A PRELIMINARY ASSESSMENT OF OPTIONS TO RECONNECT THE RAZELM-SINOE LAGOON SYSTEM TO THE BLACK SEA

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Abstract. Various studies emphasize the need to improve the water circulation in the Razelm-Sinoe lagoon system. A preliminary analysis on the possible effects of reopening the connection between the lagoon system and the Black Sea has been performed herein. Numerical modelling has been used to test several options to reconnect the lagoon system to the Black Sea. The analysis has been performed based on the water renewal time of the lagoon system, an indicator of the water quality. Our results show that reopening the connection to the sea is expected to lead to a lower water renewal time and, thus, to a better water circulation in the Razelm-Sinoe lagoon system, for all the considered options, while some of them are more efficient. In this way, the breeding habitats for many freshwater and marine fish species are expected to be restored. At the same time, monitoring of discharge and salinity in the lagoon system is highly needed. The present work can be considered as a first step in assessing the potential effects of several options and combinations of options to reconnect the Razelm-Sinoe Lagoon System to the Black Sea, and in demonstrating that this is an efficient way to improve the water circulation.

Key words: lagoon system, water circulation, connection, numerical modelling, discharge, water renewal time

1. INTRODUCTION

The Razelm-Sinoe Lagoon System, covering about 1000 km^2 of the Danube Delta Biosphere Reserve, used to be one of the richest coastal environments in the northwestern part of the Black Sea. Over the years, the lagoon system has been significantly affected by human interventions, which have changed its natural evolution. The main lakes of the Razelm Unit are: Razelm, with a maximum depth of 3.5 m, Golovița and Zmeica. The maximum depth of the Sinoe Lagoon is 2.5 m. Detailed studies on the evolution of the lagoon system have been presented by several authors (i.e., Panin, 1996, 1998, 1999; Giosan *et al.*, 2006, Vespremeanu-Stroe *et al.*, 2013, Constantinescu *et al.*, 2023).

The Razelm-Sinoe Lagoon System (Fig. 1) started to be affected by human interventions at the end of the 19th Century (Antipa, 1894; Staras, 2000; Bretcan *et al.*, 2008). The dredging of the Dunavăț and Dranov canals, connecting the Razelm Lagoon to the southern arm of the Danube River, ended up at the beginning of the 20th century. Thus, more freshwater discharged to the lagoon system. During the 1950s, management plans were made to decrease the salinity of the lagoon system waters, to increase the freshwater fish culture productivity. Between 1960 and 1990, the lagoon suffered severe changes, being used mainly for irrigations and, secondly, for fish breeding.

The Razelm-Sinoe Lagoon System was connected to the sea by means of several inlets. The most important inlet was Gura Portiței, connecting the Lake Golovița to the sea, which was closed artificially in 1973, by a system of breakwaters and groins. The erosion increased in intensity south of the former inlet, due to the hard coastal defense structure (Spătaru, 1990; Vespremeanu-Stroe *et al.*, 2007). The Sinoe Lagoon used to be connected to the sea by the Edighiol and Periboina inlets (Fig. 1), as well as at Gura Buhazului, in its southern part. This last inlet was clogged in the late 1980s – early 1990s.

