Monitoring Coastal Waters Close to a Sea Outfall

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Abstract

The design of a water treatment plant and its outfall should respect receptors' environmental quality standards as well as physicochemical parameters of the discharge itself. Moreover, in order to avoid polluting the outfall, because of the natural processes of dilution and self-depuration, coastal outfall pipes are used to issue the depurated water at a sufficiently long distance from the preserved shoreline. Once recognising that sea currents play a pivotal role on physical and microbiological effects, the following study aims at describing the results of some monitoring surveys carried out in the Italy's Southern coastal area of Bari. The target area is close to the Eastern wastewater sea outfall system of the city, thus, its analysis is necessary for investigating the process of diffusion and transport of the wastewater outfall and to validate predictive hydrodynamic models.

Firstly, monitoring surveys were carried out during the period from summer to autumn 2001 and successively, they were repeated in the following winter 2003 and spring 2003. A Vessel Mounted Acoustic Doppler Profiler was used to measure the components' speed at different depths. Also, salinity and water temperature data were collected by means of a CTD recorder system while wind intensity and air temperature were recorded with an anemometer and a thermometer respectively, for each station's measurement.

Keywords: wastewater discharge, outfall, current measurements, monitoring.

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1.Introduction

One of the main aim of the analysis of a sea outfall determines an area that could be influenced by natural processes of dilution and self-depuration in order to preserve the shoreline and to guarantee the occurrence of the hydrodynamic effects necessary to fulfil the quality standards set by regulation. Outfalls are designed to use the natural assimilative capacity of the oceans in order to guarantee a minimum environmental impact of wastewaters. This is accomplished by promoting vigorous initial mixing followed by efficient turbulent sea dispersion due to spatially and temporally varying currents (Carvalho et al., 2002). Therefore, it is important to provide preliminary investigations which can determine local effects and can help being familiar with the sea circulation in the outfall region.
Reliable field measurements of coastal outfall plumes become scarce due to high costs, variability of discharge flow-rate, currents, stratification and large areas to be monitored (Carvalho et al., 2002). In situ measurements are also necessary to validate mathematical models developed for predicting coast hydrodynamics (De Serio et al., 2007) and behaviour of plumes under steady conditions.
This work focuses on the sensitivity and vulnerability of sea areas close to the eastern wastewater outfall pipe in located in Bari. In order to guarantee the respect of prescribed quality regulations, the monitoring of the plant outfall is unavoidable in terms of (i) physicochemical and bacteriological measurements; (ii) current, wave and wind measurements (Nash and Jirka, 1996; Mossa, 2004a,b). Measurements necessary for the monitoring process cannot be concentrated in the wastewater outfall pipe zone only but should be extended to neighbouring areas an extension which depends on wastewater discharge, polluting charge and magnitude of sea currents and typical winds of the area under analysis. In fact, the so-called near field region (responsible for rise height, initial mixing and dilution) occupies a very small part of the overall impact on the discharge (Roberts, 1999). Beyond the nearest field, the waste field is drifted by the

sea current's turbulence and diffuses into a region called the far field where mixing occurs at a much slower rate.
For this reason, the objective of this paper is to analyse and later discuss about the results of a survey program carried out in a target area, roughly delimited by 10m and 50m bathymetric lines, including the Bari eastern wastewater outfall (Fig.1). Surveys were executed in the summer-autumn period in the year 2001, again in winter 2002 and in the spring of 2003, thus allowing to evaluate a seasonal variation of measured parameters.

2.Study site and experimental equipment

The location map of Bari (Italy) and the target sea area, monitored during all the surveys is shown in Figure 1. The red dot in the figure located between 15m and 20m bathymetric lines represents the end of the wastewater outfall pipe of the Bari East plant. Its distance from the shoreline is about 950m in a direction which is almost normal to the shoreline itself. During the first cruise program the following surveys were carried out: summer-autumn surveys on the 12th, the 17th, the 20th and the 25th of July, the 3rd of August, and the 22nd and the 26th of September 2001. In the present paper only the observations referring to the 22nd and the 26th of September 2001 will be discussed (respectively named as 22S01and 26S01). Particularly, the measurement of the 26S01 survey has been assessed in a very limited area, near the wastewater outfall, in order to better evaluate the spreading of its discharge.
During the second cruise program, surveys conducted on the 17th of December 2002, the 3rd and the 10th of March 2003 were executed (in the following it refers to 17D02, 03M03 and 10M03, respectively).
The true sea currents had always been measured by a Nortek VM-ADP Vessel Mounted Acoustic Doppler Profiler (Fig. 2), connected to the gyro and the DGPS in order to take into account the vessel velocity. In order to provide the true sea currents, in fact, all current vessel-mounted profilers must take the ship velocity out from the measured data. The traditional

