MODELING OF FLOW PATTERNS AND MICROBIOLOGICAL PARAMETERS FOR HAZARD ASSESSMENT OF BATHING WATERS AFFECTED BY COMBINED SEWER OVERFLOWS

Giuseppe Locuratolo, Elvira Armenio, Enrico Barbone, Cosimo Giannuzzi, Antonietta Porfido, Nicola Ungaro

Abstract: ARPA Puglia carried out a numerical study to simulate the evolution of the turbidity plume geometry and to describe the bacterial dispersion caused by the discharge of a mixture of raw sewage and surface runoff from the so called *condotta Matteotti* into the marine-coastal waterbody close to the urban beach (bathing area) called "Pane e Pomodoro". The *condotta Matteotti* is an underground concrete pipe connected with a spillway to the main sewer system: it acts as an emergency weir to prevent flooding during or soon after intense rainfall events. During these rainfalls the seaward sluice gates open, and the untreated sewage is discharged into the sea thus decreasing the water quality. The simulation, according to a heavy rainfall and overflow event occurred in July 2018, was implemented using the DHI's Mike 3 suite enhanced with the ECOlab module, both organized as step-by-step processes. The validation of the final model was performed by comparing the microbiological concentration resulted from the model application with the on-field measurements and samples collected by ARPA Puglia during its ordinary water monitoring activities.

Keywords: overflow, bathing waters, water quality, flow pattern, bacterial dispersion

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Introduction

Bathing water quality can decrease significantly due to sewage and surface runoff overflows after huge rainfalls [1] [2].

The town of Bari (close to 330 000 inhabitants) is located on the south-western Adriatic coast, and mostly of the raw sewage waters are collected and treated by two large wastewater treatment plants. Nevertheless, in the southern part of the town the drainage system is mixed, collecting both wastewater from civil settlements and urban runoff into the same underground sewage system that, during or soon after intense rainfall events, activates the emergency overflow discharge from the pipe "*condotta Matteotti*" close the urban beach of "*Pane e Pomodoro*".

The *condotta Matteotti* is a buried channel used as an emergency weir, connected to the main network with a spillway and proceeding straight towards the Nazario Sauro seafront (Figure 1), where sluice gates are located seaward.

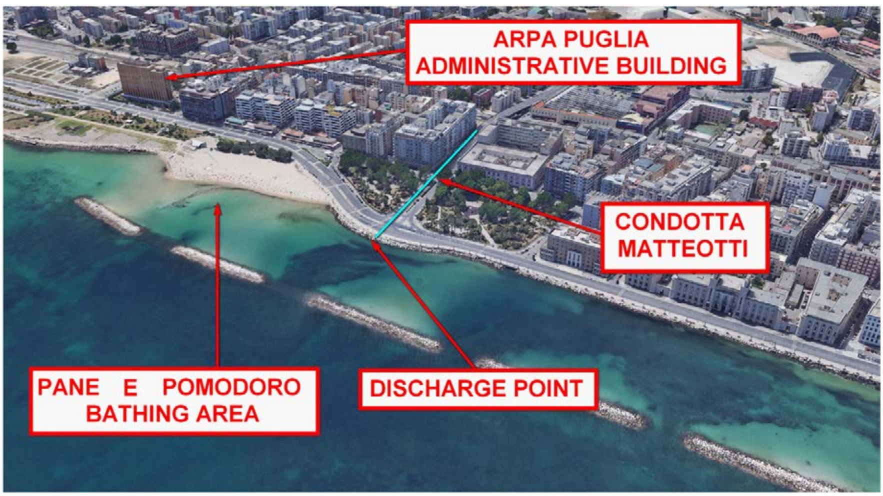

Figure 1 – Panoramic view of Bari's southern waterfront.

Due to the accumulation of rainfall, once the flow rate into the main network reaches about 250÷300 L s^{-1}, the mixture of runoff water and raw sewage rises above the crest of the spillway and begins to be released into the channel. When the water accumulated in the channel rises up to a level of 70 cm, the sluice gates automatically open and the water is abruptly discharged with its untreated bacterial load at the sea.

