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Classification of Ground Water Resources for Emergency Supply

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***Abstract*—**The article deals with the classification of alternative water resources in terms of potential risks which is the prerequisite for incorporating these water resources to the emergency plans. The classification is based on the quantification of risks resulting from possible damage, disruption or total destruction of water resource caused by natural and anthropogenic hazards, assessment of water quality and availability, traffic accessibility of the assessed resource and finally its water yield. The aim is to achieve the development of an integrated rescue system, which will be capable of supplying the population with drinking water on the whole stricken territory during the states of emergency.

***Keywords*—**Classification, Emergency Supply, Risk, Water Standby Resource.

I. Introduction

IN emergency events and under crisis situations the supply of water to population from public water supply systems is often either limited, or totally broken. Such cuts may be of local, regional, or even global nature [1].

The representatives of public administration cannot rely on the assumption that the risks of crises, connected with the limitation or elimination of public drinking water supply system, are low and will not affect their region. Only the knowledge of related risks and timely preparation for crisis management may minimize the consequences. Unresolved problems mostly cause more damage than preventive costs [2].

II. The Analysis of Current State

The emergency water supply of population by drinking water during crisis situations is not addressed by Community Law in the EU as a whole. The solution of this matter is the responsibility of each EU member state. The emergency water supply in the Czech Republic is provided by regional and municipal authorities through the Emergency Water Supply Service. Depending on the level of disturbance of drinking water supply the population may be supplied in the following ways [3]:

a) Undisturbed water supply systems or their parts;
b) Undisturbed independent intake structures, mainly wells;
c) Drinking water supplied in tanks;
d) Mobile water treatment plants and other technological facilities, which are necessary for reaching the required quality of water in case regular water treatment plants and water resources are out of operation and the emergency resources are exploited;
e) Supply of bottled drinking water as an additional way of supply;

During emergency supply the priority is given to the assessment whether water supply system is capable of supplying water even at lower quality. It is also recommended to exploit primarily the resources of ground waters, especially vertical intake structures, built and equipped for collecting the ground waters of deeper circulation, and possibly also horizontal and combined intake structures [4].

The accumulation of surface waters in water reservoirs and watercourses cannot be recommended for the emergency supply due to its high level of vulnerability. The above mentioned resources should be used only exceptionally and in well justified cases. Even not all hydrogeological structures are suitable, because they have different hydrogeological conditions, hydrological regimes, water quality, availability, traffic accessibility and richness. Besides that they are exposed to different hazards and have different levels of vulnerability [1].

At present the resources of ground water for emergency supply of population are classified in the following three categories in the Czech Republic [4]:

a) The resources of extra significance, such as ground water intake structures of increased resistance capable of supplying the required amount of drinking water;
b) The selected resources capable of resisting a small scale damage to the water supply system;
c) The other intake structures not included into the resources of the above mentioned categories, which are used for mass supply of population from public water supply systems.

The above presented classification is imperfect as it does not stem from the analysis of risks, which may damage or destroy the water resource. Therefore it seems to be useful to develop the classification methodology for the prospective alternative water resources in order to select more precisely the resources exploitable in case of extraordinary and crisis situations and include them into the system of emergency planning.

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Open Science Index, Geological and Environmental Engineering Vol:6, No:11, 2012 publications.waset.org/9966/pdf

III. Applied Methods

The "Fault Tree Analysis" method has been applied to build the registers of hazards and vulnerabilities of ground water resources in relation to the risk of being threatened by natural and anthropogenic events. The method is based on a systematic retrospective analysis of events while employing the chain of causes, which could lead to the selected top-event, in combination with "What if" method [5, 6]. The combinations of the same methods have also been used for identifying the threatened elements of hydrogeological structure and technological equipment of water resources for each considered hazard.

Brainstorming was carried out with two iterations at three joint meetings of seven experts and was aimed at assigning the meanings to index point values, depending on the hazard source activation frequency and the vulnerability level of individual water resource elements [7]. The characteristics of point intervals of modified risk quantifier [$MRQ_{j,i}(\tau)$] have been developed in an analogical manner.

The general methods of scientific work have also been employed when elaborating the classification methodology of water resources. They have been applied mostly in context and mutually conditioned.

