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The IRMA concept applied to River Cetina and Split catchment

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Integrated coastal zone and river basin management systems are being developed to meet important societal needs such as the sustainable development of coastal areas, the exploitation of their resources and the protection of the coastal environment. The sustainable development of coastal areas depends on the quality of the marine environment. In this context, the ADRICOSM project (ADRIatic sea integrated COastal areaS and river basin Management system pilot project) has developed an assessment/forecasting system that enables policy decisions to be taken in a modern and efficient way. The integrated approach imposed by the EC's Water Framework Directive has been validated in a pilot area located in Croatia that includes all the main components responsible for pollution generation and transportation: urban watershed, river basin and coastal area. An integrated model has been developed combining different tools to simulate the hydraulic and waterquality performance of the overall system. This model has then been used to forecast the benefits derived from priority works focused on reducing land-based pollution.

Key words: IRMA concept, River Cetina, Split, models MIKE 11 and MOUSE

INTRODUCTION

The high anthropic development of the river basins contributing to the Adriatic Sea leads to environmental problems for the marine environment. Almost 50 million people discharge wastewater into the rivers flowing into the Adriatic Sea, and intensive fish farming and industrial activities generate high loads of nutrients and pollutants. The problem manifests as extensive algae bloom evants and sea water anoxia.

The complexity of the problem calls for an integrated approach, as stipulated by the European Water Framework Directive, whereby pollution control in the coastal area is addressed at an integrated river catchment level, considering all the main sources of pollution and their interaction with the environment.

The key step towards integrated coastal area management is to connect tools that analyse river basin pollution phenomena with those used for coastal and marine modeling and monitoring. This link will provide a full picture of the interaction between river basin and coastal areas environments.

In the past ten years efforts have focused on the scientific and technological development of the two components in an isolated fashion, i.e. the river basin and wastewater component on one side, and the coastal areas monitoring and modeling systems on the other.

The scope of the ADRICOSM project is to develop and validate on a real case a methodology for the implementation of a River Basin Management Plan that can be extended to the entire Adriatic region.

The Integrated River basin and wastewater MAnagement (IRMA) approach applied in the project focuses on the modeling of water quality data at river basin level using numerical tools that simulate urban hydraulics and quality processes (models of sewers, treatment plants and river basins). This approach helps to optimise the new structural wastewater treatment works, forecast the effects of severe events such as flooding, disruptions to wastewater treatment facilities and define measures to minimize adverse impacts.

The project takes place in four coastal areas of the Adriatic Sea and at a Croatian test site which includes the Cetina River basin, the sewer system of the city of Split, and the corresponding coastal area between the mainland and the island of Brač.

PILOT AREA DEFINITION

Following a detailed analysis of the available information, a pilot area (Fig. 1) was chosen to demonstrate the integrated river catchment analysis. The identified pilot area includes the following components:

1. CITY OF SPLIT with a population of about 200000 inhabitants. The existing sewer-

Fig 1. The Pilot Area

age system is combined and has several coastal outfalls and Combined Sewer Overflows (CSO's). The wastewater of southern catchments (Katalinić brijeg) is released through the existing submarine outfall with only a partial primary mechanical treatment (screens, sand sedimentation and grease removal). The northern catchments discharge through three main coastal outfalls into Kaštela Bay.

2. CETINA RIVER catchment. Due to its abundance of water, the river is used for water supply of a wide area that includes the islands of Brač, Hvar and Šolta, for agricultural use and electricity production in 5 hydroelectric power plants.

3. COASTAL AREA. The coastline under study stretches from Trogir to Drvenik and faces the islands of Brač and Hvar. The overall extension of the coastal area under study is about 1500 km^2, the average water depth is about 50 m, with the lowest point being at –92 m.

Existing data on the hydrographic basin have been collected and organised into a database suitable for model representation. Data and information have been acquired for each component of the integrated catchment: Split's sewer system, river watershed and coastal area. For modeling purposes physical data like network maps and drawings, river longitudinal profiles, manholes elevation and geometry of structures have been acquired. Also, data regarding population and land use pollution load have been collated and used for models set-up.

After data acquisition, the following single models have been built:

1. Split Sewer System Hydraulic Model using the MOUSE model developed by the Danish Hydraulic Institute (DHI),

2. River Cetina Hydraulic Model using MIKE11 (HD and AD module) developed by DHI,

3. Coastal Area Model using RMA2 and RMA4 developed by US Army, Engineer Research and Development Center Waterways Experiment Station Coastal and Hydraulics Laboratory.

BUILDING OF THE MODELS

Split sewer model

The existing sewerage system of Split is combined (Fig. 2). The system is characterised by several Combined Sewer Overflows (CSO's) operating during wet weather periods. In the near future wastewater from northern watersheds and the Solin area will be collected and conveyed to a Waste Water Treatment Plant (WWTP) under construction in the Stobreč area.

The model is based on the data from maps of the sewer systems and a sewer database coming from a detailed field survey.

After model building, the boundary conditions to perform the simulation were defined. Regarding the dry weather condition, a *per capita* water consumption of 180 l/PE/day was assigned and a diurnal dimensionless profile of water consumption was linked to the model. Water levels at the outlet points of the system are given by the sea level and represent the downstream boundary conditions for the model.

To build the model of Split's sewer system, the MOUSE software was used. MOUSE is a professional engineering tool developed by the Danish Hydraulic Institute for the simulation of the hydrology, hydraulics, water quality and sediment transport in urban drainage and sewer systems.

The following computation modules were used:

- RUNOFF: surface runoff models for urban catchment applications;

- HD: hydrodynamic network model with some limited RTC capabilities;

-TRAP: pollutants process on catchments surfaces and in drainage networks.

River Cetina model

The objective of the Cetina River model is to simulate the hydrodynamics and water quality of the river in order to estimate the pollution loads discharged at the mouth into the sea water system. The hydrological schematisation of the catchment of the model does not take into

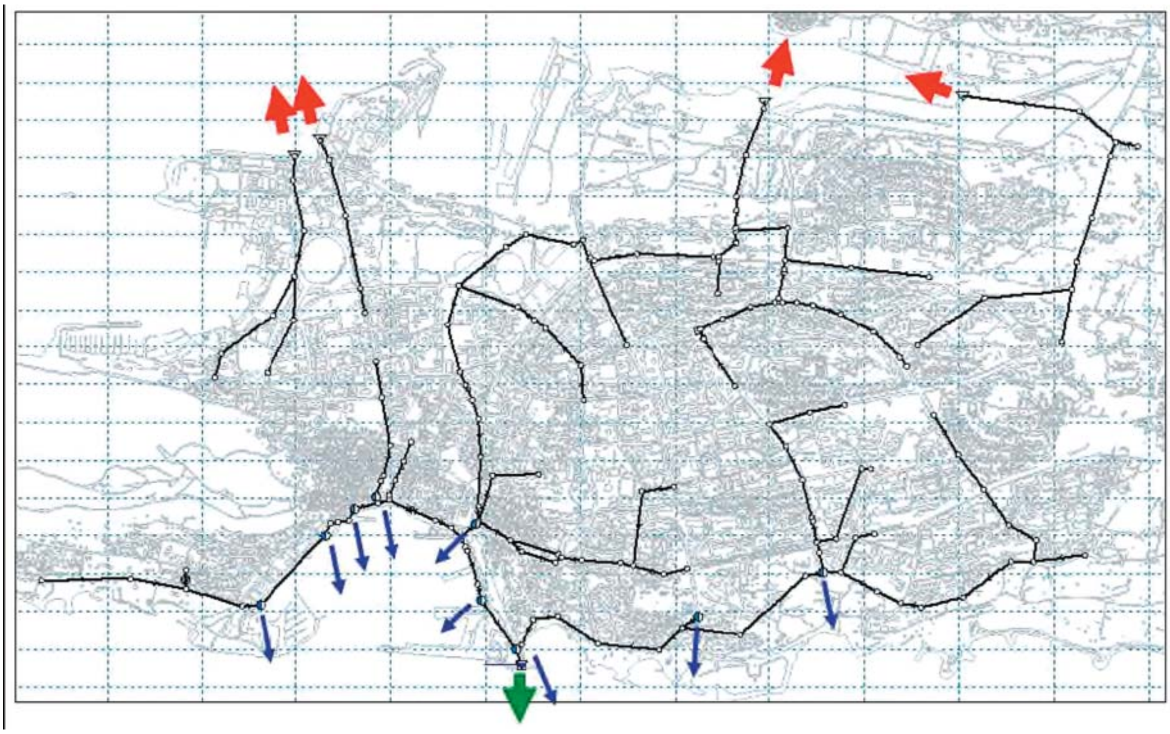

Fig. 2. The Split sewer model with main CSO's and outlets

account rainfallrunoff phenomena related to the karstic characteristics of the basin.

The total surface of the River Cetina catchment, approximately between 3,700 km^2 and 4,300 km^2, is composed of an underground watershed of about 2,700÷3,000 km^2, that covers more than half the basin surface. The boundary within the underground and the surface watersheds falls approximately on the political boundary between Croatia and Bosnia and Herzegovina.

The software selected for the set-up of the water quality model is MIKE 11 (Fig. 3), developed by the Danish Hydraulic Institute and known and applied all over the world. MIKE 11 (hydrodynamic + water quality modules) is a suitable tool, capable of representing the surface water system and the pollution discharged from the river in to the sea, in order to estimate how much intervention in pollution reduction in the watershed would result in a good impact on the water quality of the coastal areas and, more globally, of the Adriatic system. The karstic phenomena representation, due to the lack of data available to schematise numerically the underground system, has been implemented through a parametric evaluation, based on the results of a hydrologic study of the basin, which links the karstic contribution to the flow in the system.

The flow regime of River Cetina is not natural but regulated by hydroelectric power plants. Knowing the regulation schemes of the power plants is essential to determine the flow. The main course of the river has been schematised in the model, taking into account the existing reservoirs of Peruča, Dale and Prančevići, and the by-pass of the last course of the Cetina through the pipes of the Zakučac Power Plant.

Coastal area model

The model of the coastal area has been set up using the U.S. Army Corps of Engineering RMA-2 (Hydrodynamic computation) and RMA-4 (Advection dispersion computation), with the input/output software tools SMS. RMA-

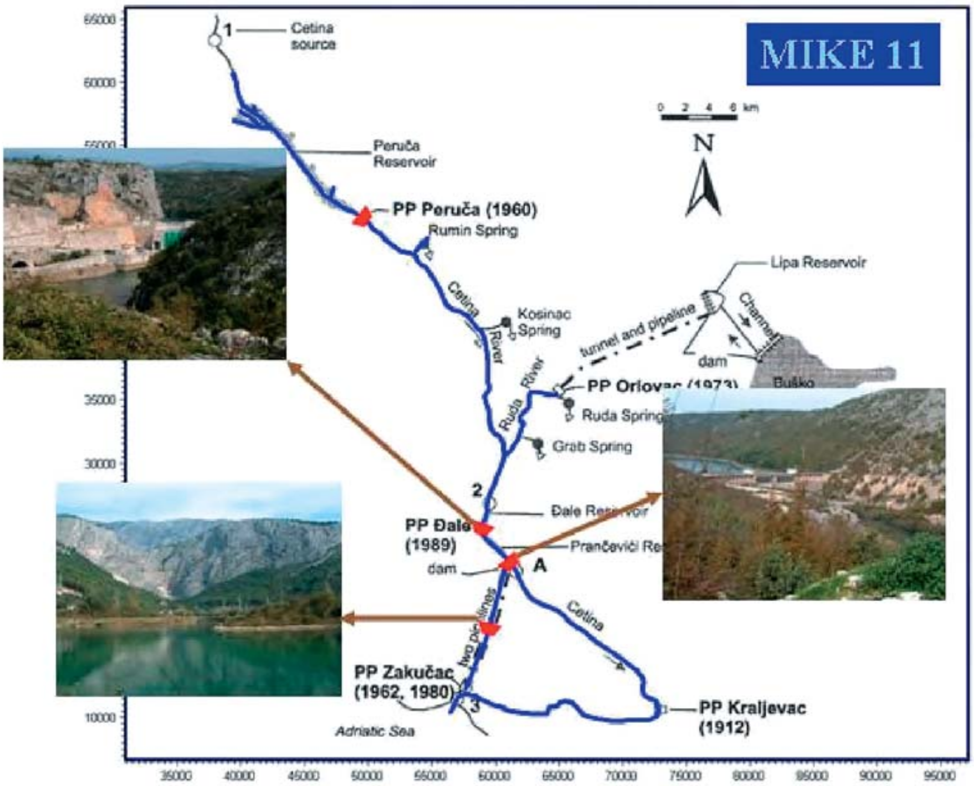

Fig. 3. The River Cetina MIKE 11 model schematisation

2, being two-dimensional, is rather simpler to use than the three-dimensional codes used for the simulation of the main Adriatic areas, thus keeping the Integrated River Management system in a "user friendly" form, in accordance with the original philosophy of ADRICOSM. A prototype set-up of the model has been defined for the coastal area whose boundaries are the Croatian coast between Split and the Cetina mouth, the island of Hvar and Drvenik Veli, including Brač island. The model area has been schematised with a square and triangular finite element mesh, in order to represent accurately all the geometric discontinuities of the coastline and the bathymetry. The final mesh is made up of 6643 elements and 19580 nodes; the element size varies from 20 m to 1200 m (Fig. 4). Generally, the widest elements lie away from the coast, or where the shoreline is quite linear and simple to be outlined; at particular points, i.e. where islands are close or where straits are present the smallest elements need to be used. Moreover, in order to better represent water quality, the smallest elements lie near the wastewater outlet and the other pollution sources. The bathymetrical data have been extracted from the local ASHELF-2 three-dimensional model that includes the same area.

RMA-2 source code has been modified to obtain a more stable model and have comparable results with ASHELF-2. In the "new" code all variables have twice as much precision and the wind stress is not computed by wind velocity, but directly read from a file. In this way RMA-2 uses exactly the same wind stress used in ASHELF-2. The boundary conditions imposed on the 3 open edges have been computed from ASHELF-2 results. The elevation or flux in each node along the open boundary has been computed using a bi-cubic interpolation. For each RMA-2 node the 16 closest points, and related values, in ASHELF-2 have been determined; then cubic interpolations along the

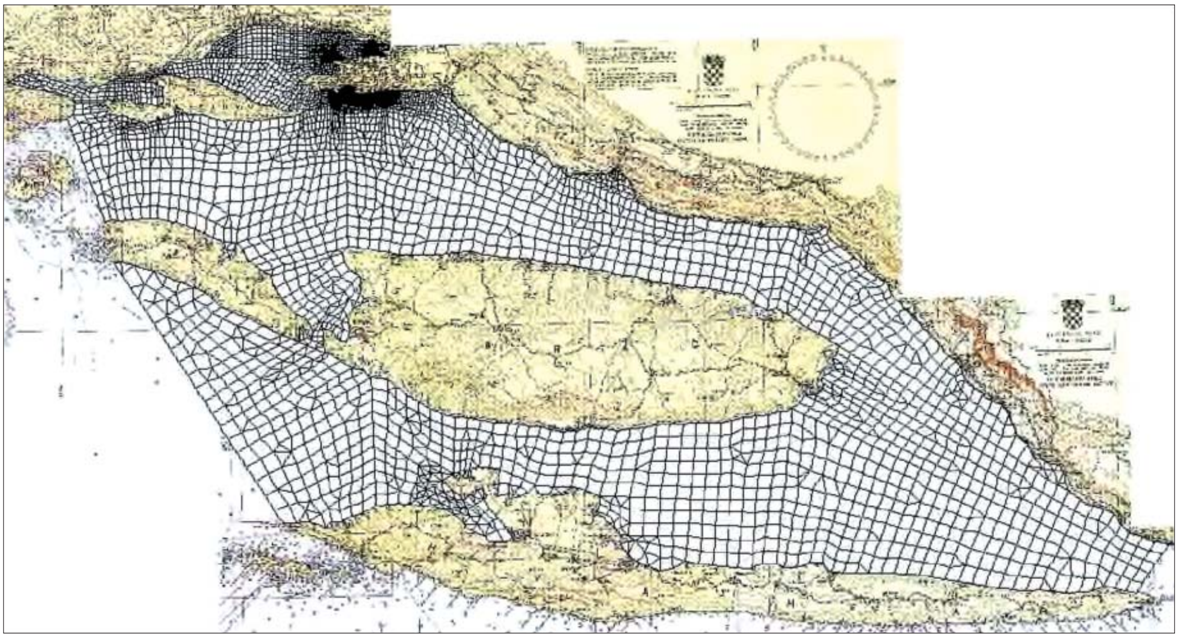

Fig. 4. Mesh of coastal area

horizontal direction and along the vertical direction have been made. The ASHELF-2 results are daily averaged whereas the input data for RMA-2 have a 3 hour time step. A linear interpolation has also been made over time.

FLOW AND QUALITY SURVEY

In order to increase the forecasting reliability, models have to be calibrated to ensure that measured and simulated values of flow, water level and water quality are comparable within

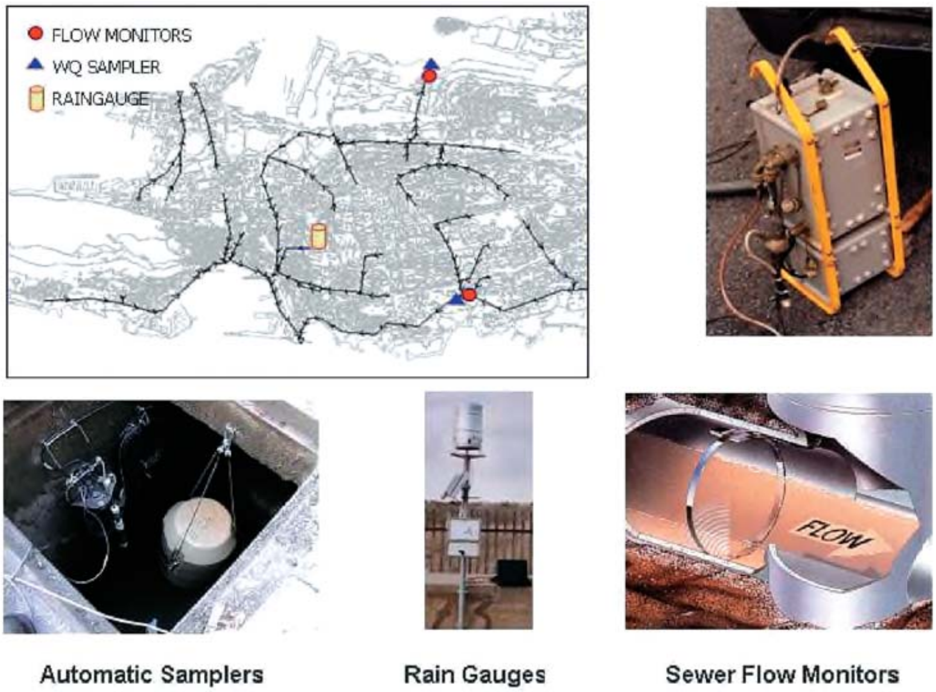

Fig. 5. Flow, quality and rain survey in the Split sewer system – examples of portable equipment that has been installed

chosen tolerances. Water quality data have been obtained by means of automatic samplers placed at suitable locations in the sewer network, river and coastal area (Fig. 5). Subsequent laboratory analysis gave measurements of Suspended Solid, Total Nitrogen and COD. One of the fundamental objectives of water quality monitoring is to provide data for the calibration of the Advection Dispersion (AD) modules. When these modules are integrated with the hydrodynamic models they are capable of simulating advection-dispersion of pollutants both in dry weather conditions and during storm events. Regarding the sewer system, the following meters have been installed: N° 2 flow meter at the main sewer outlets, N° 2 automatic samplers in sewer outlets, N° 1 weather station in Split.

Measurement of the water quality parameters has been taken concurrently with measurements of hydraulic parameters such as flow rate. This allows the impact of the combined sewer overflows on the external environment to be assessed. More generally, the relationship between rainfall, flow and water quality can be determined.

When considering urban drainage, water quality assumes a high level of importance both in evaluating the impact of discharges on the receiving water body and in planning measures to reduce pollution. It is also important to consider water quality when deciding how to manage the sewerage system and the WWTW.

Many international experiences have demonstrated that the pollution load generated from CSOs (Urban Combined Sewer Overflows) causes a high impact on the receiving water. The concentration of a CSO is generally much higher than foul water during the initial part of the discharge and then, thanks to dilution, it decreases correspondingly. This phenomenon, called “First Flush”, being generally responsible for heavy pollution of receiving waters, has to be seriously addressed according to the EU-WFD (Water Framework Directive).

The flow monitoring campaign has been carried out in order to calibrate the model for two pilot watersheds (see Figs. 6 and 7).

The instrument package used is manufactured by ISCO Limited. To take into account changes in water surface slope, backwater

Fig. 6. Rain gauge on the roof of a Split University buildings

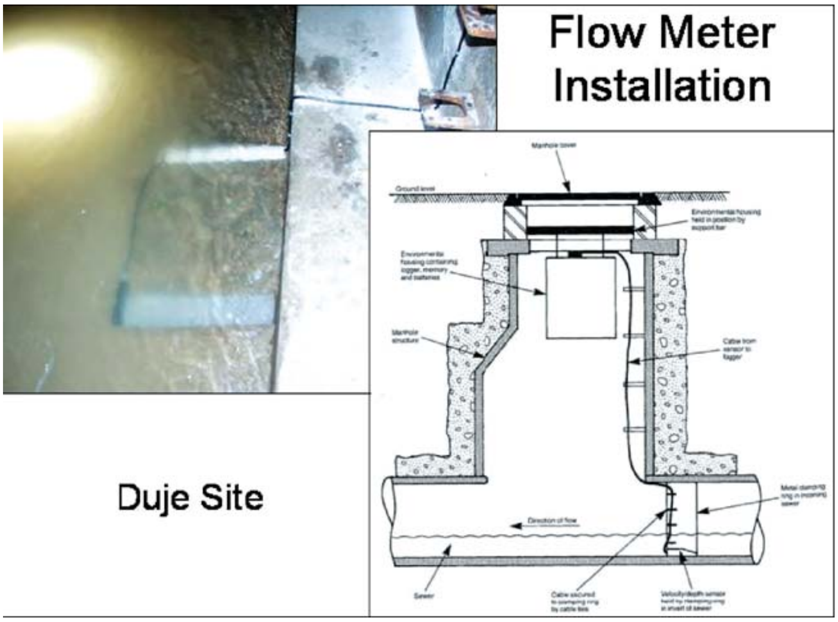

Fig. 7. Installation scheme of a flow monitor inside the sewer (Duje site)

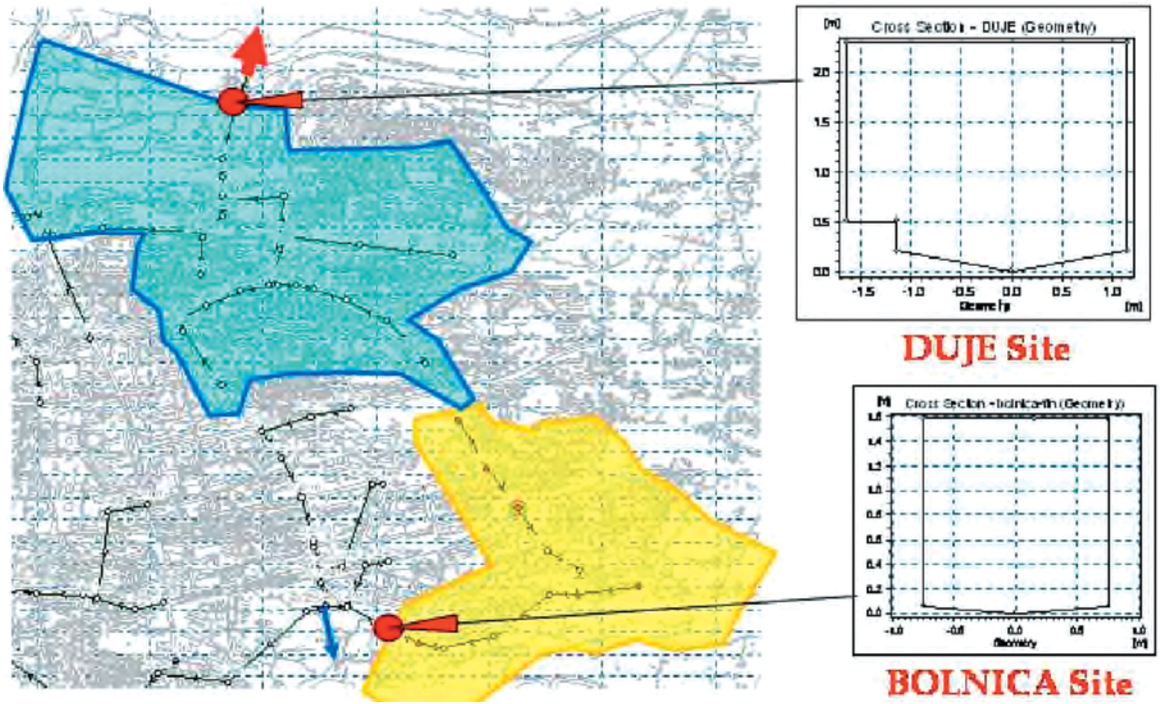

Fig. 8. Flow and quality measurement - site location and contributing pilot catchments

effects and surcharge, the instrument measures both the velocity and depth of flow occurring in the sewer. The sensors consist of a pressure transducer for depth, and a Doppler shift transducer for velocity.

As can be seen in Fig. 7, the transducers were mounted in a small streamlined housing which was fixed on the sewer invert. They were installed as near to the invert as possible, but clear of any existing silt. The installation has been kept as unobtrusive as possible so as not to collect rags or other debris which would obscure the velocity signal. The cable from the sensor was fixed up the wall of the sewer or channel.

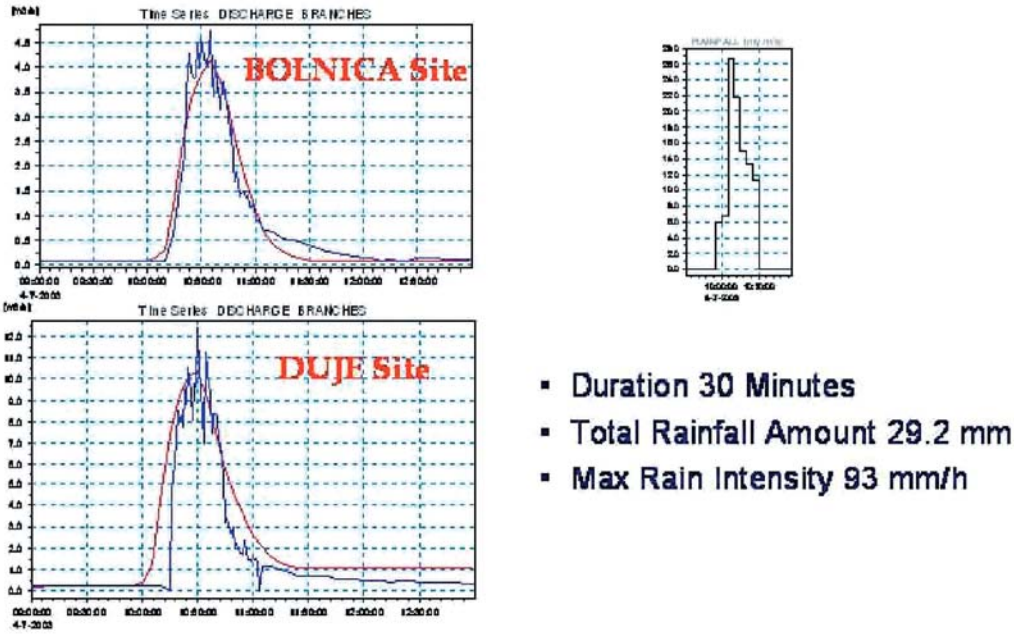

Fig. 9. Storm flow calibration during a rain event 1 (4 July 2003) - measured flow in blue color, simulated flow in red color

The recording package was located inside a suitably small shelter (Figs. 8 and 9).

The velocity sensor has a normal range from about 0.2 ms^{-1} to 6.1 ms^{-1}. The sensor's calibration does not drift with time, but it is necessary to take site check measurements to see how uniform the velocity is at the site being monitored and whether the recorded velocity is representative of the average. There are many factors which affect the velocity measurements. The transducer operates by measuring the Doppler shift of the signal reflected back from particles or air bubbles in the flow. To obtain a satisfactory signal it needs sufficient particles or air bubbles passing through its field of view. The transducer requires a depth of flow of about 50 mm before a satisfactory response is obtained.

MODELS CALIBRATION

Split sewer model

Following the model build, the calibration activity was carried out. Model calibration is the process whereby internal model parameters are adjusted so that model prediction is in good agreement with observed data. The Split model was calibrated using data collected during the flow survey exercise initiated in June 2003.

As noted in the previous paragraphs, measurements were conducted in two significant pilot catchments chosen to suitably represent the Split sewer system: Duje catchment, where foul water is directly discharged into the Kaštela Bay, and Bolnica catchments which delivers water to one of the main CSO operating only during rain events. Calibrated parameters for these catchments have been applied to other non monitored catchments.

The first stage of calibration was carried out in DWF conditions. Then the model was calibrated during selected rain events, checking and modifying surface catchment data such as impervious area and time of concentration.

Once the hydrodynamic models were calibrated, quality parameters such as pollutants' initial concentrations, daily variation and surface runoff coefficients, have been defined. The simulated values have been compared with data recorded during the sampling campaigns, and adjusted to obtain a good fit between observed and modeled data. As regarding the sewer model, the following computation modules have been used:

- AD (Advection Dispersion),
- SRQ (Surface Runoff Quality).

The AD module simulates the transport of dissolved substances and suspended fine sediments in pipe flow. Conservative materials, as well as those that are subject to a linear decay, can be simulated. The computed pipe flow discharges, water levels, and cross-sectional flow areas are used in the AD module computation.

The solution of the advection-dispersion equation is obtained using an implicit, finite-difference scheme which has negligible numerical dispersion. Concentration profiles with very steep fronts, such as discharge from CSOs (Combined Sewer Overflows) can be accurately modeled and displayed as longitudinal concentration profiles and pollutant graphs.

The primary role of the Surface Runoff Quality (SRQ) module is to provide a physically-based description of the relevant processes associated with sediments and pollutants due to surface runoff.

The following processes have been simulated:

- Build-up and wash-off of sediment particles on the catchment;
- Surface transport of pollutants attached to the sediment particles;
- Build-up and washout of dissolved pollutants in potholes and stilling basins.

River Cetina model

The river model has been calibrated using field data and information related to the operation of power plants. Data from the River Authority were used to represent the volume curves of the three reservoirs – Peruča, Dale and Prančevići – and to investigate the time of residence of water in the reservoirs and the related water quality phenomena.

With respect to the hydrological system, data on the main sources were available in terms of monthly average flows. These data were not enough to correctly describe the system; in fact Peruča reservoir has a seasonal regulation, while Dale has a day by day regulation and Prančevići has an hourly rule according to Zakučac power plant requirements. Available reservoirs flow data consisted of a measurement series of Zakučac flows, collecting just the flow of one week in twelve months. The aim of the hydrodynamic model was to simulate the river flows in a typical year: thus the flows of a typical year have been assembled starting from measured data.

It has been determined that the power plants operation is not regulated by a strict and repeatable rule, but they work in accordance with the system requirements. Generally power plants work at full capacity at least once per day during peak demands.

For this reason the flow in power plants has been generated randomly by fixing measured discharge for Zakučac and generating flow for the non-measured period using a continuity equation of the system based on an analysis of monthly average flow available at various points along the river. Specifically, a hydrologic study of the basin, carried out by the River Authority in 1997, has provided measured monthly average discharge data for about 50 years (1947-1993). Karstic phenomena have been considered particularly significant in the course between Silovka and Han; the representation has been implemented through a parametric estimation, based on the results of a hydrologic study of the basin, carried out by the River Authority in 1997. A simulation for a typical year has been made with the hydrodynamic module in order to analyze the discharge regime during the entire year. Despite power plant regulation the seasonal variation of discharge is evident: winter discharges are well above summer ones.

COD (Fig. 10) and Total Nitrogen were the water quality pollutants analysed. Data regarding the pollutants investigated were available in terms of settlements and industry which constitute the most dangerous point source of pollution. The majority of settlements do not possess an adequate sewage system network. Certain parts of larger settlements utilize a system that merely collects wastewater from the dwellings and discharges them directly, without any prior treatment, into the river. All other wastewaters are mainly collected in propellant septic pits, causing the rapid absorption of wastewaters directly into the underground. The existing sewage system does not collect storm waters that often go directly into the river. Conclusively, settlements constitute the main sources of pollution. The agricultural contribution to pollution was investigated and data collected; pollution discharges due to agricultural areas have been inserted in the model as distributed input along the appropriate zones. The dispersion coefficient, D, is described as a function of the mean flow velocity, V by:

$$D = aVb$$

where a is the dispersion factor and b the dispersion exponent. Typical value ranges for D are 1-5 m^2s^{-1} for small streams and 5-20 m^2s^{-1} for rivers.

Analysed components are assumed to decay according to a first-order expression:

$$dc/dt = Kc$$

where K is a decay constant and c is the concentration. The literature suggests that the COD decay constant can be 0.25 day^{-1} and the TKN decay constant 0.26 day^{-1}. HD module results have been used to set up the AD module. In the next Fig. 10 the hydrograph of discharge and COD concentration at Omiš (river mouth) for a week is illustrated.

Results have shown that Cetina water quality is basically satisfactory, with its flow being generally little polluted. The simulated flows and pollutant constitute the input for the coastal model.

Coastal area model

The coastline model is strictly linked to ASHELF-2, because boundary conditions have been obtained directly from ASHELF-2 results. Actually the RMA-2 model has not been calibrated because of the link with, and dependence on the ASHELF-2 model (boundary conditions and wind stress), although the current patterns have been compared. The March and August 2003 periods have been chosen to compare RMA-2 results with ASHELF-2 results. These months have low (March) and high (August) stratification, therefore a 2D model such as RMA-2 could work better in March and worse in August.

In the next figures comparison between the results of two models are reported. The velocity patterns of two models are in good accordance: the 2-dimensional model (RMA-2) is able to represent the barotropic results of

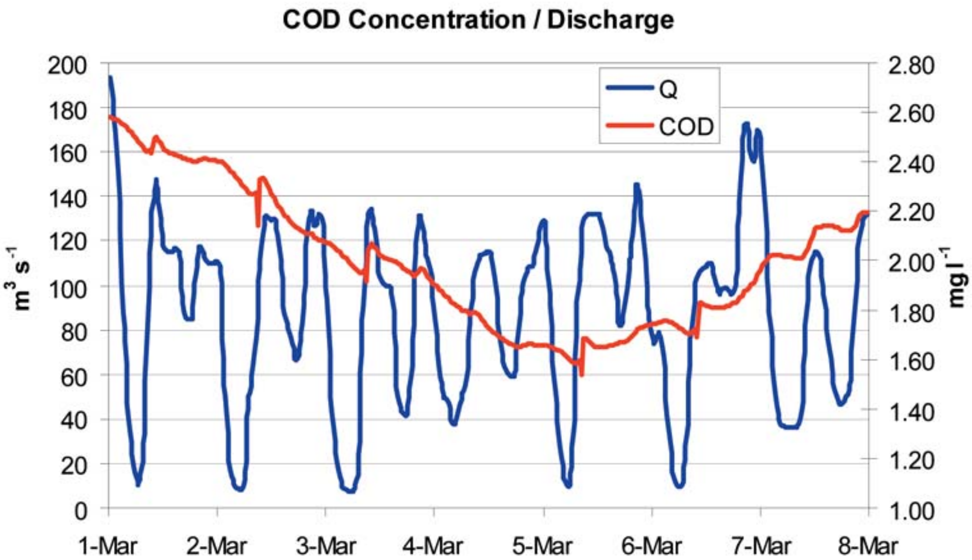

Fig. 10. COD concentration at Omiš

ASHELF-2 well (Figs. 11 and 12). Generally, circulations are qualitatively similar and velocity values are quite analogous, at least in main terms. The March comparison shows that the main differences are along the Brač coastline and in Kaštela Bay; nevertheless the general circulation scheme remains the same. The Split Strait, which is better schematised in RMA-2 than in ASHELF-2, seems to influence northern circulation. RMA-2 velocities are usually greater than those of ASHELF-2 as is particularly evident along the Brač and Hvar coastlines and in Kaštela Bay. Anyway, the general circulation layout between Brač and mainland remains quite the same. This also what happens along Hvar Channel, even if the whirlpools change their position. The main whirlpool in the eastern part of the Channel is well reproduced.

The August comparison illustrates agreement between the two models, even if for August stratification in the bi-dimensional model is not able to represent velocity as well as in March. The stratification effect can be seen in ASHELF-2 results, particularly between Brač and the mainland, where the velocity pattern is less defined.

Roughness values do not influence very much the results of the model where the Manning coefficient used in the simulations is n=0.025 $sm^{-1/3}$. Eddy viscosity moderately influences model results. In the simulations eddy viscosity is calculated as indicated below according to Peclet number = 40.

THE INTEGRATED MODEL, A DSS FOR ENVIRONMENTAL MANAGEMENT OF THE COASTAL AREA

The entire water quality study, directly linked to hydrodynamic conditions, uses three different numerical models: MOUSE for the sewer system, MIKE 11 for the river, and RMA (RMA-2 and RMA-4) for the coastline area.

Considering the configuration of the system, it is possible to run simulations in sequence (Figs. 13 and 14) and not all at the same time (the coastal model does not influence sewer model simulation): thus, integration of the models is quite simple and is basically a

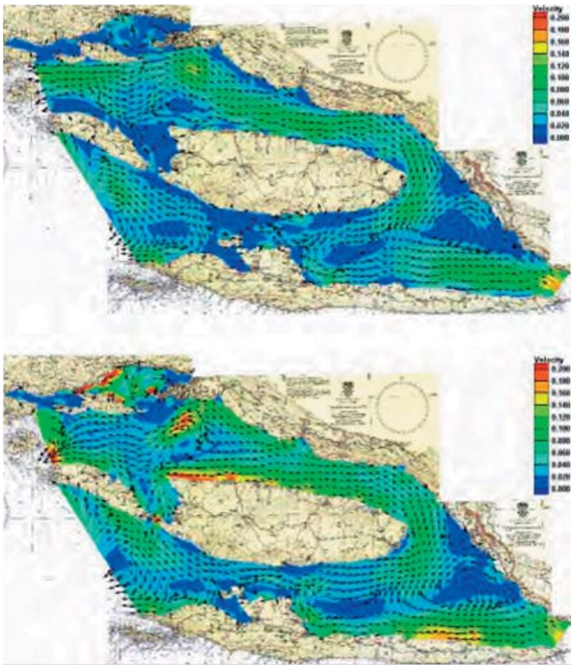

Fig. 11. Results on 15 March, ASHELF-2 (above) RMA-2 (below)

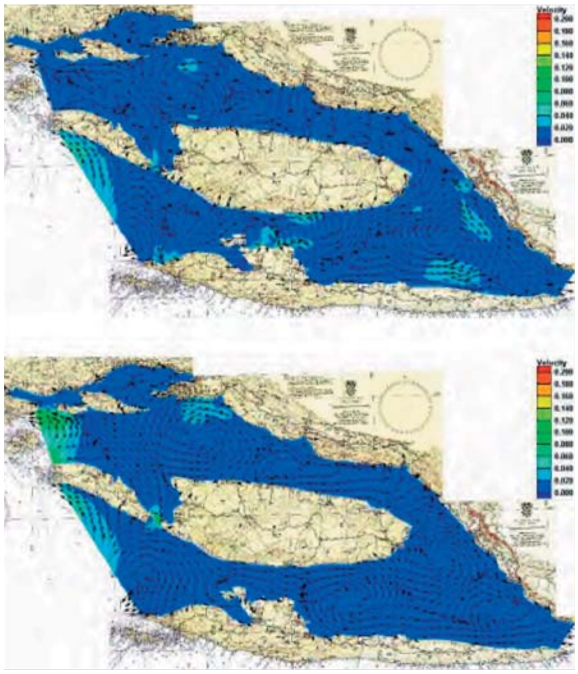

Fig. 12. Results on 15 August, ASHELF-2 (above) RMA-2 (below)

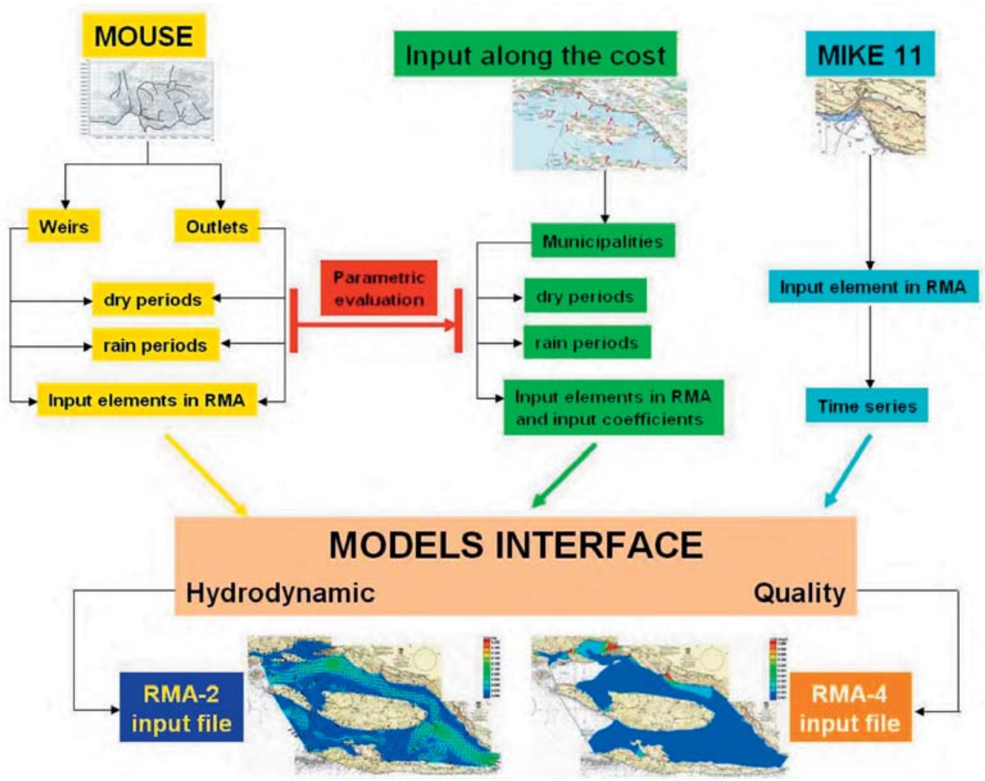

Fig. 13. Integrated simulation sequence

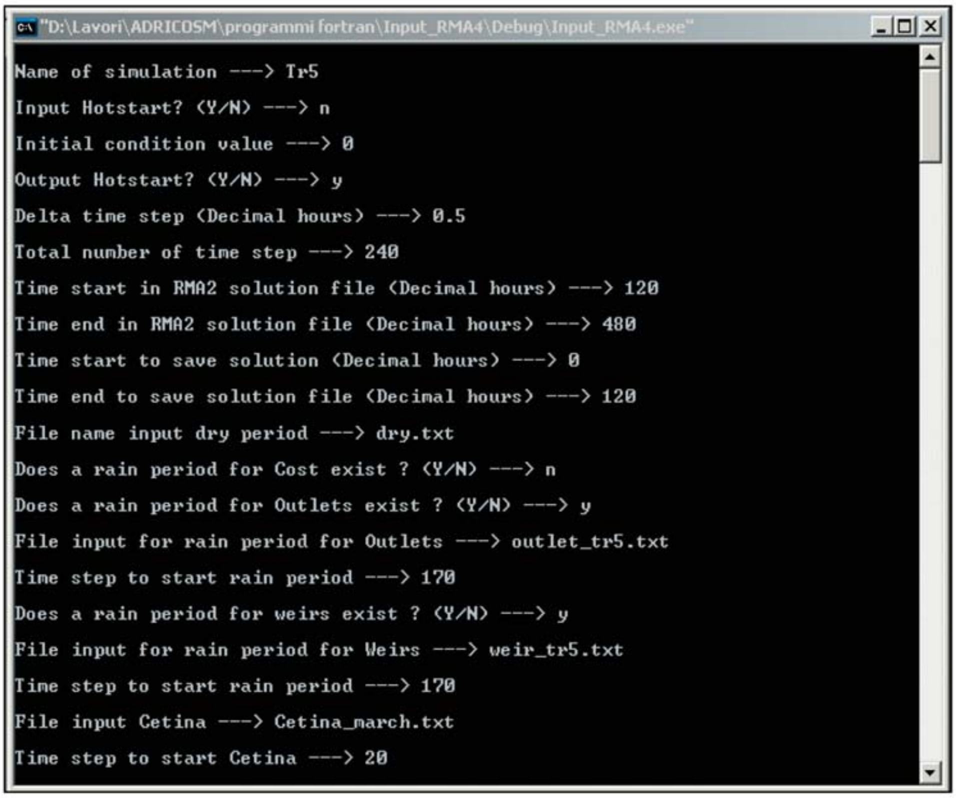

Fig. 14. Integrated simulation sequence

data exchange between mainland models and a coastal model; discharge and pollutants load given by MOUSE and MIKE 11 are input data for the RMA model. The next figure shows a scheme which summarises data exchange between the individual models.

MOUSE results are exported as discharge and pollutants load (COD, SS and TKN) from outlets and weirs. A file for each kind of output is written, defining output number and corresponding mesh element. Another file contains information about discharge and pollutants load during the dry period, that is to say it defines what happens during 24 hours for each output. These files will never change if the finite element mesh and MOUSE sewer system remains unmodifield.

Other municipalities and discharges along the coast have been evaluated through a parametric estimation based on Split results. Another file contains these data, and gives the chance to divide discharge and loads into more than one element, specifying each element percentage. This option is useful for large municipalities, i.e. the islands of Brač or Hvar.

For the Cetina River, one file is used to specify the mesh element number associated with the river mouth and another file contains discharge and pollutants load.

Unfortunately MOUSE and MIKE 11 source codes are not editable, and data extraction cannot be made automatically, so it is necessary to go through the model graphic interface and set the data format by employing a worksheet (i.e. MS Excel).

The interface model is basically a programme which reads all created files and produces an input file for the hydrodynamic and water quality coastline model.

The quality model interface creates an input file for RMA-4 where the file defines the time step and number of time steps, that is to say simulation duration where the time step must be equal to or greater than the one defined in the input files. If the time step is greater than the one defined in the input files, the interface programme calculates the integral of the data so that total loads within the established interval are calculated.

The next image illustrates the DOS code interface that links MOUSE and MIKE 11 results file to the RMA-4 coastline water quality model.

HYDRAULIC AND WATER QUALITY PERFORMANCE OF THE EXISTING SYSTEM

Following models' development and calibration, performance analysis of the current situation was carried out. The final objective of the analysis is to evaluate the status of the coastal area by considering all the pollution inputs coming from urban discharge, industries, rivers and diffused load from agriculture.

Simulations have been conducted using a design rainfall event with a return period (TR) of 5 years and the shape (Fig. 15) of a "modified Chicago diagram". Taking into account the short time of concentration of the local sewer system, a duration of 60 minutes was chosen as the most critical - h = 37.67 t 0.482 where h = rain height (mm) and t = time (hour).

In order to evaluate the effect of CSO's in the coastal area real events were also simulated (Fig.16). In particular, 2 typical events were chosen from the historical rain time series of 2001-2002 having different intensity and duration: one intense and relatively short summer event and a second longer and less intense winter event. The following scenarios were simulated:

- dry weather conditions (DWF);
- design event with 5 years return period and 60 minutes duration (E1);
- event 2 (E2) – 3 September 2000, h=28 mm, duration=115', av. intensity j=13 mmh^{-1}, max. intensity=66 mmh^{-1};
- event 3 (E3) – 26 November 2000, h=68 mm, duration=1080' (18 h), average intensity j=3.7 mmh^{-1}, max. intensity=6 mmh^{-1}.

In order to evaluate the current performance of the sewer system, four main performance indicators were considered:

- Length of overloaded pipes (pressurised flow);

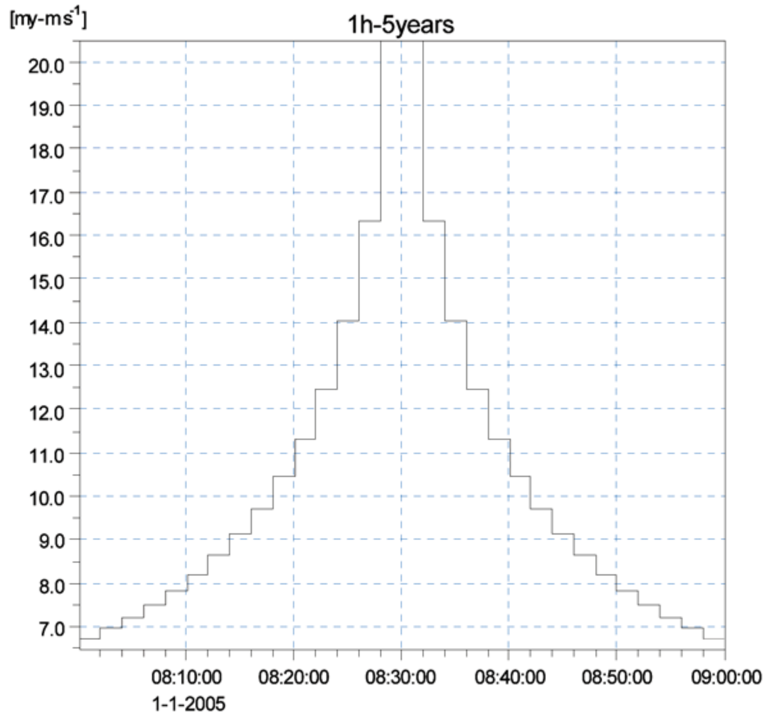

Fig. 15. Design rain event 5 years return period 60 minutes duration (5Y60)

- Duration of pressurised flow in overloaded pipes;
- Number of nodes where the maximum water level exceeds ground level (indication of possible flooded areas);
- Total volume discharged into the sea from CSOs and outlets.

Model results using the 5 years design rainfall indicated that five main CSOs out of twelve discharge an overall volume greater than

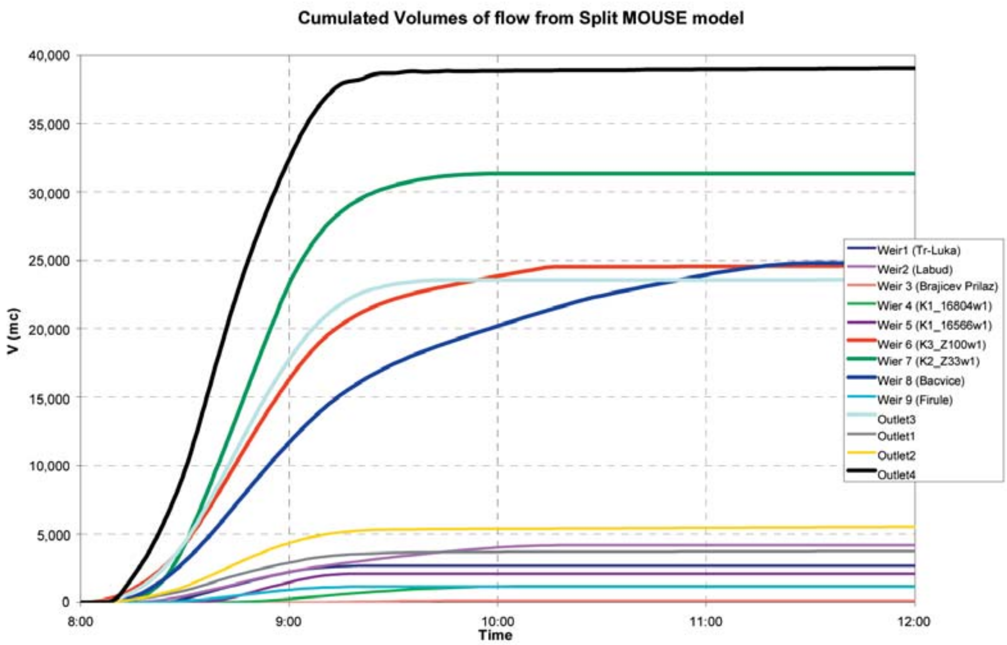

Fig. 16. Cumulated discharged volumes from CSOs (Split MOUSE model with 5Y TR 60')

80% of the total discharged volume (168.000 m^3) and an overall amount of pollutants close to 90%. (see figure below). The total load of COD discharged during the event is 11.300 kg.

The results are presented as concentration/discharge and as pollutant amount/discharge at Omiš for a regular week. Both discharges and pollutant concentrations represent the input for the coastal model.

All of the quality simulations use the hydrodynamic circulation in March. Pollutants to be analysed are COD, Suspended Solids and Total Nitrogen. Input data regarding the pollutants investigated derives from the Mouse and MIKE 11 models. Mouse results provide pollutants concentrations due to Split wastewater in the dry period and in the rainy period; the other towns' contribution was evaluated in a parametric way, based on the number of inhabitants. The MIKE 11 model gives the input for the Cetina River, while Jadro River supply was estimated on the basis of the Cetina results. The following figure illustrates the study area, with COD concentration after 14 days of a dry period (Fig. 17). The areas in the image where the concentration is less than 1 mgl^{-1} have been set to transparent. As can be seen, the most polluted area is around Kaštela Bay. The operation of the new treatment plant will highly improve the water quality by eliminating the discharge during DWF from sewer outlets in Kaštela Bay.

EVALUATION OF ADAPTATION MEASURES TO REDUCE POLLUTION LOAD

It can be concluded from the previous paragraph that the main pollution sources in the study area are wastewater discharges and CSO's during rain events. In order to evaluate the beneficial effects of remediation works, the following scenarios were simulated:

Case 1 - Allocation of WWTP in each municipality included in the study area. This is a priority task considering that the municipalities in the study area do not normally have an operational WWTP. Only in Split has the WWTP been set-up and is currently operating by collecting wastewater from the upper part of the city, and which was originally discharged in to Kaštela Bay.

Case 2 - Building of storage tanks to collect at least the initial part of the discharged volume (first flush) from the main CSO's. Simulation results highlighted that by collecting only 20% of the total discharged volume into storage tanks a reduction of COD and SS load of around 75% could be achieved. Five storage tanks (total volume of 35.000 m^3) have been simulated

Fig. 17. COD concentration after 14 days of dry period

upstream of the main CSOs that discharge more that 80% of all CSOs.

The results of simulations have been evaluated in terms of reduction of pollutants concentration at different locations (Fig. 18) along the coastal area as shown in Fig. 19.

It can be noticed from the figure above that the WWTP + Storage Tank layout significantly improves the overall quality of the receiving waters, thus achieving a very important reduction in CSOs impact (at point A the COD concentration decrease is 95%).

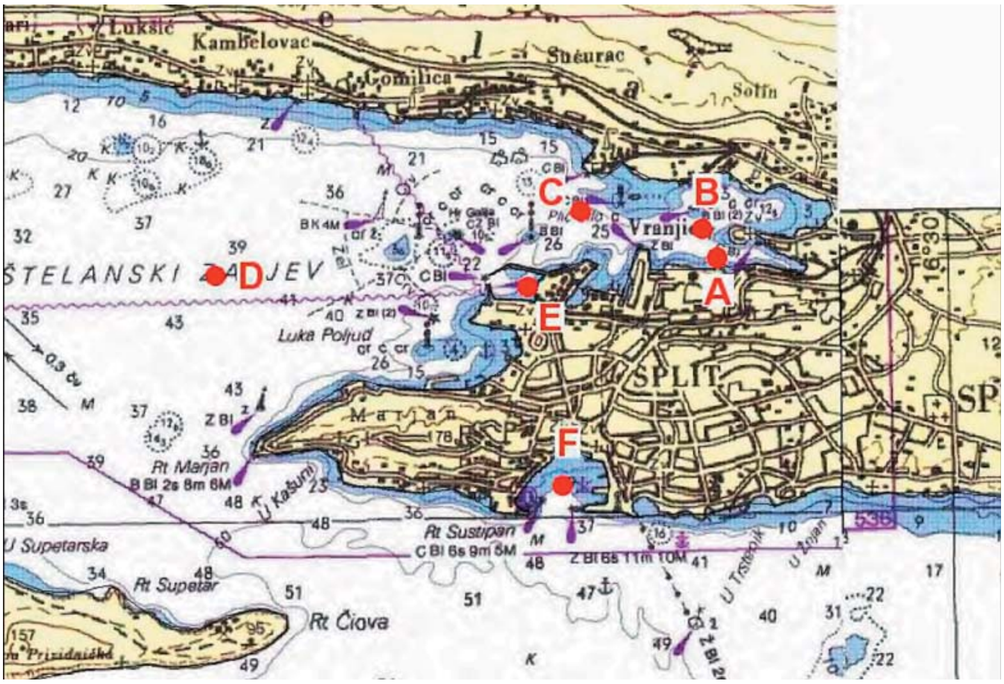

Fig 18. Location of analyzed point A, B, C, D, E, F

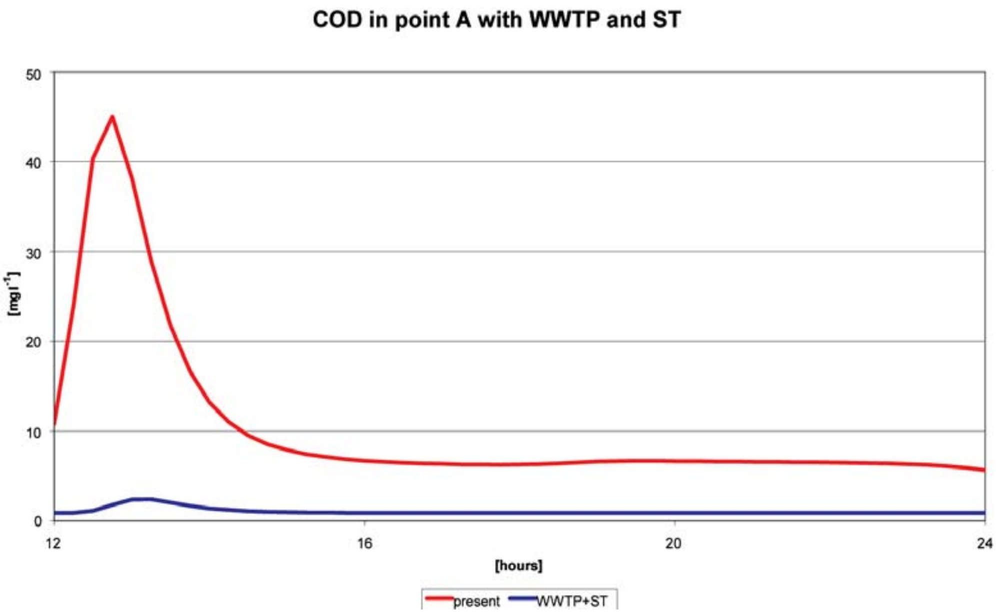

Fig 19. COD at point A; present layout (red) and WWTP+ST layout (blue)

CONCLUSIONS

The integrated river basin and wastewater management system focuses on the modeling of water quality data, and the simulation of urban hydraulics and quality processes, with numerical tools (models of sewers, treatment plants and river basins). This approach helps to plan new structural wastewater treatment priorities, forecast the effects of severe events such as flooding, disruptions of wastewater treatment facilities, and take measures to minimize their effects. Single models of the Split sewer system, River Cetina and surrounding coastal area have been built and calibrated using historical data and information gathered from a detailed flow, rain and water quality survey. The single models have been integrated using a software interface in order to simulate advection/dispersion of pollutants in the bay coming from urban settlements and river watershed (agriculture, industries and urban discharges).

Using the integrated model a performance analysis of the current situation has been carried out. The hydraulic performance of the sewer system in critical conditions has been assessed using design rainfall events and real events collected during the flow survey. The results of simulations have indicated main hydraulic malfunctions such as flooding, surcharging, bottlenecks, etc. In this context, it has been possible to establish the quantity and quality of the combined sewer overflows, and identify the main anomalies in the network.

The integrated model has been used to simulate some remediation structural works to abate pollution, specifically the installation of WWTP and building of storage tanks at the main CSOs. Simulation results have highlighted that by collecting in the storage tanks only 20% of the total discharged from Split sewer CSOs, a reduction of 75% in COD load (kg) would be achieved. The simulation indicates that the improvement in the coastal area attained with remediation works is very important.

On the basis of this experience, the integrated model can be envisaged as a complete tool for management and planning of the wastewater facilities and receiving waters, and will promote a collaboration among the various bodies in charge of the operation and regulation of the "integrated system".

SYMBOLS

AD = Advection/Dispersion Module;
DWF = Dry Weather Flow;
CSO = Combine Sewer Overflow;
ST = Storage Tank to collect urban drainage during rain events;
WWTP = Waste Water Treatment Plant;
COD = Chemical Oxygen Demand;
TKN = Total Nitrogen;
SS = Suspended Solid;
5Y60 = Design event with 5 years return period and 60 minutes duration.

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Koncept IRMA primijenjen na rijeku Cetinu i splitsko slivno područje

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SAŽETAK

Izrađen je integralni sustav upravljanja obalnim područjem i riječnim bazenom s ciljem ostvarenje društvenih ciljeva veznih uz održivi razvoj obalnih područja te korištenje i zaštite prirodnih resursa - okoliša. Održivi razvoj obalnih područja u znatnoj mjeri ovisi o kakvoći morskog okoliša pa se isti mora cjelovito obuhvatiti i tretirati. U skladu s tim ciljem izrađen je ADRICOSM projekt (Pilot projekt Integralnog sustava upravljanja jadranskim obalnim područjima i riječnim bazenima). To je jedan moderan i učinkovit sustav - alat za analizu i prognozu stanja okoliša koji pomaže i omogućava donosiocima odluke da donose dobre dugoročne razvojne odluke. Integralni koncept i pristup upravljanja vodnim bogatstvima koji se zahtjeva EU okvirnom direktivom o vodama je u ovom projektu primijenjen, analiziran i vrednovan. Razvijeni su modeli za simulaciju i prognozu stanja u urbanom vodnom sustavu, riječnom bazenu i obalnom moru te integrirani u jedan jedinstveni upravljački sustav. Ovaj alat je primijenjen na rješavanje problema vezanih za upravljanje rijekom Cetinom, kanalizacijskim sustavom Splita i splitskim obalnim područjem. Rezultat ovog projekta su smjernice za upravljanje vodnim resursima pilot područja, te integralne mjere za kontrolu zagađenja mora i vode riječnog bazena.

Ključne riječi: integralni koncept upravljanja, rijeka Cetina, Split, Modeli MIKE 11 i MOUSE