The discharge of the mixed water produces a turbidity plume (Figure 2) dispersing its bacterial content at the sea according to the current regime at the time. Subsequently, the Municipality of Bari issues an order for a temporary bathing closure in the *Pane e pomodoro* area, one of the most crowded beaches on Bari's urban coastline, until ARPA Puglia verifies the restoration of bathing water quality standards according to the limits defined by Italian laws (Italian Legislative Decree n. 116/2008).

The sewage outflows generally occur during or soon after intense and time-concentrated rainfalls: it was verified that even rainfall events lasting one hour or less may be sufficient in case of heavy rain [3].

This study, in particular, was focused on reproducing the geometrical spreading of the plume fronts, including its bacterial concentration, over time, triggered after the discharge event started on July 23rd, 2018: this event was also recorded by ARPA Puglia with video and photos.

Figure 2 – Turbidity plume recorded on July 24th from the ARPA Puglia administrative building.

Study area

The simulation involved an enlarged marine area of 12 x 15 km.

In this area, the hydrodynamic regime close to the coastline is strongly influenced by the presence of two ports (the new port structures much bigger than the old-historic one) and wave defence structures.

In particular, a defence system consisting of 10 emerged breakwaters (on average 10 meters wide and 150 meters long) run parallel to the shoreline, with a top berm about 1 meter above the mean sea level. Moreover, concrete blocks protect as wave attenuators the seafront road.

The discharge point of the *canale Matteotti* is located approximately 200 meters north-west of *Pane e Pomodoro* beach and less than 1 km south-east of the old port.

Materials and Methods

The simulation was carried out step by step. The first step was the implementation of the hydrodynamic model by using the three-dimensional flow model MIKE 3 [4].

A large mesh in the offshore water zone, appropriately nested in the study area, was used to discretize the domain. The nodes of this mesh represent the calculation points of the model (Figure 3).

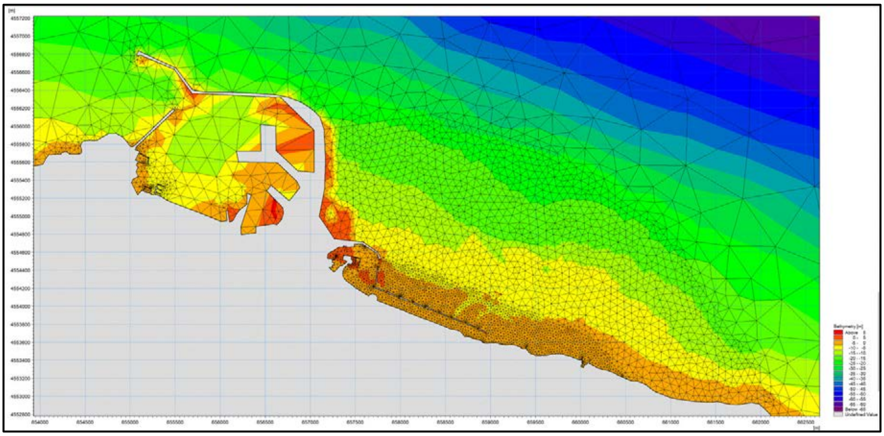

Figure 3 – Triangular shaped mesh and bathymetry to compute the hydrodynamic model

Once the mesh was created, the set-up window was filled with two main digital records: weather time series and sea state conditions at regional scale.

The weather time series of temperature, atmospheric pressure, humidity, rainfall, wind speed, wind direction and solar radiation were collected by the meteorological control unit located at the ARPA Puglia headquarters, located close to the beach.

The rainfall time series from May to October 2018 is shown in Figure 4: the red triangle highlights the events that forced the opening of the sluice gates, including the event of July 23rd, 2018.

