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Modeling of brine outfall at the planning stage of desalination plants

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ABSTRACT

The growing demand for drinkable water and its reliable supply have persuaded populations from many parts of the globe to construct desalination plants. The need for seawater means locating these plants in coastal areas and then naturally to dispose of their brine waste into the sea through outfalls at some distance from the shoreline. However, determining the optimum site for water intake and brine outfalls is the key issue at the planning stage of coastal desalination plant projects.

Modeling studies are outlined on the spread of salt concentrated waste that is continuously released into the sea. The principal aim of this case study was to establish a choice of brine outfall location with the least impact on the marine environment. In particular, the increase in salinity in coastal waters where protected vegetation species live was considered as the selection parameter for the disposal of the dense discharge source. Contrary to expectations, the modeling results reveal that the potential impact of salt disposal on vegetation can be alleviated by planning a shorter outfall.

1. Introduction

Seawater desalination contributes to humanity as well as to nature preservation because it provides a basic need for populations, industries and agriculture where traditional water resources are scarce. However, it also results in environmental damage, most of which is of a local nature. There are five mean fields that can be damaged by the presence of a desalination plant [1,2]:

- land usage; this kind of industrial plant is generally constructed near the coast line, and often in areas preferably designated for recreation and tourism;
- the aquifer, as the increase in salinity of coastal water, due principally to continuous brine discharge, enhances seawater intrusion into coastal groundwater;
- the use of energy, increased to generate the electricity required by the desalination plants, causing indirect but well-documented environmental pollution;
- noise; directly produced by equipment such as pumps and turbines, this can be controlled with correct positioning and minimized by means of appropriate technologies; and
- the marine environment, essentially due to the pumping of salt concentration back into the sea.

The sea has been always a final destination for waste discharge coming from the land, and especially so in Italy after a recent regulation that prohibits discharge into groundwater. Nevertheless, if the release is controlled and pre-treated when necessary (e.g. for waste water), the quality of the receiving body of water, except for a limited zone around the outfall, can be acceptable and the coastal ecosystem will be protected from risks and will continue to be used for tourism, water sports, bathing, seafood supply, and so on.

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 [3], 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 [4].

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.

Brine dilution is a combination of two physical processes [5]: (i) primary (jet) dilution which occurs in the so-called near field and depends primarily on discharge characteristics, such as the density

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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; (ii) 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. Theoretical studies indicate that brine dilution is significant in the first few meters, after which the salt discharge tends to sink to the bottom once the effects of the discharge jet are reduced and it reaches its balance with the surrounding environment according to its density. Nevertheless, Talavera and Ruiz [6] and Malcangio and Petrillo [7] carried out interesting environmental impact assessments about the discharge into the sea of water with relative concentrations of dissolved salts. Both studies showed that brine deriving from a desalination plant was diluted in the whole column of seawater, and that above all, this phenomenon was emphasized and sped up by the presence of treated water outfalls located near the brine discharge area. As a result, the desalination outfall together with the treated waste water did not negatively affect the marine life and the quality of the bathing waters of the area; in actual fact, their proximity had a mutually positive effect.

Features of the sea (bathymetry, currents, waves, tides, temperature, salinity), as well as characteristics of the brine outfall (concentration, discharge rate, pressure) can influence the extent of damage caused by salt concentration discharge in the marine environment. The extent of this damage depends on the sensitivity of the environment. Höpner and Windelberg [8] selected typical sub-ecosystems at the side of the target environment, and then ranked them in a sensitivity scale based on d'Ozouville et al. [9] following the AMOCO Cadiz accident (Brittany, France) in 1978. Even if the adopted model of the authors' sensitivity scale must be applied in a different way to desalination plants, they suggest locating the brine outfall along coasts with high energy and coast parallel currents, while it is preferable to avoid discharge close to rocks where the presence of biota is especially high.

