Modelling of impacts from a long sea outfall outside of the Venice Lagoon (Italy)

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Introduction

A new Adriatic Sea outfall has been designed in order to discharge the wastewater after treatment in the Fusina plant, a large treatment plant located in Porto Marghera, the industrial area of Venice (Italy). The outfall is one component of the so-called Fusina Integrated Project, which is a key element of a Master Plan set up by the Veneto Regional Government in 2001 aiming to control and reduce the pollutant loads flowing from the catchment into the Lagoon of Venice.

The lagoon drainage basin extends 2,038 km² and has a population of more than 1 million inhabitants. The Master Plan aims to reduce the annual nutrients loads discharged to the lagoon in order to prevent the proliferation of macroalgae and the risk of environmental crises. During the past 10 years the nutrient loads were reduced by pollution control measures and a further decrease is planned to fulfil the quality targets.

The Plan also aims to reduce the concentration of micro pollutants in water and sediments to levels that ensure the protection of human beings from adverse effects associated with the consumption of fish and shellfish.

The Fusina Integrated Project deals with the most densely populated part of the lagoon watershed. It is based on simple concepts: use water twice, reduce sewage flow, treat all waters to higher standards, and discharge the residual outflow to the sea, away from the lagoon.

Scope of this study was to evaluate possible effects of the discharge on Adriatic Sea outside of the Venice Lagoon.

The dispersion and dilution of sewage from submerged sea outfalls involve a multitude of time and spatial scales. The technical approach to the study has been to use a 3-dimensional numerical model that simulates currents and transport of sewage and pollutants in the Adriatic Sea and in the coastal waters off Venice. Two versions have been used, each addressing part of the problem: a short-term model that describes in detail the plume trajectory and identifies impact areas during a limited period of time; and a coarser model that addresses longer-term effects during a one-year period. Finally the initial dilution in the near-field has been addressed using integral plume model.
Models and methods

The hydrodynamic model is based on DHI’s general 3-dimensional oceanographic model, MIKE 3 Flexible Mesh (FM). It is based on the 3-dimensional shallow water equations, extended with equations for turbulence and transports of salt and heat. It uses a flexible mesh based on horizontal triangles and a generalized sigma-level system in the vertical. The model is extended with modules for transports of tracer components and transport of suspended sediments. Transports and decay of E.Coli is described using the general ECOLab process interface. Details of the numerical methods and the processes can be found in /DHI, 2005/.

Figure 1. Model mesh used for the long-term model (right) and subsection of the short term mesh (left)

Hydrodynamic Model set-up
In order to obtain a realistic description of the circulation in the Venice Golf, the model domain covers the Northern Adriatic down to the Ravenna - Pula section. A smaller domain makes it difficult to get the correct dynamics of tides and currents along the coast in the Golf. The basic mesh is shown in Figure 1. The constraints of the mesh development are that the number of elements should be minimized while still providing a sufficient representation of the flow structure in the gulf. Further, due to the numerical solution method of the hydrodynamic equations, there is the constraint that the surface gravity wave can only cross one element during a time step. This means that if elements are small in deep waters the time step needs to be very small. Part of the mesh optimization is thus to adapt element sizes to water depths in order to achieve as large time step, and thereby fewer steps per simulation scenario.

Both the long-term and short-term models share the same domain size and boundary conditions, but differ in the number of elements and the resolution in the interest area.

The model is forced by elevations along the southern boundary, extracted from the archived results of the CVN Venice storm surge forecast model. For salinity and temperature boundary conditions are taken from climatological data (WOA). Wind forcing and atmospheric heat exchange are derived from the Piattaforma weather station, located 20km off Malamocco. Finally, fresh water inflows from the 11 largest rivers are applied.

Model verification
The model is calibrated and verified using tidal observations during 2002 along the coast, current measurements at the Piattaforma and temperature and salinity observations along the NW coats of
the Venice Gulf. In Figure 2 is shown an example of modelled and observed elevations and currents during a typical Bora period, characterized by winds from Northeast.

Figure 2 Example of model verification at the CNR Platform: Observed and modelled current speed and direction (upper), tidal elevations (lower mid) and observed wind speed and direction (lower).

Initial dilution

The outfall is planned to consist of a pressurized part crossing the shallow waters of the Venice Lagoon, a head tank located near the Malomocco Inlet and a diameter 1.4m steel pipe extending 10 km into the Adriatic Sea as indicated on Figure 3. The nominal discharge is estimated to be XX m$^3$/sec. The pipe will be equipped with a diffuser section, the specific design of which has not been
addressed. In order to reach an acceptable dilution at the surface, the initial dilution has been studied using simplified methods based on Cederwall’s empirical estimates. However, due to the spatial resolution of the numerical model, the actual dilution can not be resolved, thus in the numerical model, the outfall is described as a point source at the surface.