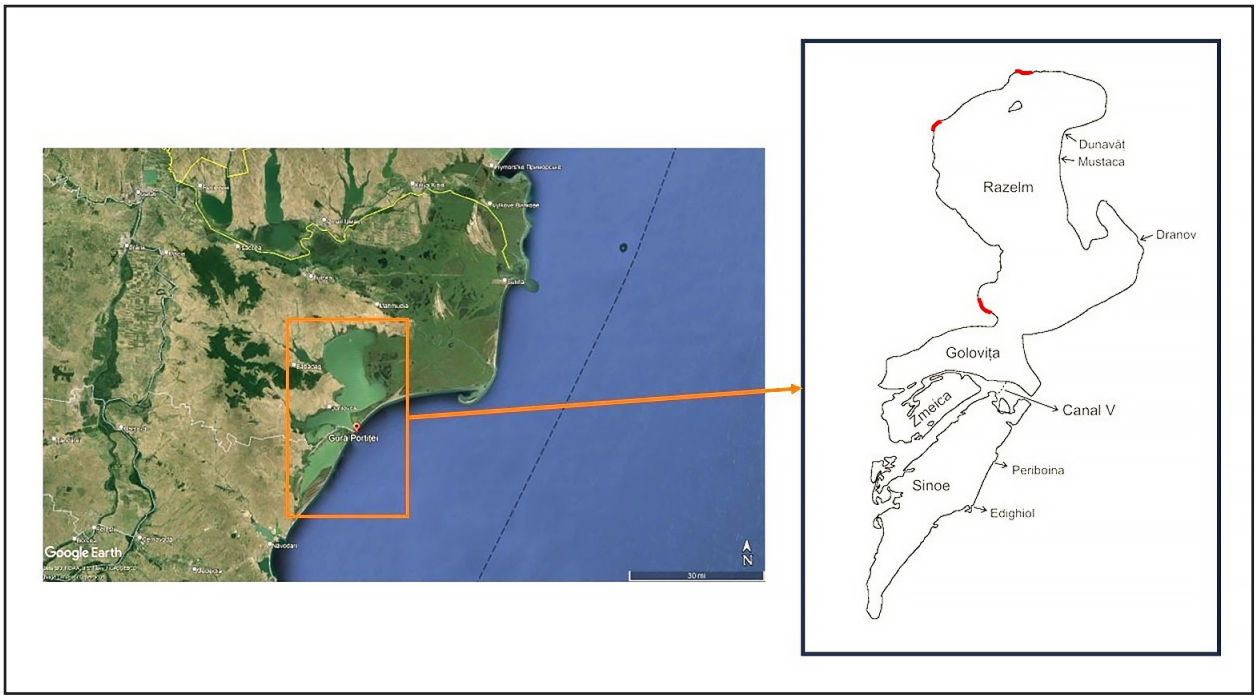

Fig. 1. Location of the Razelm-Sinoe Lagoon System on the Danube Delta coast; the right panel shows a sketch of the lagoon system and the red segments along the Razelm contour mark the zones with junctions with irrigation canals.

The permanent circulation between the Sinoe Lagoon and the Black Sea has been restored by the beginning of 2000 and has been controlled by the Periboina and Edighiol inlets. But, starting from 2017, the zone around the Periboina inlet has become clogged. Nowadays the Sinoe Lagoon is connected to be Black Sea only by the Edighiol inlet. The water discharge from the Razelm Lagoon to the Sinoe Lagoon was foreseen to be achieved by two artificial canals – Canal II and Canal V. The water fluxes and the navigation were controlled by locks. Nowadays the water depth of the Canal II is very low, around 20 cm. Thus, the northern and southern lagoons are connected mainly via the artificial canal No V (Fig. 1), which is 1.5 m deep.

There is a system of irrigation canals west and north of the Razelm-Sinoe Lagoon System. The red segments marked on the detailed sketch, shown in the right panel of figure 1, represent the zones where there are junctions between the irrigation canals and the lagoon system.

Present-day research emphasizes the need to improve the water circulation in the lagoon system, which involves restoration of its connection to the Black Sea, by means of new 1.5 m deep inlets. In this way, the breeding habitats for many freshwater and marine fish species, of economic importance, are expected to be restored.

Reopening the connection between the Razelm-Sinoe Lagoon System and the Black Sea is under consideration by local communities and authorities. Therefore, several options and combinations of options to reconnect the lagoon system to the Black Sea have been tested using numerical modelling. The hydrodynamic model SHYFEM (Shallow water HYdrodynamic Finite Element Model) (Umgiesser, 2024; Umgiesser *et al.*, 2004) has been used for this purpose.

The SHYFEM model has been applied on several lagoons in Europe (Ferrarin and Umgiesser, 2005; Bellafiore *et al.*, 2008; Ferrarin *et al.*, 2008; De Pascalis *et al.* 2009; 2012; Umgiesser *et al.*, 2014), as well as on the Razelm – Sinoe Lagoon System (Dinu *et al.*, 2015). A preliminary assessment of the effect of reconnecting the lagoon system to the Black Sea is performed in the present work, which is a follow-up of a previous study (Dinu *et al.*, 2015).

2. METHODOLOGY

The analysis has been performed by means of the water renewal time (WRT) in the lagoon system, which can be considered as an indicator of the water quality (Braunschweig *et al.*, 2003; Pham Van *et al.*, 2020).

