Wastewater concentration dynamics during joint operation of several submarine outfalls

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Abstract

It is a frequent case that larger coastal towns have several wastewater submarine outfalls in relatively close vicinity. Thus, it happens that acceptable wastewater concentrations at a particular outfall affect the concentrations in the vicinity of another outfall and may change them considerably. This refers in particular to the situations where the action of sea currents is present. Theoretically, linear superimposition in the spatial and temporal sense can be assumed. In this work an attempt was made to determine it by means of a physical model.

On a distorted physical eco-hydraulic model the discharge of wastewater during parallel operation of three outfalls of different capacity and length designed for implementation within the framework of Split MEIP (Municipal Environmental Infrastructure) was modelled. The model was tested under the conditions with and without the presence of sea currents and under the assumption of vertical stratification absence.

The spatial way of the effluent concentration propagation was researched, and the effluent concentrations during separate operation of each particular outfall and their joint operation were measured. Three types of tracers were used as effluent in order to measure the concentrations and visualise mixing, i.e. flow.

1 Introduction

The city of Split is situated in the southern part of Croatia. With a view to find out a more acceptable ecological solution of the Split city sewage system, the implementation of two new submarine outfalls (I,II) is planned in addition to the
already existing one (III). The flows, diameters and lengths of the outfalls are given in Table 1, and their locations are shown in Figure 1. The borders of the area covered by the physical model are also indicated in Figure 1.

![Map showing submarine outfalls](image)

**Figure 1**: Locations of the submarine outfalls (I,II,III) of the city of Split.

**Table 1**: The lengths, diameters and flows of the outfalls

<table>
<thead>
<tr>
<th></th>
<th>Length (m)</th>
<th>Diameter (mm)</th>
<th>Flow (l/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>2750</td>
<td>900</td>
<td>860</td>
</tr>
<tr>
<td>II</td>
<td>1750</td>
<td>400</td>
<td>120</td>
</tr>
<tr>
<td>III</td>
<td>1350</td>
<td>1000</td>
<td>1250</td>
</tr>
</tbody>
</table>

2 Oceanographic data

In the past ten years, several oceanographic investigations have been done in the region of sea waters belonging to the city of Split. All these investigations have proved a high assimilative capacity of these waters regarding the disposal of adequately treated municipal sewage wastewater. In addition, the investigations have also shown the existence of conditions favourable for designing of submarine outfalls, if the regulations concerning the maximum allowable concentrations of pollutants in recreation zones are obeyed.
The measurements of currents [1][2] simultaneously done on several locations in the region of sea waters of the city of Split have shown that there is a dominant E-W direction along the whole vertical profile of the water column, and that the characteristic magnitudes range between 1-10 \( \text{c} \cdot \text{m} / \text{s} \) in the situations without wind. The maximum recorded magnitudes of currents within the surface layer amounted to 60 \( \text{c} \cdot \text{m} / \text{s} \). During the summer season the most frequent is the wind from the NW direction, and in the periods of its intensive activity there is temporary local movement of the surface layer in the direction of east. During the winter season the most frequent are the winds from the NE and SE directions. In the periods of strong wind from the NE direction there is local movement of the surface layer in the S-N direction, whereas in the periods of strong wind from the SE direction there is an intensive movement of the surface layer in the E-W direction. The E-W direction and a magnitude of 10 \( \text{cm} / \text{s} \) were selected for the currents generated on the model.

3 Hydraulic model

3.1 General

While making the physical model, the interests of primary importance were reproduction of the form of the pollution cloud and the direction of water/effluent mixture transport in typical hydrodynamic conditions of sea currents in the region of the sea waters of the city of Split. The principle of the analysis involved the checking of the effluent hydrodynamic dispersion and dilution within the pollution cloud, and tracking of its motion towards coastal recreation zones. In this way the analysis of the suitability of the selected locations of submarine outfalls regarding meeting of the criteria prescribed for waters used for recreation purposes was enabled.

Generally, modelling of effluent discharge from submarine outfalls is quite complicated if taking into account the fact that the effluent can disperse as a result of the activity of various mechanisms, and although one process may be dominant, in some cases several of them may have a significant influence on the final image of effluent motion. Theoretically speaking this process has been described with advection/diffusion equation, within determination of some equation parameters could be very complicated and often followed by high cost of field examination.

