Analysis of Crisis Management Water Supply System

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Summary

The majority of inhabitants in Europe depend nowadays on a supply of drinking water mainly from public waterworks systems.The risk of an emergency situation being created that exceeds the possibilities of a satisfactory solution for emergency water supply for all customers is growing together with the growing number of inhabitants, who depend on water supplies mainly from central sources. In particular subjects of critical infrastructure are threatened, which depend completely by their character and the technologies they use on direct supplies of pressurised water from the water main; for example, medical services and food production, but also some objects of public infrastructure and fire safety of vast built-up areas. In order to minimise the given risks we need to become aware of weak as well as strong parts and properties of the operated system by means of a risk analysis and by applying diagnostic and computer techniques, including accepting the corresponding preventative measures. Preconditions and possibilities are different in different the 28 EU member states.

Water mains for public consumption supply potable water for approx. 93% of inhabitants in the Czech Republic. In 2012, 481 mil. m^3 of potable water supplied by public water mains were invoiced, and the value of water supply infrastructure property reached CZK 1000 bil. [1]. Almost 2000 of legal persons are engaged in the production of potable water and its distribution to the users – inhabitants and technical elements of critical infrastructure; however, the decisive role is played by approx. 120 legal persons in Czech water supply [1]. The given strategic importance of water mains must be matched not only by legislative protection, but also by the protection of water supply systems in real practice. For this reason, water supply infrastructure is classified as one of essential elements of critical infrastructure. Considering that the risk of interruption of potable water supply from natural or anthropogenic reasons cannot be prevented, negative impacts on the consumers should at least be minimized.

The paper discusses how this complex task can be resolved under the real conditions of water supply systems, and how to ensure, at least for strategic consumers, a minimum amount of water in crisis situations.

Keywords: water supply system, water sources, hydraulic efficacy, contamination, accident, risk analysis, monitoring and management

Current situation in Europe

In the EU, the problem of critical infrastructure started to be addressed especially after the terrorist attack in New York City on September 11, 2001, by adopting the EPCIP programme [2]. Elimination of such risks in the Czech Republic is reflected by Act No. 240/2000 Coll. on crisis management (the Crisis Act) [3]. However, this act has not yet been elaborated to obtain an implementing regulation for the field of water supply that would define clear powers and duties of government authorities and water supply system operators. The Government Regulation No. 462/2000 addresses only the elements of crisis plans. Individual elements of technical infrastructure for communities and regions have not been determined yet on the level of state administration, either. Therefore the field of management in the critical infrastructure mode is not sufficiently addressed in the Czech Republic and remains on the level of infrastructure management as a whole within the framework of an integrated rescue system, but not as management of an independent water supply system aimed at ensuring water supply in extraordinary situations.

Brief topology of the water supply system

The water supply system is a system of interconnected water mains fed from various types of water sources (dams, rivers, deep water wells, water well pumps). These water mains include technological structures including water treatment plants, water towers, pumping stations, pressurized repumping stations, fitting and hydrant systems, the end user (small consumer – household; large consumer – industrial and administrative buildings, companies, elements of technical infrastructure of the state).

The technological scheme of a typical water supply system is illustrated in the figure 1.

In terms of operative management, water supply systems are connected to a single control system composed of the central control station – control centre and a system of local technological objects. Elements of the whole system are connected through a radio network, thus forming a computer network of an automated control system of individual water supply systems. As it thus follows, it is a water supply system interconnected both in terms of technology and water supply in this case (not only in the Czech Republic, but also in the world), which must primarily ensure:

- Timely water supply to the consumer;
- Adherence to qualitative and hygiene parameters of water;
- Minimization of occurrence and consequences of extraordinary situations and events.

Considering the required extent of the paper, the author has focused on the field of minimizing the occurrence of extraordinary and crisis situations that would pose a threat to water supply not only to the population but especially to persons of national technical infrastructure (medical facilities, food industry, etc.).

