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USING GIS TO DETERMINE THE FAILURE RISK IN THE WATER SUPLY NETWORK. THE CASE STUDY OF A SQUARE FROM BAIA MARE CITY

BY

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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.

Key words: water network, model simulation, GIS.

1. Introduction

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.* 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, 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 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)

2. General Causes of Failures in the City of Baia Mare

The analysis of the causes that produce the failures is of utmost importance in determining the measures to be taken. These causes are multiple and they occur in different life cycle stages, being of a great diversity, depending on the material the pipes are made of, on the calculation, execution and technical exploitation conditions, on their age, on the flows they are submitted to during their life cycle.

It would be a mistake to consider that any loss of water is caused by execution faults or that any loss would turn into a fatality that cannot be solved. Researches that had been carried out showed multiple causes of the failures, and the measures taken allowed the limitation of the water losses. The measures to be taken cover the whole life cycle of the systems, from the layout phase, the execution phase and a special attention is paid to the system using phase which represents the longest of the life cycle.

Knowing the causes is crucial in order to be able to take the right correction measures for the remediation of the failures. Sometimes these causes are obvious, thus the measures can be taken immediately; this situation is generally characteristic to failures. But there are also situations when the causes of serious failures or breakdowns that produced great losses of water cannot be easily identified, either because of the complexity of their effects or because of the engineers lack of experience or even because of the length of time necessary for the searches that need to be carried out for an adequate determination of the causes.

During the past 10 years, in the city of Baia Mare significant changes were done concerning the supply of water based on categories of consumers, especially as a result of the decrease in the water demand in the eastern and western industrial areas (these areas have their own adequate transport networks) and the increase of the demand in the residential areas where the number of constructions is very high and the supply systems are overflowed considering their optimum transport capacity, this taking to the under-dimensioning and the decrease of the pressure level. *This capacity transfer from a section to another within the system caused the modification of the hydraulic level (speed, pressure, running way), the pipes being submitted to a heavy exploitation level in the residential areas.*

In the layout phase of the transport pipes, supply and connecting pipes, the properties of the drinking water supplied by the Water plant and those of the land where they were to be situated were not taken into consideration. The study prepared by the Institute for Research and Environmental Engineering emphasises the *dealkalinization aggressiveness towards the concrete and the heavy aggressiveness towards the metals. In order to cut the execution costs, the anticorrosive protection was neglected.*

These two causes determined a life cycle *of at most 7-8 years* for the pipes (especially those made after 1980), afterwards those made of steel and asbestos-cement need expensive maintenance because of the frequent cracks and bursts.

Failures also occur due to the old age of the pipes in some cases, due to the inadequate quality of the metallic pipes, due to the poor quality in the installation works and to the anticorrosive protection of the pipes against the heavy aggressiveness of the soil, etc.

3. Impact Caused by Failures in the City of Baia Mare

3.1. Technical and Cost Impact

The multiple failures of the pipes cause financial difficulties for the company. 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.*

3.2. Social Impact

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.)

