The Identification of Hazards to the Selected Source of Emergency Water Supply

ALENA BUMBOVA¹, MILAN CASLAVSKY², FRANTISEK BOZEK¹
¹Civil Protection Department
University of Defence
Kounicova 65, 662 10 Brno
CZECH REPUBLIC
alena.bumbova@unob.cz    frantisek.bozek@unob.cz    http://www.unob.cz/Default.aspx
²GEOtest, a. s.
Šmahova 1244/122, 627 000 Brno
CZECH REPUBLIC
caslavsky@geotest.cz    http://www.geotest.cz

Abstract: - The paper deals with the application and results of a case study made on a selected source of emergency water supply in a selected region of the Czech Republic. The hazard identification to the assessed water source is based on a developed methodology and a compiled general register of selected types of hazards under the current acceptation of historical data, general and natural conditions, including an assessment of an environmental burden in the vicinity of the source and its infiltration area. The developed hazards register is the essential prerequisite for the subsequent assessment of the risk level of the water source and its classification within the system of crisis planning.

Key-Words: - crisis state, emergency water supply, groundwater, hazard identification, hazards register, source of emergency water supply

1 Introduction

Since the beginning of the history of civilization, water has played a vital role. For long centuries it has been appreciated as a gift of nature, which is available without limits. Due to the social activities of human society, especially by the change of production and consumption patterns, water of adequate quality has become a precious asset. Reserves of drinking water on the planet Earth are limited and its quality and quantity is continually decreasing. At present, more than a billion people suffer from the lack of drinking water and have very limited access to it [1].

The worldwide significance of water was emphasized by proclaiming the “European Water Charter“ on 6th May 1968 in Strasbourg, which is founded on 12 points [2]. In 1993, The United Nations General Assembly declared March 22 as the World Water Day [3]. The United Nations and its member states in collaboration with significant international organizations (FAO, UNESCO, WHO, UNICEF, and others) recommend and implement specific measures for the protection of water resources. Each year the World Water Day announces a different theme. The provision of access to sources of drinking water and basic sanitation for all people in the world by 2015 is included in the indicators of the performance of one of the Millennium Development Goals [4].

The need and necessity to provide drinking water in adequate quantity and quality rises in the advanced world particularly during crisis situations when the water supply to population by public systems is being restricted for a short- or long-term period or completely fails. Such situations can be effectively solved by putting into operation substitute sources which are groundwater structures unused [5].
2 Problem Formulation

Many organizations and associations are involved in the issue of the provision of emergency water supply. The matter of the drinking water supply to population in crisis situations is not addressed by the community law of the European Union. The solution is within the power of the individual member states [6].

Most countries have delegated the responsibility for emergency water supply to a great degree from the public sphere to the citizen. It is recommended and assumed that every household will acquire a sufficient reserve of water as part of preparation for an extraordinary event or a crisis state according to the number of persons and pets in the household. The public sphere deals particularly with the situation with water supply in reception camps and assembly centers if a residential area has been afflicted for some reason and a large number of people without homes have to be accommodated [5].

Emergency water supply in the Czech Republic belongs to the gestion of the Ministry of Agriculture and is regulated by legal standards [6, 7, 8]. The system of emergency water supply in the Czech Republic is activated after a crisis situation has been announced. Drinking-water supply in a crisis situation is conducted in the normal extent with the use of the water-supply system, if not affected. Otherwise, sources of emergency water supply are used. The system of emergency supply prefers the use of groundwater to surface water because groundwater is less vulnerable and is usually of higher quality, too. For this reason, sources of emergency water supply must be pre-classified in relation to resistance and be prepared so that they can be put into operation immediately.

At present, the following classification is the basis for the selection of sources of emergency water supply to population [7]:

a) “Sources of extraordinary significance”, which are considered to be intake structures of groundwater with increased resistance, enabling the necessary amount of water to be provided for drinking purposes. These structures are to serve its function in all crisis states and are equipped with basic operative means for providing sanitation, pumping and treatment of water for drinking purposes even under the conditions of power cut.

b) “Selected sources”, which are intake structures of groundwater capable of resisting a disruption of the water supply system of a smaller extent. They have adequate equipment and are used solely in the cases of higher effectiveness in relation to the sources “extraordinary significance”.

c) “Other intake structures not included in the sources for emergency water supply”, which are used for mass water supply to population from water mains for public needs. They serve solely as alternative water sources for drinking purposes.

