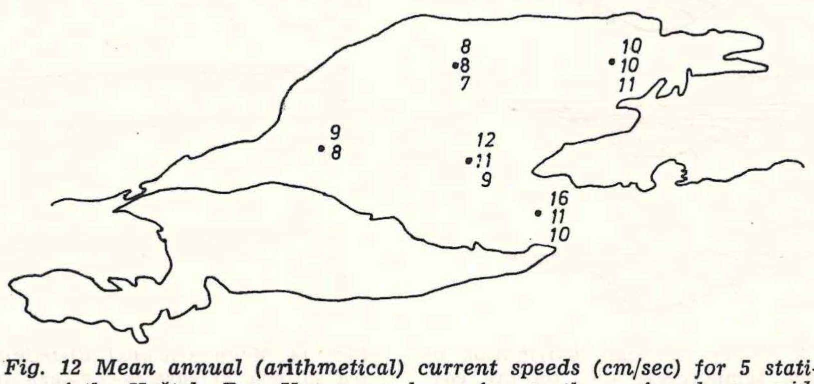


Fig. 12 Mean annual (arithmetical) current speeds (cm/sec) for 5 stations of the Kaštela Bay. Upper number refers to the surface layer, middle number to the intermediate layer and lower one the bottom layer.

speed of 0.01 cm/sec is obtained, or approximately 8 m/day. If the calculation carried out takes into account only the net incoming component in the surface layer (10 cm/sec), the obtained values are for about 1/3 lower.

Vertical speed thus calculated may be understood only as a climatic mean. On some occasions with wind forced vertical circulation, it may be considerably greater.

If the mean surface flow speed in the bay (11 cm/sec) is compared with the mean vertical circulation (0.01 cm/sec), their ratio is about 1000:1. Relationship between vertical and horizontal dimension of the basin (18 km in length, mean depth about 20 m) is also about 1000:1. Thus it may be concluded that topography of the basin determines the relationship between the speeds of horizontal and vertical circulation.

HYDROGRAPHIC PROPERTIES AND DYNAMICS

To make easier the determination of seasonal variations in hydrographic properties of the bay, it was devided into three zones (Fig. 13). Mean values of the long-term sampling of hydrographic parametres were available for each zone. The graphs enclosed were constructed on the basis of these data (Figs. 13, 14, and 15).

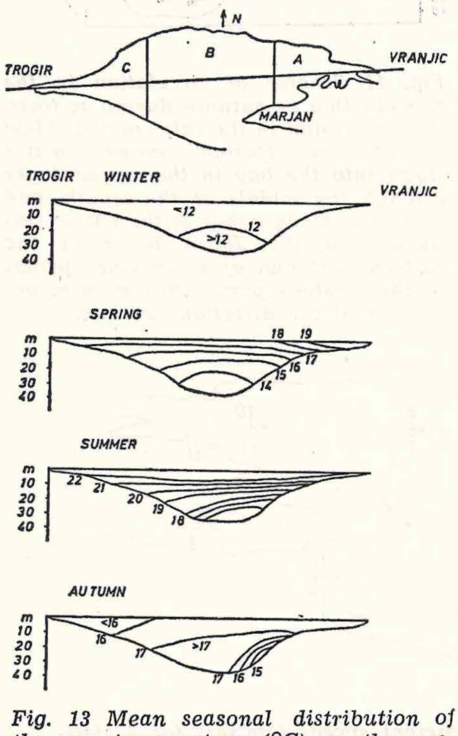


Fig. 13 Mean seasonal distribution of the sea temperature (°C) on the eastern-western transcet of the Kaštela Bay. The transect and 3 zones for which mean vlaues were calculated are plotted.

