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Towards Situation-Dependent Regulations for the Prevention of Ship-generated Sewage Pollution in Specific Areas

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ABSTRACT: The objective of this paper is to present a background for a concept of situation-dependent adjustment of environmental regulations for the prevention of ship-generated sewage pollution. Unlike the standard rules based only on a constant distance from the nearest land that routinely disregard the effect of drift caused by local surface currents, tidal streams, or winds, we consider taking into account the situational dependence in addition. This includes the available hydrometeorological data on the seawater flow, the initial position and time of disposal, and ultimately, sea state, the physical and biochemical properties of the substances (sewage, wastewater) discharged overboard. Computing the approximate dynamics of drifted sewage yields estimated information on the prohibited (permitted) zones of discharge and the boundary subareas of the predicted distribution or the maximum (minimum) concentrations of contaminants, respectively. This can be further applied to the innovative decision support systems aimed at preventing local pollution, involving stakeholders on both sides: ship masters and shore services on marine environment protection, as well as to developing local legislation. In order to justify the proposed approach and to emphasize the relevance of situational dependence concerning the natural motions of sea water bodies, our study is illustrated with some examples based on real-world data including various drift effects.

1 INTRODUCTION

Due to the multiple anthropogenic pressures world's marine ecosystems are seriously degraded and nations worldwide have to take measures to achieve Sustainable Development Goal 14: "Conserve and sustainably use the oceans, seas and marine resources for sustainable development" adopted in September 2015 by all United Nations (UN) Member States [25]. To stimulate actions by stakeholders working at the science/policy interface to strengthen the management of oceans and coasts the UN has proclaimed "A Decade of Ocean Science for Sustainable Development (2021-2030)" [26]. Sewage discharges, particularly if untreated, contribute significantly to marine pollution [15]. Pathogens, nutrients, heavy metals, and various regulated and emerging organic micropollutants entering water bodies pose a risk to human and animal health, particularly in coastal regions exposed to intense human activity.

Ships, depending on the number of people onboard, length of the voyage, and type of toilets, may generate large quantities of sewage [20]. Moreover, sewage from some types of ships, such as cruisers, contains a wide range of chemicals with different properties (heavy metals, polycyclic aromatic hydrocarbons, pesticides, fragrances, UV filters, pharmaceuticals, flame retardants, anionic surfactants, and food additives), sometimes in higher concentrations than urban wastewater. Once entered into the receiving marine environment contaminants may evaporate, float, dissolve, and sink in various combinations, and duration of these processes may take a relatively long time. Dissolvers and sinkers endanger aquatic organisms in the water column and the sediments, while birds, marine mammals, and benthic life forms along the coast are mainly exposed to floaters [14]. Pollution by ship-generated sewage can bring serious damage to marine ecosystems and it is of great significance to determine and implement measures to reduce it.

Currently, various legislative solutions are referring to discharges of sewage from ships [5]. The common characteristic of legislative measures is that the discharge of sewage into the sea within a specified distance from the nearest land is prohibited. Annex IV of the International Convention for the Prevention of Pollution from Ships (MARPOL), defines 3 NM for comminated and disinfected sewage using an approved system and 12 NM for untreated sewage. The U.S. Clean Water Act also determines 3 NM as the distance within the discharge of untreated sewage is forbidden. Specified distances from the nearest land which occurs in the mentioned regulations originate from the law and present the breadth of the territorial sea. However, the transport and fate of contaminants from sewage in natural environments depend on their physical and chemical properties and circulation patterns of the receiving sea and vary substantially [19]. Therefore minimum of 3 NM for discharge of comminated and disinfected sewage or 12 NM for raw sewage may be unnecessarily too large. Moreover, the inconvenience of travelling offshore may contribute to violations, which occur frequently [6]. On the other hand, the discharge of wastewater from ships at an allowed distance may affect the migration routes and behaviours of animals or significantly contribute to the degradation of water quality [4]. Accordingly, we believe that an approach based on the fixed distances from land, ice shelf, or fast ice could be improved.

This work aims to propose an improvement of the existing regulations that refer to discharging wastewater from ships into moving water bodies. We suggest a situation-dependent approach that makes use of updated environmental information (reliable prediction) for local regulations or recommendations, not being based only on the fixed distances from, e.g. the nearest land, irrespective of natural drift effects. Such a concept enables us to ensure at least the same level of environmental protection as the current regulations and could prove to be more efficient for the vessel operators and shoreside.

