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Integrated Modeling of the Sewer System and the Receiving Waters for the Island of Ischia

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Abstract

The paper describes a comprehensive feasibility study carried out to resolve a principal conceptual dilemma concerning the Ischia's (Italy) wastewater problem: Should the wastewater be treated and disposed on the island or should the concept of remote wastewater treatment on the Italian mainland be applied? The study was based on modeling of the impact from the continuous wastewater emissions and combined sewer overflows (CSO) on the water quality in the sea surrounding the island. The simulations were carried out by the application of integrated generic simulation tool - Integrated Catchment Simulator (ICS) - for addressing the environmental impact from urban catchments on the receiving waters.

The pollution loads from the present and future sewer network was simulated by use of a deterministic pollution transport model for urban drainage networks (MOUSE TRAP). This provided a detailed information on hydraulic and pollution loads at any point of interest in the island's sewer network. The highly variable pollution emissions from the wastewater system, together with the recipient dynamics (sea currents, wind, and tides) and the water quality processes in the sea (dispersion and fate of Coliform bacteria and dispersion and settlement of suspended solids) create a very dynamic situation concerning the impacts in the surrounding sea. Description of these effects required a 2-D hydrodynamic and water quality model (MIKE 21) to be setup for the waters around Ischia. ICS was applied in order to perform easy and consistent analyses of the entire system, facilitating the transfer of the urban pollution loads to the sea.

Simulations were carried out for the present situation and for alleviation schemes, including local wastewater treatment in the island's municipalities, centralised treatment in one large WWTP on Ischia, and with the transport of wastewater to mainland.

1. Introduction

The location of the study is Ischia, see figure 1, - a volcanic island in the Italian part of the Mediterranean. The island with approximately 50,000 inhabitants has developed a very intensive tourist industry, counting up to 150,000 visitors on peak weekends. This plays a significant role for the island's economy. The pollution created by uncontrolled emissions of untreated wastewater during the peak load periods has the most significant negative effect on tourism.

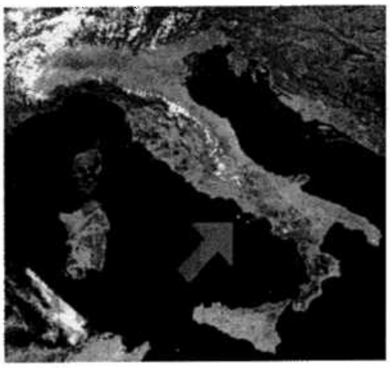


Figure 1 Location of Ischia

The wastewater problems take the form of continuous spills of untreated wastewater at or very close to frequented beaches and excessive combined sewer overflows during rainfalls. The existing wastewater treatment plants are outdated and non-functioning. These problems are caused by the disproportion between the structural, operational and technological configuration of wastewater systems on one side and the high seasonal loads on the other.

Both European and national laws require a much higher level of wastewater collection and treatment than currently takes place on Ischia. Furthermore, polluted beaches put the image of the island as a preferred bathing destination at stake with unpredictable economic consequences.

Loading of the wastewater system of Ischia is highly distributed in both space and time. This makes it impossible to study and evaluate the wastewater system performance without advanced modeling tools. The temporal and spatial load distribution has the following main dimensions:

- Expected population and load changes in the following years, see figure 3.
- Seasonal load variation due to the large tourist fluctuation – in the peak days during summer, there are 3-4 times more people on the island than during the winter, i.e. outside of the tourist season, see figure 2.
- Diurnal wastewater variation – hydraulic and pollution loads vary in wide limits during one day (approximately 1:4), which exposes the wastewater system to very different operational conditions during the night and day.
- Storm water runoff loads – the wastewater system of Ischia is partially combined, i.e. storm runoff is collected and evacuated using the same facilities as the wastewater. The amplitude and dynamics of storm runoff create very demanding situation for the drainage system, due to the problem of combined sewer overflows, which are potentially the most difficult source of environmental problems in future.