IV. Outcomes and Discussion

The primary prerequisite for the classification of potential resources of drinking water to be used for the emergency supply of population is the quantification of either natural or anthropogenic risks threatening the monitored resource and the subsequent assessment of health risks resulting from the possible water contamination, as well as the assessment of availability, traffic accessibility and richness of the resource. The text also includes the procedure, which may be recommended for the classification of alternative ground water resources with regard to the emergency water supply of population and their implementation into the regional crisis plans. The procedure is based on fulfilling the phases in the following time sequence:

a) The selection of ground water resource as a prospective resource for emergency drinking water supply of population during extraordinary events.
b) The identification of hazard source for the assessed water resource carried out on the basis of general register of hazards. It is the identification of all sources of hazard, the activation of which could lead to damage, disturbance, or total destruction of individual elements of hydrogeological structure and technological equipment of the structure for ground water intake, treatment and distribution.
c) The implementation of semi-quantitative point indexation for the activation of each identified source of hazard in compliance with the data presented in Table 1.
   When building the register and quantifying the hazards it is necessary to accept general and historical data, including natural conditions in larger surroundings with focus not only on their protection zone, but also its infiltration area [8].

TABLE I
The Meaning of Index Point Values for the Assessment of Hazard Source Activation

Index point values	Hazard activation frequency [year^{-1}]	Description of the probability of hazard activation frequency
1	$(0; 10^{-3}\rangle$	Very low
2	$(10^{-3}; 10^{-2}\rangle$	Low
3	$(10^{-2}; 10^{-1}\rangle$	Middle
4	$(10^{-1}; 1.0\rangle$	High
5	$(1.0; \infty)$	Very high

d) Building the register of vulnerabilities of those elements of the assessed ground water resource which could be threatened by the activation of hazard sources. The register of vulnerabilities may utilize the general register of vulnerabilities. This register should be built either at the same time with the activities mentioned in sections b) and c), or right after them.
e) Implementing the semi-quantitative point indexation of vulnerability of each element of hydrogeological structure and technological equipment of water resource in relation to each identified hazard. When indexing the vulnerability of the assessed water resource elements it is necessary to consider their vulnerability to each hazard. Such a process should accept similar general and historical data, including natural conditions in the larger vicinity and infiltration area of resource, as in case of indexing the hazard resources activation frequency. It is also necessary to assess former extraordinary events with regard to the range of damage caused to the assessed water resource elements [1].
   The meaning of the assigned indexes as the function of vulnerability of individual water resource elements was presented in our previous papers. [1].
f) The calculation of risk quantificator $RQ_{j,i}(\tau)$, which represents the product of j-hazard activation probability point index Pj(τ) and the vulnerability point index $V_{j,i}(\tau)$ of *i*-element of hydrogeological structure and technological equipment of the assessed water resource in relation to *j*-hazard in time τ, in compliance with relation (1) [9]:

$$RQ_{j,i}(\tau) = P_j(\tau) \times V_{j,i}(\tau) \quad (1)$$

g) The consideration of criticality of i-element of the assessed water resource and its incorporation into risk assessment through the modified risk quantifier $MRQ_{j,i}(\tau)$ in time τ. The point value of the modified risk quantificator $MRQ_{j,i}(\tau)$ may be calculated according to the equation (1) as the product of the constant $C \in \langle 1; 3\rangle \wedge C \in Re+$ considering the criticality of the assessed water resource element and the risk quantificator $RQ_{j,i}(\tau)$ acquired from the relation (1). The symbol Re+ represents the set of all positive real numbers [9].

$$MRQ_{j,i}(\tau) = C \times RQ_{j,i}(\tau) \quad (2)$$

h) Setting the priorities of risks in relation to each source of hazard and the threatened water source element according to the calculated point value of modified risk

Open Science Index, Geological and Environmental Engineering Vol:6, No:11, 2012 publications.waset.org/9966/pdf

quantificator $MRQ_{j,i}(\tau)$.

i) Based on the maximal point value of the modified risk quantificator $[MRQ_{j,i}(\tau)]_{max}$ the decision has to be made on the exploitability of resource in relation to the level of threat imposed by natural and anthropogenic events in compliance with the characteristics of particular risk category presented in the Table 2. Even this resource can be the subject of further assessment in case the implementation of countermeasures may efficiently reduce the risk of damage or destruction of water resource to the level of modified quantificator $[MRQ_{j,i}(\tau)]_{max}$ meeting the requirements for the category of negligible or acceptable risk. Either Cost-Benefit Analysis method or the multicriterial assessment is recommended to be used in order to find out the efficiency of implemented countermeasures.