2 A DESCRIPTION OF THE APPROACH WITH EXAMPLES

Pathogens, one of the most prevalent contaminants in natural waters, have been associated with a wide range of sicknesses. However, instead of their direct monitoring, fecal indicator bacteria (FIB) (fecal coliforms, total coliforms, enterococci, Escherichia coli) have been used worldwide for the assessment of sanitary water quality. The fate and transport of FIB in the marine environment depend on many factors. Biotic (predation and competition), and abiotic (salinity, nutrients, dissolved oxygen, temperature, visible light) environmental factors affect their survival [3]. Natural attenuation depends also on dilution, sorption, advection, and dispersion [10]. Therefore, meteorological data, water quality data, coastal geometry, and bathymetry are required to apply mechanistic models to predict its concentration [24]. However, research data indicate that regardless of conditions, fecal pollutants become diluted at distances less than 3 km from a source toward the open sea or deeper water [7,17,23]. Taking into account the above-mentioned facts, "the worst-case scenario" of contaminants from the raw sewage reaching the nearshore includes FIB. For the purposes of this study, concerning the permission to discharge raw sewage, it can be assumed without loss of general concept that it behaves like a perfect persistent floater that will first reach the shore or a particular sea area, and its dynamic is based on the resulting horizontal current/stream-driven motion of the surrounding seawater.

The numerically simulated Lagrangian paths of seawater or pollution parcels are often used as test elements to evaluate the risk of an impact by pollution discharged in a particular position. In fact, the paths are usually not Lagrangian, that is, they are locked in the surface layer and only advection driven by two-dimensional (horizontal) currents is exerted. Such treatment surely does not represent the propagation of oil spills that are also affected by additional reasons, e.g., chemical processes, buoyancy effects, met-ocean drivers, and Stokes drift [8,13]. This can be applied to persistent substances dissolved in the thin surface stratum, e.g., different contaminants or radioactive materials. The quasi-Lagrangian models of such type enable us to evaluate the contribution of propagation driven by currents or streams in terms of environmental risks. For instance, oil spills under the combined effect of wind and currents were investigated by applying an advanced model in the Gulf of Finland [13]. The essential outputs are the probability distributions for the parcels released in various areas at sea to reach the nearshore regions as well as the duration, i.e., particle age or residence time at sea [21].

To clarify the concept of situation-dependent local regulations, it is sufficient to use some simplified models for our purposes. Knowing the discharge data including drift enables us to monitor the environmental situation more efficiently and predict the consequences of the discharges from ships into seawater at least in some particular cases (local areas), and therefore the impact on the local environment, e.g., coastlines, special zones, sensitive sea areas. For illustrative goals, the drifting paths and applied flow fields presented below are based on some real-world data, simulating planar seawater motions. It is assumed that the sea areas under consideration are local. Thus, the two-dimensional Euclidean plane can be chosen as background. In an extended global approach, the spheroidal cups should be considered in order not to neglect the curvature of the Earth but this falls beyond the scope of this paper. For the sake of simplicity and without loss of generality, the floater will be modelled as particle-type, i.e. the physical- and chemical dispersion is neglected in particular. Thus, the numerically obtained trajectories of flowing seawater (a perfect floater with the simplified dynamics) are considered. The scenarios with some tidal streams and surface currents are shown in a sequel. Their directions and speeds vary in time or sea areas (geographical position) under consideration. Depending on the software and preferred methods, the computational part can be refined and some of the existing algorithms can also be used in this regard; see, for example, [8,13,21].

2.1 *Time-dependence based on local tidal stream area*

We start with a scenario concerning drift in a tidal stream area. In this case, the corresponding data, i.e. set and rate (for both neap and spring tides) are repeated periodically and refer to high water at a specific place. Consequently, water motion is predictable with high accuracy and the corresponding tidal stream atlases present hourly motion vectors. For clarity and example, see the self-explanatory charts of the area of the Channel Islands off the coast of Normandy (Figure 1). The black arrows show the tidal streams 2, 4, and 6 hours after high water at the reference port (Dover in this case), and the same distribution is repeated twice a day (a semidiurnal tidal cycle including two high tides and low tides every lunar day). At each measuring point (the so-called "tidal diamonds" marked on the marine navigational charts) the flow direction and speed are a known function of time. Tidal flow timings and velocities appear in tidal stream atlases, tide charts, or modern electronic navigational databases, e.g. Electronic Chart Display and Information System (ECDIS) installed onboard the ships, following the requirements of the SOLAS Convention (Chapter V, "Safety of navigation"). Tidal flows are significant for navigation, and serious errors in position occur if they are not taken into account. In general, the resulting drifting paths are different as they depend on position and time, like the streams. As a consequence, the points of the intermediate/final destination or the concentration areas of the discharged floaters vary. However, by knowing the environmental data and characteristics of the substances the trajectory can be computed and predicted in sufficiently accurate way.