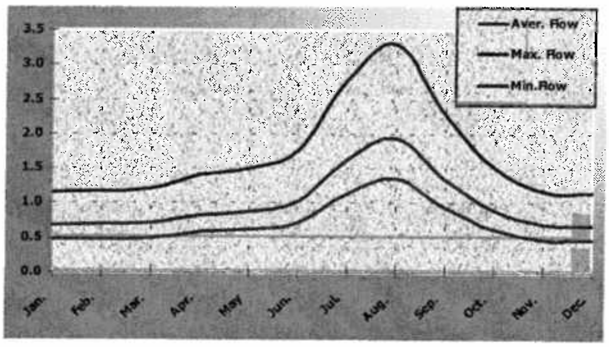


Figure 2 Expected relative variation of hydraulic dry weather load in the year 2025.

In addition to these elements of temporal load distribution, an important difficulty arises from the urbanisation patter and the topography of Ischia. The residential and tourist populations of Ischia are concentrated in six municipalities, each having its' own wastewater system. These have to be integrated into unique operational system based on identical functional criteria. The very rugged topography imposes important limits to the possibilities for the hydraulic integration of the system.

In the receiving water, the situation is not any simpler. The extremely variable pollution emissions from the wastewater system, caused by the variation of pollution and hydraulic loads, jointly with the recipient dynamics (sea currents, wind, tides) and the dynamics of relevant processes (bacteria and particle dispersion, bacteria decay, particle dispersion, etc.), create a very dynamic situation concerning the impacts.

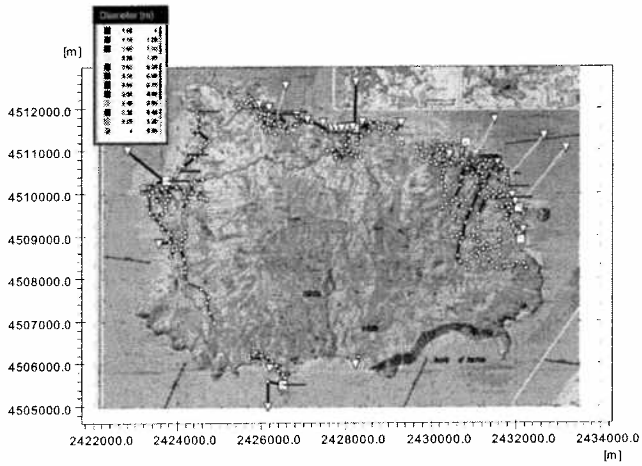
This underlines the need for an application of tools for the simulation of dynamic interaction between the sewers and the sea. The tools selected for the task are dynamic, deterministic numerical models, described together with the methodology in detail in the further text.

2. Modeling of the Urban Wastewater and Drainage System

The modeling approach

The model of urban wastewater and drainage system of Ischia has been developed on the basis of deterministic hydrodynamic and pollution transport model MOUSE TRAP (Garsdal et. al, 1994). The model has been setup to describe the surface runoff, the open channel flow, the pipe flow and the pollution transport in the sewer system.

The pollutants transport has been simulated in parallel with the hydrodynamics. The correct initial conditions in the network (flows, concentrations) for the events were created by a previous dynamic simulation of the diurnal dry weather conditions.