3.3. 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.*

4. Failure Risk in the Study 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.

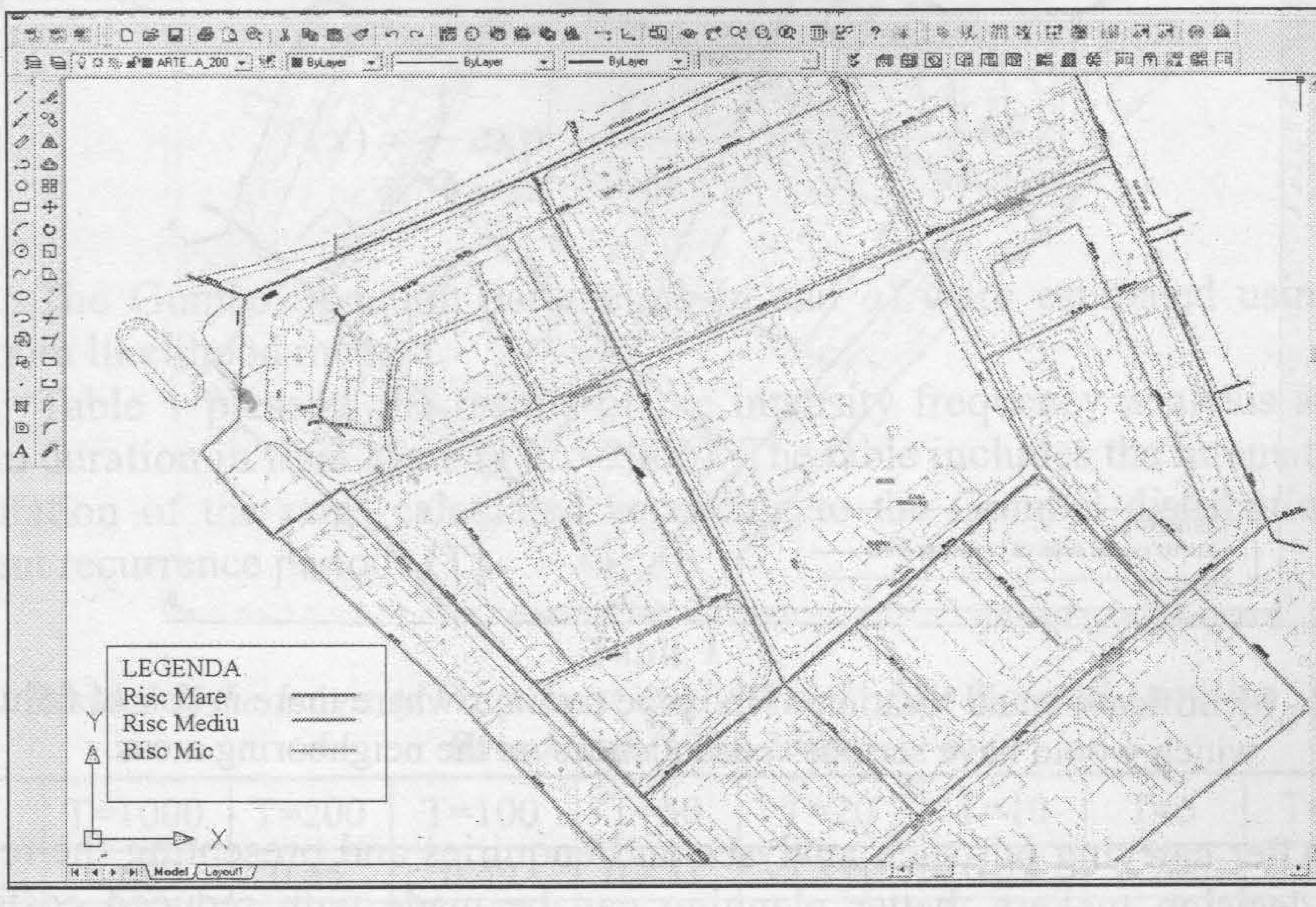

Fig. 1 – Map showing the failure risks in the study area.

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 Fig.1.

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*. Fig. 2 presents the results obtained in graphic format.