Potential damage to the aquatic environment due to brine discharge can be minimized by the appropriate and careful planning of desalination plants and outfalls. The need to mix the concentrated solution release and transport it offshore is well known. Bleninger and Jirka [10] have recently shown summary of state of the art design methodologies for brine discharges. Several alternative techniques are available to ensure the proper disposal of brine into the sea, and their choice depends on environmental, engineering and economic aspects. Einav et al. [1] suggest the following four different alternative techniques for brine discharge:

- the use of long pipes with diffusers in the terminal section offshore;
- the discharge of brine water directly on the coastline;
- the dilution of brine with hot water from power stations in order to discharge both of them via the same outfall; and
- re-using concentrated brine for salt production.

The design of a desalination plant and its submarine outfall must also take into account the use of the receiving water body, the values of the chemical–physical parameters to be fulfilled for its protection and the quality of the environment. Therefore, the outfall system plan has to carefully consider the physical, chemical and biological phenomena that allow the mixing and dilution of the salt concentration. To this end, essential preliminary research is required to provide information about (i) the marine circulation around the area under investigation, (ii) the wavy state typical in that domain and (iii) the chemical–physical characteristics of the receiving water body.

The evaluation of the range of concentrated brine effects necessary to plan the outfalls is based mainly on mathematical models. This modeling is often a complex task because of the variety and variability of the mixing processes and changes in sea currents, temperature, salinity and density. Following an agreement between the Municipal Waterworks of Bari (Italy) and the Technical University of Bari, the preliminary results of the development of such tools are presented in this paper. Particular attention was paid to the existing flora in the area under study, which is considered a protected species in the Mediterranean sea.

2. Case example and numerical results

2.1. Site description

The present study focuses initially on the hydrodynamics of a coastal zone in southern Italy and then on the current generated by several environmental factors that act simultaneously and that subsequently dilute, spread and transport the brine plume. This area is environmentally vulnerable because of its 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 Salento (South Italy) face the critical problems of seawater intrusion.

In order to avoid this problem, a coastal desalination plant has been planned in Brindisi by the AQP s.p.a., in the coastal zone around Torre Punta Penne, up to Punta Riso and southward (Fig. 1). One special feature of the seabed concerned is that of the presence of a protected vegetative species, the oceanic Posidonia. It is an endemic plant in the Mediterranean area with roots, stalk, leaves and fruit that lives under water between the surface and a maximum depth of about 40 m. The plant forms prairies of Posidonia, also called seaweed fields (although they are not formed by seaweed) which are the most important ecosystem of the Mediterranean, equivalent to forests in land ecosystems. The prairies of Posidonia are also a great source of biodiversity as they are the habitat of numerous vegetable and animal species, some of which are in danger of extinction. Therefore, this plant species is protected by EU regulations such as the Habitat Directive 92/43/CEE that requires member states to identify areas with animal and vegetative species and habitat whose conservation is considered a priority. This regulation was ratified by the Italian government with the D.P.R. 357/97 decree, which assigns the task of locating areas of community interest to the regions (SICs in Italian) as well as their periodic monitoring.

The aim of the present study was to find an optimal site for the desalination outfall in order to minimize the impact of salt concentration release on the local biota. Fig. 2 shows a map of the existing biocoenosis and a preliminary overview of the intake and outfall pipe location in the area under assessment.

2.2. Model description

To study a complex situation such as aquatic ecosystems altered by the presence of anthropic structures, e.g. desalination outfalls, mathematical models that describe seawater circulation in the analyzed system, together with the chemical–physical–biological phenomena that regulate internal activity, are needed. In fact, a full understanding of oceanic and coastal circulation is fundamental in comprehending strictly correlated processes, such as pollutant diffusion and advection, as well as in interpreting phenomena linked to ecosystem activity and the prediction of external intervention effects through suitable control policies. This kind of model is known as hydrodynamic–ecological.

An assessment of the environmental impact of brine outfalls in the sea by means of mathematical modeling is a multi-sided issue. The principal difficulties derive from the variability and variety of mixing processes with subsequent dilution, diffusion and transport of the salt plume, in addition to changing environmental conditions such as currents, tides, temperature, salinity and density. Bathymetry is a further factor on which salt concentration dispersion depends, with water mixing generally favoured in deeper waters. In any case, if well calibrated, these models can provide scientific explanations related to