USE OF HYDRAULIC MODELING FOR RIVER OIL SPILLS. 2. INFLUENCE OF RESPONSE METHODS ON TRAVEL TIME IN A CASE STUDY

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Lucrarea prezintă un studiu de caz al unei poluări accidentale cu petrol produsă pe un râu. Accidentul a fost monitorizat şi s-au aplicat măsurile de urgenţă specifice unor astfel de situaţii. Pentru modelarea curgerii în spaţiu şi timp, s-au efectuat calcule hidraulice pe sectorul analizat. Compararând timpii de parcurs ai frontului peliculei petroliere obţinuţi din calcule şi măsurători, s-a evidenţiat eficienţa metodelor de intervenţie aplicate pentru limitarea poluării. De asemenea s-a analizat modul în care raportul dintre viteza calculată şi cea maximă dintr-o secţiune, poate fi utilizat pentru prognozarea timpului de parcurs în eventuale cazuri de poluări accidentale ulterioare.

Present paper presents a case study of accidental oil spill on river. The accident was monitored and response actions were taken. A 1D hydraulic model was set up and calibrated to reproduce the flow in space and time. Computed travel time was compared with the observed travel time of the oil slick leading edge and conclusions were drawn on how the response methods delayed slick propagation. An analysis was also made on how the ratio between computed velocity and maximum velocity in a cross-section may be used for prognosis of the travel time in possible future cases of oil pollution.

Keywords: river oil spill**,** travel time**,** HEC-RAS, leading edge, oil slick, oil pollution accident, response methods

1. Introduction

As it was shown in the first part of this paper, *"Use of 1D hydraulic modeling for oil spills on Rivers. 1. Travel time computation for quick response"*, knowledge of the physical-chemical processes and hydrodynamic parameters is indispensable in order to predict the position, spreading, and characteristics of the oil slick in time and space.

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Various methods are used today to limit and clean contaminated waters from hydrocarbons after accidental spills. There may be containment, or recovery methods, the former being more effective in marine than in riverine environments. Many papers deal with control and cleanup methods, as well as with recommendations and contingency plans for emergency cases [1], [2], [3], [4], [5].

After containing the slick with mobile booms or floating barriers, usually the oil is removed by mechanical methods and transferred to a storage tank. The floating barriers may be made of plastic, metal, straw, or other materials that are commonly placed across the river [6].

By spreading or dispersing certain chemicals or dispersants over the oil slick dispersion rate increases through chemical processes. The role of these chemicals is to disperse the oil into the water column, so that much less remains at the surface, where it could affect beaches and riverbanks [6]. In this case pressure water jets are used to wash the remaining oil from the shore/banks.

Oil recovery from water surface may be made with certain devices such as: skimmers, conveyors that use absorbent polypropylene, minicollectors, vacuum tanks and vacuum pumps [7].

Another response method is in-situ burning, after containing the slick with floating barriers. The method is applied only to limit situations (as the pollution is transferred from water to air), in which the slick is thick enough for the oil to burn [2].

Use of absorbents (powder, pads, socks, blankets, pillows) is one of the most efficient removal methods in case of reduced spilled quantities. It is however preferred the use of biodegradable absorbents, as they do not affect the aquatic ecosystem [8].

Natural cleanup is the method „applied" by nature when meteorological conditions (storms, strong currents, waves, wind) are favourable to pollutant dispersion.

In Romania, even though the accidental oil spills produced on rivers are more frequent than the ones happened on sea, it has not been developed a specific clean-up system. According to case, combined methods are used such as: straw barriers, temporary earth dams, absorbents, and in-situ burning.

To make quick decisions in applying these methods one must have information on pollutant, as well as data regarding hydrology, meteorology and water use for the affected reach and period of time in question.