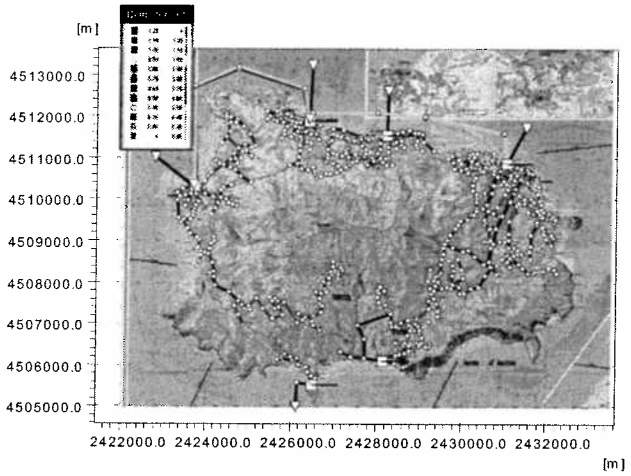


Figure 3 Models of the present (above) and future (below) sewer network

Selection of pollutants

Suspended solids and Total Coli have been considered as the most relevant for the evaluation of the environmental performance of the system. Hence, the study has focused on these two pollutants. The presence of suspended solids in the sea-water causes the loss of the sea-water transparency. Although the simulated concentrations in the sea are far from violating the EU Bathing Water Directive, the relative contribution of the wastewater discharges to the overall loss of natural sea transparency is an important indicator of the functionality of each of the simulated solution alternatives, under comparable loading conditions.

The sources of suspended solids are the wastewater and the surface runoff. The suspended solids have been simulated as conservative matter in the sewer network. However, removal of suspended solids in the treatment process has been simulated assuming that the outflow from the wastewater treatment plant is constantly exactly at the threshold level as prescribed by the EU Directive for Wastewater treatment – 35 mg/l. This is a very conservative assumption, and it is reasonable to expect that the proposed wastewater treatment plant(s) will normally achieve much higher level of treatment. The Coli bacteria, a micro-organism used as indicator for pathogens in wastewater, is the most important parameter for the evaluation of the bathing water quality. The simulation of Coliform in the sewer system has been based on the same principle as for the suspended solids, i.e. as conservative transport and a fixed removal (90%) in the treatment plant(s).

Quantifying the hydraulic and pollution loads

The urban pollution in Ischia is predominantly generated by the residents and tourists, as there are no significant polluting industries on the island. The pollution model is therefore based on the concept of "person equivalents" (PE) which includes all the people on the island and their domestic and professional activities. The unit pollution loads (PE/day) have been taken based on European experience, see Table 1.

Table 1: Unit pollution loads

Component	Unit	Load
BOD	g/PE/day	60
COD	g/PE/day	132
SS	g/PE/day	72
Total N	g/PE/day	12
Total P	g/PE/day	2
Bacteria Coli	x 10**9/PE/day	250

The total amount of pollution loads on the wastewater system from individual sub-catchments is calculated as multiple of the unit load and the population connected to the sewer. Since the MOUSE model operates with concentrations of pollutants in wastewater, rather than with pollution mass, these loads have been consequently converted into concentrations. In order to relax the pollution situation in the summer peak situation, the unit pollution loads for tourists have been reduced by 20%. Argumentation for such reduction is in the fact that pattern of behaviour and pollution emission for an average tourist (typically daily visitors) is different compared to resident population. For the computation of the pollution loads relevant for the dimensioning of the biological wastewater treatment processes, the peak loads have been further reduced by 10%, in order to account for the legal requirement which in the present case is linked to a maximum weekly load, and NOT maximum daily load.

Table 2. Summary of the total pollution loads collected by the wastewater system of Ischia in summer and winter seasons of the years 1996 and 2025.

Category	Unit	Year 1996		Year 2025	
		winter	summer	winter	summer
Population		53,529	174,216	67,951	199,618
Connected to sewer system		22,517	76,576	53,697	158,680
Equivalent number of PE		22,517	65,765	53,697	123,915
BOD	kg/day	1,351	3,946	3,222	7,435
COD	kg/day	2,972	8,681	7,088	16,357
SS	kg/day	1,621	4,735	3,866	8,922
Total N	kg/day	270	789	644	1,487
Total P	kg/day	45	132	107	248
Faecal Coli	count*10**12	5,629	16,441	13,424	30,979

2. Modeling of the Receiving Waters around Ischia

Model structure

For the modeling of the aquatic environment surrounding Ischia a fully hydrodynamic 2-D, depth average model has been setup (MIKE 21) including a description of the water quality. The calculation of the depth-integrated current is carried out in a two-dimensional computational grid with a horizontal resolution of 100 m. The horizontal extension of the model is 42*40 km having approx. 150.000 water points included in the HD calculations. The model bathymetry is based upon depths as provided in the electronic sea-chart.

