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Brine Outfalls: State of the Art

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1. Introduction

With the growth of urbanisation, industrialisation and intensive agricultural practices, all superficial and underground, inland and marine bodies of water have become the repository for large quantities of every type of substance extraneous to the natural aquatic environment. In particular, the use of the sea as a dumping ground for a wide variety of waste has become a well-established practice worldwide over recent years. Increasingly greater stress is placed on the potential of these waters to dilute and disperse a greater quantity of waste pollutants created by continually growing populations. However, reliance on the self-purification capacity of the sea must be constantly monitored and not overestimated in order to protect the marine environment.

This is the point of departure for the author's desire to synthesize the complex phenomenon of the diffusion of discharge in the marine environment: a process which is governed by the hydrodynamic conditions of miscible fluids with different proprieties and which primarily depends on typical aspects of the environment which are often overlooked.

Particular attention will be paid to a certain type of discharge, called brine or concentrate, which is the salty water obtained from desalination plants that produce fresh water by separating dissolved salts from saline water. This waste water is generally disposed of through a pressurized conduit which carries the brine from the desalination plant to the shoreline. At this point, a specific submerged pipe, either buried or laid along the natural seabed, completes the discharge process. In order to guarantee the correct functioning of the discharge system, it is a good idea to provide the discharge conduit with a piezometric water supply tower of the appropriate dimensions. It must have a planimetric size sufficient for the water in transit and a sufficient height to guarantee that the system function under pressure all the way to its opening into the sea, and the entry of the wastewater into the sea must be carried out at a speed that favours the dilution of the brine. A loading tank will further ensure regular flow in the case of sudden oscillations in pressure in the underground conduit. The brine discharge outfall pipe should start at the piezometric tower, situated adjacent to the tank for the accumulation of the desalted water at the desalination plant. The submerged conduit should start from the shoreline, as previously mentioned, and be suitably coated so as to guarantee an effective passive protection against corrosion, and possibly thickened, if not buried, to create optimal mechanical protection and, at the same time, render the system perfectly stable on the seabed. At the head of this outfull pipe there is usually a diffuser, preferably with various shafts in decreasing diameter to guarantee a variable range of internal flow speeds so as to avoid possible deposits (low speed), and to safeguard the conduit against the effects of erosion (high speed). This design technique minimises the otherwise common phenomenon of sedimentation inside the diffuser itself, especially in low capacity systems. Discharge openings, called nozzles, are set into each branch of the diffuser in the appropriate size both to allow for a speed of effluence adequate for diffusion and arranged with a discharge speed and direction that will make it possible to avoid the overlapping of the plume rise at a short distance from the nozzles.

The theoretical excursus is performed in the discharged salt fluid direction considering the global system outfall pipe-diffuser-sea and focusing on the following different phases of the diffusion process:

1. the brine waste conveyance in the outfall pipe;
2. its release in the sea through the diffuser;
3. primary dilution, which occurs in the so-called near field and depends primarily on discharge characteristics, such as the density difference between the concentrated brine and the seawater (the buoyancy flux), as well as on the momentum flux, the flow rate, the outfall geometry and the seabed depth;
4. natural dilution in the far field which is further away, considered as a result of the diffusion and mixing processes produced by the sea currents and waves, i.e. the environmental conditions and turbulence.

As integral part of the diffusion process, it muts be mentioned in the lead the seawater desalination treatment, which will not be analyzed in this work. However, it is important to rememeber that nowadays two desalination processes are prevailing: the so-called multistage flash distillation (MSF) and the reverse osmosis (RO) making up about 89% of the total capacity (Glade, 2005). A sharp distinction in brine volume exists between the two desalination processes. RO plants have a conversion ratio from 20 to 50%, while MSF plants have lower recovery rates (10-20%) because of being additionally mixed with cooling water (Goebel, 2005). Thus, the effluent flow rate is 4-5 times higher for thermal desalination than for RO processes referring to the same amount of produced fresh water (Niepelt et al., 2008).

The rest of the aforementioned processes will be analysed later, following the direction of the movement of the brine (and then of the mix) within the system. All of the processes, which, in actuality, can be seen for any type of discharge, are analysed under the various aspects which characterize submerged outfalls: sanitary, construction, technological, environmental, managerial and, primarily, due to the professional background of the author, hydraulic.

A few practical mathematical modelling examples will be presented to support the planning of the brine outfall pipes carried out during the course of the research by the Department of Water Engineering and Chemistry at the Laboratory of Research and Experimentation for the Defence of the Coasts (LIC), both of which are affiliated with the Technical University of Bari, Italy.

The authors intention is to report on the state of the art in waste water discharge in general and brine waste in particular, without intending to offer a single solution to the many problems linked to such a complex issue. We would also like to underline that many of the size values cited in the following paper refer to Italian scientific and technical studies and, therefore, are closely correlated with the characteristics of the Mediterranean Sea as a repository body of water and the national regulations regarding discharges.

2. The sea ecosystem

To understand the impact of the possible alterations of the sea ecosystem as a result of the pollutants discharged into it, one must be familiar with its salient ecological characteristics. First of all, its considerable vastness, considering that about 70% of the earth's surface is covered with water; its depths, which are home to different animals and plant life at different depths; the continuity of its sections, in the face of variations of temperature, salinity and depth; and finally, its ionic neutrality, which makes it a chemical system with high buffering capacities, able to resist variations in pH and remain an alkaline environment.

Another determining factor in the life of the sea ecosystem is its currents which, with their different horizontal and vertical movements, help to mix the waters. There are various types of currents, depending on the marine weather conditions that cause them. There are currents caused by the tangential action of the wind on the surface of the sea; currents in the shallows caused by the wave movement; gradient currents caused by differences in horizontal pressure, which in turn are caused by changes in atmospheric pressure; tidal currents generated by the vertical movements of the marine surface, as a result of astronomical forces; and finally, density currents, caused by variations in the temperature and/or salinity of the water.

The sea is populated by an enormous quantity of biotic factors, for example microscopic animal and plant organisms which form plankton, invertebrates, vertebrates, algae and marine plants. The complexity of pelagic life, in number of species and variety in the food chain, depends on environmental factors, the most important of which are light and the salinity of the waters. In particular, the former determines a subdivision of seas and oceans in regions, with different environmental conditions and, therefore, different species of flora and fauna. The two most important regions are the photic region, which reaches 200 m below the surface and in which photosynthesis takes place, allowing flora to exist, and the pelagic region, below the photic region, where it is only possible to find fauna.

Considering the sea ecosystem as the final container for discharges has, for millennia, essentially been due to the size of the diluter-diluted relationship, which creates a means for dispersal of practically infinite capacity. In truth, its ability to self-purify is determined by the metabolic activity of bacteria, microscopic organisms which participate in the formation of plankton. If, however, the substances extraneous to the marine environment, but discharged into it, are of such a quality and quantity to counter the homeostatic power of the marine ecosystem and damage the cleansing power of its organisms, leading to a permanent alteration of the ecological parameters, the sea system can be defined as polluted.

With an extreme range of types of water pollutants from something as ubiquitous as waste heat to deathly chemicals, environmental strategies must obviously related to the substance to be disposed of. For example, the strategy of wide dispersal is suitable only for heat and natural organic materials, which are to be re-assimilated in the global ecosystem. Trace metals in small amounts and non-toxic compounds can be dispersed in large bodies of water if the resulting increases in the background concentrations are minimal, but the strategies of containment or prevention of the discharge of the pollutant is by far preferable for persistent organic chemicals as well as for trace metals.

