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WATER RENEWAL IN THE BASINS ALONG THE EASTERN ADRIATIC COAST

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Fast urbanization raises the problem of possible saturation by waste water of numerous bays and channels along the eastern Adriatic coast. Therefore, some of them were investigated with regard to the renewal time of their water. Large numbers of measurements were carried out of fundamental oceanographic characteristics and of currents, and efforts made to interpret them for practical applications.

The two sources of data used for this study were: (1) all the available data on currents; and (2) the salinity time series for characteristic points of the basin (Zore-Armanda *et al.* 1974, 1976, 1977a, 1977b). Water renewal time was determined by three very simple methods.

First two methods are based on the simple fact that water renewal time (t_i) of the channel or of semiclosed basin is

$$t_i = \frac{V}{T}$$

where V is the volume of the channel or of bay, and T the characteristic transport of water renewal which in the simplest case may be understood as the ingoing transport at the entrance of the bay, or at the one end of the channel.

The volume of the basin is relatively easily determined if the isobaths are known. However, the characteristic transport at the entrance of the semiclosed basin is particularly difficult to determine because eddies usually occur there and they cannot be neglected. In addition, it is necessary to determine which oscillations affect the transport within the whole water body of the bay, and which ones affect only the entrance or a small portion of the bay.

Therefore, to calculate the characteristic water renewal transport it would be necessary to determine the ratio between the size of the basin and the time interval needed for calculation of average transport, and from this the length of oscillation periods that can be neglected.

However, even these neglected oscillations may affect the characteristic water renewal transport. An analysis of eight 24-hour time series current meter records in the Brač Channel near Split showed that greater transport occurred even though the amplitudes of the short period oscillations were smaller.

Table 1. Brač Channel, station depth 58 m

Date of measurements	Mean 24 hour transport	Change of tangential velocity component max	mean
	m^3/sec	cm/sec	cm/ces
30. 5. 1973.	3920	2.0	1.0
26. 7. 1972.	3680	2,3	1.2
23. 3. 1973.	2300	1.2	0.4
26. 6. 1973.	1910	2.0	1.2
27. 1. 1973.	1460	4.0	1.2
4. 12. 1972.	610	3.0	1.4
23. 8. 1972.	406	4.4	1.8
21. 9. 1972.	41	3.2	1.2

Water transport and change of velocity refer to the component tangential to the coast (absolute values). Water transport was calculated from the current meter data for 3 depths (3, 20 and 50 m), and the cross section area of the channel at that point.

Small period oscillations, occurring there, have periods of 3—5 hours. The amplitudes of the oscillations are variable, and the data suggest that the contributions of the oscillatory motions to the water transport are of an inverse nature. At present, the reasons for this are not understood.

Table 1. displays another difficulty occurring in transport calculations. This one refers to the great differences (two orders of magnitude) of mean transport at different points in time. This indicated that sporadic, short measurement series are not reliable. Two different methods were employed to eliminate these difficulties.

First one consists in the use of averaging to avoid the non-reliable transport values. Current roses were constructed from the 24-hour current meter results, for all the basins where a large number of 24-hour measurement series were available. This procedure eliminated the tide currents and all the oscillations with periods shorter than 24 hours.

With regard of seasonal fluctuations, characteristic for the Adriatic, the construction of seasonal current roses of principal directions, proved to be the most convenient.

In the construction of current roses the data from different parts of the basin were also used in order to get as true an estimate as possible of the flow which is present, not only at the entrance. but in the whole of the water body in the basin. Thus the influence of eddies might be neglected. The data obtained from the center of the basins were particularly convenient.

Current roses were then constructed for each of the characteristic layers separately. These layers were determined according to the T-S diagrams.

Two easily identifiable layers are to be usually found in the Adriatic coastal basins, but there may occur three or even more of them.

In the process of averaging a further step was to determine seasonal mean flow velocity from 24-hour resultants for each of the layers using all the measurements (and directions). Then the percentage of ingoing transport was calculated. If for example, mean velocity was 10 cm/sec and the ingoing transport occurred 25% of the time, the velocity of 2.5 cm/sec was used of the characteristic transport calculation.

This method was used for preliminary determination of the whole Adriatic water renewal. The time required for total water renewal of the Adriatic obtained by this method was about 5 years (Zore-Armanda and Pucher-Petković, 1976).

This method is useful when seasonal current roses can be constructed with certainty.

The second approach to the characteristic renewal transport determination is based on the current meter data from the basin entrance, from the ingoing flow component is calculated for each of series of measurements. The data from the central point of the entrance profile were used. With regard to the channel we may presume the water flow to be uniform in the whole of the channel.

However , in the semiclosed basin the water flow is reduced going towards the closed end of the basin, so that a correction is needed for the transport at the entrance. Namely, only a part of the water spreads to a certain point of the basin. The further from the entrance, the less the water takes part in circulation.