2. Case study

As a case study it was considered the accident happened in July 2002 on Prahova (a tributary of Ialomiţa) and Ialomiţa rivers, Romania, during a flood event. The pollution started at Brătăşanca, where an under passing oil pipeline

was broken by boulders at an eroded site and a considerable amount of oil was spilled into the river. During the next four days, the pollutant plume was transported downstream to Ialomiţa up to Slobozia and finally Ţăndărei, along a 290 km distance. Several straw barriers were placed across the river along the studied reach in order to retain the oil slick.

A 1D hydraulic model was developed with the help of River Analysis System code (HEC-RAS) [9] for the entire reach, taking into account the main tributary of Prahova – Teleajen river, (Fig. 1). The geometry of the model was built up with the help of 45 cross-sections (including floodplain) whereas hydrologic data during this period was collected from the 8 gauging stations along the entire reach (Fig. 2).
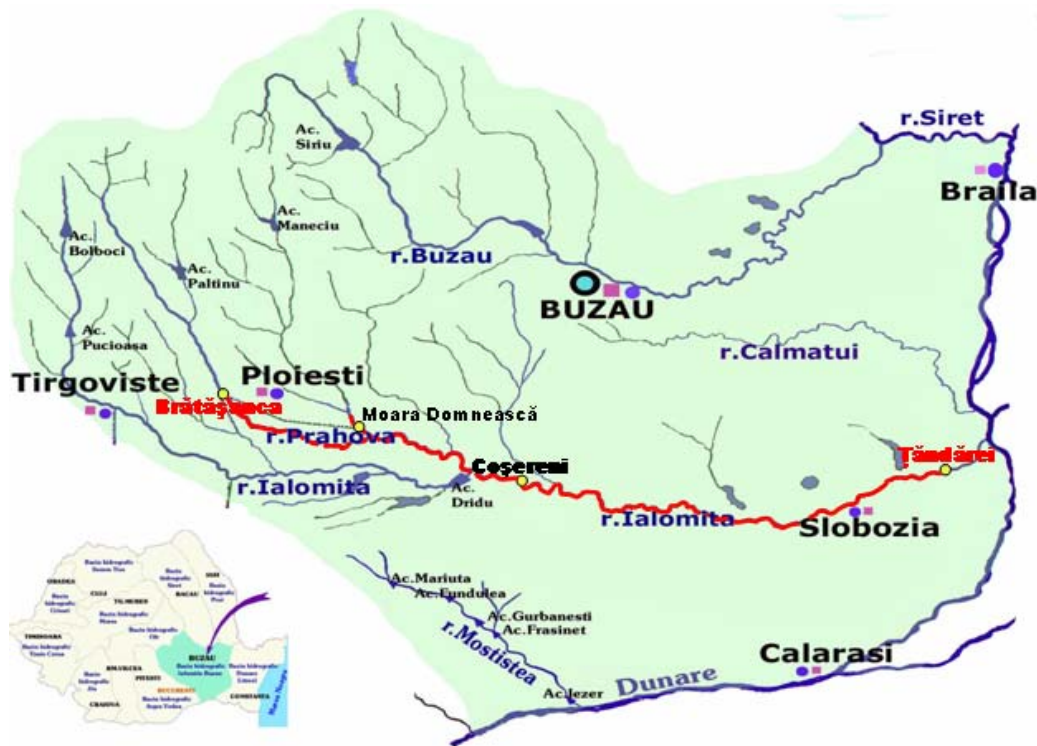

Fig. 1 Polluted reach (290km) along Prahova and Ialomita rivers, for which the hydraulic modelling was performed

The daily mean values of discharge (time step of the approximated hydrograph was taken to be one day) were considered to perform steady flow simulation under the mixed (subcritical and supercritical) regime.

3. Accident monitoring and control methods

The oil spill was monitored during the entire period of time: measured values of velocities, discharge, travel time of the oil slick leading edge, and concentration of extractible fractions.