The polluting agents not included in the processes of transformation of materials and energy which take place within the marine ecosystem, come from the land, the sea and the air. The polluting sources coming from the land can, in broad terms, be detected in the currents which very often transport a considerable quantity of pollutants spilled along river channels: direct cloacal sewage (not passed through a purification plant), civil, industrial and agricultural waste, brine discharged as waste in the desalination process, as well as the cooling waters of electrical power plants. There are also indirect discharges such as soil washout waters or the discharge of solid waste accumulated in the territory and purposely sunk in the sea (macro-pollution). Other sources of pollution that end up in the sea include combustible oils discharged from the petrol tanker washing and the accidental loss of hydrocarbons. Although these last are important and have a great impact on public opinion, accidental spills of hydrocarbons are only a small part of all discharges in the sea. In fact, most discharges are caused by routine operations, such as washing cisterns, discharge of ballast waters, sewage and bilge.

Therefore, pollutants can be released into the environment through point and non-point sources. A point source is the discharge from a structure that is specifically designed for the outflow of waste water, for example from some industrial process or municipal sewerage system. This kind of source has been the target of most of the laws and regulations for water pollution control. The accidental spill of oil from a ship and the release of radioactive wastes from a power plant can also be considered as point sources. On the other hand, non-point sources are defined as widely distributed points where pollutants are introduced into the hydrologic cycle. In such cases, water treatment is usually not feasible. Examples are the runoff of salts used for de-icing highways in winter, soil erosion, acid rainfall and street drainage.

Alterations to the ecosystem's state of health, due to an inferable type of wide-ranging pollutants, are chemical, physical and biological in nature. The chemical-physical characteristics of the sea that influence the self-purification processes are, for example, hydrodynamics, water volume, temperature, thermal stratification, salinity, type of substratum and clearness. The biological properties which play a role and influence these same self-purification processes even more strongly, as previously mentioned, are organisms such as bacteria and fungi, including heterotrophics, and planktonic algae (phytoplancton) and benthic algae (phytobenthos) among the autotrophics. The aforementioned properties act on the pollutants introduced into the marine environment with specific mechanisms, based on processes which take place during the self-purification of the sea system. These chemical-physical processes include reactions of chelation, neutralisation, salification, as well as phenomena of absorption, entrapment, dilution and dispersion. The aforementioned organisms, with their metabolism and mineralisation of the organic substance, define the biological processes essential for purification, together with the photosynthetic processes. In truth, these last mechanisms can paradoxically worsen the pollution of the marine ecosystem when the quantity of the organic substance is too great to be handled, causing phenomena of anoxia and, therefore, the death of the organisms.

The environmental damage that derives from the highly complex possibility of pollution of the recipient water body are at times irreparable, in part as a result of the duration of the repercussions. Thus, there can be:

- damages to natural marine resources, in particular the death of organisms due to eutrophication of the waters as a result of the excess of nutrients carried to the sea by fluvial and/or urban discharges;
- danger for public health, as a result of bathing in polluted waters, ingestion of contaminated raw shellfish, and, although to a lesser degree, the inhalation of sea spray in the presence of high microbial concentrations;

- degradation of recreational activities connected with sea bathing, as a result of aesthetic, but more importantly, hygienic damage;
- impairment of maritime activities, in primis fishing and mussel farming.

In particular, the desalination of sea water can have an impact on five basic environmental domains (Einav et al., 2002):

1. Use of the coastal strip, which instead of being destined exclusively for tourism and/or recreation is also used for industrial activity.
2. Impact on the aquifer. The increased salinity of coastal waters intensifies the problem of saline intrusion into the underground aquifers near the shoreline. A remedy to this potential effect of the discharge of salt waters on the coastal waterbed is the creation of longer pipes into the sea which carry the discharge farther out from the coast. Therefore, this is an intervention strictly linked to the planning stage of the discharge system.
3. Noise pollution, especially in the case of reverse osmosis, which requires high pressure pumps which often generate noise. To remedy this inconvenience it is a good rule to position the plants at the correct distance from inhabited areas.
4. Intense use of energy, which in truth has an indirect effect on the environment, causing, for example, an increase of atmospheric or thermal pollution.
5. The impact on the marine environment, essentially due to the discharge of brine in the sea, and its intensity depend on environmental factors and hydro-geological characteristics of the sea, such as currents, tides, temperature, bathymetry, salinity and density, as well as changes in them. The living organisms that populate the sea environment, both flora and fauna, suffer the greatest consequences. The main effects on the marine biota can be varied and are essentially related to the increase in the concentration of salt. Some animals and plants resist up to certain salinity values and even improve their productivity, while other species succumb in particular conditions. Generally, the larvae and young individuals, especially of invertebrates, are more sensitive than the adults to changes in salinity. Moreover, because of the presence of the brine discharge, fish migrate offshore, so endangering their chances of survival because of the longer distances covered and the wider and wilder marine environment. Hopner &Windelberg (1996) divide marine habitats into 15 different classes on the basis of their sensitivity to the effects of desalination plants. A possible model for the scale of sensitivity is the one formulated by d'Ozouville et al. (1981) on the occasion of the AMOCO CADIZ (Brittany, France) accident, in 1978. According to the hierarchy defined by d'Ozouville, the most appropriate sites for the construction of desalination plants are on the shores of the ocean, characterised by high energy capable of favouring mixing the waters, while he advises against discharging brine near rocks, where the presence of marine organisms and biota is very high. Particularly, the effect of brine on the marine environment is mainly evident in the vicinity of the discharge pipe, where its release creates a "salty desert". In fact, the high specific weight of the salt concentration and the presence of chemicals accumulated during the pre-treatment of the desalination processes, especially for reverse osmosis plants, necessitate brine mixing and increase the risk of potential damage to local flora and fauna. In addition, for desalination plants that use evaporation processes, the effects of temperature increase must also be considered.

With particular reference to dumping waters with a high concentration of salt from desalination plants into the sea, Talavera & Riuz (2001) have reported a specific evaluation of their environmental impact.

The treatment of all the parameters and mechanisms that determine the quality of water, presented in this paragraph, is indispensable when discussing discharges, since the correct location of the submerged outfalls and, above all the point of exit, a definition of the limits for tolerance of the discharge and an evaluation of its impact on the marine environment and the possible damage that it may receive, depend on the chemical-physical and biological characteristics of the recipient body of water. For example, it is not surprising that, in the planning stages, as a parameter of reference for the sizing of a discharge conduit for sewage, the colimetric index is used. This is a microbiological parameter that measures the quantity of bacteria and, specifically, total coliforms and fecal coliforms, estimating the MPN (Most Probale Number). Instead, for the planning of brine discharge conduits, the system is generally sized on the basis of technical data about the flow of the discharge of the desalination process of sea water. In addition to that flow, the brine discharge system can be sized taking into consideration the effluent, or, alternatively, the water that, for management reasons or possible anomalies, by-passes the desalination process. Therefore, besides the verification of the ordinary functioning of the system, the flow to be calculated can be the one which corresponds to the worst possible conditions, i.e. the by-pass of the entire flow of seawater at the entry to the desalination plant.

It is also necessary to consider the legal situation together with the biological criteria, which are aimed at regulating what enters a body of water, determining the acceptable limits needed to protect the water in general, and with the multidisciplinary research, carried out in concert with technicians and ecologists both during the phase of design and that of verification.