Tidal forcing along the north western and south-eastern boundaries of the model is used to drive the circulation in the model area. As no measurements of tidal elevations are available, time series of tidal amplitudes are calculated from tidal constituents prior to the HD modeling. The four major tidal constituents, M_2, S_2, K_1, O_1, which constitute by far the major part of the tidal elevation signal are used for creating the model boundary tidal levels in the HD modeling. The time series of tidal levels used in the model are based on constituents from a station at Ischia. Introducing a phase shifting of two identical time series of tidal amplitudes at Ischia creates the time series for the two model boundaries.

The model area includes steep slopes extending seawards from the coastline reaching water depths of 1000 m. All water depths within the modelled area exceeding 30 m have been excluded and the model bottom is flat in the areas having a depth of 30 m. The flattening of the slopes is done to ensure that the model performs in a sound manner. A maximum depth of 30 m is applied as the salinity and –temperature boundary layer has a mean level of approximately 30 m in the modelled period. Thus the water column is reduced to the layer above the upper pycnoline.

Since no information is available from simultaneous current recordings, graphically displayed current recordings as well as other information about current measurements in the area are used in the calibration of the hydrodynamic model. The measurements show a clear tidal variation in Canale di Ischia, which it is attempted to reproduce in the hydrodynamic model. Calibration was done with the phase shifting and scaling of the tidal amplitude at the model boundaries.

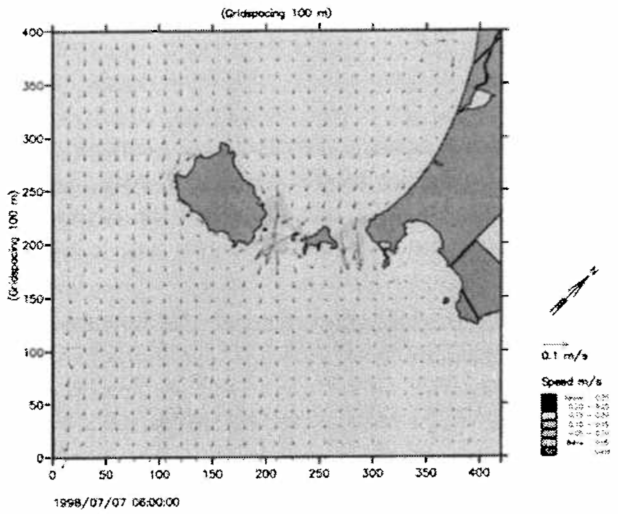


Figure 4 Layout of the MIKE 21 model

3. Water Quality Processes in the Models

Coliform and organic matter cannot be considered to be conservative i.e. without natural decay in the recipient. Hence, the die-off of Coliform and the degradation of organic matter has been modelled by a first order reaction. The mortality rate of Coliform organisms due to bacterial inactivation at 20°C, fresh water and darkness is estimated to 0.8/day. In the model the decay rate is set to 1.0/day as the main controlling parameters for bacterial decay (salinity, temperature and light intensity) obtain higher values in the modelled area than mentioned above. The degradation rate of organic matter is set to 0.1/day. The mortality rate of Coliform as well as the degradation rate of organic matter is probably slightly underestimated in most of the scenarios. This leads to a conservative estimation of the amount of Coliform and organic matter in the water. This is considered to be acceptable in the simulations as an overestimation favours the worst case scenario.

Modeling of the pollution transport and fate

The transport and spreading of pollutants in the wastewater loads is simulated using a lagrangian approach, where the particles are transported by advection in the two-dimensional flow field calculated by the HD set-up. In addition to the advection, the particles are dispersed as a result of random processes in two dimensions allowing settling and resuspension of particles as well as random horizontal dispersion. After release from the wastewater outlets the material is represented by single particles.