First time the oil slick was seen at approximately 65 km of the pollution source. Its colours were between light brown and black, which correspond to thickness values between 1 mm and 10 mm. Approximate volume of spilled oil (18 t) was estimated on the basis of mean slick thickness (5 mm) and dimensions (length – about 8 km and width – about 50 m).
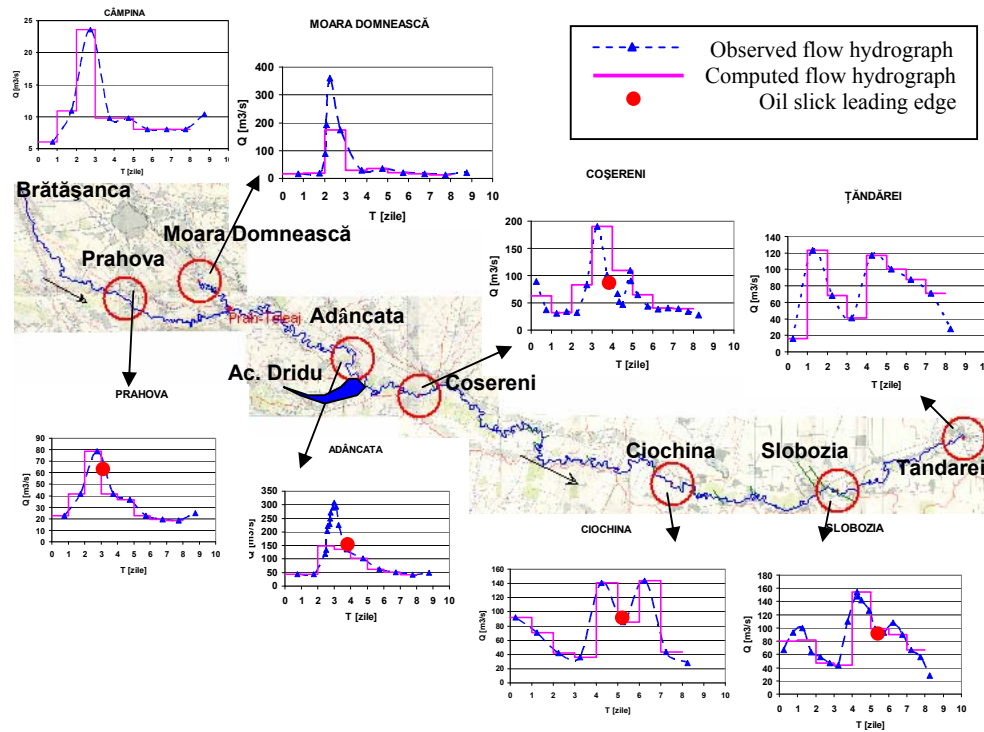

Fig. 2 Flow hydrographs in the gauging stations from Prahova, Ialomita and Teleajen. Position of oil slick leading edge is marked on the hydrographs

In five of the cross sections situated downstream the confluence with Teleajen river (Brazii, Adancata, Cosereni, Manasia si Buiesti) straw barriers were placed. They succeeded in retaining an important quantity of the spilled oil from the water surface. However, it is difficult to apply this type of containment method in a short time and to maintain it for several days on rivers with considerably velocities and width. Biodegradable and absorbent materials (Peat Sorb) were also

used, and they were very efficient for the thin slicks that could not be retained by the barriers.

4. Hydraulic model

The code used to build up the 1D hydraulic model is made by Hydraulic Engineering Centre (HEC-RAS), and relies on difference finite method: standard step procedure for steady flow simulations and implicite numerical scheme for unsteady flow simulations [9].