Veltri & Maiolo (1992) define two types of discharge acceptability criteria. One is an absolute standard, objectively simpler and more economical in terms of time and cost because it does not require particular and specific investigation of water quality through the acquisition of basic general data, and, therefore, assumes more restrictive standards. The other is a relative criterion, which sets variable limits for discharges on the basis of the quality of the recipient body of water and the destination for its use.

The law on the protection of waters and management of water resources in Europe is the EU Water Framework Directive 2000/60/CE. The goal of Directive 2000/60/CE is to institute a complete and shared European framework for the protection of superficial internal waters, transition waters, coastal and underground waters, underlining the concept of protection through the future objective of the reduction and elimination of discharges of dangerous substances. In particular, regarding the inspection of discharges, the combined approach of point and diffuse sources is indicated in Article 10 and is based on the contextual application of emissions and the best techniques available to check the pollution provoked by point sources (the discharges) and the application of controls and the best environmental practice to contrast the pollution from diffuse sources.

There is no specific law regarding the discharge of salty waters from desalinators located near the coastline. This is, perhaps, because the concentration of salt water, the brine, is considered to be a natural compound and not a pollutant. Unfortunately, these assumptions can not be confirmed in toto. In fact, brine is a liquid product with characteristics similar to seawater, but with approximately double the salt concentration. However, what renders the discharged waters more polluting is the presence of possible chemical products used in the phases of desalinating the seawater, especially in systems using reverse osmosis (Morton et al., 1996). In the case of plants that use the principle of evaporation, account must also be made of their higher temperature (for example, see the study by Anschutz et al., 1999).

3. Outfull pipes

The most important examples of submerged outfall pipes were built from the 1930s onward, like, for example, the cast iron conduit with flexible joints laid in 1930 to cross the New Orleans ship canal. The types, sizes and number of these projects increased rapidly over time, passing from siphons for crossing natural waterways to aqueducts to supply water to islands, to large gas and oil pipelines, conduits for capturing and releasing cooling waters for thermal power plants and industries, and on to the discharge pipes for brine from desalination plants, which we are discussing here.
The sizing of an outfall pipe is done keeping in mind all the factors which condition its functioning. In general, for the choice of the course, the length of the conduit, the depth of the discharge and the characteristics of its ending section, generally made of a diffuser, it is important to consider the morphology of the seabed, the biotics present and the sea weather characteristics of the area concerned. The evaluation of the location is additionally linked to an analysis of possible damage to the marine ecosystem (see considerations made in paragraph 1). Near the seabed the sea is least able to dilute pollutants, as will be further discussed later and defined as "initial dilution", this creates an even greater risk to marine life considering that this zone is ecologically richer. This area is at risk for the sedimentation of the substances transported by the effluent in the conduit. For this reason, it is necessary to carry out a correct analysis, particularly a biological analysis, of the seabed before choosing the point of outlet. During the design phase, the study of the plant component (phytobenthos) can be carried out with the "synecological" method (study of the community), which is performed directly in loco by researcher-divers, and in special cases of the suspected introduction of toxic substances, with the "autoecological" method (study of single organisms), slower than the first since it requires a laboratory for the analysis of samples. The detailed study of the course also requires the study of bathymetric profiles, the lateral configuration of the seabed, the consistency of the seabed's superficial strata, obtainable with surface echosounders used by a swimmer, or by direct observation submarines. All of the above serves to further identify the characteristics of the possible location for the conduit, like, for example, possibly uneven surfaces or the impossibility to build an underground trench.
For a coastal area characterised by an assigned bathymetry, an assigned sea weather climate and an assigned chemical-physical water regime, the correct length for the outfall pipe depends on the other fundamental fact for planning, the effluent flow, maximum and minimum, to be transported far from the seashore, or rather, on the number of inhabitants served, for sewage discharges.
The choice of the diameter of the submerged discharge conduit is made using economic criteria, which take into consideration the cost of supply and laying the conduit in the sea, the capitalisation of the annual energy expenditure, and the expenditure necessary for the acquisition and installation of the electrical pumps.
The design of an outfall pipe requires a series of calculations aimed at determining the project's minimum construction requirements. Among these, the sizing of the conduit is of fundamental importance, as is the resulting definition of the thickness of its walls. Considering that the diameter of a pressurised pipe linked to its functional and hydraulic requirements and, therefore, known a priori, the construction requirements for the conduit are the following:

- the state of the circumferential stress caused by the internal design pressure must be less than the limit established by the applicable law;

- the condition of sectional collapse as a result of the external pressure must coincide, as much as possible, with the maximum acceptable combined state of stress, established by the applicable law.

Note that while the first requirement is essentially related to safety, the second tends to optimise the use of materials, avoiding redundancy in the less critical condition of collapse. However, the choice of the diameter depends primarily on economic criteria, which consider for example the cost of the pipe supply and laying in the sea, and the cost for the purchase and the installation of the electro-pumps.

Of great importance is the evaluation of the type of material to be adopted for the outfall pipe because not only do the conduits determine the velocity of effluence and, above all, the laying procedure and, therefore, the impact on the biotics, but they also determine the duration of the project itself. After shrewd application of interior and exterior surface protection against the chemical aggressions of the sea and the effluent, steel discharge conduits are generally preferred given the fact that they are heavier than the other materials commonly used. Keep in mind that protection carried out with cement mortar casings, if of the passive type, or induction currents and zinc or graphite anodes, if of the active type, increase the costs of the conduits, but, at the same time, render them technologically competitive on the market. There are still some problems for small to average sized pipes because the restoration of the continuity of internal protection near soldered joints is unfeasible. In cases like this, it is a good idea to provide for steel tubes with rapid socket joints and elastic gaskets. In the past, cast iron tubes were very commonly used. Their limited mechanical resistance and extreme fragility was improved with the introduction of spheroidal cast iron, while in the specific case of discharge, conduits were protected internally with cement plaster and weighed down with an external casing in reinforced concrete. The use of plastic materials, like, for example, high density polyethylene (PEAD), has shown itself to be particularly competitive over time for medium-small diameter conduits. PEAD is known for its resistance to the aggressiveness of the marine environment and the transport of fluids, for its lack of roughness, for its flexibility and lightness which facilitate moving it on land and at sea while laying it. However, because of this material's lightness, ballast is necessary, for example with flexible materials, with cast iron collars, with concrete rings, and, to further protect the pipes from the action of the waves, these conduits are generally buried in special trenches. If that is impossible due to the nature of the seabed, the conduit is encompassed in a concrete box. Reinforced polyester with fibreglass (PRFV) is one of the most recent materials to be developed. It is used for tubes of large diameter, and is of better quality than PEAD. It is particularly heavy, so it does not need ballast. It is, however, always a good idea to bury these tubes in special trenches to protect them from the action of the waves and currents.

The cost of the material is, actually, less than that of the installation of the pipelines and, therefore, the choice falls to the material that is easiest to install. The criteria for the choice of methods of launching and laying the tubes depend on local situations, on the depth to be reached, on the type of seabed, on the material the conduit is made of and the type of joints, as well as the type of protection planned for the tubes (Figs. 1-2). Generally, flexible tubes with limited diameters are laid down with techniques derived from those used for deepsea cables. For rigid pipes, instead, the procedure for launching can be divided into three categories: the pull on the seabed, the pull of floating pipe and, finally, the launching of the pontoon with various methods.