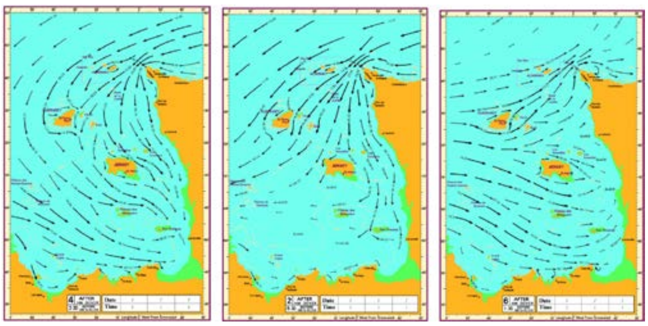
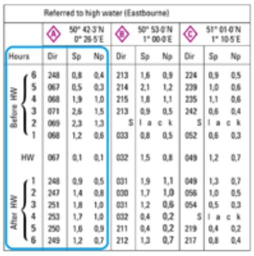


Figure 1. The varying flow directions and speeds of tidal streams repeated periodically in the area of the Channel Islands off the coast of Normandy 2 (left), 4 (middle), and 6 hours (right) after high water at Dover [27].

We make now use of the data coming from an actual measuring point of the streams, which is positioned in the northern part of the English Channel. The details are presented in a tabular and graphical form in Figure 2.



Referred to high water (Eastbourne)										
		A 50° 42·3'N 0° 26·5'E			B 50° 53·0'N 1° 00·0'E			C 51° 01·0'N 1° 10·5'E		
Hours		Dir	Sp	Np	Dir	Sp	Np	Dir	Sp	Np
Before HW	6	248	0,8	0,4	213	1,6	0,9	224	0,9	0,5
	5	067	0,5	0,3	214	2,1	1,2	239	1,0	0,6
	4	068	1,9	1,0	215	1,8	1,1	235	1,1	0,6
	3	071	2,6	1,5	213	0,9	0,5	242	0,6	0,4
	2	069	2,3	1,3	S l a c k			S l a c k		
	1	068	1,2	0,6	033	0,8	0,5	052	0,6	0,3
HW		067	0,1	0,1	032	1,5	0,8	049	1,2	0,7
After HW	1	248	0,9	0,5	031	1,9	1,1	049	1,3	0,7
	2	247	1,4	0,8	030	1,7	1,0	056	1,0	0,5
	3	251	1,8	1,0	031	1,2	0,6	054	0,5	0,3
	4	253	1,7	1,0	032	0,4	0,2	S l a c k		
	5	250	1,6	0,9	211	0,4	0,2	219	0,4	0,2
	6	249	1,2	0,7	212	1,3	0,7	217	0,8	0,4

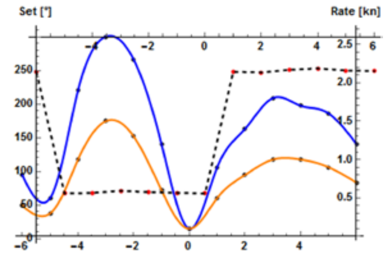


Figure 2. Left: the tabular form of the tidal stream data referred to high water at Eastbourne (tidal diamond "A"). Right: the corresponding graphs of set (dashed black) and rate (spring tide - blue, neap tide - orange).

For practical applications, it is often assumed that the streams in the local area near the reference positions are approximately the same. Thus, a modelled vector field that is time-dependent locally, but not position-dependent will be considered in the sequel. We simply aimed to show how the trajectory of the drifted floaters looks like while being considered as a function of time, where the initial position (discharge) is located at the measuring point (Figure 3). The fact that the semidiurnal tides have a period of ca. 12 hours 25 minutes is taken into account.