To get an insight into this process, the data for one basin were analysed (Bay of Kaštela), for several locations in the basin. The transport component normal to the basin axis was calculated for three cross sections of the bay. The first cross section is at the entrance, the second at the middle of the basin, and the third at three quarters of the distance from the entrance to the closed end. The calculation was made for two seasons.

Table 2. Mean transport in 24 h for unit breadth in 10 cm²/sec at 3 profiles in the Kaštela Bay (central point of the profile)

	Entrance of the bay	Profile at the middle of bay	Profile at the third quarter of bay
	40 m	32 m	19 m
Summer 1972	— 244	— 91	— 5
Autumm 1972	— 47	— 23	— 38
Sum	— 291	— 114	— 42
Corrected for the same depth	— 291	— 81	— 19

It can be seen that at the middle of the basin the transport is about 4 times smaller than it is at the entrance, and at the three quarter point about 16 times smaller. Similar relationship was obtained by the detailed measurements simultaneously carried out at several points in the north-eastern part of the same basin. In December 1972, in the northeast basin, the transport at the middle was again one fourth of that at the entrance

($48 \times 10^2 : 7 \times 10^2$ cm^2/sec). The measurements were made under conditions when the tangential transport component was, practically, not present.

Therefore simple empirical formula, which takes account of gradual decrease of water transport going off the entrance is proposed for the water reneval time in semiclosed basins

$$t_i = \frac{V}{T_u} e^{\frac{T_u - 1}{T_u}}$$

where V is the volume of the basin (expressed in km^3) and T_u normal transport at the central point of the entrance expressed in km^3/month (for $T_u > 1$).

Third method starts from the salinity time series.

It is presumed:

1) that the increase or decrease of salinity is always influenced by the waters of extreme salinity
2) that water mixing is carried out in unit volume
3) that fluctuations within defined time interval are in one sense, either the increase or decrease of salinity. Thus water of only one extreme salinity takes part in mixing.

If S_1 is the initial salinity, S_2 the extreme salinity, S_3 salinity at the end of interval, and x the quantity of the renewed water of S_2 salinity, then $(1 - x) S_1 + xS_2 = S_3$.

$$x = \frac{S_1 - S_3}{S_1 - S_2}$$

With $S_3 > S_1$, S_2 is the upper extreme, and with $S_3 < S_1$, S_2 is lower extreme. If $S_3 = S_2$, it means that the whole body of water is renewed and x is equal to 1. In the case when $S_1 = S_2$ the value obtained is infinite one, for at the same time the fundamental assumption has not been satisfied, and it has no physical meaning.

Assuming that basin has unit volume, then x becomes the water renewal factor per time interval observed. In applying this method it is necessary to chose characteristic salinity values. This was achieved by use of the long time series, chosing the representative points in the basin, and by carefully chosen extreme values. Several years extremes proved to be the convenient ones.

Stations from the centre of the basin were selected as being reliable. In addition mean values were obtained for several stations of the bay.

Renewal time is

$$t_i = \frac{1}{x} \Delta t$$

where Δt is the time interval within which the salinity increase or decrease were observed. The time interval is important as well, because the assumption of the method is that fluctuations are in one sense. Examination of some good time series for the middle Adriatic showed 10-day intervals to be convenient.

However, the data obtained during one month intervals are most frequently available.

The renewal time was calculated by all the three methods for a number of bays and channels along the eastern Adriatic coast.

Table 4. Renewal time for some of the eastern Adriatic coastal basins

Basin	Volume (km^3)	Mean renewal time (months) I method (from currents roses)	II method (from entrance transport)	III method (from salinity)	Mean renewal time (months)	Cross-section of bay entrance or cross-section of channel (km^2)
Northeastern part of Kaštela Bay	0.3	0.1	0.3	1.0	0.45	0.10
Kaštela Bay	1.4	0.8	0.5	0.7	1.00	0.05
*Zadar Channel	5.4		5.5	7.2	6.4	0.14
Vir Sea wider	33.4	11.0		15.6	13.5	0.70
„ narrower	20.2	7.0				
Brač—Split Channel	31.0	3.1	0.8	4.3	2.7	0.75

* Calculated with formula for the bay.

As expected, renewal time is shorter in channels than in semiclosed basins (bays).

The calculation made from the data on salinity fluctuations gives somewhat slower renewal than the calculation from current meter data. This is probably due to the fact that salinity distribution is affected by diffusion processes, which were not taken into account when applying current meter data.

Although currents along the eastern Adriatic coast are not fast, renewal time is favourable from the pollution aspect. Ventilation of the basins is rather good and since production is this area is not too high, the area has good natural possibilities for urbanization.

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SUMMARY

Renewal time was calculated for a number of eastern Adriatic coastal basins. Three simple methods were used. Two of them used current meter data and the third one, salinity time series data.