method relies on a bottom tracking technique where the Doppler profiler is to measure the speed of the sea bottom relative to the ship. The Nortek VM-Profiler primarily relies on the connection to the gyro and the DGPS in order to obtain the vessel velocity. It consists of a rugged transducer assembly made of marine bronze and designed for permanent installation, a computer with an intelligent multi-port serial interface card and a software to handle ingoing and outgoing communication (Fig.3).

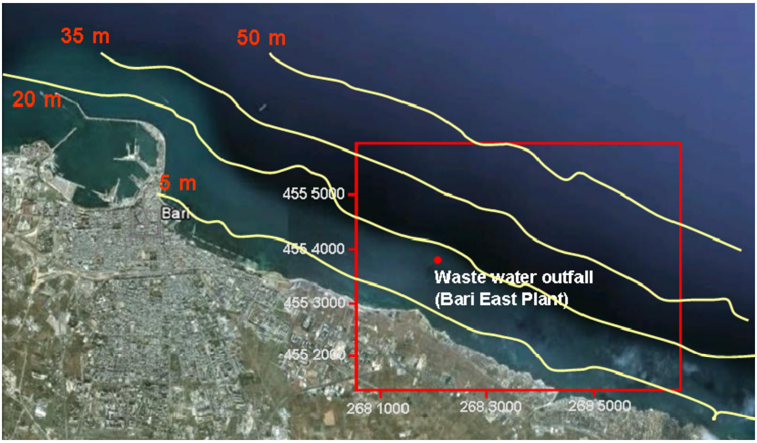

Fig. 1. Bari' s coastline and geographical position of the analysed areas. Gauss-Boaga reference system used. Source Google Map

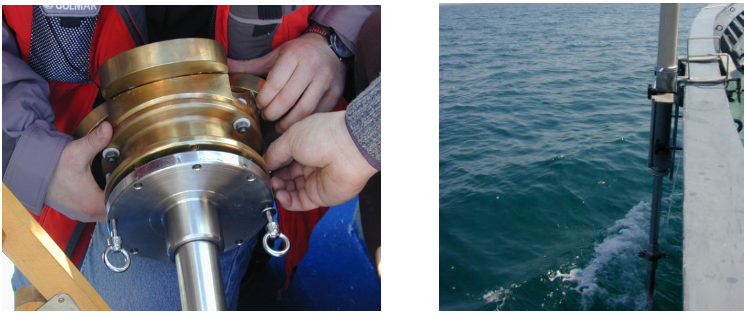

Fig. 2. Mounting of the probe to the support (left) and probe attached to the boat (right)

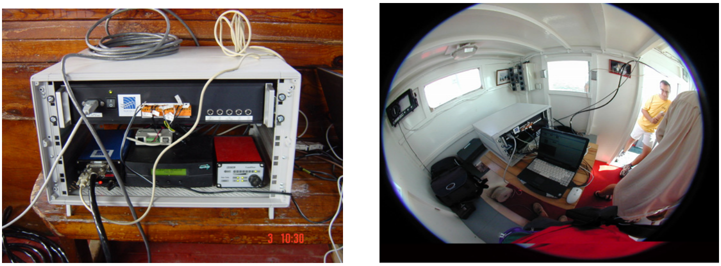

Fig. 3. The VM-ADVP in the boat cabin.
Process computer on the right

The CTD recorder system Ocean Seven 501 by Idronaut Srl was used to measure the water temperature and salinity. The practical salinity is calculated with the formula adopted by UNESCO in 1980. In order to measure the wind intensity and the atmosphere's temperature, an ASV200 anemometer by Cometeo and an HD9215 thermometer by Delta Ohm were used. The detailed characteristics of the used instrumentations are described in Mossa (2006).