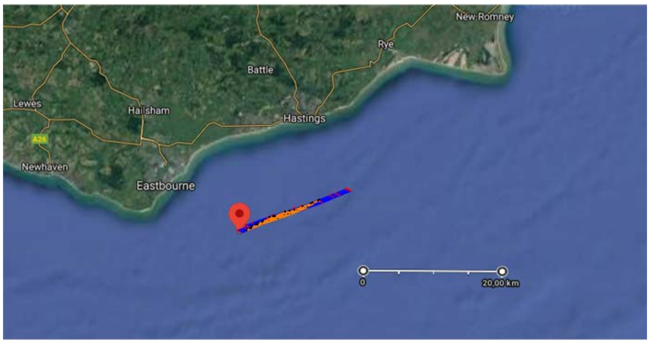


Figure 3. The approximated drifting paths at the spring (blue) and neap (orange) rate, where the maximum ranges of drift are generated for 3 tidal cycles (t = 37.25 hours), with the corresponding map in the background. The tidal stream data refer to high water at Eastbourne, starting from the position of the tidal diamond "A" (the simulated release of the floaters marked by a red mark) 6 hours before high water.

2.2 *Position-dependence based on surface currents in the open sea area*

Now the open sea area in the Atlantic, i.e., 31° - 35°N and 035° - 031°W has been considered. This covers 10 forecasts for the surface currents' motion with 24-hour steps from 11 Nov. 2019, 03:00 UTC till 20 Nov. 2019, 03:00 UTC. The related data have been saved in GRIB2 (GRIdded Binary or General Regularly distributed Information in Binary form) format. This is standardized by the World Meteorological Organization's Commission for Basic Systems and used in meteorology to store weather forecast including numerical weather prediction output as well as historical data. They are analysed and transformed with the use of Mathematica software from Wolfram Research to obtain the approximated analytical formula of the corresponding vector field in the area under consideration. Such mathematical operation requires finding the appropriate fitting functions that represent the flow of seawater in the area of disposal.

First, to create a comparison to the tidal area mentioned above, we obtain a trajectory in the vicinity of one measuring point, located at (33°N, 035°W). For simplicity, we assume that the current is only time-dependent herein. Thus, the scenario is similar to the previous example, however now the sea current is no longer cyclic, by contrast to the tidal stream. The corresponding data of direction and speed as the functions of time are presented in Figure 4 (left). The linear model with the best-fit function based on the trigonometric functions has been constructed. The resulting trajectory is shown in Figure 4 (right). In this case, the drifting distance after 2 days equals 23.9 Nm (north-north-west direction) in the presence of a time-dependent vector field under consideration.

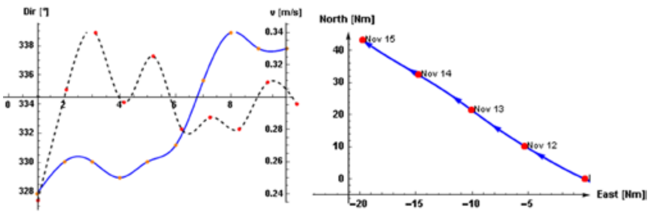


Figure 4. Left: the graphs of the surface current (direction - dashed black, speed – solid blue) in position (33°N, 035°W) for the period: 11 Nov. 2019, 03:00 UTC - 20 Nov. 2019, 03:00 UTC (24 hours steps, i.e., 10 days). Right: the simulated local drifting path (NNW-bound) generated from the position (33°N, 035°W) which is the origin (0,0) in the presented local coordinate system, and starting on 11 Nov. 2019, 03:00 UTC.

As already mentioned a surface current is in general position-varying as well. Therefore, we now take into account 81 measuring points in the entire area (every 0.5° of latitude and longitude), and the spatially-varying surface currents are analysed. The models including the data for 11 Nov. 2019, 03:00 UTC are presented graphically in Figure 5.

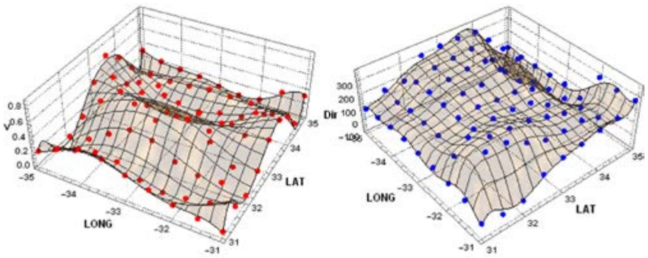


Figure 5. The models are based on the fitting functions of two variables (surfaces) being the polynomials of degree 7, which are presented graphically with the data for speed (left) and direction (right) of the surface current in the open sea area (31°–35°N, 031°–035°W), 11 Nov. 2019, 03:00 UTC.