WRT is computed by simulating the transport and diffusion of an Eulerian conservative tracer, released uniformly throughout the entire lagoon system, with a concentration corresponding to 1, while a concentration of zero is imposed on the seaward and freshwater boundaries. It is considered as the time required for each cell of the modelled domain to replace the mass of the conservative tracer, originally released, with new water.

The SHYFEM model needs to run for a long time, to be able to compute the water renewal time. For this study, the model has been run for 3 years, considering that a spin-up period of 1

year is enough for the Razelm-Sinoe Lagoon System not to be influenced by its initial state.

Daily discharge data on the Dunavăț, Mustaca, and Dranov canals, that connect the Razelm Lagoon to the Sf. Gheorghe arm of the Danube, have been provided by a 1D-2D model, and correspond to the period 2003 – 2006. These discharge data have been introduced in the model as boundary conditions at the locations corresponding to the junctions between the canals and the Razelm Lagoon. Other boundary conditions are daily time series of sea water level, salinity and temperature, at the corresponding locations of the Periboina and Edighiol inlets.

As we are investigating the possibility to improve the water circulation in the lagoon system, both inlets from Periboina and Edighiol have been considered open. Daily wind data, also corresponding to the 2003 – 2006 period, were used to force the model. The maximum wind speed has been 11 m/s and the most frequent wind direction is from the north sector.

Low, medium and high discharge regimes were defined in a previous study (Dinu *et al.*, 2015), based on the available data, corresponding to the years 2003, 2004 and 2006. For the computation of the water renewal time for every discharge regime, all the corresponding daily time series have been repeated 3 times.

The first numerical simulations have been run for the above-mentioned discharge regimes (Dinu *et al.*, 2015), using the baseline grid of the Razelm-Sinoe Lagoon System (Fig. 2):

- low discharge, corresponding to 2003 data;
- medium discharge, corresponding to 2004 data;
- high discharge, corresponding to 2006 data.

The grid has been modified afterwards, to represent new connections to the Black Sea and the simulations have been run again, with the same forcing, in low, medium and high discharge. The new values of the water renewal time were compared to the initial ones.

The following options to connect the lagoon system to the Black Sea have been analyzed:

- Option A – a new inlet between the location of the former Portița inlet and the sea (Fig. 3a);
- Option B – a new inlet between the location of the Portița lighthouse and the sea (Fig. 3b);
- Option C – a new inlet between the tail of the Sinoe Lagoon and the sea, in the Gura Buhazului zone, at the "Bosoancă Breakwater" (Fig. 3c);
- Option D – a new inlet between the northern part of the Sinoe Lagoon and the sea, south of the Portița lighthouse (Fig. 3d).

Options A to C are the main ones to be considered, while Option D is an additional one.

A new grid has been used for every one of the analyzed options. One inlet was added to the baseline grid for the simple options A to D. Each new inlet is 1.5 m deep and 80 to 100 m wide.

Discussions with stakeholders and the local community suggested that option C should be considered anyway because it would provide better access for fishermen boats from the southern part of the lagoon system. Therefore, we have also taken into consideration combinations between the connection options. Thus, other simulations have been performed for two additional combined connection options: A+C, B+C. Moreover, the combinations of options A+D, B+D, C+D have been analyzed as well.

Finally, combinations of options involving three inlets have also been taken into account. We have thought that an option A+B+D would make no sense, as inlets A and B are too close. Thus, we have also analyzed the options A+C+D and B+C+D.