The submitted classification is insufficient. It does not enable the sources for emergency water supply to population to be selected more precisely for the needs of crisis management and does not apply the risk management principles. The guideline [7] does not even contain basic steps of risk assessment, i.e. the assets identification, hazards and vulnerability for those sources which can be damaged or destroyed by the activation of a source of hazard.

The currently applicable guidelines or recommendations [9, 10, 11] and accomplished projects [12, 13] deal with the issue of risk management particularly in drinking-water sources or entire water-supply systems used under normal conditions. The methods What-if, HAZOP, FMEA (or FMECA) and Fault Tree Analysis (FTA) are used for hazard identification. Water Safety Plans (WSPs) [14] of the World Health Organization (WHO) [15] recommend using the method of Hazard Analysis and Critical Control Points (HACCP). This method has been developed for the food industry, hence WSPs place emphasis particularly on the evaluation of the quality of human health in using water rather than on the amount of water and the provision of water supply. An overview and evaluation of the risk assessment methods and estimation, suitable for the provision of drinking water supplies, is presented in Annex A of the project [16]. The aforementioned references, however, do not attention to the matter of the classification of emergency water supply sources.

The classification of water sources proposed by us on the basis of risk will also enable the operators of the water-supply infrastructure to implement more easily, at regional or statewide level, new requirements of the ongoing amendment of the European Directive for drinking water [17] in national conditions.
3 Applied Methods
The method “Fault Tree Analysis”, based on the systematic regressive analysis of events using a chain of causes that could lead to a selected top event, has been applied to the identification of hazards sources, the compilation of a register and the identification of threatened parts of a hydrogeological structure and technological elements of underground water resources [18]. The outputs of the method “Fault Tree Analysis” combined with the method “What-if” were used to identify the elements of groundwater resources which could be damaged or destroyed by the activation of a hazard source [19].

The compiled hazards register has been divided into natural and technological hazards, also taking account of the environmental burden of the vicinity of the source and its infiltration area. Natural hazards have been divided into the groups of atmospheric changes, geological changes and other effects. Other identified effects have solely included the increased radioactive background for the subsequent stage of risk evaluation. The identification of anthropogenic hazards has been made only for the group of technological hazards in the categories of accidents and common anthropogenic activities [20].

The identified threatened elements of emergency groundwater sources in the hazards register have been divided into the hydrogeological structure itself and the technological equipment for groundwater intake. The following can be threatened in the hydrogeological structure of the water source:

a) Hydrogeological conditions (HG),
b) Hydrological regime (HR),
c) Groundwater quality (WQ).

The following threatened elements have been identified in the technological equipment of the water source:

a) Water intake structures (WIS),
b) Water treatment plant (WTP),

Observed within these subsystems was only the threat to the intake structures and to the water treatment plant that are mostly located at the site of the exploited hydrogeological structure [20].

The identification of hazards and the elements of the hydrogeological structure and the technological equipment of a selected water source, potentially affected by such hazards, were conducted in the form of brainstorming [21]. Using brainstorming, the indexation of the hazard frequency was also made.

A data sheet of a substitute water source has been created for the evaluated borehole. This data sheet is divided into several parts containing information about the location of the substitute water source, natural conditions, technical specifications and construction, and a description of identified hazards. Subsequently, it will be supplemented with results obtained from the assessment of vulnerability and the determination of the risk level, and will be fit in according to a new classification of water sources. For logical and practical reasons, the data sheet will be supplemented with an annex part containing base maps, results of chemical analyses, photographs, etc. Of these conditions above, emphasis will be placed on hydrogeological conditions, hydrological regime, groundwater quality, surrounding land use, and the infrastructure of the borehole and the surrounding area.

4 Problem Solution
In all, ten sources potentially suitable for emergency water supply have been selected in the plan of the development of water mains [22] in the assessed region of the Czech Republic. These sources have not yet been classified according to the guideline [7]. In addition to these sources, other potential sources that could also serve the required function are being currently assessed in the project. All the boreholes will be subjected to risk analysis and assessment, on the basis of which the individual boreholes will be methodologically classified into the relevant groups of sources of emergency water supply.