Fig. 1. Launch of a submerged pipe with junction in the sea.

Fig. 2. Launch of a submerged methan pipe. The buoys along the launched lenght are in full view.

Following the various evaluations that must be made during the design phase of an outfall pipe, like the identification of the best plan and the choice of the safest and most economic solution from the engineering and technical point of view, it is necessary to carry out a series of verifications regarding stability, structural resistance and preservation over time of the initial conditions. The most common stresses that conduits are subject to are generally due to the following causes:

- chemical aggressions, external (sea environment) and internal (transported fluid);
- biological activity (living organisms);
- mechanical actions (wave and current movement, local phenomena of erosion);
- fishing activities (especially in the area around the diffusers).

A great number of types of protection exist to defend outfall pipelines on the seabed from these risk factors, if necessary following those already provided for the tubes before their launching. The most effective type of protection remains that of burial in a trench, as previously mentioned, with adequate coverage.

Continual monitoring, from the various phases of construction up to the phase of use of the conduits, is indispensable for guaranteeing a long life, and now easier than ever thanks to modern inspection techniques.

4. Diffusers

The ending point of an outfall pipe is generally made of a diffuser, also called a distributor, which plays a fundamental role in the functioning of the entire discharge system. In fact, the job of this device is to separate the effluent fluid to be disposed of in the marine environment into several jets, so as to favour the process of dilution which then takes place in the sea, and to reduce local phenomena of turbidity and deoxygenation.

The diffuser usually consists of sections of tubing of declining size, which at times are subdivided into two parallel sections to form a Y, but which still have a cross-section larger than the sum of the areas of all the openings present on the lateral surface. These openings, called nozzles, are positioned in alignment along a single generatrix (generally the upper one), or in two symmetrical generatrices, so that the jets of at least one row shoot up in the direction of the undersea current, which at times is reversed in comparison with the dominant one. These are then oriented in such a way as to make the jet shoot up vertically, slightly inclined off the vertical, or horizontally. This last example is often used for the disposal of effluent from urban treatment plants, to create curved density jets, which tend to rise to the surface in longer trajectories and, so, favour dilution. An excellent treatment of the various types of diffusers (Fig. 3) was made by Jirka & Akar (1991).

Regarding the arrangement of the diffusers in the design, to make sure that the dominating marine currents exercise a correct dispersion of the effluent in the recipient water body, the diffuser is generally placed orthogonally to them, as well as to the nearby coast. Instead, in a situation where there is no prevalent direction of the dominating current, the aforementioned Y-shaped diffusers are used.

Generally, a single diameter d is assigned to the n nozzles, so as, so as to evenly divide the overall flow and guarantee the correct functioning of the full section, in order to avoid the intrusion of seawater into the tubes. It is advisable to contain the diameter of the nozzles to favour the initial dilution, but within certain limits to avoid occlusion due to marine deposits.

In truth, at times it is possible to carry out a premixing process in which the seawater is pulled into the end section of the diffuser on purpose. In this way, there are two dissimilar effluents, the tout court fluid discharge and the premixeddischarge, which is denser than the first and in part already undergoes a type of dilution in the conduit. Experiments have shown that the beneficial effects on the initial dilution provided by this methodology are minimal and, in any case, not comparable with the negative effects, like the less effective functioning of some nozzles, the entry of marine organisms and the deposit of solid substances which increase the roughness of the tubes.

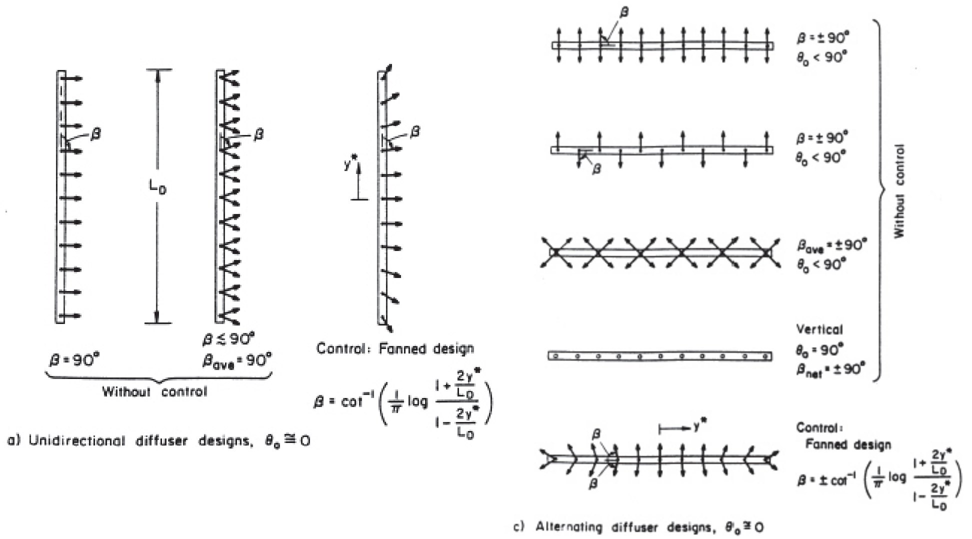

Fig. 3. Different types of unidirectional (left) and alternating (right) diffusers.

The hydraulic load at the exit point of an outfall pipe is not equal to the head *H*, but considering the contracted section of the effluent of density ρ_0 greater or lesser than the density of the sea ρ_a, depending on the type of discharge, the relative piezometric level is superior to the hydrostatic level *H* of a quantity $H' = H(\rho_a - \rho_0)/\rho_0$, having placed the balance of the pressures inside and outside the edge of the same section. In general, it can be assumed that the load does not vary before and after each single opening, so, ignoring the kinetic height, it is possible to obtain the simplified expression of the piezometric difference along the entire diffuser, by means of an iterative calculation. The increase of the load (increase of the piezometric level) at one point and before the same point can be seen as a way of indicating conditions of anomalous circulation in the whole system, due to the entry of seawater in the final nozzles of the diffuser. Another way to proceed is to attribute to the kinetic load in the orifices 10-20% of the available difference in gravity systems, or of the overall dissipated load (difference plus prevalence of the pump) in the case of pumping systems.

An important aspect of the sizing of a diffuser lies in considering the dilution of the first phase *Si* to be a fundamental parameter, which will be covered in detail in the following section, to which is assigned a prefixed value defined as "acceptable" on the basis of the characteristics required both by the seawater near the diffuser and by the inshore water. Besides this parameter, other sizes come into play in the sizing of the diffuser, such as the total discharge load, a component of the cross current and the difference of density between seawater and effluent. Once these measures have been designated as project data, together with the velocity of effluent from the diffuser, it is possible to determine the length of the diffuser as well as the diameter and arrangement of the openings which guarantee the prescribed value of dilution *Si*. In principle, if greater dilution is desired, the length of the diffuser should be increased instead of increasing the velocity of effluent, so that the distance between the nozzles is great enough to guarantee reciprocal contact at the lower border of the mixing field

In any case, during the design phase it is important to anticipate an effluent velocity V_0 of at least 0.6- 0.8 m/s, to guarantee the self-cleaning of the diffuser and annul the possibility of deposits, but, above all, to ensure a value of the densimetric Froude number:

$$F = \frac{V_0}{\sqrt{\frac{\rho_a - \rho_0}{\rho_0} gd}} \tag{1}$$

much greater than the unit, since the initial dilution along the jet depends on this. The latter is defined as:

$$Si = \frac{\rho_0 - \rho_a}{\rho - \rho_a} \tag{2}$$

in which ρ_0, ρ and ρ_a represent respectively the densities of the effluent in the effluent section, in the generic section of the jet, and of the sea, which generally must be superior to 60-80. To avoid the erosion of the submerged outfall pipe, it is also a good idea to guarantee a maximum value of the velocity of effluence for the single nozzles, no greater than 2.5 m/s. Equally important is that the jets not interfere with each other during their upward flow, which takes place at a short distance from the discharge. To do this, the interaxis distance between the nozzles is generally equal to one third of the trajectory, which is usually considered as equal to three quarters of the head *H*.

