Using GIS to determine the flooded areas and risk assessment in the water supply system

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Abstract: *The water supply system is subjected to different flows varying within very large limits, the nature of these flows running through the pipes and fittings of the system are great diversity. The different situations the system is submitted, cause a number of disturbances, which can turn into serious failures if they are amplified.*
*By integrating graphic and alphanumeric data, the GIS turns into a computerised system for automatic elaboration of maps or diagrams, a general-purpose computerised graphic system, as well as a system that can store, process, combine and analyse data and information on the water systems, it can produce new added-value information. Thus, we can obtain information on the areas at risk of failure in the water supply systems and the flooded areas***.*** *After having carried out such interrogations and analysis and having presented the results to the decision-makers, more efficient planning and reduced planning costs can be achieved for the maintenance works, repairs and replacement in the water supply systems.*

Keywords: *GIS, water supply systems, risk of failures, thematic maps, flooded areas*

1. Introduction

When talking about public utilities, we have in mind those things that are characteristic to life in the 21st century. As far as the public utilities are concerned, the urban networks include: electric networks, gas networks, telephone networks, cable networks and the last but not the least *water and sewerage systems.* The dynamics of the urban development, even under the difficulties of the transitions period, formed another vision with respect to the public services; currently, due to the past inheritance (urban infrastructure) we have to organise the databases proper for a *modern and efficient* system.

The water supply system is subjected to different flows varying within very large limits, the nature of these flows running through the pipes and fittings of the system are great diversity. The different situations the system is submitted, cause a number of disturbances, which can turn into serious failures if they are amplified. The supply system are generally formed of buried pipes, thus the losses can be easily identified when waterholes appear on the surface of the pavement or in the inspection manholes; sometimes great losses occur and they need long searches, which can take days or weeks in order to precisely determine the spots where they occurred and to dig out the pipe, and afterwards identify the causes and eliminate them.

By integrating graphic and alphanumeric data, the GIS turns into a computerised system for automatic elaboration of maps or diagrams, a general-purpose computerised graphic system, as well as a system that can store, process, combine and analyse data and information on the water systems, it can produce new added-value information. Thus, we can obtain information on the areas at risk of failure in the water supply systems and the flooded areas**.**

2. Importance of GIS technology use in the management and analysis of water supply

The GIS system can be considered as an *information management system or as a support for the decision-making system.* GIS provides the possibility *to entry, to maintain and especially to interpret and to analyse rapidly and efficiently the data regarding the water and sewerage systems.*

The GIS processing results are not only much more effective in the information process – decision-making, production, inventory – where they are used, but also they entirely change our perception with respect to the surrounding reality: they provide a quicker and better understanding of the facts and phenomena we analyse and act on.

According to the studies that had been carried out, more than 80% of the data used by the water and sewerage companies have a geographical reference, thus the GIS support is necessary for the efficient development of the activities and for the informational flow fluidisation. Considering the importance of the geographical data in the work of these companies, the GIS applications have a great contribution to the optimisation of the informational flows. Currently, the focus is on the interoperability of the GIS systems, and several efficient functions are integrated with the existing solutions provided by the authorities. *Moreover, the integration of GIS solutions with other systems can provide an exhaustive image on the management process efficiency.*

GIS can easily operate large data quantities, can offer the possibility to perform complex analyses on spatial data, and advanced possibilities to display the results of these analyses. More and more lapped models, (mathematic model – geographic information system) have the tendency to absorb the specific forecast and simulation systems (*simulation models for the flows in the water and sewerage systems***,** underground water flow simulation models, air pollution simulation model, surface water flow simulation models, etc.).

*The Geographic Information Systems together with hydraulic modelling of sewerage systems simulate critical situations that could take to failures or to their inadequate operation***.** Moreover, the Geographic Information Systems together with the hydraulic modelling of the water supply networks, correlated with a *SCADA* system (*Supervisory Control and Data Acquisition*), can be used for the automation and supervision of the complex water supply networks.