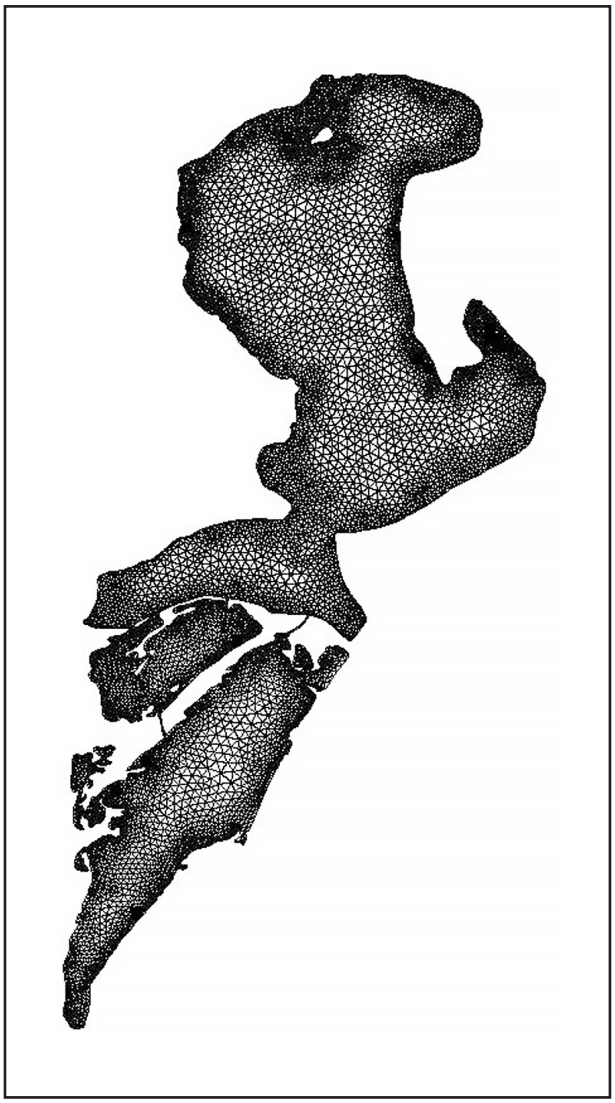

Fig. 2. Baseline grid of the Razelm-Sinoe Lagoon System.

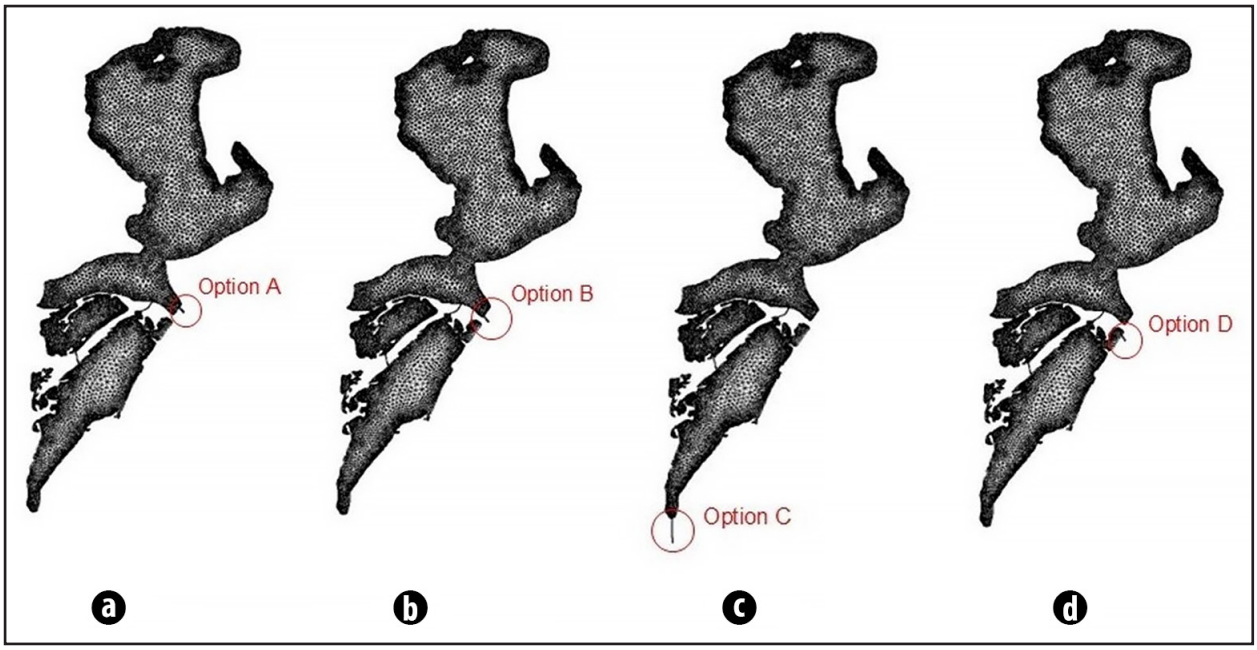

Fig. 3. Modified grids to represent (**a**) Option A; (**b**) Option B; (**c**) Option C; (**d**) Option D.