4. Modeling of the Interaction Between the Sewer System and the Receiving Waters of Ischia

Urban drainage and wastewater systems are often considered as three independent sub-sectors -collection network, treatment plant, recipient - and hence modelled and analysed individually. In the present study, the Integrated Catchment Simulator (ICS) has been applied to ensure an easy and consistent transfer for information in terms of time series of water and concentrations from the sewer model to the recipient model. The present ICS version is limited to single-event simulations, which is a restriction if a statistical base of the system functionality should be established. In principle, the "long-term" simulations involve some special provisions for the computationally "heavy" models as MOUSE and MIKE21. So the time-consuming dynamic simulations are carried out only during the periods of special interest – e.g. during rainfall events of interest.

The present ICS, which includes models for sewers, rivers, wastewater treatment plants and coastal areas. In the future ICS will be extended to include some other models, e.g. a distributed hydrological and groundwater model. Further information on ICS can be found in (Clifforde et. al 1998) or (Tomicic et. al, 2000).

5. The Impact from the Sewers on the Recipient

The wastewater system has been modelled for the present development and loading conditions (1996). This system configuration represented a reference situation and served for the identification of the scale of the existing pollution problem at present and for the comparison of the achieved results after the implementation of the proposed solution schemes. The future situation has been modelled for three different development strategies which reflect different solution philosophies, as discussed and studies already for many years. These development strategies include:

- local wastewater treatment in municipalities,
- centralised wastewater treatment on Ischia,
- transport of wastewater to WWTP Cuma, on the Italian mainland near Naples.

The three alternative solutions have been designed for approximately identical level of environmental protection. While there will always be some differences in dry weather operation, due to the different position of the WWTP's outlets, operation under wet the weather conditions, i.e. emissions associated with storm runoff would remain the same, assuming the system operating after design specifications.

In dry weather operation, permanent outflow from the WWTP outlet(s) would remain the only source of pollution from the wastewater system. Assuming the implementation of very high standards for the waste water treatment and the disposal of the effluent through relatively long sea-outfalls on a large depth (approx. 50 m), operation of these outflows cannot be compared and associated with the present situation where, although discharging much smaller volumes than predicted in future, these outfalls are sources of serious degradation of the local sub-marine environment. The noticeable impact of the WWTP effluent will be localised to the closest vicinity of the outfall. In the case of solution with the wastewater transport to the WWTP Cuma, there would not be any effluents on Ischia at all. For the wet weather operation, all solutions will provide the following (identical) functionality:

- Full wastewater treatment for the flows 2 to 6 times dry weather flow (daily average), and disposal of the effluent through deep-sea outfalls. The actual ratio of the treated flows depends on the season. The smallest ratio is obtained during the peak summer loading. The implementation of the treatment capacities may be programmed in steps, both what concerns the treatment capacity and the treatment level.
- Disposal of all untreated flows (above the actually installed treatment capacity), up to 5-15 times dry weather flow (daily average), through deep-sea outfalls. The actual ratio of the treated flows depends on the season. The smallest ratio is obtained during the peak summer loading. Before disposal, excessive flows are subject to fine screening and mechanical separation of floating solids.
- All flows above 5-15 times dry weather flow (daily average), are disposed in a controlled way at selected locations as overflows into the shallow water. Before disposal, overflows are subject to fine screening and mechanical separation of floating solids.

All this implies that the sewer collection and transport network is identical for all three solutions. The network should be designed to provide sufficient flow attenuation capacity for the storm runoff, so that the flows at the inlet to the WWTP exceed the controlled evacuation capacity only for the programmed short rainfall (min. 20 mm total depth). This can be achieved by the provision of storage for storm runoff and active real-time control of the flows in the network.

Simulated loading scenarios

The simulations have been done for three different events (dry weather, 30 mm and 2-year rainfall) and for maximum summer wastewater load (August). The simulation with the minimum winter wastewater load has not been considered as relevant for the environmental performance assessment, since it would result in smaller pollution occurring outside the bathing season. However, performance of the system under the minimum load has been found relevant for the hydraulic design of the collection network and the underwater pipelines, where some minimum flow velocities must be maintained, in order to prevent sedimentation and related problems.