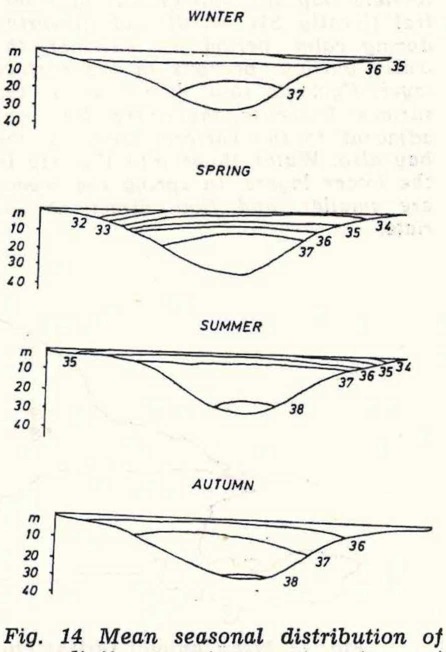


Fig. 14 Mean seasonal distribution of sea salinity at eastern-western transect of the Kaštela Bay

As far as the temperature (Fig. 13) is concerned, the eastern part of the bay (A) is more stratified (continental) than the central and western parts. In winter the water is heavier in the eastern part, in summer lighter. Continentality of the eastern part may be in connexion with the less strong dynamics of that part of the bay (Table 10).

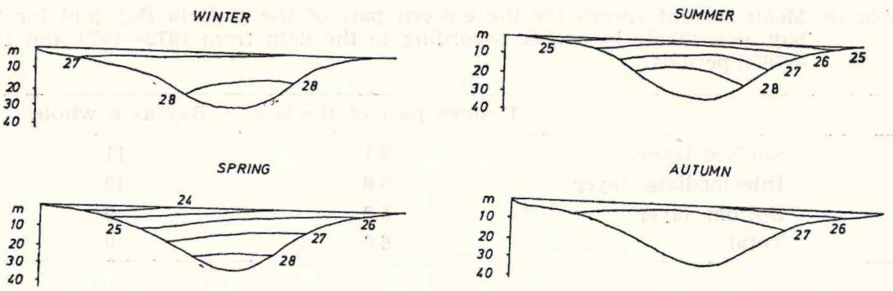


Fig. 15. Mean seasonal density distribution (σ_t) at the eastern-western transect of the Kaštela Bay.

Table 9. Seasonal mean values of temperature (°C), salinity (‰) and (σ_t) for three zones of the Kaštela Bay according to the data from 1934—1974 period

Para-meter	Depth m	Zone	Winter	Spring	Summer	Autumm	Annual Mean
T°C	0	A	11.20	19.53	22.42	16.70	17.46
		B	11.86	17.78	22.93	16.55	17.28
		C	11.54	17.53	22.47	15.93	16.86
	10	A	11.64	15.87	19.78	17.54	16.20
		B	12.09	15.56	20.44	17.16	16.31
		C	11,57	16.34	20.59	16.02	16.13
	20	A	11.88	14.47	17.38	15.51	14.81
		B	12.47	14.62	17.40	17.47	15.49
		C	11.90	15.48	18.66	16.75	15.69
	35	B	12.80	13.83	15.32	17.48	14.85
	30	Č	11.96	15.45	18.49	16.66	15.64
Sal‰	0	A	34.76	34.89	33.90	35.72	34.43
		B	35.21	34.37	36.67	35.96	35.55
		C	35.20	32.75	35.55	35.57	34.28
	10	A	36.54	36.85	37.48	36.71	36.90
		B	36.26	36.54	37.33	37.10	36.81
		C	36.42	36.46	37.44	37.03	36.84
	20	A	36.84	37.38	37.79	37.22	36.93
		B	37.17	37.32	37.75	37.69	37.48
		C	36.83	37.03	37.83	37.39	37.27
	35	B	37.52	37.76	38.15	38.00	37.86
	30	C	36,65	37.16	37.84	37.25	37.25
σ_t	0	A	27.30	24.15	24.87	25.95	25.17
		B	26.92	24.86	25.08	26.53	25.85
		C	26.75	23.53	24.49	26.25	24.88
	10	A	27.92	27.35	26.70	26.66	27.16
		B	27.67	26.86	26.56	27.17	27.09
		C	27.71	26.78	26.49	27.17	27.04
	20	A	28.14	27.66	27.29	26.92	27.53
		B	28.17	27.81	27.54	27.47	27.75
		C	27.96	27.43	27.26	27.34	27.50
	35	B	28.48	28.32	28.24	27.79	28.19
	30	C	27.75	27.55	27.44	27.38	27.53