The corresponding contour plots of speed and direction are presented in Figure 6.

As a consequence, the exemplary trajectories of a perfect floater in the area passing through the positions (32.5°N, 033.5°W) (solid white) and (34.0°N, 031.6°W) (dashed white) are shown in Figure 7. One can easily observe their different intermediate positions in the same time instants and related destinations.

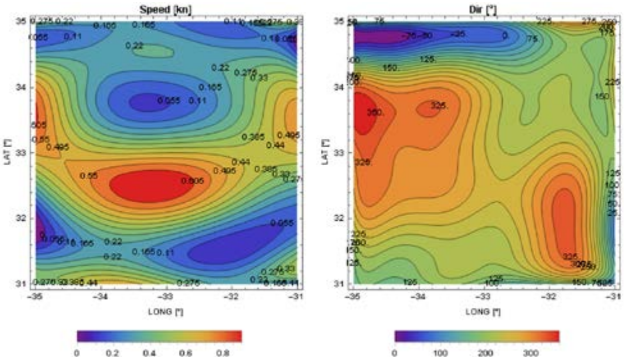


Figure 6. The contour plots of speed (left) and direction (right) of the surface currents in the open sea area (31°–35°N, 031°–035°W), 11 Nov. 2019, 03:00 UTC.

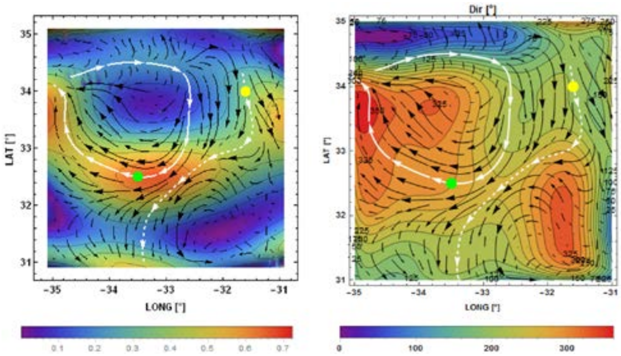


Figure 7. Left: a comparison of two drifting trajectories of the floaters passing through the positions (32.5°N, 033.5°W) (the green dot following the solid white path) and (34.0°N, 031.6°W) (the yellow dot following the dashed white path); in the background: the colour-coded stream density plot referring to speed of the current in knots (11 Nov. 2019, 03:00 UTC). Right: as on the left, however with the color-coded density plot referring to direction of the currents in the background.

Furthermore, four different ship's routes (dashed red in Figure 8) are considered, where the floaters are discharged overboard in five various positions (grey dots) along these routes.

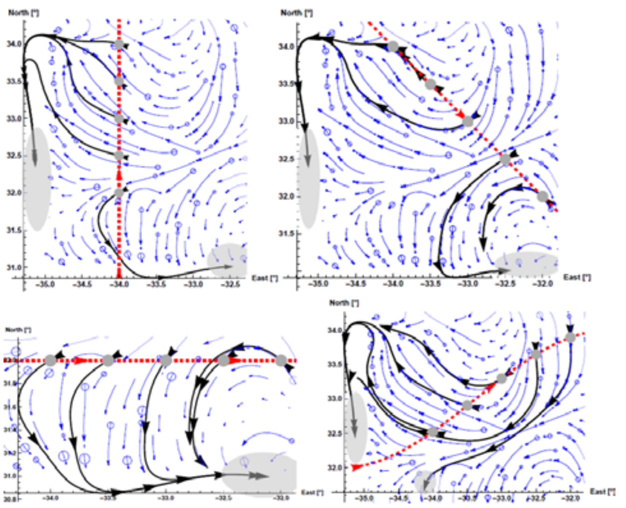


Figure 8. The simulated drifting paths of the perfect floaters (black) after discharging from a ship following 4 different routes (dashed red), and starting from 5 various positions (grey points), under the stationary currents (blue, on 11 Nov. 2019, 03:00 UTC) in the same open sea area (31° – 35°N, 031° – 035°W). The subareas of approximated destinations (concentrations) of the floaters are indicated illustratively by grey ellipses; t = 480 h.