### Results

The analysis of the effects of the outflow was carried out by simulating scenarios representing historical meteorological and tidal conditions derived from observational data. Two types of scenarios were simulated representing short term scale (about 2 weeks of simulation) and long term scale (1 year), for different environmental aspects and parameters.

#### Short term analysis

The short term analysis was carried out considering the results of three scenarios representing typical meteorological conditions:
- from May 24 to June 5 2002, a period characterized by wind velocity always lower than 5 m/s, was used to evaluate effects in calm conditions;
- from April 8 (12.00 AM) to April 11 (12.00 AM) 2002, a period with wind speed around 15 m/s from north-east, was used to characterize bora conditions;
- From June 5 to June 8 2002, a period with wind speed between 10 and 15 m/s from south-east was used to characterize scirocco conditions.

These scenarios were applied to analyze different aspects related to the presence of the outfall:
- plume dispersion of a conservative tracer was analyzed to describe the location, the shape and the extension of the area influenced by the discharge;
- dispersion of Escherichia coli was simulated to evaluate possible impacts on bathing areas and mussel farming areas (Figure 3);
- Dispersion of suspended matter was simulated to evaluate possible impacts on bedrocks or mussel farming areas (Figure 3).

Figure 3 - Location of the new outfall, mussel farms and bed rocks in the coastal area next to the Venice Lagoon.
Due to density gradient the freshwater plume quickly moves from the sea bottom, where the outfall is located, to the sea surface. Therefore, highest values for conservative parameters are found at the most superficial simulation layer. Because of this, all the following considerations refer to concentration of parameters in surface waters.
For suspended matter the total sedimentation rate was also calculated and used in the evaluations.

Plume dispersion modelling results show under calm weather conditions a plume, characterized by a dilution factor lower than 2000 and confined in an elliptic area around the discharge point. This elliptic area has a major axis of 17-21 km (depending on the outflow rate) parallel to shore line and a minor axis of about 10-12.5 km (Figure 4).

*Bora* wind restricts the plume and moves it southwards, parallel to the coast. The area characterized by a dilution factor lower than 2000 is much smaller than in calm conditions (major axis = 9-12 km) and is located south of the discharge point as shown in Figure 5.

Under *scirocco* conditions, the plume is deformed but is once again confined in the vicinity of the discharge point, as shown in Figure 6.

Figure 4 - Short term scenario – average concentration in 24 hours of the conservative tracer in the surface layer, under calm conditions.
Figure 5 - Short term scenario – average concentration in 24 hours of the conservative tracer in the surface layer, under *bora* conditions.

Figure 6 - Short term scenario – average concentration in 24 hours of the conservative tracer in the surface layer, under *scirocco* conditions.
*Escherichia coli* results were simulated by considering a concentration of 5000 UFC/100 ml at the discharge point, as required in the definitive outlet design. The same three wind scenarios described for the conservative tracer were simulated. The results are shown in Figure 7. The shape of the distribution is oriented by the wind-driven currents, towards south-west in the case of *bora* wind and towards south-east in the case of *scirocco*. In the close vicinity of the discharge point the values vary in the range of 10-100 UFC/100 ml, then they rapidly decrease to values lower than 10 UFC/100 ml. Values lower than 1 UFC/100 ml have to be considered not detectable (experimental limit of detection); therefore in all meteorological conditions the effects of the discharge disappear within about 500 m from the discharge point. Bathing areas and mussels farming areas located in the vicinity of coastline are not affected by the presence of the discharge.

Figure 7 - Short term scenario – average concentration in 24 hours of *Escherichia coli* in the surface layer, under calm conditions (a); *bora* conditions (b), *scirocco* conditions (c).

Suspended matter results were obtained by considering a concentration of 10 mg/l at the outfall, as required by the definitive outlet design. This is generally considered a low concentration, but not negligible in comparison with background values for marine waters off-shore the lagoon of Venice which is between 2-8 mg/l (OBAS Interreg III Project – CNR-ISMA Italy), increasing from offshore toward the coast.

The area affected by a detectable increase of suspended solids (more than 0.1 mg/l) remains confined under all wind conditions within 1 km from the discharge point. This also excludes any effect on the mussel farming areas located close the coastline.

To evaluate possible effects on the bedrocks present in the area the suspended matter sedimentation rate was also computed for the different wind conditions. The results show that effects remain confined in an area in the vicinity of the outfall, within a radius of 2 km, therefore excluding possible effects on bedrocks.