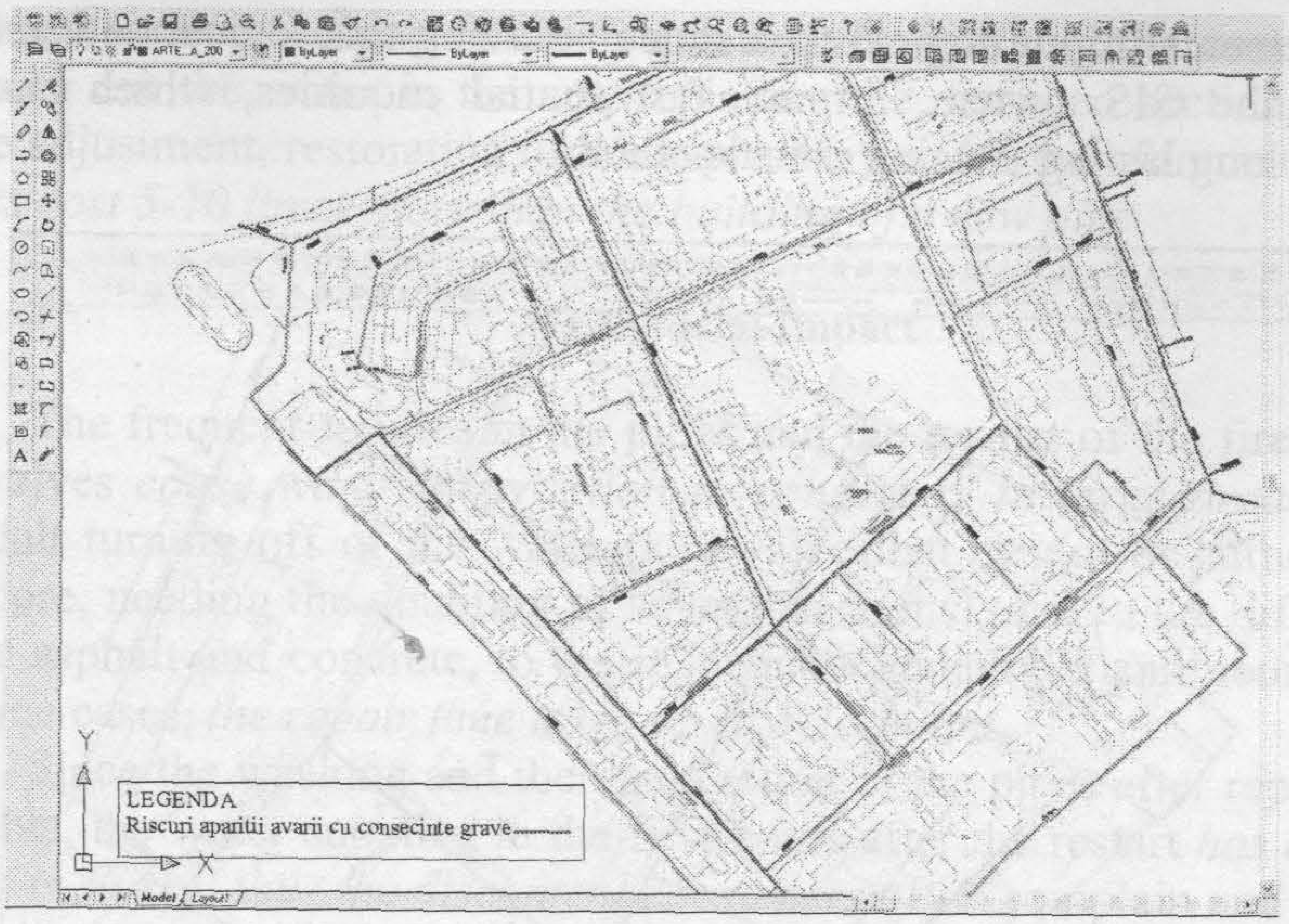

Fig. 2 - Identification and location of the pipe sections where there is risk of failures which would have serious consequences on the neighboring areas.

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.

5.1. 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.

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:

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

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
	22.6	20.7	19.9	19	17.9	17.1	16.2	14.8
I= 30min	0.518	0.417	0.373	0.329	0.271	0.226	0.178	0.107
	37.3	35.4	34.6	33.8	32.7	31.9	31	29.7
I= 45min	0.249	0.203	0.183	0.163	0.136	0.115	0.093	0.061
	67.3	61.5	59.1	56.6	53.3	50.7	48.1	44.1