The analysed rainfall time series provides twofold information:

- the precipitation rate for a single weather event causing the opening of the floodgates is highly variable, from around 18 mm/h to less than 2 mm/h;
- there is no minimum rainfall limit above which the sluice gates are opened.

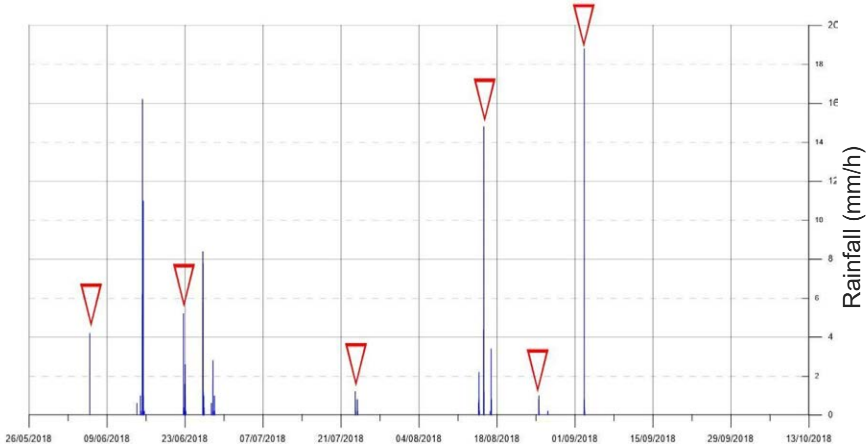

Figure 4 – Rainfall time series (mm) from 26/05/2024 to 13/10/2018: the red triangles show the weather event triggering the discharge activation (including the event of July 23rd, 2018).

The downscaling from regional to local sea circulation was based on the data available from the Copernicus Marine Service[1], which provides free, regular and systematic information on the state of the sea (wave, current, temperature, atmospheric pressure, etc..) on a regional scale.

The set-up was completed using the bathymetric model downloaded from the EMODnet portal[2] and the tidal data obtained from the National Tidal Network (RMN) managed by ISPRA, for the tide station located in the port of Bari (the computing period was the whole month of July 2018).

Different and time-consuming runs were completed to fix any failures. In the end, the hydrodynamic model was finalized, and the local sea circulation was reproduced as the main output (Figure 5).

After that, the *ECOLAB Entorococci* and *E. coli* module was coupled with the hydrodynamic model in order to simulate the simultaneous processes of bacterial transport and dispersion. The decay processes describing the decrease of the two bacteria in time and space are dependent on factors such as the salinity, water temperature, and the solar radiation: these parameters were directly achieved from the hydrodynamic model, whereas the flow rate in the discharge point and the initial bacterial content were provided by the *Acquedotto Pugliese* water service company[3]. The decay model adopted is described by *Erichsen et alii* [6]. For the bacterial transport and dispersion, the simulation of the spillage started at 11 p.m. on the July 23rd, 2018, when the sluice gates effectively opened, assuming that the discharge lasted 1 hour.

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[1] https://marine.copernicus.eu/

[2] The European Marine Observation and Data Network (EMODnet) is the European Commission (EC) in situ marine data service (https://emodnet.ec.europa.eu/en)