The submitted case study is concerned with the hazards identification to one of the potential sources of emergency water supply to a selected region. On the left bank of the local brook, a water intake area for a prospectively considered supply of drinking water to the population of adjacent municipalities has been established within a hydrogeological survey. The original intake structures were repeatedly rehabilitated and new ones were also built there progressively. At present, at the site there is a functional abstraction borehole designated as HV 10001, which has been subjected to the specific evaluation of the hazards identification.
The borehole lies at an altitude of about 310 m above sea level and is 125 m deep. It was installed using the full hole drilling method without a borehole log. The geological profile can be derived using borehole HV 1001, which is located at a distance of 8 m. The borehole passed to a depth of 5.5 m through the Quaternary cover formed of fluvial to deluvial-fluvial sediments with prevailing clayey-loamy and sandy soils, and clayey-sandy gravels in the lower part. From 5 m to 78 m, there are deposits of Neogene sediments of the Upper Miocene, stratigraphically falling into the Upper Badenian. These are calcareous clays to claystones designated as tegels. From 78 m to the final depth, the borehole intersected weathered bedrock consisting of Palaeozoic sediments of the Upper Carboniferous formed of greywackes and conglomerates. The bedrocks are loosened and create block debris and bouldery gravels with an interstitial clayey-sandy to gravelly filling. During drilling, the groundwater level was encountered at depths of 1.5 m and 78 m. After drilling, the groundwater level was stabilized at a depth of 52 m.

The borehole is cased to a depth of 78 m with a solid steel tube of 216 mm in diameter, and from 78 m to its final depth with a perforated steel tube of 108 mm in diameter. The borehole head was modified constructionally and technically by terminating it into a valve chamber fitted with a lockable steel cover. A short steel ladder leads to the valve chamber. The valve chamber is covered with an earthen mound having a grass surface.

Groundwater is abstracted from a water-bearing horizon in the weathered and loosened bedrock in an interval from 78 to 125 m. The main recharge of groundwater to the borehole occurs along a pronounced fracture zone of the Saxonian direction (northwest – southeast), which passes across the Drahany Upland and follows the valley of the brook. Groundwater flows along this tectonic line from the northwest through the evaluated borehole and towards the southeast. The infiltration area of the evaluated borehole can be estimated at 30 km$^2$, which guarantees the yield of the evaluated borehole being around 10 l.s$^{-1}$.

Slightly neutral to slightly alkaline (pH not exceeding 7.1), good-quality groundwater has been abstracted from the borehole over a long time. It is medium-mineralized; fairly hard (around 14°N) according to Herle’s classification; of the hydrochemical type Ca(Mg)-HCO$_3$-SO$_4$. Organoleptically, only the randomly increased content of manganese is harmful. The other parameters of the accomplished evaluation of the quality of drinking water are satisfactory. Neither chemical nor microbial pollution, which would exclude the use of water abstracted form the borehole, has been proved.

The plots of land in the vicinity of the borehole have been used in various intensity for agricultural purposes (crop farming). Forestry activity is carried out in the more distant surroundings located against the direction of groundwater inflow and in higher parts of the valley slopes.

The hazards identification has been made on the basis of the developed general hazards register, a reconnaissance of the area and a review of relevant data and information provided by the operator. Hailstorms and torrential rain, floods, soil erosion, slope movements, escapes of gases from the Earth’s depths, increased radioactive background, agricultural and forest production have been identified as potential sources of contamination, damage and destruction of the water source. An overview of hazards and threatened elements of the hydrogeological structure, including the technological elements of the water source, is given in Table 1.

4.1 Hailstorms and torrential rain
In recent years, extreme and torrential precipitation has been the cause of extraordinary events in some regions of the Czech Republic. The studied region is not an exception.

Neither hailstorms nor torrential rain can affect the hydrogeological conditions or the quality of groundwater in the hydrogeological structure. The infiltration of a large amount of surface water in the infiltration area of the evaluated borehole leads to the rise of the groundwater level and to a change in the gradient of the piezometric level of the groundwater table, affecting the velocity and direction of groundwater flow. They have practically no effect on the intake structures.