To end the specific discussion of the hydraulic design of diffusers, it is worth reasserting the importance of the verification of their functioning with timely monitoring techniques, and at times even to compensate for possible design errors. In truth, an issue presented by the installation of these devices is that, differently from the existing conduits, these can not be protected with trenches; since they lack any coverage for the tubes they need adequate protection from fishing activities. For example, in the case of a spill of effluents rich in substances nutritious for fish species, the zone around the diffuser becomes an attractive site for fishing boats, which can cause serious damage to the diffusers with their anchors and trawl nets. Expedients aimed at protecting the outlet can be of the passive type, like signal buoys and steel nets around the diffuser, and of the active type, like concrete blocks equipped with hooks to break fishing nets.

5. Diffusion and dilution processes

The subject of diffusion, interpreted as “turbulent transport associated with dilution,” is a highly complex topic and has a consolidated history in terms of research and both theoretical and experimental analysis. The term dilution, first expressed in (2), can be considered as the reduction of the concentration, in comparison with the initial concentration, of a specific effluent introduced into a recipient body of water. In truth, in the literature there are a series of formulas with which to identify the total dilution of a generic discharge, which depends essentially on the various phases in which the process itself can be divided, namely:

1. first phase or initial dilution, near the outlet into the marine environment;
2. second phase or following dilution, in proximity to the free surfaces.

The two phases take place in two distinct zones. In particular, the first happens in the so-called near field, it has a prevalently vertical development in which transport and mixing depend on the intensive magnitude in correspondence to the exit outlet (density, velocity of the fluid and turbulence index). Instead, the second phase takes place in the far field, in a practically horizontal direction, along which transport and mixing depend on the surrounding movement field (e.g. sea, wind and density currents) and on the characteristics parameters of the discharge (flow rate, average dilution). In the particular case of sewage discharge, a third phase must be taken into consideration, that of bacterial decline, which takes place at the end in the far field, and which will not be treated in this paper.

The various density differences between the effluent and the receiving water represented by the buoyancy flux causes different flow characteristics of the discharge. When the waste water density is higher than the sea water density, the dense effluent flow has the tendency to fall as negatively buoyant plume. In the contrary case, the effluent is distinguished by a neutral to positive buoyant flux causing the plume to rise. Figure 4 illustrates the typical behaviour of positively or negatively buoyant jets discharging into the receiving water through a submerged single port, for the particular case of brine discharge. The same Figure 4 underline also the different behaviour of the salt buoyant jet depending on the desalination processes from which it comes.

Hereafter, a detailed analysis will be made of the phenomenon of dilution, starting with the first phase, during which the aforementioned process of diffusion takes place. The current that carries up the effluent dumped into the sea, which has a different density than the sea itself, is indicated with the term buoyant jet, because this fluid dynamic structure has all of the characteristics of the current itself. In the exit section a zone, called zone of flow establishment (ZFE), is created. It contains a conical nucleus with constant density and velocity and is the starting point for the jet's turbulence structure. Then there is the so-called zone of established flow (ZEF), in which the field of turbulent flow reaches the axis of the jet and the velocity and concentration (the inverse of the dilution) diagrams assume the typically Gaussian flow, with decreasing values both from the axis of the jet towards the periphery and along the axis itself, as the distance from the source increases. A reference parameter for the identification of these two jet development zones is the densimetric

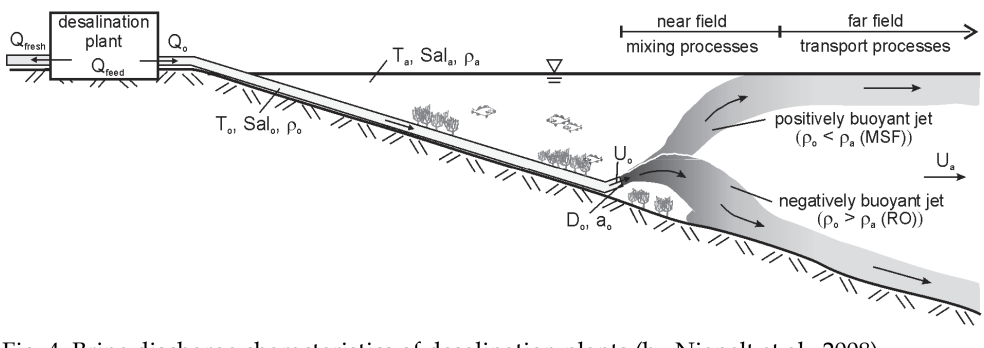

Fig. 4. Brine discharge characteristics of desalination plants (by Niepelt et al., 2008).

Froude number F defined in (1), which represents the relationship between the forces of inertia and the forces of buoyancy.
Using this parameter, it is also possible to formulate the initial dilution:

$$Si = Si\ (F', z/d') \tag{3}$$

where F' is the Froude number referring to the contracted section of diameter $d' = 0.61d$, where d is the diameter of the single nozzles, and z is the depth. In the preceding section, the importance of the determination of the initial dilution, in its acceptable value, was highlighted as being indispensable, for example, for the sizing of the diffuser. It was also pointed out that the initial dilution increases with the increase in the number of orifices that the diffuser has, as long as the distance between them is great enough to guarantee that the jets do not overlap, which would, on the contrary, reduce its dilution.
The active forces which push the jet to rise through the overlying seawater are the momentum flux at the outlet, and the buoyancy flux due to the difference of density between effluent and sea. In its permanently delayed movement, the sea water is pulled into the jet, thus expanding it. This process is known as entrainment, which Pedersen (1986) defines as "the diffusion of a fluid characterised by a field of turbulent flow within an environmental fluid in nonturbulent flow." Therefore, in conditions of dynamic equilibrium, the forces of inertia and buoyancy are opposed by the resisting forces which act on the surface of separation between the jet and the recipient body of water and are the cause of elevated velocity gradients in the directions transversal to the main flow. This causes, in part because of the effect of the density gradient, coherent hydrodynamic structures, or toroidal vortexes which transport heat, momentum flux and mass, and, therefore, favour the diffusion of the effluent in the surrounding marine environment and the intrusion of seawater into the jet. Their presence was detected by the analysis of velocity surveys carried out in both recent and past experimental laboratory models, with both pioneering and advanced measuring techniques.
All researchers agree that the conditions of flow in the marine environment and the turbulent agitation in the initial section of the jet favour diffusion considerably, although for this last aspect it is difficult to quantify the turbulence intensity which, clearly, depends fundamentally on the form of the nozzles. There is a series of recent studies on the effect of turbulence on the diffusion process of the jet. One of particular interest, for its use of various approaches, is by Malcangio (2004).
Then, the presence of seasonal effects must be pointed out: for example, in the summer, since the temperature of deep seawater is lower than the surface temperature, the gradient of negative density is enhanced along the vertical, which is generally always present. In such circumstances, the jet, which during its upward rise varies in density due to the effect of progressive dilution, can remain entrapped under the thermocline, and be unable to reach the surface, since the structure of the jet deteriorates in a formless cloud of increasingly large volume. Often this phenomenon is considered desirable, as it makes it possible to obviate the impairment of qualitative standards linked to aesthetic factors, as in the case of sewage effluent.
For more details on jets, consult for example the pioneering work of Rajaratnam (1976), Fisher et al. (1979), Papanicolau & List (1988), as well as the vast literature by Abraham (e.g. 1960, 1963, 1965).
As the jet moves away from the nozzle, the cloud of effluent, which we will now call "mix," expands horizontally and tends to dissipate as a result of the dilution of the second phase,