The Internet and information technology development had a great impact on the GIS application architecture, determining substantial changes in the distribution and accessibility of the solutions in this category. Having these reasons in mind, we could say that accessing the applications by a simple Web browser met the need of a world characterised, among others, by dynamism and economic phenomena globalisation. During the past years, there were changes with respect to the needs related to information or equipment that are used by different users. Therefore, currently, not only computers are connected to the Internet, but also a lot of other equipment, such as mobile telephone networks or hand-held devices. Under these circumstances, the *GIS applications must provide a high level of interoperability and integration with different systems or applications. The standardisation of the data transfer models among different solutions became a compulsory request for most of the actual users.*

The new "wireless" technologies and those designed for the information distribution in the field prove their usefulness in GIS, as well; therefore in the past years we have noticed the need of scalable and efficient web applications, capable to share large data sets to large audiences spread out in the space.

The data base applications are also an important factor in the generation of GIS solutions as they are the element that defines the performance level of these implementations.

As compared with other European countries, Romania is currently far behind with respect to the information summarization and access to information. The creation of a geographical *information system implies exactly the access to diverse and updated information. The settlement of these disparities is part of Romania's efforts to integrate in the Euro-Atlantic structures.* (Bălteanu D., 2002)

Nowadays, the success of an organisation depends on the *possibility to reduce the decision process time, to make better decisions and to share strategic information within the organisation.* The employees in the public and private sectors found that they could take better decisions using the spatial element of the existing information. *The possibility to view the spatial information and to make spatial analyses provide them a strategic advantage.*

GIS is successfully applied in urban public works thanks to multiple benefits it has in the management and analysis of water supply systems.

Amongst the main benefits of GIS use for the public utilities represented by the water supply and sewerage systems, besides the traditional models, we would like to mention:

- *Improvement of the service quality;*
- *Optimization of the information circuit among departments;*
- *Reduction in the number of employees;*
- *Quick recovery of data;*
- *Capacity of data maintenance and updating;*
- *Interactive production of maps;*
- *Avoid to keep duplicate databanks;*
- *Planning of the network maintenance and repair works, the equipment inventory and the analyses become automatic procedures integrated in the system;*
- *Cutting the planning costs for the network maintenance and repair works;*
- *Better planning for the network maintenance and repair works;*
- *Quick finding and documentation of damaged sewers, badly sealed or that need drainage;*
- *Inventory of the consumers' needs and planning of the network extension works;*
- *Identification of the lines affected by the infiltration of pollutants;*
- *Obtaining information on the sewer maintenance and inspection (condition, failures, types of failure) using different devices (cameras);*
- *Increase of the analysis quality together with the reduction of the time necessary for the analysis, as well as the capacity to carry out integrated analyses – network pressure and outflow analysis in the water supply network, the pressure of the network and the analysis of the leakages in the water supply network, analysis of the water losses and detection of the failure cracks, analysis of the leakages in the sewerage system etc.;*
- *High quality presentations at the decision-making level;*
- *Improvement of decisions.*

3. Failure risk in the study area

The occurrence of flaws or failures in the water supply system causes technical, economic and social impacts. For these reasons, the study on the causes of the failures represents a priority in the sector of water supply systems. There are a lot of causes for the occurrence of flaws and failures, but except for the physical failures, there are also artificial failures, most of them being caused by operation or management errors (Gould N.C., 2005).

According to a report elaborated in 1991 by IWSA (International Water Supply Association – Asociația Internațională a Furnizorilor de Apă), the water losses in the water supply systems are *between 20 and 30 % . The most frequent cause of these losses is the fracture of pipes or the break of the junctions between them (Hueb J.A., 2001)*

All over the world, the water systems need rehabilitation and maintenance measures for the improvement of their performances and the prevention of failures. Moreover, due to these failures, the water companies lose important amounts of money.

Due to recent technological development, by applying the GIS technology and the hydraulic modelling, and with the presentation of the outputs to the decision-makers, a great number of problems can be prevented by taking efficient measures in conformity with strategies fore the identification and prevention of problems before they occur. In order to support the abovementioned, the great software producers offer a series of GIS and hydraulic modelling products that can generate solutions, which are different from one country to another and from beneficiary to beneficiary.