Intensive precipitation can result in very dangerous floods called torrential rain floods. Torrential rain can cause soil erosion or trigger slope movements.

Hailstorms and torrential rain pose potential hazards for the studied threatened elements with the frequency at an interval of (1; 10) year$^{-1}$. 

4.2 Floods
A brook flows at a distance of 30 m from the evaluated borehole. During the spring thaw and torrential precipitation, there is a hazard of affecting the quality of water source by flood. It is estimated that the activation of a threat can happen even during the five-year discharge of the brook when the water discharge becomes almost hundred times higher as compared to the normal state.

Due to the large thickness of the protective capping layer, the hydrogeological conditions and the quality of groundwater cannot be seriously affected. The infiltration of a large amount of surface water in the infiltration area of the evaluated borehole leads to the rise of the groundwater level and to a change in the gradient of the piezometric level of the groundwater table, affecting the velocity and direction of groundwater flow. Floods can damage or destroy the technical equipment of the head of the intake structure.

The subsequent effects can cause the water logging of the rock environment, undermine the base of the slope east of the borehole and partly damage the borehole.

The frequency of the occurrence of flood has been estimated by a value of $1.10^{-1}$ year$^{-1}$.

4.3 Soil erosion
As a result of the use of unsuitable sown crop types and procedures, topsoil can be washed out or carried away from the farmed land around the borehole. The cultivated slope is located east of the studied borehole.

Soil erosion cannot immediately affect the hydrogeological structure, or the hydrological regime, or the quality of groundwater. Exceptionally increased transport of soil can damage or destroy the intake structure of the borehole; the hazard frequency has been estimated at $5.10^{-2}$ year$^{-1}$.

Soil erosion around the water source can cause the increased occurrence of floods.

4.4 Slope movements
An “on-site interview” carried out with employees of the operator of the water source has proved that deformations of the equipment of the previously installed hydrogeological boreholes were observed in the water intake area in the past. Deformations result from movements in the rock environment. These movements can also be indicated by a morphologically conspicuous transverse ridge in the slope east of the borehole under investigation. A hidden sign of slope movements can also be differential movements of the sedimentary fill of the valley.

In the hydrogeological structure, slope movements can affect the hydrogeological conditions and the hydrological regime. However, they cannot affect the quality of groundwater. As for the technological equipment, they can damage or destroy the water intake structure.

The subsequent effect of slope movements can be floods and difficult cultivation of surrounding agricultural land.

The frequency of the occurrence of slope movements posing a potential hazard to the studied threatened elements of the water source is about $5.10^{-2}$ year$^{-1}$.

4.5 Increased radioactive background accompanied by escapes of radon
The infiltration area of the water source is known as an area with increased radioactive background. The cause is the origin of the sedimentary material of rocks from the area of the Bohemian-Moravian Highland, containing potassium and a number of ore deposits of radioactive materials that were mined in the past. The particular radionuclide causing the radioactivity of the environment will be specified by subsequent radiochemical analyses.

The increased radioactive background cannot affect the hydrogeological conditions or the hydrological regime in the hydrogeological structure. It can adversely influence the quality of groundwater. It has no effect on the water intake structure of the borehole.

The synergic effects of the increased radioactive background accompanied by escapes of radon at the site have not been identified.
The hazard frequency of the increased radioactive background accompanied by escapes of radon posing a potential hazard for the studied threatened elements is estimated as continuous.

4.6 Agricultural and forest production
Agricultural and forest production can affect the infiltration area and the site in the vicinity of the borehole during routine economic activity or when an accident occurs. The nearest vicinity of the water source is used for crop production; higher parts of the slope are forested. When cultivating agricultural land, synthetic and natural fertilizers and pesticides are used. The use of agricultural and forest mechanization can lead to spills of fuels and other working liquids (oils, lubricants, windshield washer fluids) into the rock environment.

Agricultural and forest production cannot immediately affect the hydrogeological conditions or the state of the intake structure of the borehole. Long-term intensive agricultural production, however, can strongly reduce the quality of groundwater and affect the hydrological regime.

Due to the fact that agricultural and forest production is continuous, the hazard frequency to the threatened elements of the water source has also been assessed in this sense.

The subsequent effect of agricultural and forest production is soil erosion.