The related drifting paths in the same area under consideration are obtained and presented in black (Figure 8), being the numerically simulated simplified trajectories of flowing seawater, i.e. the perfect floaters. It is clear that the discharge data (situational dependence) may cause different consequences in this case similar to analogous real-world scenarios because of the drift effects that vary in time and position. By the discharge data it should be understood in practice: time (t) and position of discharge (x0, y0), set and rate of the current in situ as well as the significant physical and biochemical properties of the substances (sewage, wastewater) discharged overboard. The subareas of simulated destinations (concentrations) of the floaters after t = 480 h are marked illustratively by grey ellipses in Figure 8.

3 DISCUSSION

Considering the possible harmful effects of ship wastewater, it is important to formulate and implement instruments that address discharges and reduce the related risks as much as possible. Regardless of the level of environmental regulation developed so far (international, state, or local regulation), discharge of sewage not treated by a sewage treatment plant is allowed at a certain distance. The designation of these specified distances from the nearest land is based on the assumption that on the high seas, the oceans can assimilate and deal with raw sewage, and the varying hydrometeorological sea conditions are not considered [16].

Sea drifters are used for various applications, including the gathering of scientific data and climate monitoring. The above examples and simulations show how the intermediate/final points and times of arrival of the drifted particles depend on the discharge data. Having this information in hand, one can support the decision-making on sewage disposal at sea, especially when the conditions are reliably foreseeable. The approach depicted can also help determine the optimized position and/or time of potential discharge as well as the range of propagation (boundaries) and concentration of the contaminants in the sea areas involved.

Therefore, by applying the proposed approach improved monitoring and management of the local (marine and shore) environment could be achieved. Namely, states that ratified MARPOL Annex IV need to develop additional state and local regulations, because passenger ships undertaking domestic voyages, recreational boats, and fishing boats, which are not covered by Annex IV, may represent a significantly higher risk of sea pollution by sewage than cruisers or cargo ships [11]. Instead of defining specified distances, future regulations or individual decisions on discharging procedures can be made based on the discharge data, since the accuracy and availability of hydrometeorological data are constantly improving. Furthermore, better protection of the sensitive areas could be achieved. Current regulations allow discharge at any location provided that an approved sewage treatment plant is used. However, many organic micropollutants are poorly removed by wastewater treatment plants [22], which means that sewage treatment does not make a significant difference when it comes to pollution by many of the contaminants that may have serious adverse effects. For example, a study of nine aquaculture sites in seven European countries revealed a potential risk of contaminants of both legacy and emerging concern, particularly UV filters [1]. Considering high spatial and seasonal variability in the occurrence of UV filters and other pharmaceuticals and personal care products related to tourism, applying the proposed approach, which is based on situational awareness and situation-adapted warnings in the areas of interest, when formulating local or regional regulations could be appropriate.

Moreover, sewage is only one of the problems related to pollution from ships. Many of the chemical contaminants entering the marine environment originate from operational discharges [29]. The MARPOL permits the discharges of noxious liquid substances, oil, and garbage (cargo residues, food waste, cleaning agents, and additives), provided that discharges are made in compliance with certain provisions. The number and quantities of discharges into the marine environment from shipping and other sea-based sources and the land are continuously increasing. Concurrently, harmful effects are better understood, and increased vulnerability of the marine ecosystems as a result of other human activities has been acknowledged. Therefore, there is a need to review the regulatory control in the sense of broadening regulated substances and/or completely banning discharges. For example, research on the effects of treated bilge water revealed that its discharges would be toxic to certain organisms in the ambient water and a higher degree of regulation regarding surfactants has been proposed [28]. Similarly, an analysis of the chemical substance transport from 1996 to 2016 showed that an increase in the number of tankers and the growth of the capacities justify reconsidering the regulations toward banning discharges [18]. However, the availability of port reception facilities, in many states is not adequate [12], and coming into force of new regulation may be a slow process. As a temporary solution at least the discharge of chemicals under such conditions that would enable the transport of contaminants toward specific areas such as national parks or mariculture sites should be prohibited. Since the current situation concerning the flow of seawater, sea state, surface wind or the different behaviour of discharged chemicals in specific seawater may significantly influence environmental disturbance [9], the designation of "no-discharge zones" could be based on the approach described in this article.