Impacts caused by failures are:

- **Technical and cost impact -** The multiple failures of the pipes cause financial difficulties for the Romanian water companies. Basically, the Department for repairs and maintenance and most of the available technical equipment deal only with the keeping the supply system operational. *The repair works at the pipes* include the following operations: the emptying of the valve manholes, manipulating the valves so as to seal the damaged section, cutting out the asphalt layer, breaking the concrete, digging, draining out the water in the cut, replacing the damaged section, refilling and valve adjustment, restoration of the asphalt layer. All the aforementioned *repair works cost 5-10 times more than the building of a new pipe.*
- **Social impact -** Due to the overflow of the maximum running capacity in the pipes, in the connecting pipes and in the interior columns in the blocks, the water supply to some consumers (at the superior floors) shows deficits, thus the number of complaints increases. The frequent failures in the pipes and the repairs of the fire cocks and of the valves *cause water interruption to consumers in large areas.* Due to the difficult turning off of the water (key valve that cannot be turned off tightly anymore, needing the doubling of several sections), due to the difficult digging in the asphalt and concrete, to the inadequate equipment and poor organisation in some cases, *the repair time takes up to 5-12 hours.* Since the washing and the disinfection of the pipes after repairing are not possible, the water supplied in the first hours after the restart *has high turbidity and it is slurry; thus the discontent consumers* often complain and refuse to pay the entire amount of the bill. *The water interruptions cause problems in the activity of several trade companies,* especially those at the ground-floor of the residential blocks, where they do not have the possibility to store water in their own tanks, which causes production loss (at the backer’s, at pizza places, in restaurants, etc.) or the interruption of the service (at the barber’s, at the beauty shop, for drink batching devices etc.).
- ***Environmental impact*** - *The repair works at the pipes damage the roads,* because of the excavation works and of the water and sludge leakages. *In other cases, the green areas, the natural surroundings, the scrubs and the trees are damaged.* Efforts are made to rehabilitate the damaged areas, but there are still dissatisfactions of the Municipality, as well as of the citizens due to the multiple works of the type. During the works in the inhabited areas, *the equipment used cause air and noise pollution, this creating discomfort for the inhabitants in the area.*

The study area is one part of the Garii neighbourhood in the city of Baia Mare, Maramureş county. It is located in the south-east part of the city of Baia Mare and it covers an area of approximately 25 ha. It is bordered in the north part by Traian Blvd., in the east part by Gării Blvd., in the south part by the Vlad Ţepeş street and in the west part by the Republicii Blvd.

For the study area, I captured and integrated several types of data regarding the locations, forms, relations (spatial or geographic data) and descriptive figures (attribute-type or alphanumeric data) of objects or geographic elements in one logical data model. Having this logical data model together with the GIS system, I made fast spatial enquiries, which can be expensive and long lasting if using other methods.

For example, I generated thematic maps of the diameters and of the materials the water supply pipes are made of in the study area (Figure 1).