Ss. This dilution takes place thanks to sea weather agents which are often unrecognised, and so are presented as a complex mixed process. They are of a small entity in comparison with the initial phase, but nonetheless can not be neglected. In terms of size, this process can be expressed in the relationship:

$$Ss = Ss\ (\beta,\ x/b) \tag{4}$$

in which β is the opening angle of the sewage plume, expressed as:

$$\beta = \frac{12 \cdot \varepsilon}{U \cdot b} \tag{5}$$

where ε is the coefficient of turbulent diffusivity computable through experimental interpretations, U the current velocity, b the diffuser length, while x represents the horizontal x-axis evaluated in the direction of the flow hypothesised as the normal axis of the diffuser.

Keeping in mind that in the sea the action of the currents generated a continual exchange of seawater mixed with the discharge, the mixing field above the diffuser assumes a thickness of h so that

$$Q\ Ss = U\ cos\alpha\ \ h\ b \tag{6}$$

where Q is the overall flow rate of the effluent exiting from the diffuser, Ss the dilution at the entry of the accumulation cloud created over the discharge, $Ucos\alpha$ is the velocity of the current in the direction parallel to the axis of the diffuser and b is the length of the diffuser itself. This formula makes it possible to verify the risk of nutrient accumulation and, as a consequence, the rise of eutrophic processes as a result of an insufficient exchange of the recipient water mass. Therefore, it is wise to make reference to the maximum discharge of effluent introduced by the diffuser into the marine environment and the minimum current velocity. Note, however, that the conditions which are created between the effluent cloud rate and that removed by the currents are not stationary, since the cloud tends to gradually increase in thickness and concentration with a reduction of the intensity of currents or an increase in the discharge, and viceversa.

Therefore, transport to the far field is essentially due to sea weather agents, such as currents and wave motion, as well as the different density between effluent fluid and the recipient water body. Also in this phase of dilution there is turbulent agitation of the fluid mix and, therefore, a highly complex process is generated which has a strong influence on the quality of inshore waters.

In the literature there are various mathematical expressions of the various phases of dilution, and, in general, the overall dilution is indirectly evaluated as their product. However, it is always important to consider individually the various phases which the process of dilution is divided into, their singularity and specificity should never be forgotten if the goal is to obtain a complete, well-structured result in the analysis of the global conduit-distributor-sea system.

A different approach that can be adopted for the analysis and anticipation of discharge transport and dilution phenomena in the sea uses mathematical models which make it possible to resolve the equations that govern these phenomena numerically. As a result of the complexity of a process as composite as dilution, both in the near and far fields, there is a tendency to use zone models, which examine the single processes on a more local scale. For matters in the near field, reference is made to the traditional mathematical and experimental type of formulation, described in the same section, which supply the initial dilution and, therefore, the distribution of the concentration of the effluent, which in this phase assumes the structure of a buoyant jet. Regarding the phenomena of the far field, often a coincidence can be found between the reference equations and those that govern any hydraulic phenomenon, which are the classic Navier Stokes equations. In truth, these equations lack a specific identification with the particularity of the phenomenon of circulation of pollutants in coastal waters. The results obtained are, actually, quite far from being a real answer to the prediction of phenomena of transport and diffusion, if they are not accompanied by a physical comprehension of the mechanisms of coastal circulation, characterised by time-space scales which are quite various and complex. These mechanisms, which supply any numerical model with the boundary conditions, together with an adequate experimental basis, are able to render a numerical simulation able to understand the fundamental characteristics of the physical issues at play. For this reason, along with the traditional equations of Navier Stokes and of continuity, which express the principle of the conservation of the momentim and mass which govern flow, it is also important to take into consideration the equations which express transport, descriptive of the advective and dispersive processes, and the biochemical equations which consider chemical and biological factors which reduce the mass of the polluting mix.

The resolution of such a mass of equations, both when they are adopted in their complete forms and when simplifications are allowed, is possible with diagrams of numerical integration, to finite differences or to finished elements, together with the definition of the boundary conditions. It is fundamental to underline the importance of thorough field survey to correctly validate the simulation models of the diffusion of pollutants in the sea, as well as the estimation of the physical parameters of the simplified models, such as the density of the effluent and the recipient body, the drift velocity of the current, and the dispersion coefficient.

Applicable examples of mathematical models of the dispersion into the sea of brine discharge from desalination plants are shown in section 7.

6. Wave motion and current effects on dilution

The realistic situation facing any fluid introduced by an outfall pipeline into the marine environment includes the presence of currents in the recipient water body. Setting aside the effect of the hydrodynamic actions wielded by the flow fields on the discharge conduit, in this paper we will simply underline the effect that the currents and waves have on the process of diluting the solute. Regarding this, as mentioned in the previous section, the diffusion phenomena are increased by the presence of these motions, therefore in the hydraulic design of the pipe and the diffuser a condition of calm sea or weak superficial currents should be considered a cautionary situation. Instead, in the definition of the position and depth of the conduit and the diffuser it is very important to take into consideration the flow and the currents; the flow so as to position the diffuser far enough offshore from the area of the reefs, and the currents to ensure that the prevalent direction of diffusion be toward the open sea.

Speaking of currents, the following is a classification of types, on the basis of what causes them:

- convection currents, due to differences in density and only found in particular conditions in large basins like the Mediterranean, which in turn generate coastal currents;
- drift currents, determined directly by the action of the wind, which moves the surface strata of liquids in the same direction, also creating an action of uplift which is accompanied by ebb currents;
- compensation currents, generated by the encounter of a marine current with the shoreline and everything that makes it not uniform;
- tide currents, due, as the name itself indicates, to the effect of the tide, generally reduced in closed basins, like for example the Mediterranean.

Currents and wind work, in particular on the medium-term effects, due for example to the introduction of hydrocarbons, oils and fats, heavy metals, differently than on the short-term localised effects around the point of the introduction of the waste. To correctly be able to evaluate the effect of currents on hydrodynamic dispersion in the far field it is important to identify the resultant of the velocity vector in direction and intensity. There are different measurement techniques, which can be distinguished essentially by the depth to which they refer. For surface measurements, buoyant bodies are left to drift on the surface and, today, also equipped with sensors that indicate their position, like modern equipped buoys, while for deep measurements current meters are generally used.

Additionally, it is necessary to make a distinction between currents depending on the depth at which they take place. Therefore, there are submarine currents, to be enumerated in the group of convection currents since they are due to variations in density, which distribute themselves parallel to the coast and can be considered useful for the phenomenon of dilution because of their diluting effect on spilled wastewater, and there are surface currents, due, above all, to the wind, which instead can play a harmful role if they carry back to shore a mix that has not yet been completely diluted.