[3] www.aqp.it

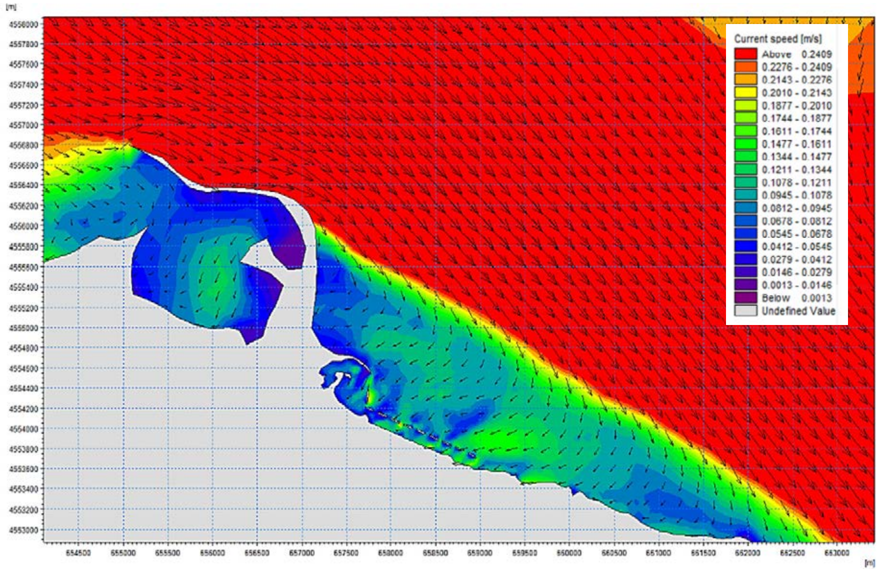

Figure 5 – Sea surface currents circulation on the July 24th, 2018, at 10.00 a.m. (after three days of computing).

Results and discussion

The validation of the hydrodynamic model was performed comparing the physical parameters measured by the model and the values measured by ARPA Puglia during the institutional monitoring of the bathing waters in the period April – September 2018.

In particular, time series were extracted from the hydrodynamic output of the Mike 3 model at the same positions monitored by ARPA Puglia, named T1, T2 and T3. The average value of sea surface temperature calculated by the model was 24.7 °C (averaged over the time interval), which well fit with the values measured in field (approximately 24.4 - 25.6 °C). The average velocity values of the surface currents from the numerical model were 0.093 m s^{-1} at point T1, 0.079 m s^{-1} at point T2 and 0.068 m s^{-1} at point T3, respectively. The range of the model's current velocity values for the overall simulation period varies from 0.01 to 0.3 m s^{-1}. Also in this case, the comparison with the surface current velocity values measured during the ARPA Puglia bathing waters monitoring (2018) shows the same order of magnitude.

The ECOLab module produced the simulation of the bacterial concentration over time, and the results are reported in the maps showed in the Figures 6,7, 8, 9, 10 and 11, corresponding respectively to the scenarios at time steps of 3 hours each other.

Looking at the same maps, and assuming the law limit of 200 CFU mL^{-1} for the Enterococci, the simulation highlights that, according to the local sea current regime at the time, the bacterial content discharged from the *canale Matteotti* affected the compliance of the bathing area *Pane e Pomodoro* only for twelve hours after the overflow event. This means that the bathing quality standards were restored in less than one day. Moreover, the geometry of the plume as simulated by model is very similar to the effective geometry recorded in field by ARPA Puglia at almost the same time (Figure 12).

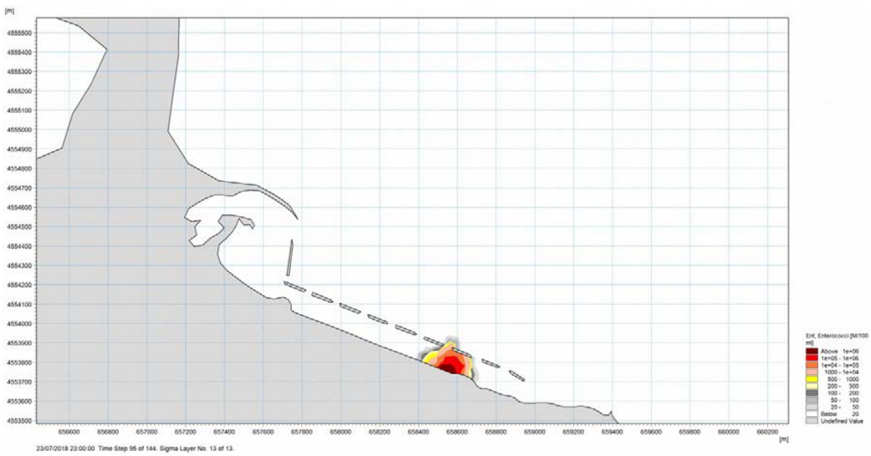

Figure 6 – Bacterial concentration plume at about 11.00 p.m. on July 23rd, 2018.