3. RESULTS

The calculated water renewal times for the whole Razelm-Sinoe Lagoon System, for all the analyzed connection options are presented in Table 1. Comparing the results for the modified grids with the ones for the baseline grid, a decrease of the water renewal time can be noticed when the discharge increases. So, an increased water inflow from the Sf. Gheorghe arm, by the Dunavăț, Mustaca, and Dranov canals, improves the water circulation in the lagoon system, as expected. The same simulations, in low, medium and high discharge conditions, have been repeated for all the analyzed options, using the corresponding modified grid for each.

For all the 11 analyzed connection options, the calculated water renewal times are lower than the initial ones, in all the three analyzed discharge conditions. These results show that reopening the connection to the Black Sea leads to an improved water circulation in the Razelm-Sinoe Lagoon System.

Table 2 presents the difference in the calculated Water Renewal Time (WRT), for the analyzed connection options, comparing to the baseline simulations. These differences are between certain limits, depending on the Danube discharge regime.

3.1. One inlet

The results suggest that, if only one option is considered, the most efficient is Option B, with the lowest WRT, while the least efficient is Option C, with the highest WRT. Options C and D give WRT that are close, at less than 3 days difference.

Moreover, Option C would involve higher cost, as the proposed inlet is longer than for the other options. The main reason for building an inlet to connect the tail of the Sinoe Lagoon to the sea would be to facilitate the access of fishermen.

3.2. Two inlets

The simulations of combined two options show that Option C is worth taking into account together with options A or B. The B+C combination seems to be more efficient than A+C combination as it leads to a WRT decrease of 6 to 13 days. The B+C combination is comparable to B+D from the WRT point of view, but it is better to use it, to improve the access by boat to the southern part of the lagoon system. So, if a combination of two options is to be foreseen, B+C seems to be a better choice.

We can also notice that the values of the water renewal time for the combined options A+C and A+D are very close to the ones in the case of option B. The least efficient combination of two options appears to be C+D, leading to a less significant WRT decrease (Table 2).

3.3. Three inlets

The A+C+D combination of options leads to a very low difference in the calculated WRT, comparing to B+C: between 2 hours, for high discharge, and 9 hours for low discharge.

Strictly taking into account these results on water renewal time, the B+C+D combination appears to be the most efficient. The calculated WRT difference, comparing to the A+C+D combination is between 6 days, for high discharge, and 12 days, for low discharge. The B+C+D combination of options would lead to a significant decrease of the water renewal time in the Razelm-Sinoe Lagoon System.

Table 1. Calculated Water Renewal Time (days) in the Razelm-Sinoe Lagoon System for the analyzed connection options

Regime	Baseline	Option A	Option B	Option C	Option D	Option A+C	Option B+C	Option A+D	Option B+D	Option C+D	Option A+C+D	Option B+C+D
low Q (2003)	558.57	440.93	427.58	540.71	538.82	426.30	413.50	426.86	414.62	522.36	413.86	402.10
medium Q (2004)	426.25	350.42	340.32	415.83	418.06	339.78	329.89	339.83	330.01	407.47	330.16	320.62
high Q (2006)	287.04	248.35	242.45	281.68	284.42	240.49	234.48	242.00	235.75	278.70	234.57	228.34

Table 2. Decrease in the calculated Water Renewal Time (days) in the Razelm-Sinoe Lagoon System, for the analyzed connection options, comparing to the baseline simulations

Regime	Option A	Option B	Option C	Option D	Option A+C	Option B+C	Option A+D	Option B+D	Option C+D	Option A+C+D	Option B+C+D
low Q (2003)	117.64	130.99	17.86	19.75	132.27	145.07	131.71	143.95	36.21	144.71	156.47
medium Q (2004)	75.83	85.93	10.42	8.19	86.47	96.36	86.42	96.24	18.78	96.09	105.63
high Q (2006)	38.69	44.59	5.36	2.62	46.55	52.56	45.04	51.29	8.34	52.47	58.7