The beneficial effect of currents on the diffusion of discharges in the sea is well known in the literature. A valid example is seen in the experiences of Platten & Keffer (1968), who arrived at the important conclusion that intrusion, as defined in the preceding section, from the (vertical) jets introduced into a fluid field in flow in a direction transversal (horizontal) to their axis, is one order larger in size than jets in still water. When considering a uniform current directed in the same direction as the jet (horizontal), Lee & Nerville-Jones (1987) propose two different expressions for initial dilution, depending of the prevalence of the effect of buoyancy on the effect of the current, and viceversa. In the first case:

$$Si = k_1 (A/d)^{5/3} F^{-1/3} \tag{7}$$

where k_1 = 0.36, and where A represents the greatest height of plume rise, while in the second situation the result is:

$$Si = k_2 (A/d)^{5/3} F''/F \tag{8}$$

where F'' is the Froude number relative to the current velocity. It has been seen experimentally that with these expressions, and in special conditions, values of initial dilution that are 3 to 5 times greater than those corresponding to the condition of a calm fluid environment can be obtained.

Let us now focus on the effect of the wave flow field of the fluid environment on the phenomena of diffusion of the waste dumped into it. In these conditions, the process of the mixing and diffusion of the solutes benefits from a considerable advantage, as Chin (1987) also affirms, "waves are almost always present in oceans and seas, a proper consideration of their beneficial effect in the dilution of underwater discharges can serve for design economy."

To identify a subsector of reference of origin for the characteristics of the wave flow which transfers the inshore energy contents, it is necessary to carry out an analysis of the frequencies of occurrence and the classification of the sea weather events which have historically happened during the period of observation and in the area being studied. This analysis is fundamental, for example, in the choice of the planimetric device for the outfall pipes, in those cases where it is impossible, because of the geological nature of the seabed, to completely bury them. Therefore, it is advisable to place the axis of the pipe parallel to the maximum nodal incidence of the wave motion, so as to offer it the section of least resistance. As a result of the increasing deformation and rotation of the front closer to the shallows, it is indeed preferable to provide the conduit with a planimetric layout that varies with the depth, according to the evolution of the orthogonals to the wavefront.

In truth, the effect of the wave motion does not always manifest itself for the entire depth of the recipient body of water. This depends, according to Airy's theory, on parameters such as the measured depth in comparison with the average level of the calm sea h and the wavelength L, therefore leading to the following cases:

- $h/L>0.5$ refers to deep waters, in which the effect of the wave flow extends to the depth of $L/2 < h$;
- $0.05<h/L<0.5$ refers to intermediate waters, in which the effect of the wave extends for the entire depth but with variable intensity;
- $h/L<0.05$ refers to shallow waters, in which the effect of the wave motion extends for the entire depth but uniformly.

Although Chyan &Hwung (1993) showed scant knowledge of the action of the wave motion on the diffusion of the jets, in contrast with a rich literature on discharges in the sea with regards to the processes of intrusion and interaction with the currents, Ger (1979) and Chin (1987) had already experimentally demonstrated that wave allows for the improvement of dilution of the solute transported by a jet. Therefore, consider a horizontal jet introduced into a recipient water body in the presence of a monochromatic wave motion. The initial dilution that it undergoes can be expressed by means of the following functional relationship:

$$Si = f\,(d, V_0, g', h', \theta, a, T, L) \tag{9}$$

where V_0 is the exit velocity of the jet, g' is the acceleration of reduced gravity defined as

$$g' = \frac{\rho_a - \rho_0}{\rho_0} g; \tag{10}$$

h' is the depth of the seabed in correspondence with the plume, θ is the angle between the exit direction of the jet and the propagation direction of waves, finally, a, T and L respectively represent the amplitude, period and length of the wave. Following the criteria of adimensionalisation proposed by Chin (1987), by means of following simplifications which allow for the grouping of the quantities indicated in (9) they are rendered adimensional, the author goes so far as to represent the physical process of average dilution Si on the surface of a horizontal jet of a solution of set initial density and velocity, introduced into a field of wave motion, by means of the following relationship:

$$\frac{S_i}{S_0} = 1 + 6.15\left(\frac{L_Q}{Z_M}\right). \tag{11}$$

In (11), *Si* represents the average surface dilution in the case of a calm recipient water body, L_Q the distance starting from the nozzle beyond which the port has an effect on the flow and Z_M the distance from the nozzle beyond which the wave flow prevails over the initial momentum in jet behaviour. Following his experiments, Chin (1987) observed that, as a global result of the interaction between the wave flow field and the jet, there is a spraying effect at the level of the nozzle and an oscillating movement during the rising phase (Mossa & Petrillo, 2001; Mossa 2004). Other experiments were carried out analogously (e.g. Fischer et al., 1979), and all reached the conclusion that the presence of a wave flow field determines initially greater dilution values, even doubled, in comparison with those of calm in the surrounding fluid.

7. Mathematical modelling case studies

The results obtained by means of the theoretical analysis of the dilution in the sea of a brine discharge coming from a desalination plant are effective for a comparison with those obtained from mathematical models. The result of this comparison has often been positive, thereby it would seem profitable to join theoretical studies with both mathematical and experimental analyses. In this paragraph two practical applications of relative mathematical models will be briefly illustrated, already seen elsewhere (Malcangio & Petrillo, 2009; Malcangio & Petrillo, 2010), both carried out at the Department of Water Engineering and Chemistry at the Technical University of Bari, Italy. Both the area under investigation are environmentally vulnerable because of their dryness and lack of natural watercourses. Therefore, underground water resources have been intensely exploited to meet the growing demand for water, in particular through extraction from wells. Moreover, as the replenishment of the aquifer is very low due to the shortage of rainfall, coastal areas of South Italy face the critical problems of seawater intrusion.

Considering the first case study (Malcangio & Petrillo, 2009), in order to avoid the aforementioned problems of water lack, a coastal desalination plant has been planned in a coastal zone in Brindisi, southern Italy, and not constructed yet. One special feature of the seabed concerned is that of the presence of a protected vegetative species, the oceanic Posidonia, which is an endemic plant that forms prairies of Posidonia, also called seaweed fields (although they are not formed by seaweed). This prairies are the most important ecosystem of the Mediterranean, equivalent to forests in land ecosystems, as they are also a great source of biodiversity being the habitat of numerous vegetable and animal species, some of which are in danger of extinction. Figure 5 shows a map of the existing biocoenosis and a preliminary overview of the intake and outfall pipe location in the area under assessment.