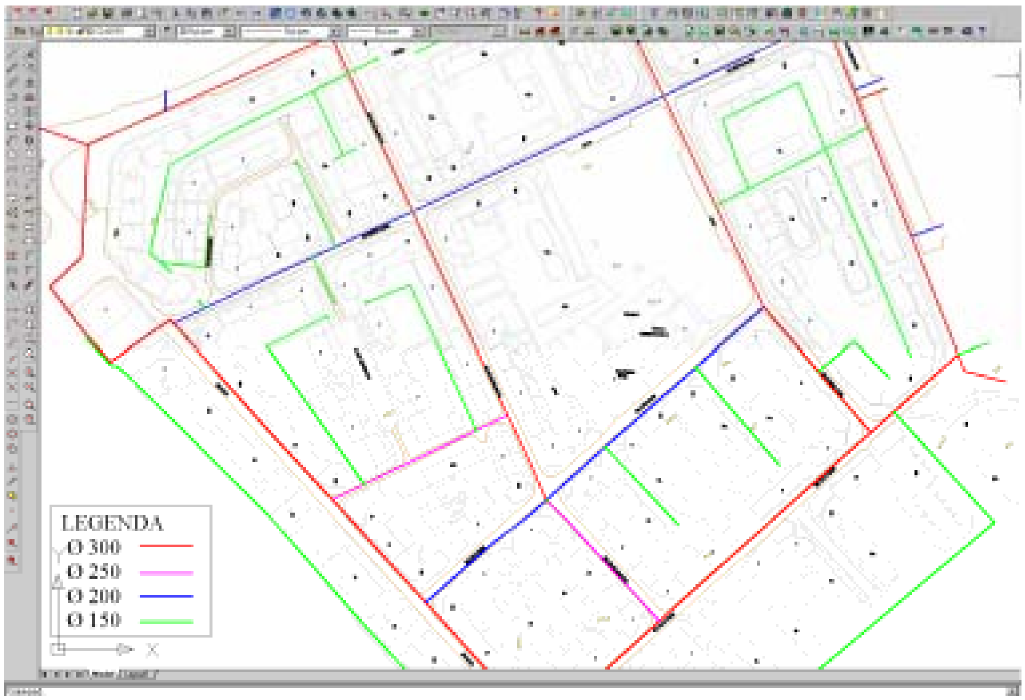

Fig. 1 Thematic map: classification of water supply pipes by diameter

In order to identify and locate the risk of flaws and failures, I considered the year of installation of the pipe sections, the material of the pipes, and the number of flaws/or failures in the study area.

I divided the risks of flaws and/or failures in the water supply system into three main categories, as follows:

High Risk – asbestos-cement pipes with more than 5 failures
Average Risk – asbestos-cement pipes with 3-5 failures
Small Risk – asbestos-cement pipes with less than 3 failures
The map showing the failure risks in the study area is presented in Figure 2.

It was also found that the failures in the city of Baia Mare with the most serious consequences on the population an don the neighbouring areas occur with *asbestos cement* pipes having the *longest diameter* where the occurrence of such failure is sudden, with massive *fractures of material*, and the repair works on the water pipe failure takes a long time due to the fact that the damaged section must be replaced; thus *there are long lasting water supply failures for the connected consumers.* Figure 3 presents the results obtained in graphic format.

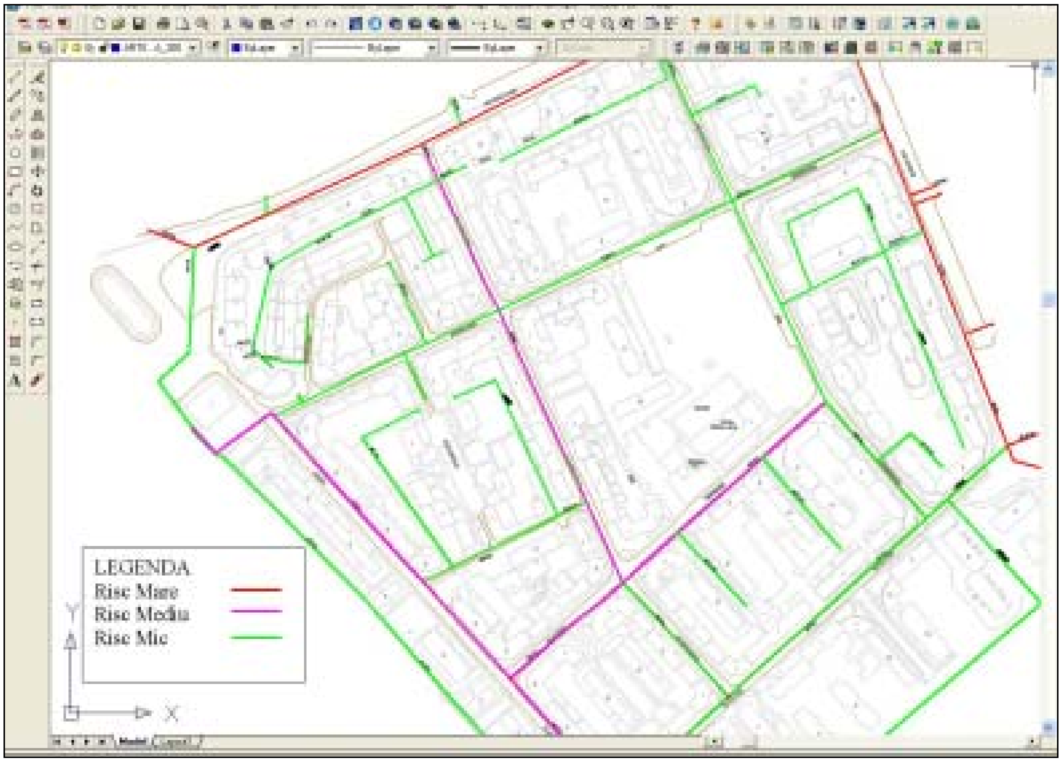

Fig. 2 Map showing the failure risks in the study area

Fig. 3 Identification and location of the pipe sections where there is risk of failures which would have serious consequences on the neighbouring areas