3. Analysis of the acquired measurements

The measurements of all the surveys were assessed by means of anchoring the boat and acquiring the speed every 2s of the total time of 300s per each investigated station.

3.1 First cruise: 22S01 survey

During this survey velocity profiles were measured starting at 10:00 and finishing at 14:20. The measurements were assessed along transepts parallel to the shoreline. The analysed motion field has a dimension of approximately 5000 x 3000 m.

The wind had an average direction of N60E. A certain variability of the wind with the time was observed, in fact, at the beginning of the survey winds were almost scarce and increased progressively by the time until reaching the maximum values of 4 m/s.

The average sea current direction was parallel to the shoreline along the SE direction (Figure 4). Measurements show a reduction of the velocity components closest to the sea bottom. Magnitude of the vertical speed components were less than the horizontal ones.

Close to the wastewater outfall pipe, measurements show the presence of water with less salinity (Figure 5). This dense water flowed offshore and was transported by the current.

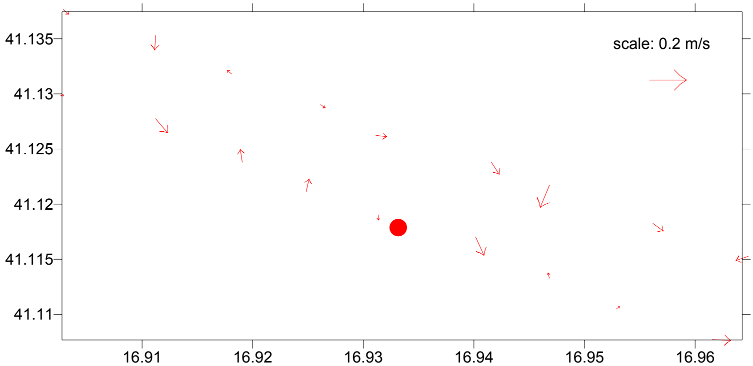

Fig. 4. Survey 22S01: horizontal and vertical velocity components of the 26th of September 2001 at 4 meters depth (red dot is the wastewater outfall; geographic reference system used)

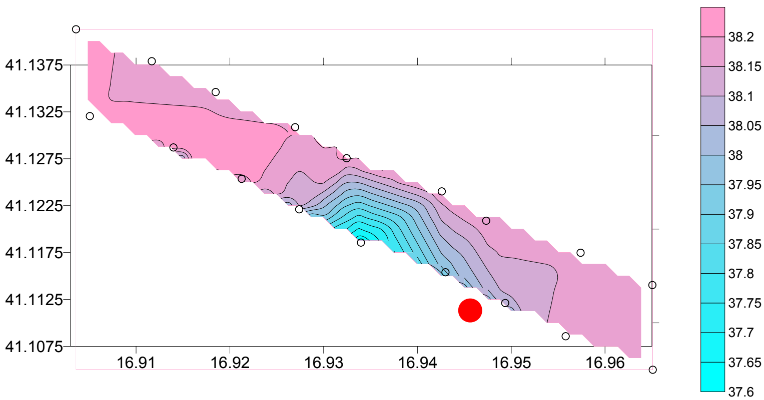

Fig. 5. Survey 22S01: salinity of the 22nd of September 2001 at a 0.6 meters depth (red dot is the wastewater outfall; geographic reference system used)

3.2 First cruise: 26S01 survey

During this survey, nine vertical profiles were assessed starting from 11:10 and finishing at 13:20. The wind was particularly strong, reaching values of about 7m/s. The mean wind direction was N300E. The area investigated during this survey was very small, limited to the points adjacent to the outfall, in order to better evaluate the spreading of its plume. Moreover, only during this survey, in addition to the sea current and CTD data, water samples were carried out for biological analysis. The water samples were taken at 5m water depth with the aim of obtaining values of the dissolved oxygen, the BOD_5, total coliform, faecal coliform and streptococci.