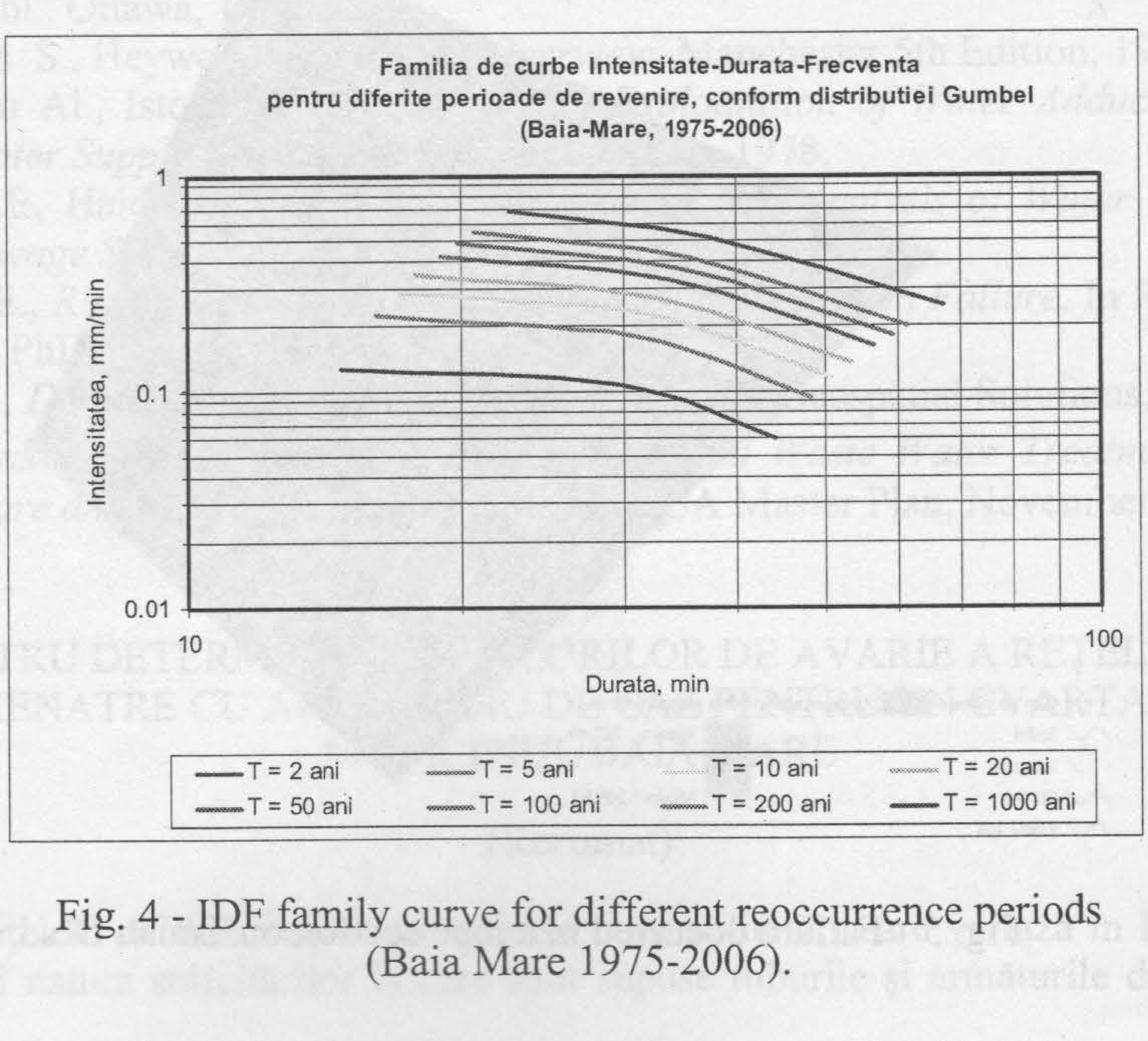

Fig. 4 - IDF family curve for different reoccurrence periods (Baia Mare 1975-2006).

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.

Fig. 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.

5.2. 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 Ţepeş street

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.