Finally, we need to mention that the proposed approach fits the currently created proposals of the new regulations and procedures in various aspects for Maritime Autonomous Surface Ships which will occur at sea in the near future [2]. International Maritime Organization aims to "integrate new and advancing technologies in the regulatory framework - balancing the benefits derived from new and advancing technologies against safety and security concerns, the impact on the environment and on international trade facilitation, the potential costs to the industry, and their impact on personnel, both on board and ashore".

4 CONCLUSIONS

There is a need for revised regulatory control and refined regulations in the context of sustainable development in the maritime sector, as well as for new and advancing technologies. This study depicted the prospective concept of refinements of the regional and local environmental regulations for the prevention of ship-generated sewage pollution. Contrary to the present-day approach, it takes into consideration the actual hydrometeorological conditions in the sense of its dynamical nature in the areas of interest, as well as the physical- and chemical properties of the sewage.

The examples illustrated clearly show that the drifts modelled by different flow fields (more general, the discharge data) yield varying destinations and zones of contaminant concentration. This influences in particular the fixed distances that are mentioned in the existing regulations. As a consequence, for instance, the difference in the initial time of discharge from the same position in the presence of time-varying currents yields different trajectories of drifters and finally their location in the same period.

Accordingly, we assert that the standard regulations based only on constant distances from the coastline can be refined depending on the local situation. Thus, this approach creates the background for situation-dependent discharge standards in the maritime sector, and the novel decision system in which the predicted behaviour of the discharged substances (sewage, pollutants) into the sea in the presence of the water (wind) flow field is also included.

Furthermore, since the new regulations are also expected for the coming autonomous ships in different aspects including environmental protection, it is reasonable to consider revising the MARPOL and the related documents to take into account the situation-dependent regulations, at least on a local scale. This covers in particular setting up novel and more efficient criteria and analogues of the constant minimum distances from the nearest land, any ice shelf or fast ice, a reef, or other special areas.

REFERENCES

[1] Aminot Y, Sayfritz SJ, Thomas KV, Godinho L, Botteon E, Ferrari F, Boti V, Albanis T, Köck-Schulmeyer M, Diaz-Cruz MS, Farré M, Barceló D, Marques A, Readman JW. Environmental risks associated with contaminants of legacy and emerging concern at European aquaculture areas. Environmental Pollution 2019;252:1301–1310.

[2] Autonomous shipping. n.d. Available: https://www.imo.org/en/MediaCentre/HotTopics/Pages/Autonomous-shipping.aspx. Accessed 20 Feb 2024.

[3] Barcina I, Lebaron P, Vives‐Rego J. Survival of allochthonous bacteria in aquatic systems: a biological approach. FEMS Microbiology Ecology 1997;23:1‐9.

[4] Chapman JW, Klaassen RHG, Drake VA, Fossette S, Hays GC, Metcalfe JD, Reynolds AM, Reynolds DR, Alerstam T. Animal Orientation Strategies for Movement in Flows. Current Biology 2011;21:R861–R870.

[5] Chen Q, Wu W, Guo Y, Li J, Wei F. Environmental impact, treatment technology and monitoring system of ship domestic sewage: A review. Sci Total Environ 2022;811:151410.

[6] Cottrell SP. Predictive model of responsible environmental behavior: application as a visitor monitoring tool. In: Monitoring and Management of Visitor Flows in Recreational Protected Areas Conference Proceedings / A Arnberger, C Brandenburg & A Muhar - Vienna, Austria: Institute for Landscape Architecture and Landscape Management, 2002 2002.

[7] Dheenan PS, Jha DK, Das AK, Vinithkumar NV, Devi MP, Kirubagaran R. Geographic information systems and multivariate analysis to evaluate fecal bacterial pollution in coastal waters of Andaman, India. Environ Pollut 2016;214:45–53.

[8] Fingas MF. Oil Spill Science and Technology: Prevention, Response, and Cleanup. Elsevier/Gulf Professional Pub., 2011.

[9] Jägerbrand AK, Brutemark A, Barthel Svedén J, Gren I-M. A review on the environmental impacts of shipping on aquatic and nearshore ecosystems. Science of the Total Environment 2019;695:133637.

[10] Kiaghadi A, Rifai HS. Natural attenuation of indicator bacteria in coastal streams and estuarine environments. Science of The Total Environment 2019;677:230–240.

[11] Koboević Ž, Kurtela Ž, Koboević N. Risk assessment model of coastal sea pollution by black (sewage) waters from vessels. Transactions of the Royal Institution of Naval Architects Part A: International Journal of Maritime Engineering 2018;160:A311–A323.