It should be noted that the mean sea current was parallel to the shoreline towards the SE (Figure 6). The horizontal velocity components reached values of about 0.2 m/s. The magnitude of the vertical velocity components is less than the horizontal velocity components.

The salinity diagram of Fig. 7 shows a diffusion process towards the SE which is consistent with the velocity measurements. The map of Figs. 8 shows the trend of the BOD5 and gives information about the water quality. The analysis of the aforementioned figure shows greater values of the BOD_5 close to the wastewater outfall pipe and a gradual reduction of these parameters towards the SE. This result is consistent with the sea current direction and therefore, with the buoyant jets discharged in the sea.

The trend of Figure 7 and Figure 8 are consistent not only with the mean sea current direction but also with the sea current velocities in the northern part of the analysed area that, as it has been written, are directed towards the South. In fact, from the aforementioned figures, it is possible to highlight that the sea current from the northern zone, characterized by biochemical parameters of the environmental water, wedges in the zone close to jets.

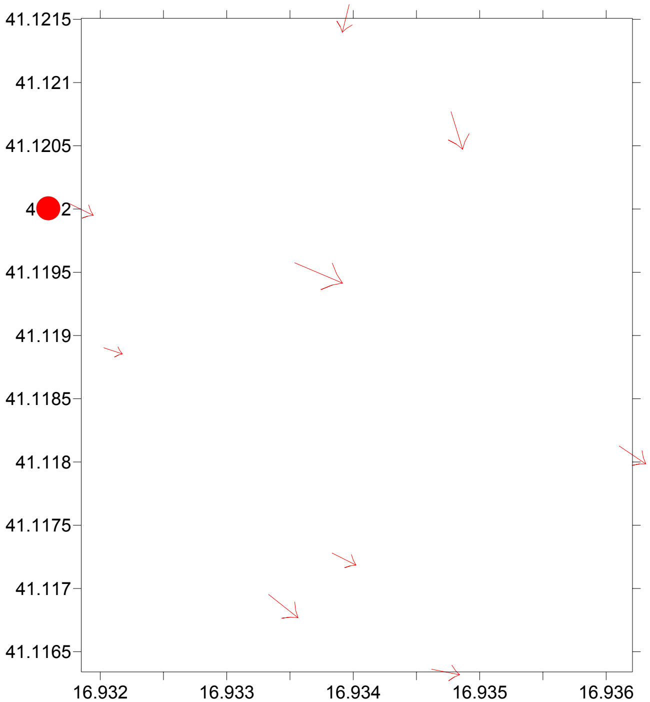

Fig. 6. Survey 26S01: horizontal and vertical velocity components of the 26th of September 2001 at 4 meters depth (wastewater outfall, on the left, outside of the figure). The geographic reference system has been used

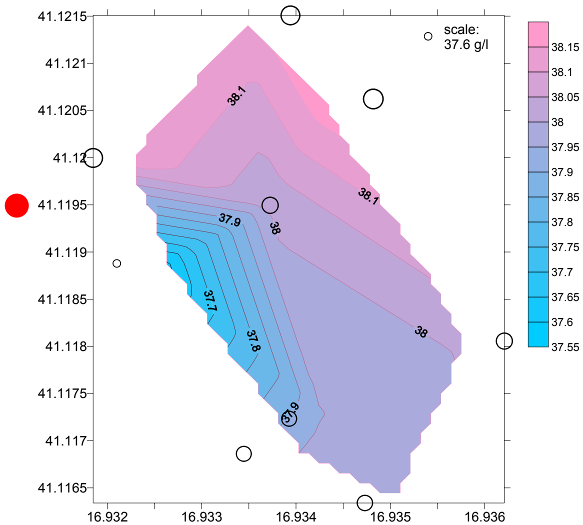

Fig. 7. Survey 26S01: salinity of the 26th of September 2001 at 0.6 meters depth (wastewater outfall, on the left, outside of the figure). The geographic reference system has been used.