After carrying out such analyses and enquiries and presenting the results to the decision makers, better planning can be made with reduced costs for planning the water supply system maintenance, repair and replacement works.

5. Determination of the flooded areas

Some water pipe sections have a higher frequency of failures (more than 3/km) indicating a higher rate of wear. The high rates of pipe failures have a negative impact on the water supply services as far as the financial efficiency is concerned (the repair costs and those related to leakages) and with respect to the provided services (risk of contamination and of temporary water supply failure). Moreover, due to the fact that only 50% of the sector gates are not operational, the possibility to isolate the pipe sections for repair works is limited.

Determination of the Intensity-Duration-Frequency Curves

In order to establish the rain frequency, as well as to determine the IDF family curves (Intensity-Duration-Frequency), I used the records regarding the rains fallen in the city of Baia Mare during 32 years (1975-2006).

The frequency is represented by the average recurrence period T of the phenomenon, T being the number of years for which the rain quantity is equal or more frequent than the given value.

The frequency is also expressed in terms of overflow probability p given by the formula $p=p(h \geq h_1) = \int f(h)\,dh$, where f(h) is the distribution curve of the annual maximum rain quantity. In this case, the connection between the frequency (represented in years) and the probability (%) is:

$$T = 100/p \quad \text{if } p \leq 50\% \quad (1)$$

$$T = 100/(100-p) \quad \text{if } p \geq 50\% \quad (2)$$

After the selection of the annual maximum values for each given time period d (min) and the alignment of each calendar row obtained this way, a Gumbel probability density function is matched for each empiric curve corresponding to the duration d:

$$f(x) = \frac{1}{\alpha}\exp\left[-\frac{x-u}{\alpha} - \exp\left(-\frac{x-u}{\alpha}\right)\right] \qquad (3)$$

The Gumbel function parameters (u and α) were estimated using the maximum likelihood method.

Table 1 presents the results of the intensity frequency analysis and of the rain duration in Baia Mare (1975-2006). The table includes the intensity and the duration of the rains calculated according to the Gumbel distribution for different recurrence periods (T).

Table 1 Results of the intensity frequency analysis and of the rainfall duration Baia Mare (1975-2006).

	T=1000	T=200	T=100	T=50	T=20	T=10	T=5	T=2	
I = 15min	0.687	0.55	0.49	0.431	0.351	0.29	0.226	0.129	Intensity
	22.6	20.7	19.9	19	17.9	17.1	16.2	14.8	Duration
I = 30min	0.518	0.417	0.373	0.329	0.271	0.226	0.178	0.107	Intensity
	37.3	35.4	34.6	33.8	32.7	31.9	31	29.7	Duration
I = 45min	0.249	0.203	0.183	0.163	0.136	0.115	0.093	0.061	Intensity
	67.3	61.5	59.1	56.6	53.3	50.7	48.1	44.1	Duration