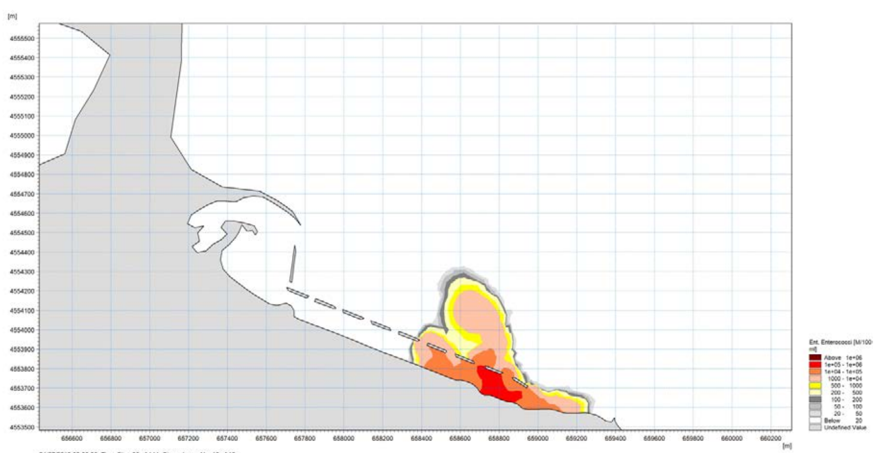

Figure 7 – Bacterial concentration plume at about 02.00 a.m. on July 24th, 2018 (3 hours after the opening of the sluice gates).

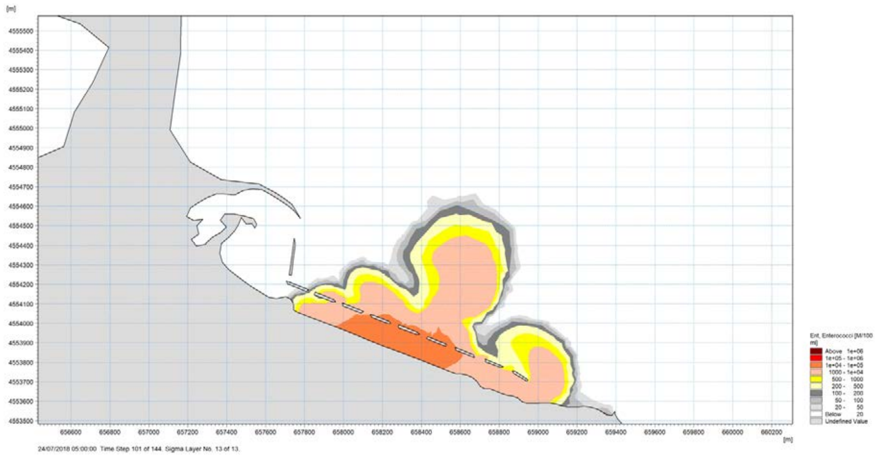

Figure 8 – Bacterial concentration plume at about 05.00 a.m. on July 24th, 2018 (6 hours after the opening of the sluice gates).