Environmental impact on aquatic environment

It has been shown that in the present situation wastewater system of Ischia appears as the largest single pollution source. This is equally the case in dry weather periods, where it creates a strong background pollution of coastal waters, which results in relatively unfavourable bathing conditions on many of the Ischia's beaches, as well as after each rainfall, when the pollution, particularly in the form of suspended organic and inorganic matter, overwhelms local waters for a period of time.

According to the study results, the designed solutions will dramatically reduce the negative impact, both in dry weather and during rainfalls. An example of the simulated bacteria concentrations in dry weather in the waters around Ischia can be seen in figure 5.

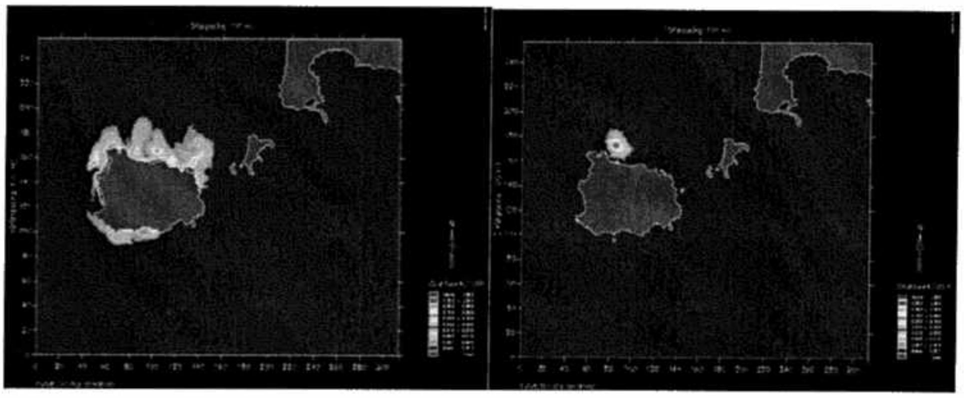


Figure 5 Simulated Coli bacteria in waters around Ischia in dry weather at peak summer loads (left: present situation, right: centralised wastewater treatment)

Another example (figure 6) presents time series of the simulated bacteria counts after a 30-mm rainfall, for the present situation and for the three studies alleviation schemes at a selected location.

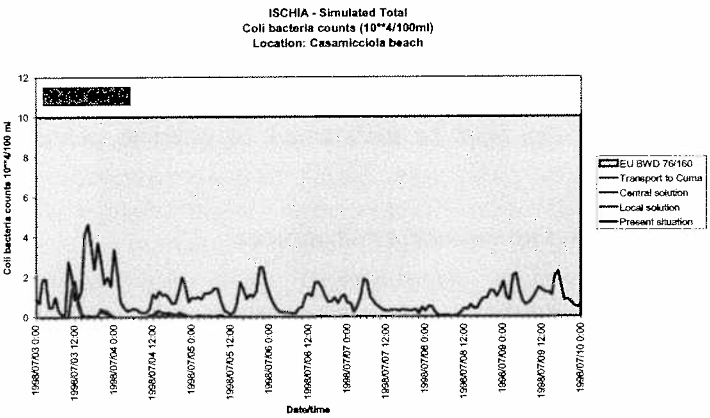


Figure 5 Example of the simulated time series of Coli bacteria counts at the selected location (Casamicciola beach) for the present situation and the three alternative solutions, for a 30-mm rainfall.

6. Conclusion

The presented study has demonstrated a tremendous potential of integrated modeling of urban drainage and receiving waters in resolving complicated conceptual dilemmas concerning comprehensive urban wastewater solutions. While each individual model contributed to a detailed description of the relevant processes in the respective sub-systems, thus enabling an in-depth analysis of the functional and operational situation, the integration of the models has allowed a cost-effective "what-if" environmental impact analyses. The latter has contributed to a more reliable selection among technically feasible solutions and has improved the public acceptance of the proposed solution by providing vivid images of the expected environmental improvements and the differences between the competing alternatives.

7. References

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