Table 10. Mean current speeds for the eastern part of the Kaštela Bay and for the bay as a whole in cm/sec according to the data from 1972—1973 and 1975—1976 periods

	Eastern part of the bay	Bay as a whole
Surface layer	8.1	11
Intermediate layer	5.6	10
Bottom layer	5.8	9
Total	6.6	10

During the whole year the water of the central part of the bay is more saline than that in the eastern and western parts (Fig. 14). In the eastern part this is due to the Jadro River influence, and in the western part to the submarine springs and Pantan stream. Isopycnals indicate the dominance of cyclonic flow (Fig. 15). This means that the tendency of reversed anticyclonic flow is due only to the wind forcing. In winter the water in the western part of the bay is lighter, and in summer heavier than that in the eastern part. This distribution does not show the obtained picture of the dynamics in the surface layer. Therefore, it may be concluded that the flow in the surface layer is under the influence of the outer forcing and not due to the seasonal distribution of properties within the bay itself, or the geostrophic balance.

CONCLUSIONS

Several types of circulation occur in the surface layer of the Kaštela Bay. These are: cyclonic, anticyclonic and their combinations. The occurrence of individual types of circulation is primarily dependent on wind forcing. Anticyclonic circulation occurs with scirocco (SE wind), and cyclonic with bora (NE wind) and maestral (NW wind and locally of SW direction, as well). In addition, scirocco drives the water into the bay in the surface layer, and bora and to a smaller extent maestral out of the bay accompanied with upwelling.

The bay's circulation is also affected by the position of the mouth as related to the current directions out of the bay and to the wind directions. Sesonal fluctuations indicate that the influence of fresh water inflow and evaporation are also of importance.

Annual variation in salinity in the surface layer is well defined by the influence of the E-P factor, vertical mixing and advection. The April minimum may, in the first place, be accounted for by the influence of the E-P factor; the October maximum by the strong vertical mixing. Considerable increase in salinity in June—July period is probably due to the upwelling, the occurrence of which is evident from the temperature data.

The coefficient of multiple correlation between different observed factors and salinity, as well as the significance of this factor are indicative of the fact that the local factors (E-P factor, and vertical mixing) and advection from the open sea affect annual variations in salinity by almost equal intensity.

Advection and vertical mixing affect salinity in deeper layers. Minimum occurs in March as the result of the winter sinking of surface water. Increase in salinity in summer is probably due to the dominance of water inflow into the bay in lower layers. Maximum occurs in September prior to the intensified vertical mixing which is the result of surface cooling from the October on.

It is presumed that local factors and advection affect the water circulation with equal intensity, as well. In general, their influence may be compared with the net inflow and outflow of the surface layer water, obtained from the current meter data.

In spring, the factors affecting flow are of the lowest intensity and the flow is most sluggish. In autumn, the maximum intensity of forcing factors is accompanied by the most rapid flow. However, the flow directions are dispersed. Vertical mixing is also most intensive in this season. In winter and summer the enclosed vertical circulation is developed. Namely, in winter the inflow of water into the bay prevails in the surface layer, with the water sinking and outflow in deeper layers; summer shows quite the opposite situation, i.e. water outflow in the surface layer, the occurrence of the upwelling and inflow in the bottom layer. Thus, the empirical modeling of circulation was made for characteristic winds and different seasonal conditions.

Mean speed of vertical flow was calculated. It was found to be about thousand times slower than horizontal speeds. The horizontal and vertical dimensions of the basin show the same relation. This may be indicative of that the topographic properties of the basin may account for the ratio of horizontal and vertical circulation.

Hydrographic properties of the bay show the more continental character of its eastern part. The flow, also, is considerably slower in the eastern part than in the western one.

Distribution of properties in the bay is indicative of the dominance of cyclonic circulation, as well as of the water outflow in winter and inflow in all the layers in summer. This shows that the distribution of properties in the bay itself (mass field) does not affect circulation to the considerable extent. The basic factors affecting circulation are, however, the wind, fresh water inflow and water advection coming from outside the bay.