Figures 4 – 6 show the WRT distribution in the lagoon system for several options, in the low, medium and high discharge conditions, corresponding to the 2003, 2004 and 2006 data. The highest WRT values occur in the western part of the Razelm and Sinoe lagoons and in the Golovița and Zmeica lakes. Changes induced by the proposed options lead to the WRT decrease, on a more or less extended area, in the eastern part of the Sinoe Lagoon and, eventually, of the Golovița Lake. Options A (Figs. 4b, 5b, 6b) and B (Figs. 4c, 5c, 6c) induce a significant WRT decrease on an extended area of the Sinoe Lagoon, as well and on the eastern part of the Golovița Lake. Options C (Figs. 4d, 5d, 6d) and D (Figs. 4e, 5e, 6e) don't have impact on the WRT in the Golovița Lake. As expected, a combination of options appears to be more efficient, leading to an improved water circulation on a wider part of the Sinoe Lagoon and Golovița Lake (Figs. 4f, 5f, 6f; 4g, 5g, 6g).

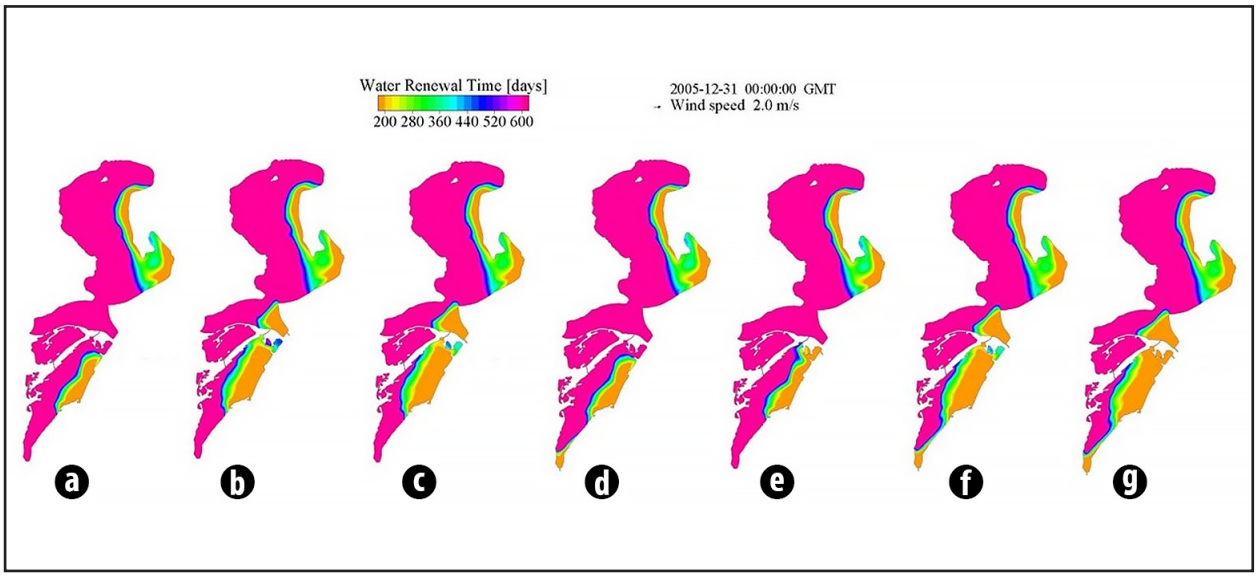

Fig. 4. Distribution of the calculated Water Renewal Time in the Razelm-Sinoe Lagoon system, in low discharge conditions (corresponding to 2003 data), for various connection options: (**a**) baseline (no additional inlet); (**b**) option A; (**c**) option B; (**d**) option C; (**e**) option D; (**f**) options B+C; (**g**) options B+C+D.