TABLE II
CHARACTERISTICS OF MAXIMAL POINT VALUES OF MODIFIED RISK QUANTIFICATOR $[MRQJ,I(\tau)]_{MAX}$ IN RELATION TO THE RISK OF THREAT IMPOSED BY NATURAL AND ANTHROPOGENIC EVENTS ON THE GROUND WATER RESOURCE

Maximal point value of modified risk quantificator $[MRQ_{j,i}(\tau)]_{max}$	Characteristics of risk
1 – 5	**Negligible.** Water resource may be immediately exploited without implementation of countermeasures.
6 – 19	**Acceptable.** Water source can be immediately exploited with implementation of countermeasures, if need be, on the basis of a statement and decision made by top-management of source operator.
20 – 32	**Undesirable.** The exploitation of source is heavily limited. If water source is to be used for the emergency supply of population, it is necessary to implement countermeasures in order to reduce the risk on acceptable level. The costs of reducing the risk have to be adequate for the value of protected source element and the social benefit. In this case it is recommended to apply the Cost-Benefit Analysis method, possibly a multicriterial assessment, which will enable us to assess the effectiveness of particular countermeasures being taken.
33 – 60	**Unacceptable.** It is not recommended to exploit the water source for emergency supply.

j) Extended water quality analysis is carried out for the water resource with negligible or acceptable risk of being damaged by natural and anthropogenic events. If all the indicators meet the hygienic requirements for drinking water [10], the assessed resource may be used for emergency supply for an unlimited period of time If water contains contaminants the concentrations of which exceed the values of indicators determined for drinking water even after a common water treatment, then it is recommended to apply the drinking water quality limits set for a short-term emergency supply of population [11] during the assessment of resource exploitability.

k) The availability of water resource is assessed. The best option is when the resource is located in the region for which emergency water supply is earmarked. A good availability is considered to be the distance within 30 km from the border of a given region.

l) The traffic accessibility of alternative water resource is assessed. The water resource should be accessible at least from two directions, while at least one access has to be from a reinforced road enabling water to be transported in tanks the total weight of which is 15-25 tons.

m) The resource richness is assessed according to the requirements for the maintenance of minimal supply of drinking water in a crisis situation, i.e. 5 dm^3 $person^{-1}$ day^{-1} during the first two days and 10-15 dm^3 $person^{-1}$ day^{-1} during other days [3].

V. CONCLUSION

Risk analysis has been the basis for the proposal of alternative ground water resource classification methodology during the failure of public water supply system in the states of emergencies and crises. Based on the proposed methodology it is possible to classify the ground water resources for emergency supply of population with an adequate protection:

a) *Resources of strategic significance* with an increased resistance against natural and anthropogenic hazards with the value of maximum modified risk quantificator in the interval $[MRQ_{j,i}(\tau)]_{max} \in \langle 1; 14\rangle$. Their water quality after treatment has to meet the health requirements for a month emergency supply. The resources have to be available, accessible for the tanks weighing m > 25 tons and the richness of which is $Q \geq 45$ dm^3 s^{-1}.

b) *Regional resources* with an increased resistance against natural and anthropogenic hazards with the value of maximum modified risk quantificator in the interval $[MRQ_{j,i}(\tau)]_{max} \in \langle 1; 14\rangle$. Their water quality after treatment has to meet the health requirements for a month emergency supply. The resources have to be available, accessible for the tanks weighing m > 15 tons and the richness of which is $Q \geq \langle 7.5; 45)$ dm^3 s^{-1}.

c) *District resources* with an increased resistance against natural and anthropogenic hazards with the value of maximum modified risk quantificator in the interval $[MRQ_{j,i}(\tau)]_{max} \in \langle 1; 14\rangle$. Their water quality after treatment has to meet the health requirements for a month emergency supply. The resources have to be available, accessible for the tanks weighing m > 10 tons and the richness of which is $Q \geq \langle 0.75; 7.5)$ $dm^3 s^{-1}$.

d) *Resources of local significance* with an increased resistance against natural and anthropogenic hazards with the value of maximum modified risk quantificator in the interval $[MRQ_{j,i}(\tau)]_{max} \in \langle 1; 14\rangle$. Their water quality after treatment has to meet the health requirements for a month emergency supply. The resources have to be available, accessible for the tanks weighing m > 5 tons and the richness of which is $Q \in \langle 0.015; 0.75)$ $dm^3 s^{-1}$.

The proposed methodology may be used by state administration authorities in the area of water management, environmental protection and crisis management, namely the emergency water supply services and the integrated rescue system. The methodology may help the Army in its effort to fulfil part of the requirements resulting from the NATO standardization agreement [12]. Its application abroad is not excluded, either.

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