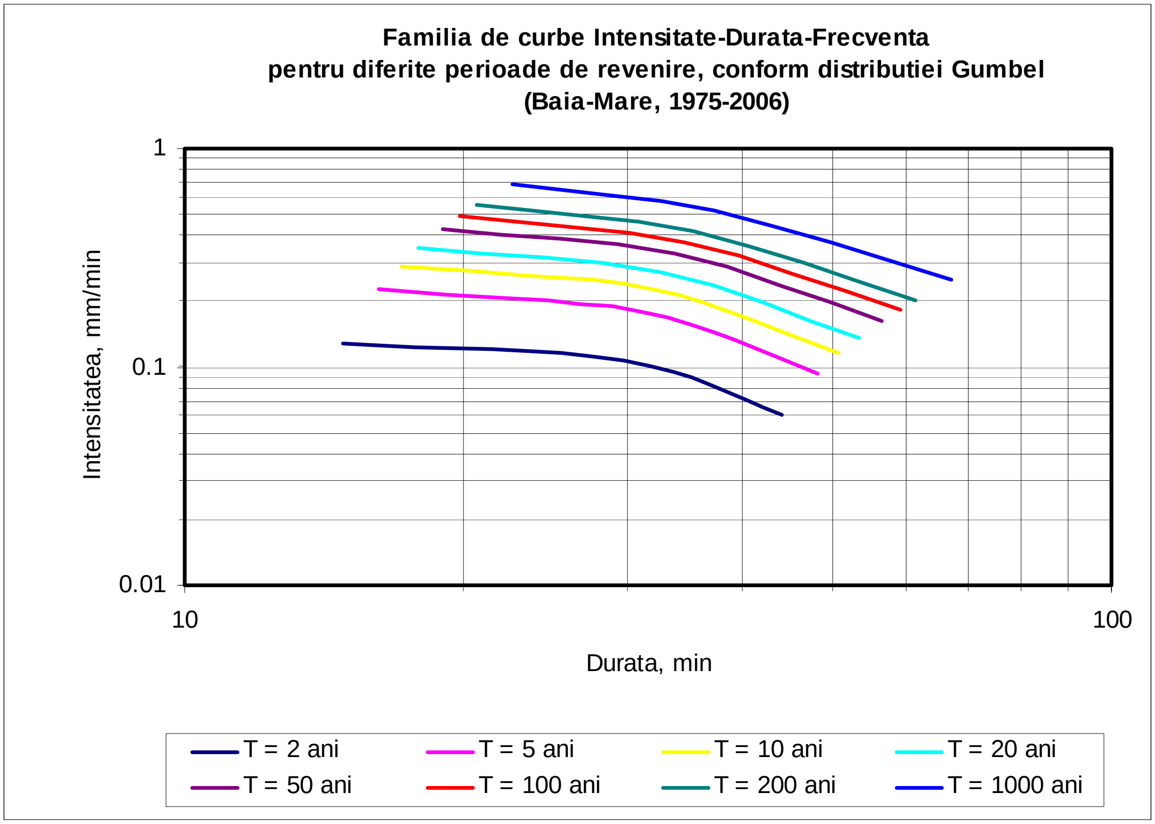

Fig. 4 IDF family curve for different reoccurrence periods (Baia Mare 1975-2006)

The rainfall intensity depends both on its frequency (probability) and on its duration and this expressed by a bidimensional function known by the name of Intensity – Duration – Frequency (IDF). The intensity according to the rainfall duration at different occurrence frequencies is represented as a series of decreasing parallel curves. The rainfall intensity decreases by their duration and increases by T.

Figure 4 presents the IDF family curves for different reoccurrence periods, in conformity with the Gumbel distribution for the city of Baia Mare.

The maximum flow rate in the urbanized areas occur shortly after the starting moment of the rainfall with large quantities of water fallen in small time sequences, lasting tens of minutes or a few hours.

Presentation of Results

In order to determine the flooded areas in the study area, 3 scenarios of failure in the water systems were simulated, on pipe sections with average and high risk of failure, as follows:

- failure on the pipe section (D=300 mm), situated on Traian Blvd. (fig. 5)
- failure on the pipe section (D=300 mm), situated on Matei Basarab street
- failure on the pipe section (D=300 mm), situated on Vlad Țepeş street