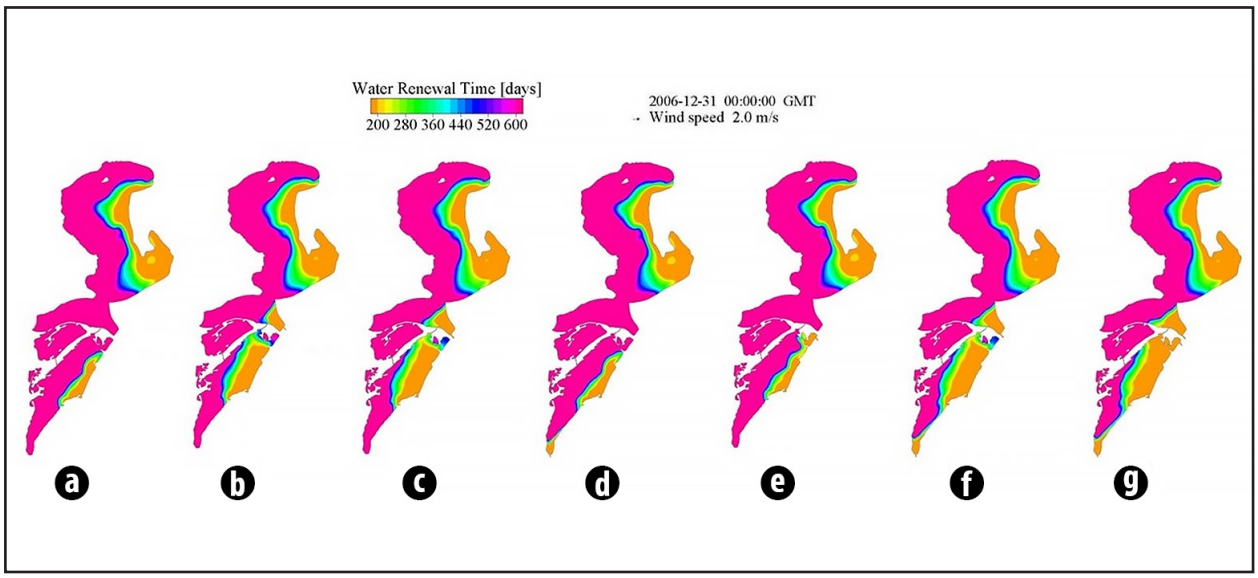

Fig. 5. Distribution of the calculated Water Renewal Time in the Razelm-Sinoe Lagoon system, in medium discharge conditions (corresponding to 2004 data), for various connection options: (**a**) baseline (no additional inlet); (**b**) option A; (**c**) option B; (**d**) option C; (**e**) option D; (**f**) options B+C; (**g**) options B+C+D.

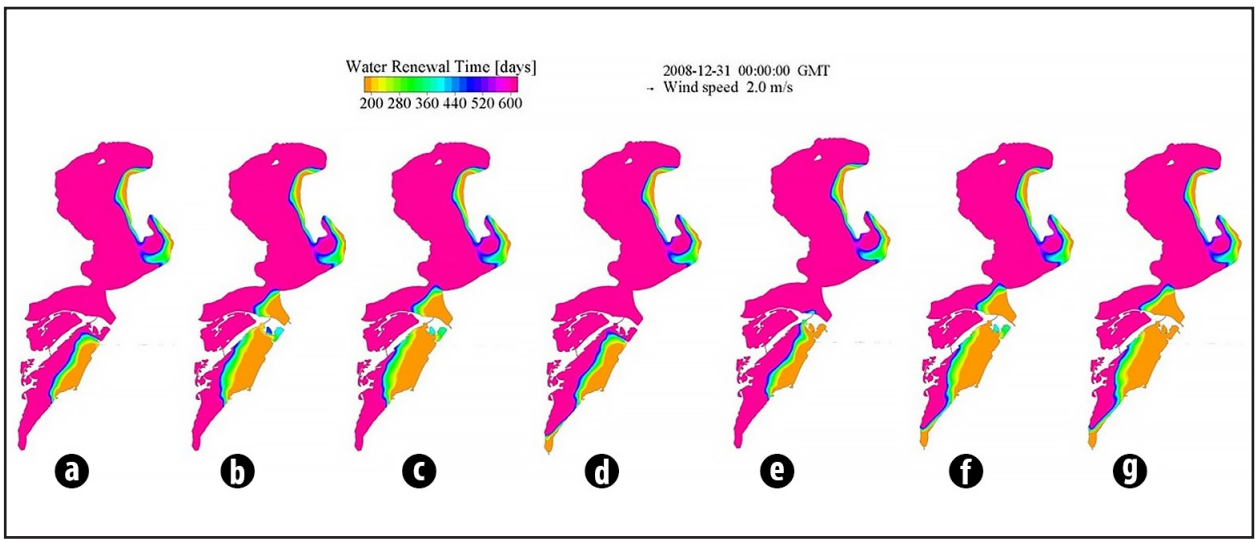

Fig. 6. Distribution of the calculated Water Renewal Time in the Razelm-Sinoe Lagoon system, in high discharge conditions (corresponding to 2006 data), for various connection options: (**a**) baseline (no additional inlet); (**b**) option A; (**c**) option B; (**d**) option C; (**e**) option D; (**f**) options B+C; (**g**) options B+C+D.