While making the model and selecting the laws of comparison, attention was paid to the identification of hydrodynamic mechanisms characteristic for the zones at distances greater than 300 diameters of the diffusion nozzle. In the closer zone, the dominant role in the mixing process is played by the roughness and configuration of the bottom, and possibly by the coast line, and the discharge of substances is a consequence of sea currents. The modelling of this process is done under the same conditions that are valid for open channels, whereas on the model it is necessary to satisfy Froude's Law of Comparison, Reynolds number
should be greater than the critical one, and it is also necessary to realise proper modelling of losses due to roughness. In the farther zone, regional spreading of pollutants happens, and the discharge is dominantly influenced by diffusion and dispersion due to sea currents and wind. The mixing at great distances from the diffusion nozzles is caused by secondary vortices and three-dimensional distribution of velocity fields.

In accordance with the above given considerations, a horizontal scale 1:1500 and distortion 8 were selected, and additional artificial roughening of the bottom was introduced in order to achieve Reynolds condition of similitude for open channels.

With the aim of determining a really possible unfavourable influence of outfalls on the quality of sea water, uniform distribution of temperature along the vertical profile was simulated on the model. Such temperature profile matches the winter period. In this way the thermocline that is formed during summer months was not taken into account. It prevents (impedes) the effluent from rising to the sea surface, which means that the results obtained on the model are on the safer side concerning this aspect.

Also, on the model discharge of an ideal tracer, i.e. tracer that does not change its total mass with time, was modelled. However, as the most relevant indicators of sanitary contamination are microorganisms that die relatively quickly after being released into sea water, the distribution of their concentration, i.e. total dilution will be much more favourable than those given in the results of this work that takes into account only dilution due to hydrodynamic dispersion in the sea. Similar decomposition processes also happen with a number of other organic waste materials.

It was also taken that the density of the effluent is approximately equal to the sea density.

3.2 Specific features of the physical model and measurement methodology

The physical model refers to the region of sea waters belonging to the city of Split with a total length of about 21 km and a width of about 5.5 km (see Figure 1).

The model is made of a solid material with a plotted raster per 1 km and appropriate bathymetry having an accuracy of ± 0.5 m compared to the full-scale one.

The depth of water on the model enabled only the analysis of non-stratified flow. As mentioned in Chapter 2, such situation (although characteristic for the winter period when the issue of sea water quality becomes less important) was defined as critical regarding the operation of submarine outfalls.
Since the most frequent currents are from the E-W direction and have magnitudes of 10 cm/s, this very situation was produced by means of a closed hydraulic circuit with pumps. The problems related to the generating of two-layer flow and boundary conditions on the model resulted with the selection of the model analysis for the cases without the action of wind, while the selected magnitudes of the currents corresponded to those with the presence of wind action.

The sea currents on the model were obtained by means of pumps and a specially designed system of perforated pipes with a number of silencers. The hydraulic scheme for the making of sea currents on the model and the formed velocity vector field of the sea currents at a depth of 20 m are shown in Figure 2. Thermocline occurs at depths of about 15 m.

The three earlier mentioned submarine outfalls (I, II, III) are built into the model. They are made in an appropriate scale and are similar to the already existing outfall and those planned by the project, and are connected to the system for effluent dosing.

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**Figure 2: Hydraulic scheme of the model.**

On the model three types of tracers were used: permanganate, water colour, and potassium-iodide. Permanganate and water colour were used for the visual checking of the cloud motion, i.e. for the quantitative analysis of the measurement of the concentration change in space and time. The concentration of potassium-iodide can be relatively easily measured with a satisfying accuracy by means of ion-selective electrodes. Based on these data, the concentration, i.e. dilution can be calculated. The maximum dilution measurable with ion-selective electrodes is $10^4$ and the measurement enabled making of isolines of relative concentrations of $10^{-4}$. The tracer used during the experiment was prepared so that water and one of the tracers for the visual checking (permanganate or water colour) were added into the container. Into a known quantity of such mixture potassium-iodide was added. Since the solution of potassium-iodide has greater
density than water, for the experiments in which it was important that the tracer had the exactly the same density as water a certain amount of alcohol was added. Thus, it was possible to obtain the same density of the tracer and the fluid in the model. Alcohol was not added in the cases when permanganate was used because that would cause tracer segregation. Ion-selective electrodes indicate selective response to a certain ion present in the solution. The potential of an ion-selective electrode logarithmically depends on the activity of the ion to which the electrode is selective and can be shown by the Nernst equation (1):

$$E = E^\circ + \frac{2.303 RT}{zF} \log(a)$$

(1)

where:

- $E$: potential of the electrode
- $E^\circ$: standard potential
- $R$: general gas constant (8.314 J/Kmol)
- $T$: temperature (in °K)
- $z$: ion charge (with sign)
- $F$: Faraday’s constant (96 485 C/mol)
- $a$: ion activity

The main part of every ion-selective electrode is its membrane that is responsible for sensitive and selective recognition of a certain ion type.

### 3.3 Measurement results

The horizontal transport of the coloured tracer was tracked by a video camera, while the concentration was measured in a number of points by means of conductivity meter. The results of the measurements in the form of isolines of the relative concentrations obtained by the measurements on the hydraulic model after 72 hours of joint and individual continuous operation of the submarine outfalls with the action of sea currents having a magnitude of 10 cm/s in the E-W direction are given in Figure 3.

It was observed that in the case of the least favourable scenario (72 hours of continuous simultaneous operation of all the three outfalls with stationary sea currents of the E-W direction having a magnitude of 10 cm/s, absence of bacterial decomposition) there was substantial dilution of the tracer concentration in the regions close to recreation zones (300m from the shore), where the values of 0.01% of the initial effluent concentration were recorded. The values of the relative concentrations on the control profiles 3, 4, 5 (3000m in width and 1500m apart) for the joint operation of all the three outfalls and for the operation of each particular outfall are given in Diagrams 1a-1c. In the same diagrams the values of the relative concentrations during individual operation of each outfall are also given.
Figure 3: Isolines of tracer concentration after 72 hours of continuous effluent discharge into the velocity field of currents of 10 cm/s magnitude in the E-W direction.
Diagrams 1a,b,c: Values of the relative concentrations on the control profiles for the cases of individual and joint (integrated) operation of three submarine outfalls, and comparison with the relative concentrations obtained by linear summing on profiles 3,4,5.
It can be observed in Diagrams 1a-1c that the position of the maximum relative concentration obtained by linear summing of the concentrations of individual outfalls does not fully match the spatial position of the concentration maximum during the integrated operation of the outfalls. Also, the deviation of the maximum value of the linear sum of individual relative concentrations from the maximum value of the relative concentrations obtained during the integrated operation of all the three outfalls can be observed in the diagrams. The width of the effluent cloud in the direction perpendicular to the current direction, and defined by the isoline of the relative concentrations of $10^{-4}$, for the case of the integrated operation of all the three outfalls is greater than the width of the effluent cloud that would be obtained only by linear summing of the relative concentrations during individual operation of the submarine outfalls. This is due to the increase of concentration at the places of the effluent discharge from individual “downstream” outfalls during the joint operation of all the three outfalls, and due to the intensification of dispersion-diffusion processes.

4 Conclusions

On a distorted physical hydraulic model the discharge of wastewater during parallel operation of three outfalls of different capacity and length was modelled. The model was tested under the conditions with the presence of sea currents and under the assumption of vertical stratification absence.

The spatial way of the effluent concentration propagation was researched, and the effluent concentrations during separate operation of each particular outfall and joint operation of all outfalls were measured. Three types of tracers were used as effluent in order to measure the concentrations and visualise mixing, i.e. flow.

The results are presented in the form of diagrams of tracer spatial propagation. The position of the maximum relative concentration obtained by linear summing of the concentrations of individual outfalls does not match the spatial position of the relative concentration maximum during the integrated operation of the outfalls. Considerable deviation of the maximum value of the linear sum of individual relative concentrations from the maximum value of the relative concentrations obtained during the integrated operation of all the three outfalls is also observed. The effluent cloud defined by the boundary isoline of the relative concentrations of $10^{-4}$ for the case of the integrated operation of all the three outfalls occupies a greater area than the one obtained by the linear summing of the relative concentrations during individual operation of the submarine outfalls.

It is concluded that for the designing of a new outfall in the vicinity of an existing one it is not possible to define precisely their influence on each other by linear superimposition, but is necessary to investigate their joint operation on a 3D turbulent mathematical or physical model.
References