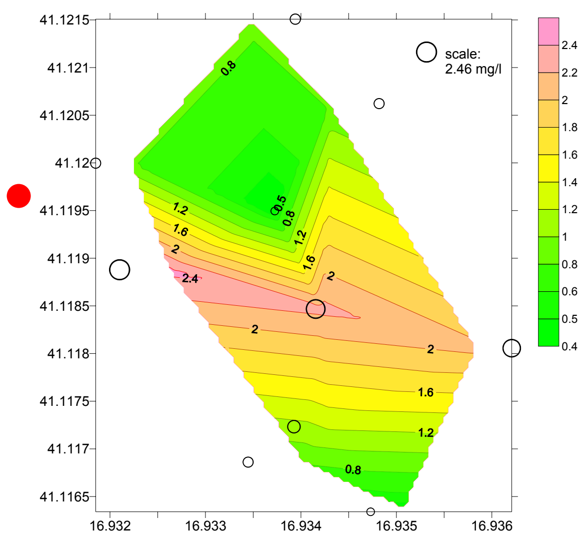

Fig.8. Survey 26S01: BOD_5 of the 26th of September 2001 at 5 meters depth. (wastewater outfall, on the left, outside of the figure). The geographic reference system has been used.

3.3 Second cruise: 17D02 survey

During this survey (17 December 2002) velocity profiles were measured starting at 10:30 and finishing at 15:00. The air temperature was in the range of 14.5÷16.2°C and a weak wind was recorded blowing from the South with a direction of 180÷200NE and an intensity of 0÷1.3m/s.

Measurements were assessed along two transepts parallel to the shoreline, about 6500m long, and lying approximately on the 10m and 35m bathymetric lines. The offshore transept followed a SE direction while the onshore transept followed a NW direction.

All measurements highlight an average current directed towards the SE, more intense in deeper waters. Figure 9 shows a flow map at a depth of 4m, where greater intensities are recorded along the offshore transect, with values fluctuating between 0.33 and 0.57 m/s and directions ranging between 110 and 140NE. Along the onshore transect current intensities are in the range of 0.09÷0.32 m/s and current directions are in the range of 95÷128NE. Measurements show a reduction of the velocity components when approaching the sea bottom. Also in this case, the vertical velocity components are of a lesser magnitude order than the horizontal ones. Taking into account the weak wind induced circulation, it could be presumed that in the investigated coastal region the measured currents are seen as a consequence of the existing thermohaline circulations which well respond to the typical winter patterns reported by Artegiani et al. (1993).

The analysis of temperature (which is not reported here) and salinity show that at all the depths are greater along the offshore transect rather than along the onshore one. Moreover, they generally increase with the increasing depth. In Figure n.10, the horizontal salinity map is plotted for all the examined stations placed on both the onshore and offshore transect. It highlights that in the proximity of the wastewater outflow denser water is present and it gradually spreads when following the predominant current.

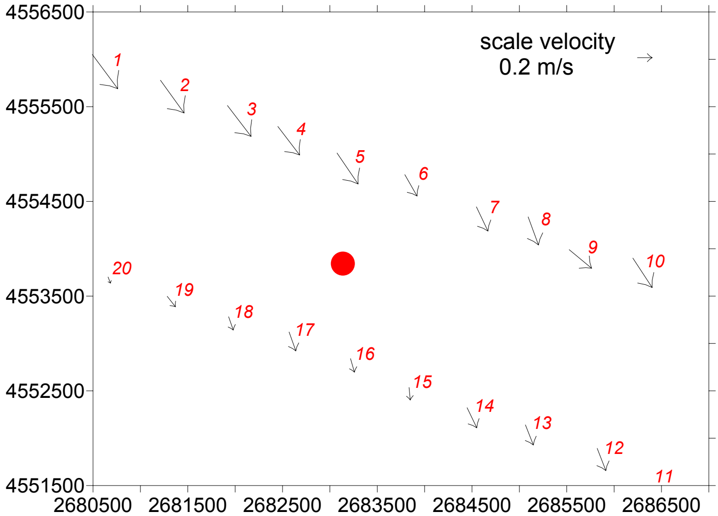

Fig. 9. Survey 17D02: measured horizontal currents at a 4m depth. The Gauss Boaga reference system has been used