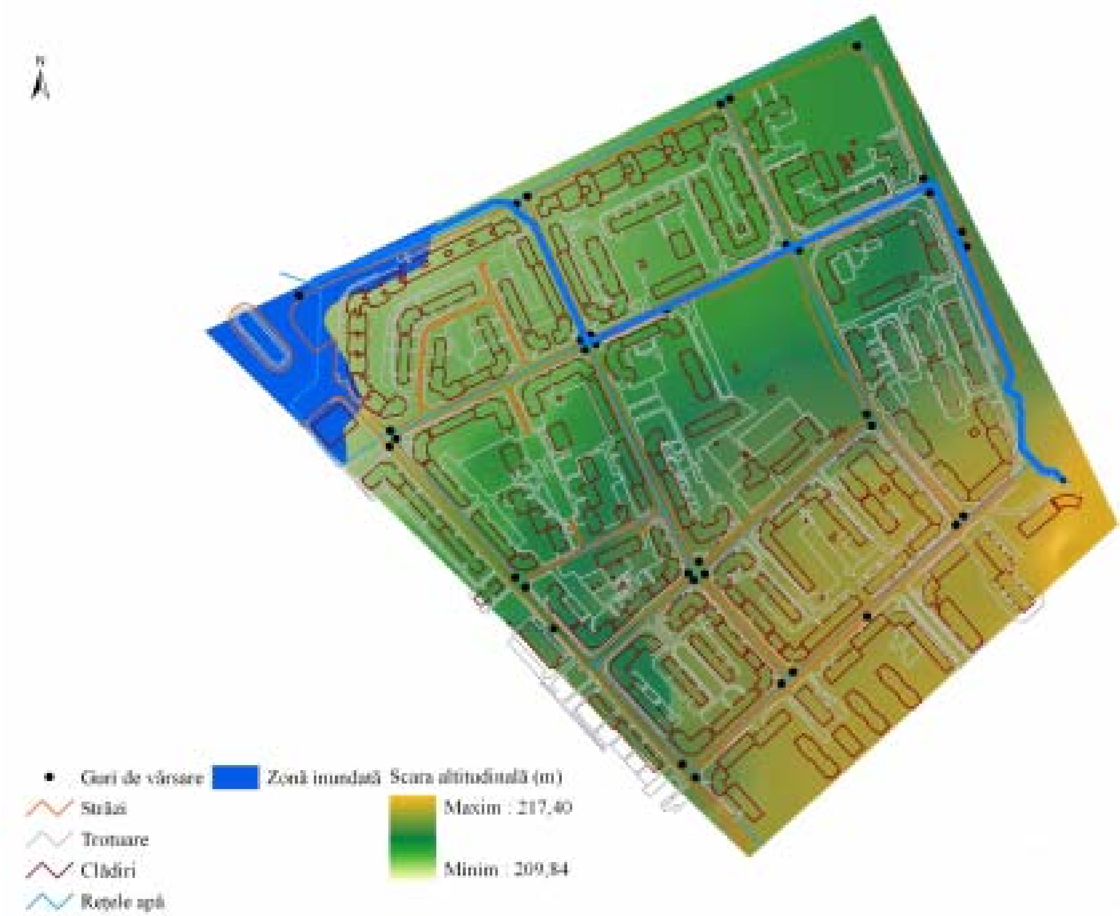

Fig. 5 Failure occurred in a pipe section on Traian Blvd.

These scenarios were also represented by three rainfalls with different intensity, duration and recurrence periods, as shown in table 1, by extracting the values from the Intensity-Duration-Frequency curve graphic, for different recurrence periods, considering the hypothesis that only 30% of the meteoric water are discharged in the outfalls.

The surfaces of the flooded areas, the maximum depths and the stored water quantities are shown in table 2.

Table 2 Surfaces, depths and water quantities in the flooded areas

No.	Broken water pipe section (area)	Rainfalls			Flooded area (ha)	Maximum depth (m)	Stored water quantity (cubic meters)
		I mm/min	D min	F			
1.	Traian Blvd.	0,107	29,7	1/2	0,44	0,5	2224
2.	Matei Basarab street	0,178	31	1/5	0,52	0,7	3862
3.	Vlad Ţepeş street	0.49	19.9	1/100	0,68	1,0	6825

6. Conclusions and proposals

This paper includes documentations and studies with respect to the use of the GIS technology for the assessment and simulation of the water flow in risk cases for a study area in the city of Baia Mare. This avant-garde field of study, which opens and creates new perspectives for the development and assertion of the specialists in water systems, has outstanding implications in the analysis and decision-making process for planning the works related to the maintenance, repair and replacement of water systems, and implicitly substantial cost savings.

Based on these desiderata, from the very beginning it was necessary to carry out thorough documentations and research on the studies, methods, tools and technologies that form the fundamentals of the water flow assessment and simulation in risk situations.

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