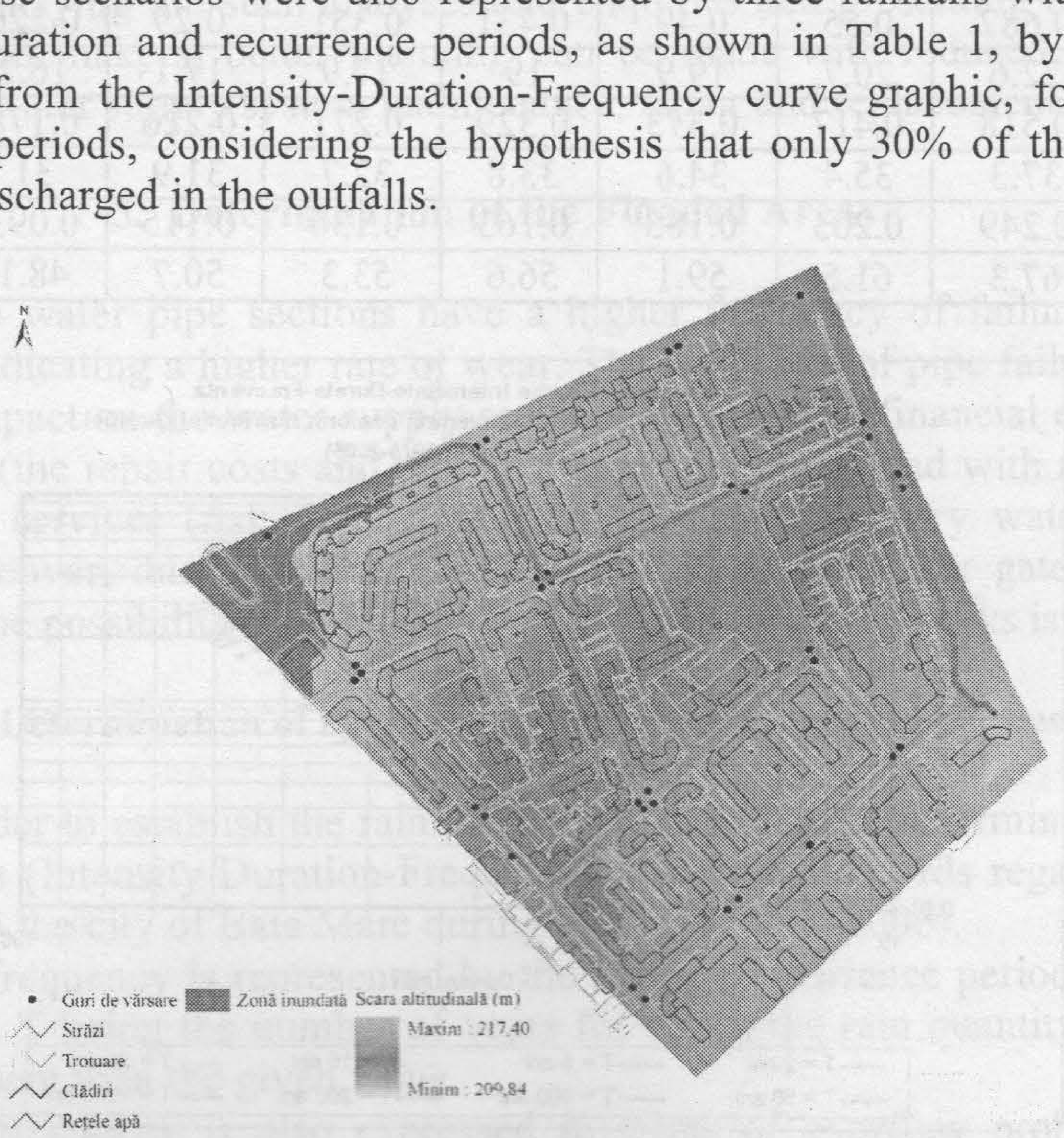

Fig. 5 - Failure occurred in a pipe section on Traian Blvd.

6. Conclusions

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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GIS PENTRU DETERMINAREA RISCURILOR DE AVARIE A REŢELELOR DE ALIMENATRE CU APĂ. STUDIU DE CAZ PENTRU UN CVARTAL DIN MUNICIPIUL BAIA MARE

(Rezumat)

Reţelele de distribuţie sunt supuse unor solicitări care variază în limite foarte largi, însăşi natura solicitărilor la care sunt supuse tuburile şi armăturile din care sunt

alcătuite reţelele fiind de mare diversitate. Ca urmare a acestor multiple condiţii în care sunt obligate să lucreze reţelele, ele suferă numeroase defecţiuni, care atunci când se amplifică pot deveni adevărate avarii.

Prin integrarea datelor de tip grafic şi alfanumeric, GIS-ul devine nu numai un sistem computerizat pentru producţia automatizată de hărţi sau diagrame, ori un sistem de grafică computerizată de uz general ci şi un sistem care poate stoca, procesa, combina şi analiza date şi informaţii despre reţelele de apă, putând produce noi informaţii, cu valoare adăugată. Astfel putem obţine informaţii asupra zonelor de risc de avarie a reţelelor de apă.

După realizarea unor astfel de interogări şi analize şi prezentarea rezultatelor factorilor de decizie, se pot întocmi planificări mai bune şi reducerea costurilor de planificare a lucrărilor de întreţinere, reparaţii şi înlocuire a reţelelor de alimentare cu apă.