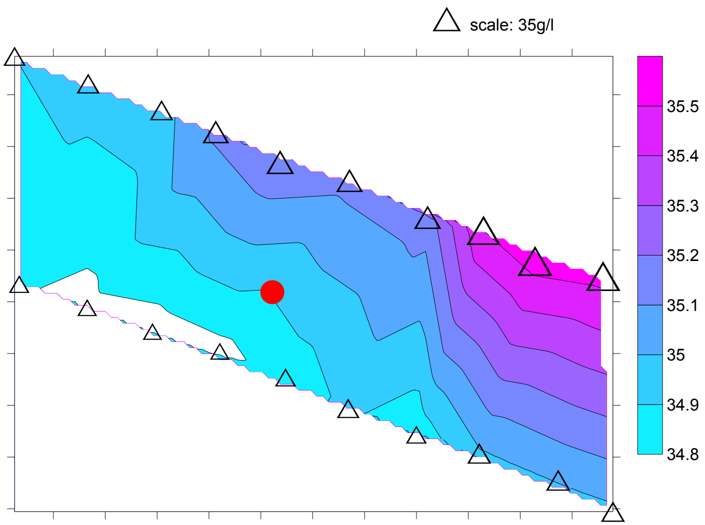

Fig. 10. Survey 17D02: measured horizontal salinity map at a 4m depth. (Same reference system of the previous figure)

3.4 Second cruise: 03M03 survey

During this survey (3 March 2003) velocity profiles were assessed starting at 10:30 and finishing at 15:00. The air temperature was in the range of 9.2÷12.3°C but it varied greatly during the measurement because of the fickle weather characterised by a strong gusty Libeccio (Southwest) wind. In fact, the wind field was characterized by an extremely variable intensity in the range of 0÷6.0m/s and by a direction in the range of 200÷230NE.

In this case, measurements were also assessed along two transepts of 5500m of length placed approximately on the 20m and 35m bathymetric lines. The offshore transept followed a SE direction while the onshore transept followed a NW direction. As it was observed during the previous survey, the most intense South East currents were recorded along the offshore transect.

In the Figure n.11 the flow map relative to the 4m depth is characterized by 0.06÷0.22m/s velocities and 105÷153NE directions along the offshore transect while, along the onshore transect, current velocities are in the range of 0÷0.11m/s and their directions are in the range of 84÷136NE. A reduction of the velocity components is observed for both transects when the depth increases.

An evident stratification is observed both for temperature T (not reported here for the sake of brevity) and salinity S. In fact, their values increase from 10°C and 36.5PSU, recorded in the first 5m of depth, respectively to 13.5°C and 38.5PSU, keeping them quite invariant as depth increases. For example, in Figure n.12 salinity horizontal trend is plotted at a depth of 4m. Temperature and salinity maps generally show, at all depths, greater temperatures and salinity values in the offshore transect with respect to the onshore one. Also in this survey, it is evident that water with less salinity is near to the wastewater outflow. It gradually spreads in the offshore direction.

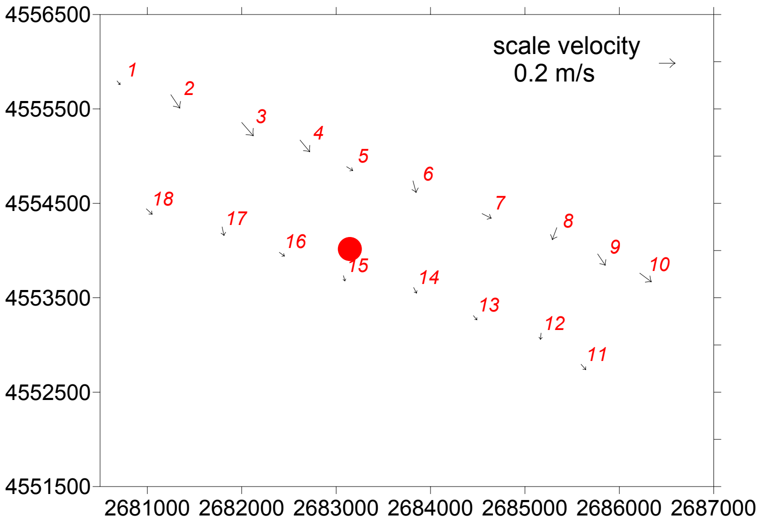

Fig. 11. Survey 03M03: measured horizontal currents at 4m depth. The Gauss Boaga reference system has been used