**Long term analysis – trophic effects on water quality**

To evaluate the effects of the outflow on the water quality trophic aspects, long term simulation (1 year) was considered. Effects were evaluated as differences between the reference scenario (without discharge) and the discharge scenario, for main water quality parameters; simulations refer to year 2002.

At seasonal scale, differences during fall-winter period (October-March) and spring-summer period (April-September) were considered. Examples of results are shown in Figure 8 and Figure 9. Differences are presented in absolute values (mg/l).

Differences in concentrations are localized very close to the discharge point, while much lower effects are estimated for the marine area off shore of the lagoon of Venice. The magnitude of
differences is very small for all parameters: for total nitrogen (TN) a maximum increase of 5% of the reference value is estimated both in winter and in summer season. This increase is limited to an area of about 4 km². For total phosphorous the maximum increase of concentration is about 10% of the reference values. The maximum increase estimated for the dissolved fraction of nitrogen and phosphorous is 10% of the reference values. Seasonal concentrations of chlorophyll-a and dissolved oxygen do not show variations due to the presence of the discharge.

Figure 8 – Long term scenarios - Average estimated differences for fall-winter period between the reference scenario (without discharge) and the project scenario (with the discharge) for total nitrogen (TN) and total phosphorous (TP).

Figure 9 – Long term scenarios - Average estimated differences for spring-summer period between the reference scenario (without discharge) and the project scenario (with the discharge) for total nitrogen (TN) and total phosphorous (TP).

A scenario of peak outflow was also simulated to evaluate the effects on water quality trophic aspects. For a duration of seven simulation days the outflow was increased from 1.4 m³/s to 2.3 m³/s; then a linear decrease of the flow was considered for the next 10 days to return to a typical outflow of 1.4 m³/s. Examples of results are shown in Figure 10 that refer to the last simulation day
with peak outflow. Maximum variation of total nutrients (TN e TP) are still around 10% of the values of reference scenario but the area is larger. Anyway this enlargement only concerns the peak outflow period.

Figure 10 – Long term scenarios - Estimated differences during pick flow between the reference scenario (without discharge) and the project scenario (with the discharge) for total nitrogen (TN) and total phosphorous (TP).

Finally no relevant differences in oxygen profiles were evaluated due to the presence of the discharge, as shown for example in Figure 11.
Figure 11 – Dissolved oxygen profiles [mg/l] at some locations in the study area (Outfall – a); Oceanographic platform - b); Mussel farms -c). X axis = depth [m]; left Y axis = dissolved oxygen in absolute values [mg/l]; right Y axis = dissolved oxygen differences [mg/l].

Conclusions

Using a 3-dimensional numerical model that has the capability to describe both the detailed impacts of the sewage plume from a submerged sea outfall and the long term effects the influence of the discharge of treated sewage from the Fusina treatment plant has been investigated.

The main environmental and territorial issues are:

In the framework of the Integrated Fusina Project, the move of the Fusina WWTP outfall from the Venice lagoon to the Adriatic sea enabled to further reduce the pollutant loads discharged into the lagoon, thus contributing to its full environmental restoration.

The present study, investigating the impacts generated by transferring the residual pollutant load to the sea, proved that the new outfall location is also compatible with the preservation of the coastal environment. Short term impacts concerning the conservative tracer distribution, the concentrations of sediments in suspension and the concentrations of Escherichia coli were studied using a high resolution model, under different wind conditions. Results show no impacts on water quality with reference to coastal water activities like bathing and mussel farming. Also for longer term effects on water quality such as eutrophication-related aspects (nutrients, chlorophyll-a, oxygen), which were evaluated using a full one
year period, the results show the full environmental sustainability of the new outfall.

References

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**Photo and short CV of the main Author (max. 10 lines); short CV of co-authors (max. 5 lines)**

Dr. Ole Petersen, DHI Water & Environment has 20 years of experience in estuarine and coastal hydraulics. The fields of interest comprise hydrodynamics, stratified flows. He has co-ordinated and participated in development of hydrodynamic models with focus on two- and three-dimensional estuarine models. He has a substantial academic and research record. He has co-ordinated international research projects, acts as external examiner for Danish universities and as reviewer for several international journals.

Dr. Jacob Tornfeldt Sørensen has a scientific background in Physical Oceanography and Mathematical Modelling. Strong experience in oceanographic hydrodynamic modelling. Expert in data assimilation techniques and responsible for the design and implementation of data assimilation in MIKE 3 of hydrodynamic and bio-geochemical observations derived from in situ as well as earth observation techniques.

M. Sc. Anja Friis-Christensen graduated in Environmental Biology and has an extensive experience in modelling and analysis of water quality and eutrophication using the MIKE modelling systems. Has participated in major international projects.

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