The initial part of the study focused on the hydrodynamics of this area, and then on the current generated by several environmental factors (wind, tide, etc.) and simulated by mean a 3D mathematical model. Then, the virtual brine discharge was implemented by the same commercial code as a punctual salt source for several simulations, and the resulting spread of the brine plume at different layers were analyzed. The aim of this work was to find both the most suitable position and length of the brine outfall pipe in order to minimize the

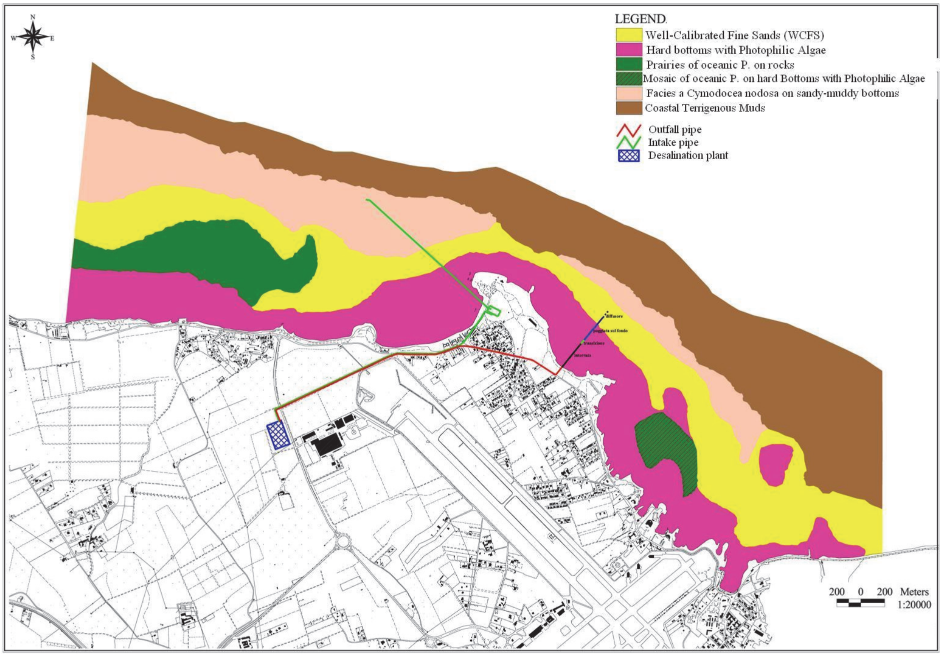

Fig. 5. Biocoenosis of the area under study and preliminary identification of the desalination intake and outfall pipes site.

impact of salt concentration release on the protected flora species in the area. The results of the simulations allowed the authors to conclude that between the two simulated project hypotheses for the outfall pipe length (605m and 770m), the best choice would be that of the shorter pipe taking into account both environmental and economic considerations.

As second test case, the authors analyzed the optimal site for an outfall pipe originating from a seawater desalination plant in Bari, South Italy, at the planning stage (Malcangio & Petrillo, 2010). As in the previous case, the study focused on the dilution of the system brine discharge in the sea determined by a punctual salt source, considering the salinity as a tracer in recognizing the brine discharge path. The same 3D mathematical model, which was utilized in the former work here summarized and previously calibrated in the same zone of interest by a measurement survey, was used to simulate brine dilution in the sea. Several simulations in barotropic conditions were performed, in order to test the interaction of the real variation in wind direction and intensity on the dilution of the brine discharge, and more importantly the best location for the brine outfall with the least environmental impact for wildlife, particularly in an area which has already been damaged by the presence of treated waste water disposal.

In Figure 6a the salinity map obtained for the test which simulated the single treated waste water and the real situation typical in a mean annual range is plotted, together with the salinity maps achieved at the end of runs where the same meteo-climatic conditions were simulated but with the added detail of brine outfall, 60m (fig. 6b) and 30m distant respectively (fig. 6c). Qualitatively, it can be deduced from their comparisons that the planning choice to locate a brine outfall pipe close to the real outfall pipe for treated waste water is environmentally more suitable than the more economically favorable option which would place the brine outfall in front of the desalination plant and about 1330m from the other outfall pipe. But which distance between 60m and 30m is not so evident.

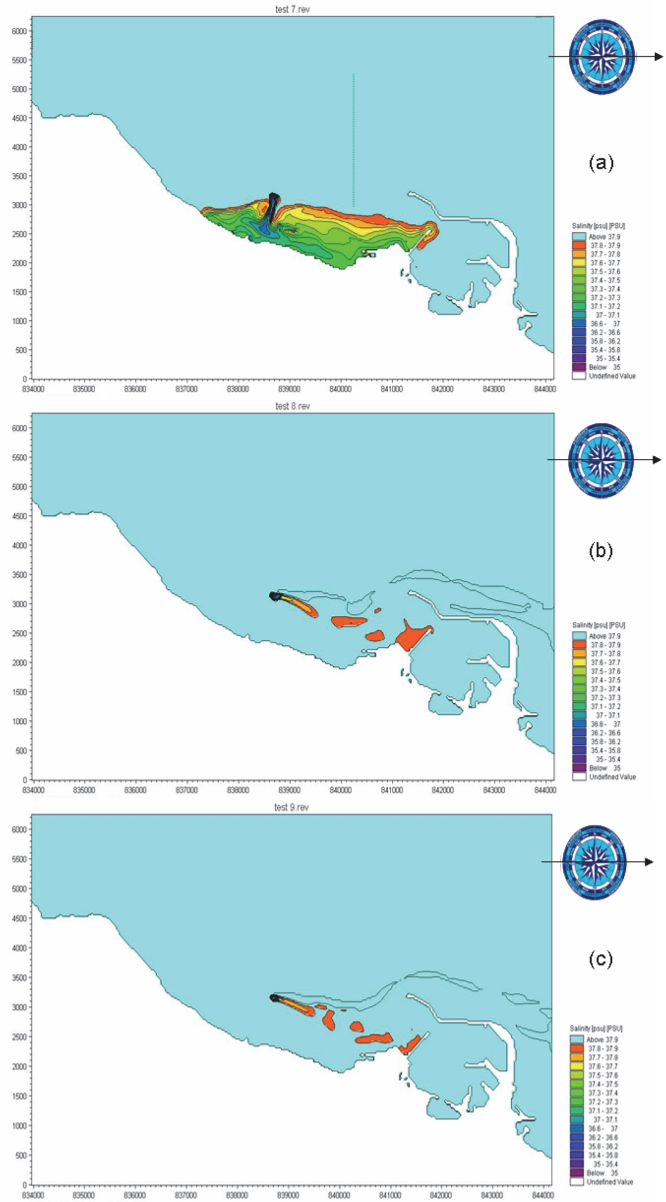

Fig. 6. Superficial salinity map (a) when the single treated waste water release is simulated, (b) with the further contribution of the brine outfall, far 60m and (c) 30m.

8. Conclusion

Protection of the marine ecosystem is one of the main environmental issues of our times. In fact, it is a common practice to subject bodies of water to the constant introduction of discharges, many of which are polluting in nature. In the field of water resource management, to protect means, above all, to know, where knowing refers to a process that, beyond the simple acquisition of data, includes gathering them, interpreting them, but, above all, using data to identify problems and interventions to be undertaken on a short timescale both in the ecosystem under observation and in those that interface with it. All of this is done while taking into consideration the aquatic ecosystem (water, sediment and biotics) and not just the water alone, trying to intersect chemical, physical and biological parameters so as to determine the ecological state of bodies of water, dictating precise rules for the development of monitoring.

In truth, to truly protect the marine environment prevention must prevent first, and therefore, taking into consideration all of the components of the outfall pipe-diffuser-sea system that have been defined and analysed in this paper, it is important to make sure, starting at the design phase of any discharge system, that each of these components be thoroughly evaluated in terms of environmental impact. It is essential to underline this point because of the too frequent use and abuse that has been made, and is still commonly carried out, on deep bodies of water, since it is known that the very dimensions of the masses of waters receiving waste, with the sea weather phenomena inherent to them, carry out a positive role in the resolution of pollution.

It is hoped that this discussion, although it only alludes to or touches on the issue of discharge of waters with high concentrations of salts deriving from the desalination process, within a much more complex and heterogeneous issue like marine pollution due to discharges in general, can in any case be cause for reflection on a concept that is essential for every person: respect for a resource like the sea is indisputably the best lesson to be learned.

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