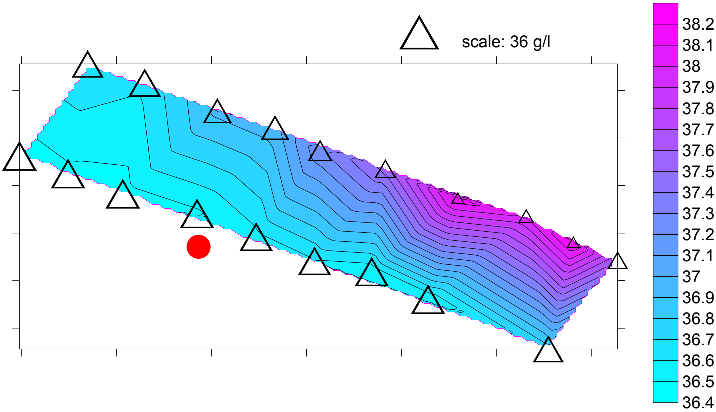

Fig.12. Survey 03M03: measured horizontal salinity map at 4m depth. (Same reference system of the previous figure)

3.5 Second cruise: 10M03 survey

The survey conducted on the 10th of March 2003 lasted from 11:30 to 16:30. The air temperature was in the range of 11.7÷13.2°C, with values which increased during the measurement. The anemometric regime was characterized by a wind with directions included in the range of 290÷340NE and time-growing intensities, ranging from 2.3 to 7.0m/s. The data were acquired along two transepts of 5000m long, following the 35m and 50m bathymetric lines respectively. The offshore transept followed a SE direction while the onshore transept followed a NW direction. Also in this case, an average current directed towards the SE was observed. The horizontal pattern of the velocity is plotted in Figure 13, at a depth of 4m, where the velocity values are in the range of 0.34÷0.69m/s. As depth increases, velocity generally decreases while velocity vectors do not vary much in their directions. In the same way as it has been shown in the previous surveys, the most intense South East flow was recorded at greater distances from the coast.

The vertical stratification of the temperature (which is not reported here) and salinity still holds true thus confirming the trend observed during the survey conducted on the 3rd of March. Their values increase from 10°C and 36.2PSU respectively to 13.5°C and 38.0PSU, in the most superficial layer and do not vary that much as depth increases. For example, the horizontal distribution of the measured salinity is shown in the Figure n.14 at the depth of 4m. Salinity values are smaller near the diffuser and, in this case, the spreading of the plume of dense water is not so regular since it is surrounded by some water cells containing a big quantity of salinity.

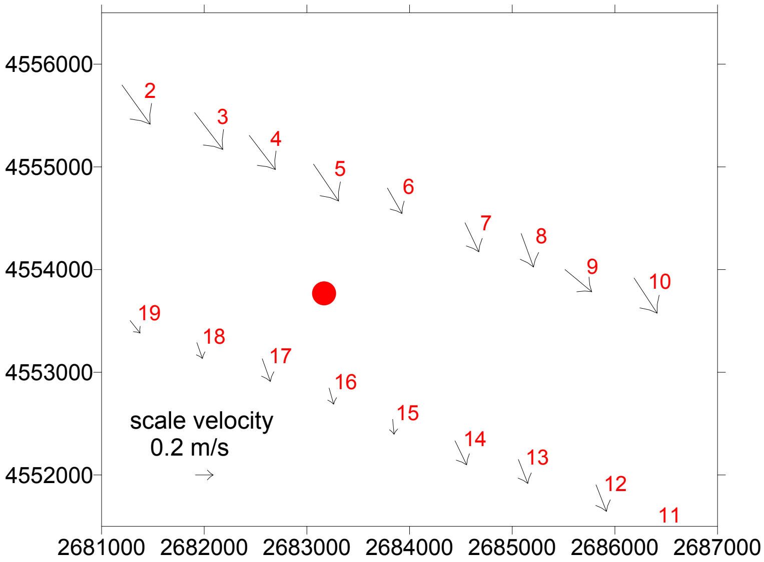

Fig. 13. Survey 10M03: measured horizontal currents at 4m depth. The Gauss Boaga reference system has been used