When using agricultural and forest machinery and equipment, accidents can happen, during which massive spills of substances detrimental to water can occur. They are caused by human failure, a defect on technical equipment, adverse weather conditions and the state of the ground surface. Accidents are accompanied by spills of working liquids, and transported media can have the character of substances detrimental to water.

In the hydrogeological structure, these accidents cannot affect the hydrogeological conditions or the hydrological regime. For geological reasons, the spill of fuels and transported media in the vicinity of the borehole or in the infiltration area cannot affect the quality of groundwater. As for the technological equipment, it can damage or destroy the water intake structure.

The hazard frequency of an accident of agricultural machinery in the cultivation of land posing a potential hazard to the studied threatened elements is estimated at $5 \times 10^{-2}$ year$^{-1}$.

Table 1 Overview of hazards and threatened elements of the hydrogeological structure and the individual technological elements
HG – hydrogeological conditions, HR – hydrological regime, WQ – groundwater quality, WIS – water intake structures, WTP – water treatment plant

<table>
<thead>
<tr>
<th>Potential hazards</th>
<th>Threatened elements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HG</td>
</tr>
<tr>
<td>1 Natural hazards (natural disasters)</td>
<td></td>
</tr>
<tr>
<td>1.1 Natural disasters caused by atmospheric changes</td>
<td></td>
</tr>
<tr>
<td>Hailstorms and torrential rain</td>
<td>+</td>
</tr>
<tr>
<td>Floods</td>
<td>+</td>
</tr>
<tr>
<td>1.2 Natural disasters caused by geological changes</td>
<td></td>
</tr>
<tr>
<td>Soil erosion</td>
<td></td>
</tr>
<tr>
<td>Slope movements</td>
<td>+</td>
</tr>
<tr>
<td>1.3 Natural disasters caused by other effects</td>
<td></td>
</tr>
<tr>
<td>Increased radioactive background associated with escapes of radon</td>
<td></td>
</tr>
<tr>
<td>2 Technological hazards</td>
<td></td>
</tr>
<tr>
<td>2.2 Common activity</td>
<td></td>
</tr>
</tbody>
</table>

Table 2 gives the frequency of the occurrence of identified hazards for the assessed source of emergency water supply.
Table 2 Hazard frequency

<table>
<thead>
<tr>
<th>Potential hazards</th>
<th>Hazard frequency [year^{-1}]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hailstorms and torrential rain</td>
<td>(1; 10)</td>
</tr>
<tr>
<td>Floods</td>
<td>1.10^{-1}</td>
</tr>
<tr>
<td>Soil erosion</td>
<td>5.10^{-2}</td>
</tr>
<tr>
<td>Slope movements</td>
<td>5.10^{-2}</td>
</tr>
<tr>
<td>Increased radioactive background associated with escapes of radon</td>
<td>∞</td>
</tr>
<tr>
<td>Agricultural and forest production</td>
<td>∞</td>
</tr>
</tbody>
</table>

5 Conclusion
The first step of risk assessment, which is hazard identification, has been undertaken for a potential studied source of emergency water supply – HV 10001. Based on all available valorized and validated background information, relevant hazards relating to the evaluated borehole have been identified. These are hailstorms and torrential rain, floods, soil erosion, slope movements, increased radioactive background associated with escapes of radon, accidents of agricultural and forest machinery in cultivating plots of land, and agricultural and forest production. All of these considered threats have been characterized purposefully in relation to the specific conditions of the site and assessed in relation to the potential hazard to the individual elements of the source of emergency water supply; possible subsequent effects have been evaluated; and the frequency of their activation has been estimated.

The results obtained from the hazards identification to the source of emergency water supply, HV 10001, will be used for the semi-quantitative evaluation of vulnerability and subsequent risk analysis and assessment. The source of emergency water supply will be classified according to the identified risk level on the basis of a newly developed original methodology which reflects the needs of crisis management. The submitted procedure of hazard identification is used as an example for the evaluation of the other sources of emergency water supply.

Acknowledgements:
The outcomes presented in this contribution have been acquired as part of the solution of the project “Security Research of the Czech Republic” on the topic “The Methodology of the Assessing the Emergency Water Supply on the Basis of Risk Analysis”, Project No. VG20102013066.

References:


