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## Decision Support System for Demining Waterways

**In the beginning of 2002, Croatian Waters, a state water management system, gave the Faculty of Civil Engineering at the University of Split a project with the main objective of determining the optimal strategy for demining waterways by using contemporary scientific methods and tools.**

by Nenad Mladineo and Snjezana Knezic, *Faculty of Civil Engineering, University of Split, Split, Croatia*

### Introduction

Mine contamination is one of the main obstacles in the development of Croatia. In 1998, the Croatian government founded the Croatian Mine Action Center (CROMAC), which took over management of all demining operations in Croatia and has closely collaborated with international institutions and organizations. CROMAC develops intensive and efficient countermine action, which, in its first years, had distinctive priorities. As time passed, priority assessment tasks became more complicated and annual evaluation of demining plans demanded a more complex methodological approach. In Croatia, there are major state systems that take care of the management and development of particular resources, such as traffic infrastructure, energy infrastructure, state forests, water resources, etc. They are interested in demining their own priority areas. One such state system is Croatian Waters, which is engaged in water resource management for the Republic of Croatia. During conflicts, watercourses were exposed to mine laying from both the enemy side and the Croatian army. Namely, watercourses were natural borders and often the separation line. This explains their high degree of mine contamination. As stated in one Croatian Waters document, mine-contaminated areas to a great extent restrain basic water management activities—flood management, water supply systems and navigation—directly influencing safety and, at the same time, limiting efficient economic development.

Demining problems, in the context of water management activities, are complex and have to be analyzed, taking into account several aspects, some of which are listed below.

- Aspects regarding water management activities are mainly mirrored in the inability to approach the structures that have to be regularly maintained for the safety of machines and the people that maintain or manage the structures. Most water resource structures are extremely large, so the inability to maintain even a small part of the structure can cause dysfunction of the whole structure, thus endangering the safety of people and goods in the wider area. Furthermore, the absence of regular maintenance activities for watercourses can change flow conditions in the riverbed, making it almost impossible to predict where the mines will eventually end up. Therefore, complete downstream watercourses, banks and inundations could be considered potential mine-contaminated areas.
- The sociological aspect of the problem of mine-contaminated watercourses is that most of the activities in the settlements near rivers take place on the river banks. These activities are transportation, commerce and especially recreation (walks, rowing, swimming, fishing). Achieving a satisfactory degree of safety is a significant challenge because the problem deals with long distances (areas) that have to be controlled. If the activity deals with hydraulically sensitive parts of watercourses (possible area for suspension fill), a restricted approach should be considered.

The aforementioned aspects point to the extreme complexity of the problem, demanding

detailed analysis in order to prevent negative consequences caused by interaction of water and mine-contaminated areas. Regarding possible consequences, the problem of watercourse mine contamination should be solved by priority assessment, but at the same time, it should be emphasized that due to the scope of the analysis and complex conditions in the demining process, high demining costs should be expected in almost every case.

## Background

According to United Nations Mine Action Center (UNMAC) estimations, by the end of the war operations in Croatia in 1995, out of 56,542 sq km of state territory, about 13,000 sq km are classified as suspected minefields. By introducing intensive general survey and data classification on minefields from army archives, suspected minefields were reduced to 1,630 sq km. Of this area, 170 sq km were mine-contaminated, and about 1,460 sq km were treated as suspected minefields. Croatian Waters, under the auspices of the state, manages the water resources of the Republic of Croatia comprising 3,935 km of watercourses, numerous lakes, artificial accumulations, hydro-melioration systems for water excess and meliorations, water supply systems, fisheries, etc. Normalization of everyday activities in the former war areas includes normal functioning water supply systems and other water resources systems; therefore, Croatian Waters has been intensively included in mine action, pointing out priorities and contributing funds for water resource demining. World Bank loans and other donations have helped to demine numerous water supply system structures, as well as channel systems in Slavonia. Establishing a digitalized database of suspected minefields in CROMAC and overlaying those data with the data about water resources obtained by Croatian Waters provides insight into rather large areas exposed to mine risk under the auspices of Croatian Waters. The significant number and scope of suspected minefields under the patronage of Croatian Waters initiated a basic approach for a definition of the strategy, namely mine action priorities. In applying the system approach to problem solving, the intention was to give complete insight into the problem and to solve the problem of mine-contaminated water resources in the most efficient way.

In the beginning of 2002, Croatian Waters gave the Faculty of Civil Engineering at the University of Split a project with the main objective of determining the optimal strategy for demining areas under the auspices of Croatian Waters by using contemporary scientific methods and tools. The project pointed out the following basic problem characteristics:

- High price of water resources demining
- Conflict of interests
- Hierarchical approach to problem solving (several problem solving levels)

Moreover, the project objectives were evaluated considering the following characteristics of the mine-contamination problem:

- Need to establish objective criteria for demining priority assessment.
- Collection of relevant data.
- Modeling of a decision process that is acceptable to the most of the stakeholders with conflicting interests involved in the group decision-making process.
- High number of stakeholders participating in the decision process.
- Evaluation of demining priority rank considering Croatian Waters' aspects and needs.

For the project implementation, using the Decision Support System (DDS) concept, two modules were conceptualized in the first phase:

- **Geographic Information System (GIS) module**, which integrated data from the Mine Information System (MIS) formed at CROMAC, and particular data from the Croatian Waters database.
- **Decision Support module**, which integrated tools and data for the decision support, mainly data and software for multicriteria analysis.

Problems recognized in the first years of mine action in Croatia (as well as in other mine-affected countries) contributed to the decision to apply multicriteria analysis. The main problem was the need for the integrated valorization of priorities from technical, safety, social, political and economic aspects. At the same time, the need for transparency of

valorization parameters (input data) was crucial, because donors and money lenders had to have complete insight into the priority assessment process and investment feasibility.

### Building DSS for Mine Action in Croatian Waters

The DSS philosophy is based on the paradigm "Data—Dialogue—Models," meaning the user communicates with the computer (mainly through menus) and special interfaces enable the management of data and model base, which are also able to communicate mutually and enable quick operation with changed input data. The conceptualized DSS is divided into a number of segments (modules) that will be built into further phases. The basic module is GIS that comprise information sub-systems about spatial and other data and provides the other modules with data and information, as shown in Figure 1.

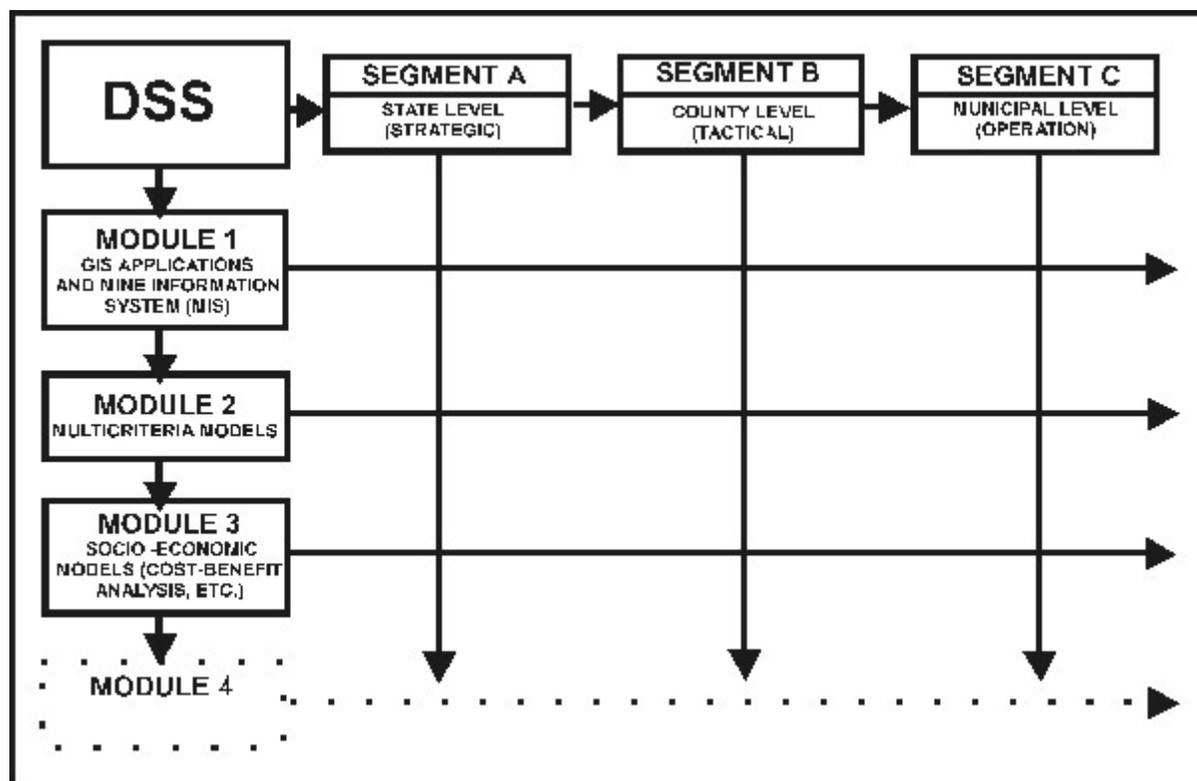


Figure 1: Conceptual layout of the DSS.

Besides basic digital topological maps and digitalized suspected minefields, GIS modules contain precise data about water resources, so it is possible to form input data for multicriteria analysis with a simple overlay of thematic layers. With this method, expensive and sometimes not very precise terrain surveys are avoided, and at the same time, it enables simple visual control of used parameters. Figure 2 shows the overlay results of mined and mine-contaminated areas with watercourse thematic layers for Zadar county. Watercourses, digitalized as lines (smaller rivers, streams, channels, ditches, etc.), are transferred into polygons using the buffer function (from both watercourse sides, the width is 50 m) and by intersecting them when suspected minefield risk areas are generated.

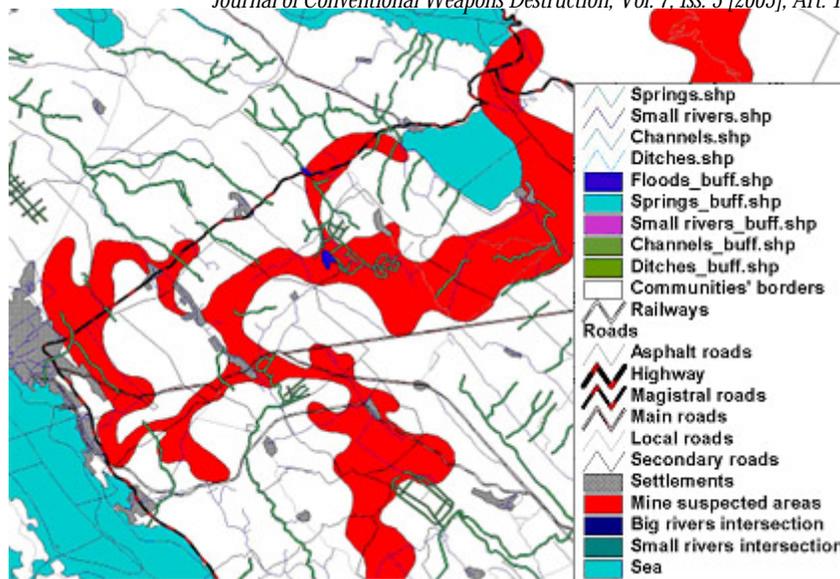


Figure 2: Layout of the thematic layers from which data for multicriteria analysis were generated.

Using the GIS module, regarding the decision level, a particular “action set” including demining projects for water resources and social and political subjects (counties, municipalities, settlements, etc.) exists for multicriteria analysis. The conceptualized DSS scheme shows three levels supported by GIS:

- **Strategic level (segment A):** At the state level, “action sets” (demining projects) that have to be ranked can be river basins, one or more watershed areas, or socio-political subjects (counties or municipalities).
- **Tactical level (segment B):** “Action sets” in county-level or smaller natural hydrographic areas, that have to be ranked can be watershed or other natural hydrographic areas or socio-political subjects (municipalities).
- **Operative level (segment C):** In municipality-level or smaller natural hydrographic areas, “action sets” that have to be ranked can be parts of river basins, parts of watersheds, particular demining projects or minefields, or in the selection process, “action sets” form demining companies, demining technology (manual or machine demining), etc.

Most discussion during project realization was about “action set” definitions, namely how to define subjects that appear in the ranking process. It is obvious that at the lowest operational level, an “action set” that has to be ranked often is called a “demining project.” The practice is to give spatial areas to a demining company chosen through a public contest.

At higher levels, polygons that represent mined areas or suspected minefields are grouped into bigger areas according to the particular homogenization criteria. Namely, it is assumed that they have some common characteristics. It should be taken into account that in the decision process of “what to demine,” representatives of socio-political bodies sit on the other side of the table as stakeholders, aggressively standing for the interests of their communities, spatially defined by administrative boundaries. Therefore, the administrative boundaries of counties, municipalities or settlements appear to be logical criteria for homogenization in the “action set.” Namely, at the state level, money for demining is divided into counties and the counties distribute the money to the municipalities in their territory. Within each municipality, the money is used in demining projects for settlements and infrastructure. Sometimes donors decide directly about demining territory, but even in this case, there is competition between the potential recipients of the donations who want to assure the donor that they are the most endangered.

Considering management structure in Croatian Waters, there were certain dilemmas about hierarchic structure regarding watercourse characteristics. For example, the highest level

would be river basins or groups of watersheds, followed by the lower level of big river watersheds with accompanied tributaries, as well as bigger lakes and accumulations. The next level would include smaller rivers with tributaries (streams, canals or channels). The lowest level "action set" would be streams (permanent or temporary), torrent waters, etc. Using this structure as the homogenization criteria was problematic, so in this project, the administrative community boundaries are used as the homogenization criteria. This approach also simplifies criteria valorizations that are related to socio-economic influence because most of the statistical data about communities (demographic data, etc.), as well as economic parameters, are attached to the communities, so it is easy to use for multicriteria analysis. Similar approaches in definitions of "action set" are used in other projects.

For different decision levels, there are different accuracies of GIS support, so at the strategic level scale, 1:100,000 is often used, and for lowest operative level scales, 1:5,000 is more precise.

<b>Thematic layer</b>	<b>Area (sq m)</b>
Small rivers (including streams, channels, etc.)	131.063.329
Big rivers	39.638.263
<b>Total mined watercourses</b>	<b>169.695.693</b>
Embankments	5.113.372
Pump stations (buffer 50m)	37.693
Accumulations and retentions	63.180
Plain retentions	11.405.651
Waterways	789.794
Bridges (buffer 50 m)	78.606
Permanent floodplains	18.978.752
Frequent floodplains	132.535.419
<b>Total flood endangered areas</b>	<b>280.719.185</b>
Table 1: Suspected minefields, obtained by GIS, under the auspices of Croatian Waters and classified according to the current Croatian Waters categorization.	

Watercourses on suspected minefields total almost 170 sq km, indicating big problems for Croatian Waters. About five sq km of embankments should be added, as well as pump stations, bridges, accumulations and retention, etc. Areas endangered by possible floods present special problems due to the risky approach to these areas, thus disturbing all activities connected to flood management. On the other side, there is a risk from eventual deposits and/or stopping of mines dragged downstream to the areas that are not suspected minefields. Such areas cover 280 sq km, and even though they are not under the direct auspices of Croatian Waters, they have to be considered as well. Figure 3 shows area classified as floodplain according to Croatian Waters categorization. Based on hydrologic data series, the probability of a flood occurring can be calculated.

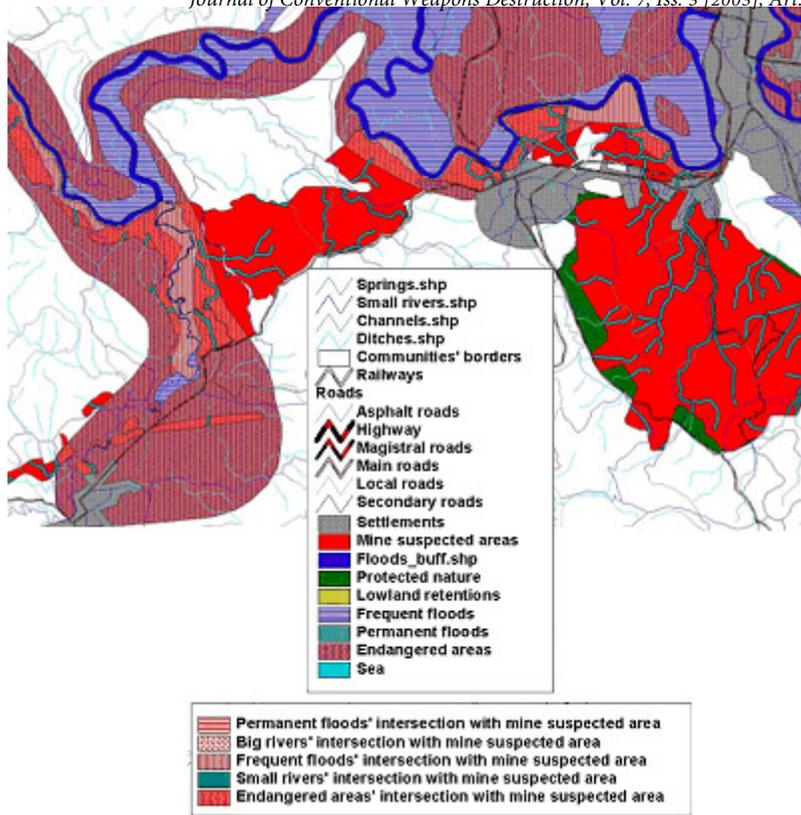


Figure 3: Thematic layers used for generation of floodplains on suspected minefields.

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