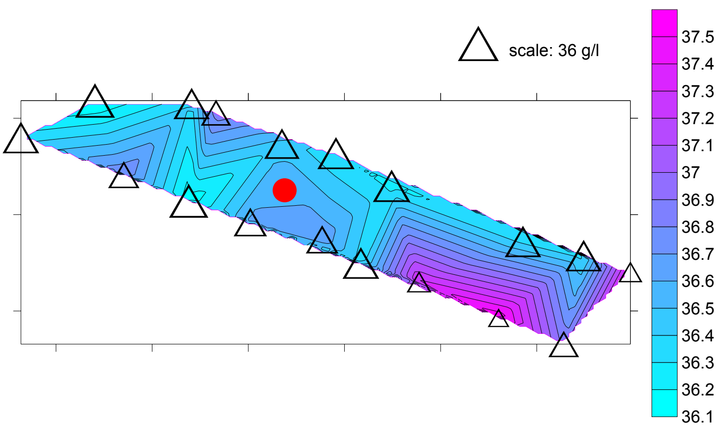

Fig. 14. Survey 10M03: measured horizontal salinity map at 4m depth. (Same reference system of the previous figure)

4. Conclusions

It is known that measurements which are necessary for the monitoring of a wastewater outfall should be extended to the neighbouring area in order to investigate the process of diffusion and transportation. Therefore, monitoring surveys were carried out in the summer-autumn period of 2001 and also in winter-spring period in the year 2003, in the Southern coastal area of Bari (Italy), thus, including the Eastern wastewater outfall of the city. Data that has been acquired such as the local wind, speed, temperature and salinity have been analysed in this paper. During the all analysed surveys, a mean flow parallel to the coastline and directed towards the SE was observed and characterized by decreasing values when approaching the sea bottom.

The vertical trends of measured temperatures and salinities show a substantial uniformity along the water column in the winter period while a strong stratification is evident in the spring/summer season. The horizontal maps of salinity generally show that the spreading of the plume with less salinity (coming from the wastewater outfall) is consistent with the observed current patterns.

Therefore, it can be concluded that field measurements are necessary in order to evaluate the mutual influence occurring between a wastewater outfall and its neighbouring circulation.

The results of this study demonstrate that the process of monitoring must consider: (i) physicochemical and bacteriological measurements which extend, not only in proximity to the wastewater outfall pipe, but also to the zone characterised by hydrodynamic conditions existing at the time when surveys had been conducted; (ii) current, wave, and wind measurements which are to identify zones at risk, provide the hydrodynamics of the interested area.

References

Artegiani, A., Gacic, M., Michelato, A., Kovacevic, V., Russo, A., Paschini, E., Scarazzato, P. and Smircic, A. (1993) The

Adriatic Sea hydrography and circulation in spring and autumn (1985-1987), *Deep Sea Research,* part II, 40 (6): 1143-1180.

Carvalho, J.L.B., Roberts, P.J.W. and Roldao, J. (2002) Field Observations of Ipanema Beach Outfall. *J. Hydr. Eng.,* 128: 151-160.

De Serio, F., Malcangio, D., Mossa, M. (2007) Circulation in a Southern Italy coastal basin: modelling and field measurements, *Continental Shelf Research,* 27, pp. 779–797; doi: 10.1016/j.csr.2006.11.018.

Mossa, M. (2004a). Experimental study on the interaction of non-buoyant jets and waves. *J. Hydraulic Research*, 42 (1): 13-28.

Mossa, M. (2004b). Behavior of nonbuoyant jets in a wave environment. *J. Hydr. Eng.,* ASCE, 130 (7): 704-717.

Nash, J.D., and Jirka, G.H. (1996) Buoyant surface discharges into unsteady ambient flows. Dynamics of Atmospheres and Oceans, 24: 75-84.

Roberts, P.J.W. (1999) Modeling Mamala Bay oufall plumes. II: Far field. *J. Hydr. Eng.,* 125: 574-583.