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NEKA DINAMIČKA I HIDROGRAFSKA SVOJSTVA KAŠTELANSKOG ZALIVA

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KRATKI SADRŽAJ

Velik broj podataka o strujanju i hidrografskih podataka je obrađen za Kaštelanski zaljev da bi se dobio uvid u utjecaj raznih faktora koji djeluju na cirkulaciju vode, te na godišnji hod svojstava u zaljevu.

U površinskom sloju Kaštelanskog zaljeva se javlja nekoliko tipova cirkulacije: ciklonalno, anticiklonalno i njihove kombinacije. Pojavljivanje određenog tipa ovisi prvenstveno o vjetru. Uz jugo (SE vjetar) se javlja anticiklonalna cirkulacija, a uz buru (NE vjetar) i maestral (NW vjetar, a lokalno i SW smjera) ciklonalna cirkulacija. Osim toga, jugo u površinskom sloju nagurava vodu u zaljev, a bura i u manjoj mjeri maestral je izguravaju iz zaljeva uz pojavu upwellinga.

Na cirkulaciju u zaljevu utječe još i položaj ušća u odnosu na smjer strujanja izvan zaljeva kao i u odnosu na smjer vjetra. Sezonske promjene ukazuju i na utjecaj veličine dotoka slatke vode i evaporacije.

Godišnji hod slanosti površinskog sloja je dobro definiran utjecajem E-P faktora, vertikalnog miješanja i advekcije. Aprilski minimum se može prvenstveno pripisati utjecaju E-P faktora, a maksimum u oktobru jakom vertikalnom miješanju. Znatan porast slanosti od juna do jula je doveden u vezu s upwellingom, vidljivom u tom razdoblju i na temperaturnim podacima.

Koeficijent višestruke korelacije između raznih promatranih faktora i slanosti, te njegova signifikantnost ukazuju da na godišnji hod slanosti s podjednakim intenzitetom djeluju lokalni faktori (E-P i vertikalno miješanje), kao i advekcija s otvorenog mora.

U donjim slojevima na slanost utječu advekcija i vertikalno miješanje. Minimum nastupa u martu kao rezultat zimskog tonjenja površinske vode. Porast slanosti u ljetnom razdoblju je u vezi s pretežnim ulazom vode u zaljev. Maksimum se javlja u septembru prije pojačanog vertikalnog miješanja zbog površinskog hlađenja od oktobra pa nadalje.

Pretpostavljeno je da lokalni faktori i advekcija djeluju s podjednakim intenzitetom na cirkulaciju vode. Sumarno promatran njihov utjecaj se je mogao usporediti s neto ulazom i izlazom vode površinskog sloja dobivenom iz strujomjernih podataka.

U proljeće su faktori koji utječu na strujanje najmanjeg intenziteta i strujanje je najsporije. U jesen je uz maksimalan intenzitet vanjskih faktora i strujanje najbrže, ali su smjerovi raspršeni. U toj sezoni je i vertikalno

miješanje najživlje. Zimi i ljeti se razvija zatvorena vertikalna cirkulacija na način da zimi u površinskom sloju prevladava ulaženje vode u zaljev, uz spuštanje vode i izlaženje u pridnenom sloju, a ljeti obrnuto, izlaženje vode u površinskom sloju uz pojavu upwellinga i ulaženje u pridnenom sloju. Na taj način je cirkulacija u zaljevu shematizirana za karakteristične vjetrove i razne sezonske uslove.

Izvršen je proračun srednje brzine vertikalnog strujanja i nađeno je da je ono cca 1000 puta manje od horizontalnih brzina. Takav je i odnos horizontalnih i vertikalnih dimenzija bazena, što ukazuje da bi morfološke karakteristike bazena mogle definirati odnos brzina horizontalne i vertikalne cirkulacije.

Hidrografska svojstva zaljeva pokazuju da je njegov istočni dio kontinentalniji od zapadnog. U istočnom dijelu je i strujanje znatno sporije.

Raspored svojstava u zaljevu bi ukazivao na pretežno ciklonalnu cirkulaciju, te na pretežan izlaz vode zimi i ulaz ljeti u svim slojevima. Iz toga se vidi, da raspored svojstava (polje masa) u samom zaljevu ne igra znatniju ulogu na strujanje, već da su vjetar, dotok slatke vode i advekcija iz vana osnovni faktori koji utječu na cirkulaciju.