In introduction of the first two methods, the problem arises of how to define characteristic water renewal transport because of the eddies occurring at the entrance; because of the small period oscillations, and because of the differences between the flow at different locations in the basin. Out of all the previously mentioned causes a part of water that enters the semiclosed basin spreads in the basin to a certain extent, and going off the entrance smaller and smaller volume of water takes part in the circulation. This difficulty was overcome either by a convenient averaging or by introduction of a special correction for the transport at the entrance.

Third method uses salinity time series and is based upon the assumptions that increase or decrease of salinity is always due to the water of extreme salinity and that salinity fluctuations are in one sense either increasing during the entire time period of the calculation or decreasing during the entire period.

The renewal time was calculated by all three methods for a number of basins along the eastern Adriatic coast. Though the currents in this area are not fast, renewal velocity is favourable from the pollution aspect. Ventilation of the basin in rather good and as marine biological production here is not too high, the area has good natural conditions for reasonable urbanization.

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IZMJENA VODE U BAZENIMA ISTOČNE OBALE JADRANA

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KRATAK SADRŽAJ

Nagla urbanizacija postavlja problem moguće zasićenosti otpadnim tvarima brojnih zaljeva i kanala istočne obale Jadrana. Zbog toga su u nekima od njih vršena istraživanja da bi se utvrdila brzina izmjene vode.

Za utvrđivanje tog parametra korištene su tri metode. Prve dvije polaze od strujomjernih podataka, a treća se koristi vremenskim nizovima saliniteta.

Pri korištenju strujomjernih podataka se je kao problem postavilo određivanje karakterističnog transporta izmjene vode. Tu se mogu javiti vrtložna strujanja a i oscilacije malih perioda u strujnom polju mogu biti dobro izražene. Jedna analiza je pokazala da se veći transport, računat prema 24-satnim nizovima, javlja uz slabije izražene kratko periodične oscilacije u strujnom polju na ušću bazena. Druga teškoća su velike razlike u transportu u različitim terminima, pa je teško dati njegovu realnu ocjenu.

Prva metoda računanja koristi sve raspoložive strujomjerne podatke iz cijelog bazena radi konstrukcije što je moguće reprezentativnijih sezonskih ruža struja koristeći 24-satne rezultante i svođenjem na osam glavnih smjerova. Sezonske ruže struja su konstruirane iz razloga jer su na Jadranu izražene sezonske promjene karakteristika. Ruže struja su konstruirane za tipične dubine određene prema T-S dijagramima.

Uz određene sezonske srednje brzine strujanja za svaki sloj izračunat je procentualni udio ulaznog smjera strujanja i tako određen transport odgovoran za izmjenu vode. Ova metoda je pogodna, ako se mogu dovoljno pouzdano konstruirati ruže struja.

Druga metoda koristi podatke samo iz središnje točke ušća bazena. Računata je normalna komponenta strujanja na ulazni profil 24-satnih ili dužih nizova, a zatim godišnji srednjak. Međutim, u poluzatvorenim bazenima se protok vode smanjuje udaljavanjem od ušća. Jedna analiza normalnih komponenti strujanja na tri profila u Kaštelanskom zaljevu kod Splita je pokazala da je u polovini bazena transport od prilike 4 puta manji, a na četvrtini bazena od prilike 16 puta manji. Zbog toga je za vrijeme izmjene vode (t_i) u poluzatvorenim bazenima postavljena empirička formula

$$t_i = \frac{V}{T_u} e^{\frac{T_u - 1}{T_u}}$$

gdje je V volumen bazena, a T_u normalni transport na središnjoj točki ušća.

Reprezentativni vremenski nizovi slanosti su korišteni na jednostavan način uz pretpostavku da zaslanjivanje ili zaslađivanje vrši voda uvijek istih ekstremnih saliniteta i da su promjene između dva promatrana termina jednosmjerne. Ako je S_1 početni salinitet, S_2 ekstremni salinitet, S_3 konačni salinitet, a x količina nadošle vode Saliniteta S_2, onda je

$$(1 - x) S_1 + x S_2 = S_3$$

$$x = \frac{S_1 - S_3}{S_1 - S_2}, \text{ uz } S_3 > S_1, S_2 \text{ je gornji ekstrem}$$
$$\text{uz } S_3 < S_1, S_2 \text{ je donji ekstrem.}$$

Uz pretpostavku da je volumen promatranog bazena jediničan, x predstavlja faktor izmjene vode između dva promatrana termina. Vrijeme izmjene vode je

$$t_i = \frac{1}{x} \Delta t,$$

Gdje je Δt vremenski interval između dva niza podataka. Za srednji Jadran se je pokazalo da je najprikladnije uzeti 10 dana, ali su obično korišteni podaci uzimani jedamput mjesečno.

Premda uz istočnu obalu Jadrana strujanje nije brzo, brzina izmjene vode je povoljna s aspekta polucije. Ventiliranje bazena je dosta dobro, a kako niti produkcija u tom području nije jako visoka, obala ima dobre prirodne uslove za razumnu urbanizaciju.