Cross-section interpolations at a maximum distance of 5 km were made to increase spatial refinement. The following boundary conditions were used: a rating curve downstream and mean daily values of discharge – upstream (Fig. 3). Also, discharge sources or sinks in gauging stations were considered in order to meet the continuity equation for each time step (day).
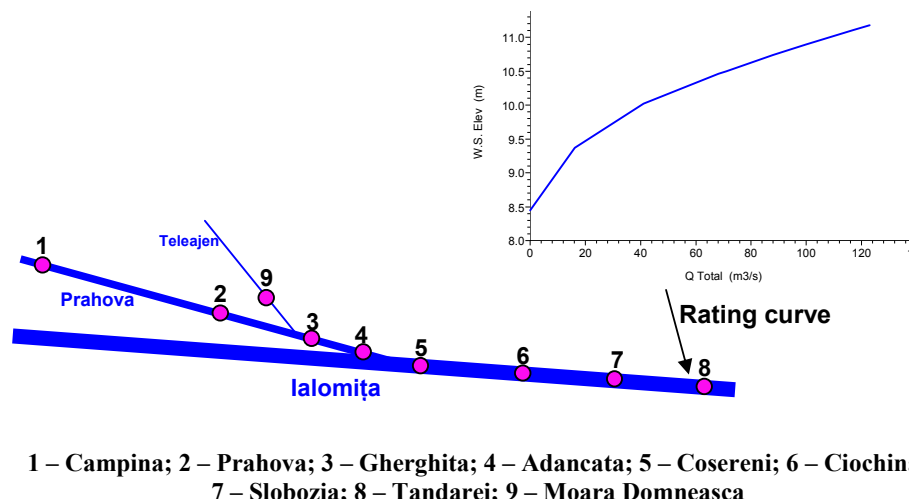

**1 – Campina; 2 – Prahova; 3 – Gherghita; 4 – Adancata; 5 – Cosereni; 6 – Ciochina;
7 – Slobozia: 8 – Tandarei: 9 – Moara Domneasca**

Fig. 3 Schematic boundary conditions

5. Results

The Manning roughness coefficients were calibrated on water stage values measured at gauging stations [10]. Maximum obtained absolute errors are of ± 30 cm whereas relative ones (with respect to depth) are of ± 25% (Fig. 4). Considering the scarcity of data regarding the stage and discharge values and also the use of steady flow simulations to describe a flood event, these errors may however be accepted. Values of calibrated roughness are presented in the Table 1.

The travel time was computed from the cross section mean velocity and distance with the help of the hydraulic model. Its dependence on distance was fitted with a regression line ($R^2 = 0.994$) in Fig. 5.
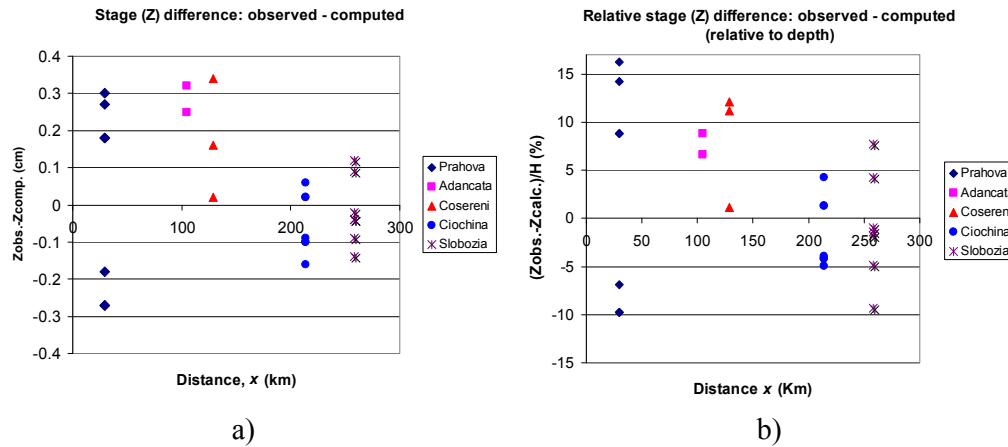

Fig. 4 Absolute (a) and relative (b) errors between observed and computed stages

Table 1

The calibrated roughness along the three main river reaches

River	Reach	Main channel Manning's Roughness Factor n (s/m$^{1/3}$)
Prahova	Bratasanca-Prahova	0.06
	Prahova - Adancata	0.045
Teleajen	Sicrita-Moara Domneasca	0.0462
Ialomița	Cosereni-Alexeni	0.045
	Ion Roata-Cazanesti	0.04
	Ciochina-Slobozia	0.022
	Slobozia-Tandarei	0.02

On the same chart were shown the values of real (observed) travel time of the oil slick leading edge along the studied reach, highlighting the cross-sections where retainment response actions were taken.

6. Conclusions

The slope of regression line fitting the observed values of travel time is bigger for the reach situated downstream the junction with Teleajen tributary than

for the upstream reach. This shows a decrease of the cross-section maximum velocity due to the retaining methods applied downstream Brazii location.

The difference between computed travel time and the observed one, downstream the first cross-section where straw barriers were placed, proved to have a constant value of approximately fourteen hours (Fig. 5).
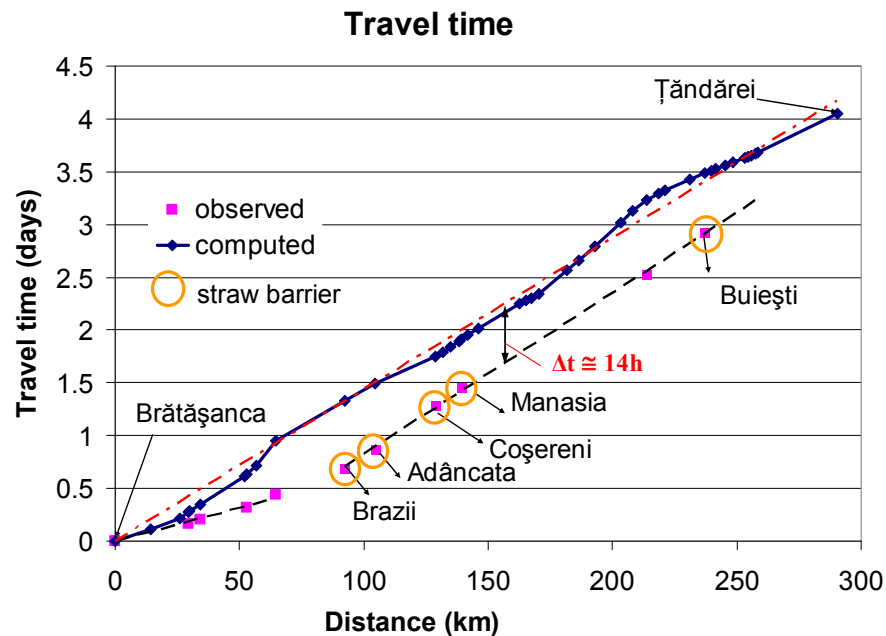

Fig. 5 Computed versus measured travel time. Influence of straw barriers on observed travel time values

As it was presented in the first part of this study, the travel time from the hydraulic model, T_c, is computed with the cross-section mean velocity (V_c). On the other hand, the measured travel time of the oil slick leading edge, T_r, depends on the maximum velocity (V_r) in a cross-section (which is supposed to be at the water surface). The ratio of these two velocities, $\alpha = \dfrac{V_c}{V_r}$ was calculated for the cross-sections where no control methods were applied, resulting an average value of $\alpha = 0.63$. The same value characterises the ratio of travel times, which means

$$T_r = T_c \cdot \frac{V_c}{V_r} = T_c \cdot 0.63 \tag{1}$$

Previous result may be applied in another possible oil spill accident along the same river reach and for similar discharge ranges to predict the arrival time of oil slick leading edge in a current cross section.

For other discharge ranges, predictions regarding real travel time may still be made for the same river reach on the basis of known ratios $\frac{V_c}{V_r} = f(Q)$. This means, one has to have previous measurements of maximum velocity (V_r) and their corresponding computed velocity (V_c) (with the hydraulic model) at gauging stations, for different values of discharge ranging from low flows to high flows (at least three, for example: 100 years, 50 years and ten years or annual flood events).

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