[12] MEPC.1-Circ.834-Rev.1.pdf. n.d. Available: https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/MEPC.1-Circ.834-Rev.1.pdf. Accessed 20 Feb 2024.

[13] Murawski J, Woge Nielsen J. Applications of an Oil Drift and Fate Model for Fairway Design. Preventive Methods for Coastal Protection: Towards the Use of Ocean Dynamics for Pollution Control 2013:367–415.

[14] Neuparth T, Moreira S, Santos MM, Reis-Henriques MA. Hazardous and Noxious Substances (HNS) in the marine environment: prioritizing HNS that pose major risk in a European context. Mar Pollut Bull 2011;62:21–28.

[15] Pinheiro HT, Teixeira JB, Francini-Filho RB, Soares-Gomes A, Ferreira CEL, Rocha LA. Hope and doubt for the world's marine ecosystems. Perspectives in Ecology and Conservation 2019;17:19–25.

[16] Prevention of Pollution by Sewage from Ships. n.d. Available: https://www.imo.org/en/OurWork/Environment/Pages/Sewage-Default.aspx. Accessed 21 Feb 2024.

[17] Rippy MA, Franks PJS, Feddersen F, Guza RT, Moore DF. Physical dynamics controlling variability in nearshore fecal pollution: fecal indicator bacteria as passive particles. Mar Pollut Bull 2013;66:151–157.

[18] Şanlıer Uçak Ş. Should chemical tankers' tank cleaning waters be banned from discharging into the sea? Transportation Research Part D Transport and Environment 2017;58:14–21.

[19] van Sebille E, Griffies SM, Abernathey R, Adams TP, Berloff P, Biastoch A, Blanke B, Chassignet EP, Cheng Y, Cotter CJ, Deleersnijder E, Döös K, Drake HF, Drijfhout S, Gary SF, Heemink AW, Kjellsson J, Koszalka IM, Lange M, Lique C, MacGilchrist GA, Marsh R, Mayorga Adame CG, McAdam R, Nencioli F, Paris CB, Piggott MD, Polton JA, Rühs S, Shah SHAM, Thomas MD, Wang J, Wolfram PJ, Zanna L, Zika JD. Lagrangian ocean analysis: Fundamentals and practices. Ocean Modelling 2018;121:49–75.

[20] Shu Y, Wang X, Huang Z, Song L, Fei Z, Gan L, Xu Y, Yin J. Estimating spatiotemporal distribution of wastewater generated by ships in coastal areas. Ocean & Coastal Management 2022;222:106133.

[21] Soomere T, Döös K, Lehmann A, Meier HEM, Murawski J, Myrberg K, Stanev E. The Potential of Current- and Wind-Driven Transport for Environmental Management of the Baltic Sea. Ambio 2014;43:94–104.
[22] Sousa JCG, Ribeiro AR, Barbosa MO, Pereira MFR, Silva AMT. A review on environmental monitoring of water organic pollutants identified by EU guidelines. J Hazard Mater 2018;344:146–162.
[23] de Souza RV, de Campos CJA, Garbossa LHP, Vianna LF de N, Seiffert WQ. Optimising statistical models to predict faecal pollution in coastal areas based on geographic and meteorological parameters. Marine Pollution Bulletin 2018;129:284–292.
[24] de Souza RV, Campos CJA, Garbossa LHP, Seiffert WQ. Developing, cross-validating and applying regression models to predict the concentrations of faecal indicator organisms in coastal waters under different environmental scenarios. Sci Total Environ 2018;630:20–31.
[25] THE 17 GOALS | Sustainable Development. n.d. Available: https://sdgs.un.org/goals. Accessed 19 Feb 2024.
[26] The United Nations Decade of Ocean Science for Sustainable Development, 2021-2030 - UNESCO Digital Library. n.d. Available: https://unesdoc.unesco.org/ark:/48223/pf0000261962. Accessed 4 Jul 2019.
[27] Tide Stream Charts. Monty Mariner n.d. Available: https://montymariner.co.uk/tide-stream-charts/. Accessed 20 Feb 2024.
[28] Tiselius P, Magnusson K. Toxicity of treated bilge water: The need for revised regulatory control. Marine Pollution Bulletin 2017;114:860–866.
[29] Tornero V, Hanke G. Chemical contaminants entering the marine environment from sea-based sources: A review with a focus on European seas. Marine Pollution Bulletin 2016;112:17–38.