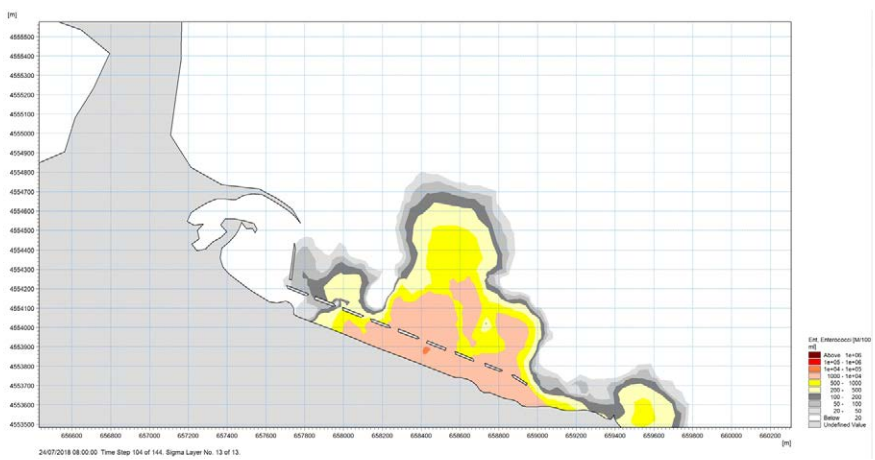

Figure 9 – Bacterial concentration plume at about 08.00 a.m. on July 24th, 2018 (9 hours after the opening of the sluice gates).

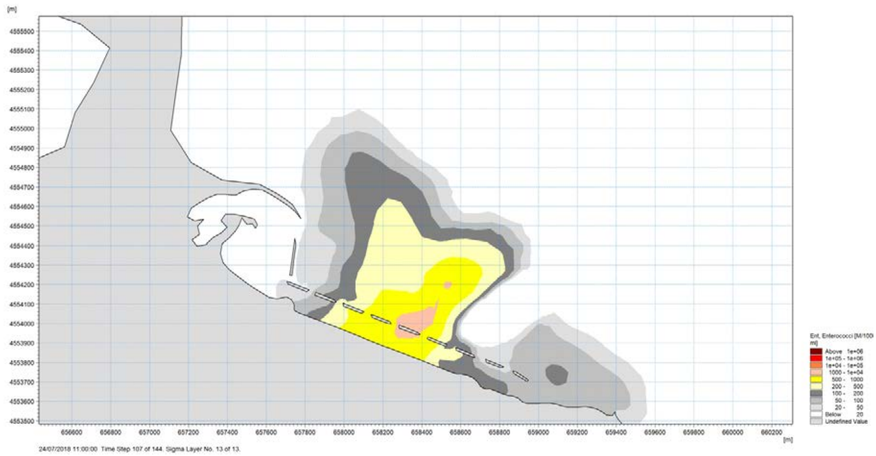

Figure 10 – Bacterial concentration plume at about 11.00 a.m. on July 24th, 2018 (12 hours after the opening of the sluice gates).

Figure 11 – Bacterial concentration plume at about 14.00 a.m. on July 24th, 2018 (15 hours after the opening of the sluice gates).

Figure 12 – Reconstruction of the geometry of the plume using the images taken by ARPA Puglia at about 8.00 a.m. of July 24th, 2018.

Conclusion

In the present study was simulated the dispersion of the turbidity plume and its bacterial content from the discharge of the emergency outflow *condotta Matteotti* in Bari, during and immediately after a heavy rainfall.

The simulation was performed by applying the MIKE 3 software, which combines the ECOLab module with the hydrodynamic model, in order to reproduce the effects of the short-term pollution on bathing water close to the emergency weir of the main drainage system. The results revealed a good comparability between the outputs of the model and the values measured in-field by ARPA Puglia during its ordinary monitoring activities, both for hydrodynamic and microbiological aspects. However, although the modelling application has provided a reliable picture, it must be noted that some of the features involved suffer a lack of information. For example, the deficit in the time and spatial coverage at local scale of the oceanographic data (wave and current parameters) should be overcome, and a high-resolution bathymetric model is needed for the area closest the coast.

In any case, the hydrodynamic model used to simulate the spreading of the bacterial concentration plume can be considered as a useful tool for the early warning system, in order to identify a possible short-term pollution and the subsequently mitigation actions (i.e. estimation of bathing closure period), as it was also suggested by the European Directive 7/2006/EC (Bathing Water -BWD).

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