4. DISCUSSION AND FURTHER STEPS

Local people, especially fishermen and owners of houseboats and pensions, are in favor of reconnecting the lagoon system to the Black Sea. Fishermen complain about certain valuable fish species, such as pike, perch, carp, that cannot develop properly in the Razelm Lagoon. They are not well fed and cannot reach their normal weight anymore. One of the reasons is that small fish, that used to be regular food for valuable fish species, have disappeared. The same fish species develop much better in the Sinoe Lagoon, reaching their normal weight and dimensions.

There is no proper salinity monitoring of the lagoon system. This is highly needed, taking into account the presence of the irrigation canals in the vicinity of the Razelm Lagoon (Fig. 1), especially in the western part, where the proposed solutions for reconnection would lead to an increase of salinity. According to standards, the salinity content of the water used for irrigation is between 0.15 and 3 PSU.

In the event of a salinity increase over 3 PSU in the Razelm Lagoon, the connection to the sea should be closed. Therefore, a system of locks will be considered as well, in a further step of the study.

The simulations performed in this study can be considered as a quick way to estimate the effects of the proposed options and combinations of options for reconnecting the lagoon system to the Black Sea, but they represent just a preliminary work. As we are discussing reconnection between the Razelm-Sinoe Lagoon System and the Black Sea, a detailed study is needed, on an extended domain, which also includes the main Danube branches and the adjacent part of the Black Sea shelf sea (Ferrarin *et al.*, 2025). This is necessary because the lagoon system and the adjacent shelf sea form a connected hydrodynamic and ecological system and there is a high need to understand the response to the proposed changes. The Razelm-Sinoe Lagoon System is influenced by the Black Sea waves, level and salinity fluctuations. Waves may enter the lagoon system through inlets and impact the sediment transport. Sediment exchange between the lagoon system and the sea can be enhanced during storms. Besides, there are many fish and crustacean species that migrate between the sea and the lagoon system.

Taking all these aspects into account, the effect of reconnecting the Razelm-Sinoe Lagoon System to the Black Sea must be investigated at wider scale. Therefore, a more extended grid is needed for this purpose, including the main distributaries of the Danube delta, the Razelm-Sinoe Lagoon System, as well as a part of the shelf sea. More advanced modelling has been performed by Ferrarin *et al.,* 2025, including validation on Danube discharge, sea level, and sea temperature, as well and a first investigation of the effects of the A, B, and C reconnection options on the extended grid. However, the above-mentioned work did not consider combinations of reconnection options.

Nevertheless, the present study can be considered a first step in assessing the potential effects of the proposed options to reconnect the Razelm-Sinoe Lagoon System to the Black Sea, and to demonstrate that this is an efficient way to improve the water circulation.

5. CONCLUSIONS

This first assessment of the effects of reconnecting the Razelm-Sinoe Lagoon System to the Black Sea shows that this leads to a significant improvement of water circulation.

Several reconnection options and combinations of options have been tested at the scale of the lagoon system, in various Danube discharge conditions. Our analysis has been based on the water renewal time.

The most efficient simple reconnection option appears to be the one that involves a new inlet between the location of the Portița lighthouse and the sea. Meantime, the most efficient combination of options appears to be one that involves three inlets: one between the location of the Portița lighthouse and the sea, one between the northern part of the Sinoe Lagoon and the sea, and one between the tail of the Sinoe Lagoon and the sea.

The efficiency of the proposed options and combinations of options depends on the discharge regime. The lower values of the water renewal time occur in high Danube discharge conditions.

Our analysis has been performed only from the hydrodynamic point of view. Reopening the connection to the Black Sea would increase salinity in the Razelm-Sinoe Lagoon System and this would affect the quality of the water used for irrigation in the adjacent western zone, especially in low discharge conditions.

Therefore, monitoring of the salinity in the lagoon system, correlated with the Danube discharge regime, is highly necessary.

This work shows that numerical modelling is a powerful and efficient tool for evaluating the impact of various reconnection options and can be useful in the decision-making process for coastal managers. This kind of analysis can be performed in coastal zones with similar issues.

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