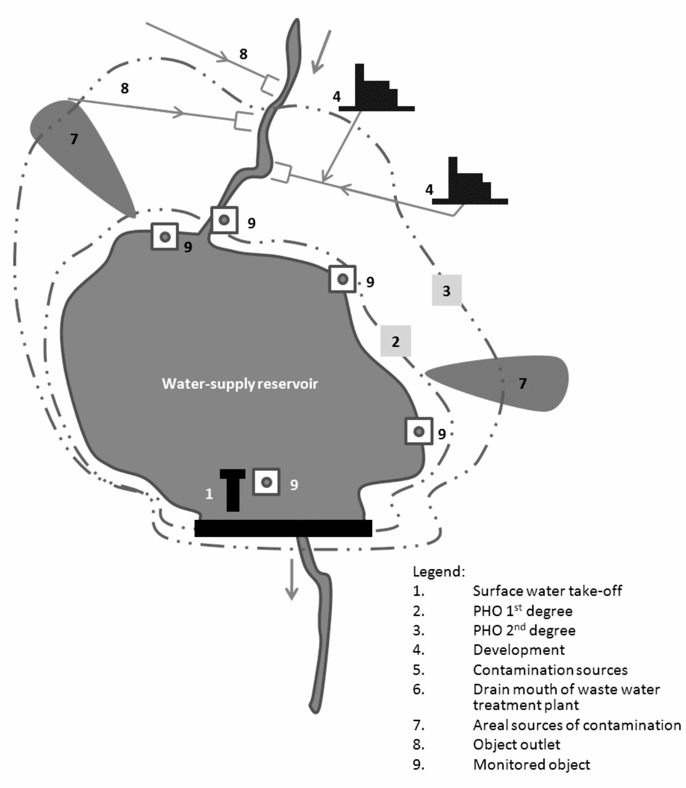

Fig. 1 Actual state of inflow of contaminating substance to the water-supply reservoir

Rys. 1 Obecny stan napływu substancji zanieczyszczających do zbiornika wody zasilającej

Definition of essential risks in the water supply system

The aim is to analyze the water supply distribution system as an essential part of the water supply system, to define potential fundamental risks of individual elements of this system, and to propose measures to minimize the defined risks or to minimize their harmful impacts.

For the very need of the risk analysis [4], partial water supply systems should be defined in the primary phase, which may be endangered by the risks, and subsequently the methods should be found that can be used to reasonably eliminate the risk. For the very need of the risk analysis, individual hazards and risks can be defined as follows [5,12].

Water sources

- Flood conditions that alter the quality of raw collected surface and ground water and flood the collection objects;
- For ground sources: their contamination particularly with inorganic substances from dumps and old environmental burdens of heavy and chemical industries, organic substances from leaky drainage systems and agriculture;
- For surface water: point and non-point sources of various types of contamination with substances, particularly pesticides, herbicides and oil substances flowing to a water supply reservoir predominantly through drainage systems from non-treated or imperfectly treated waste water.
- In addition, especially the following risks are concerned:
- Lack of water due to long-term droughts; decreased ground water levels;
- Insufficient capacity of water sources in respect of consumption requirements;
- Terrorist attack at water sources or elements of the distribution network.

Distribution systems of potable water

- Insufficient health safety provision of potable water in extremely long water mains networks;
- Overdimensioned water mains feeders and distribution network in respect of the amount of actually used water, speed of flow, and retention time in the distribution system;
- Unsuitably constructed water towers from the hydraulic point of view, from the viewpoint of temperature stability of water, contamination with organic and inorganic substances, and usually an insufficient security system to prevent unauthorized persons from entering and intentionally contaminating the water;
- Insufficient hydraulic efficacy of water mains networks – impossibility to ensure the distribution of potable and fire water in situations of its insufficient volumes in the sources and at times of occurrence of large-extent extraordinary events posing a threat to operation of urban and community critical infrastructure persons;
- Damage to facilities in flood areas during flood situations, particularly bridging of waterways and culvert siphons under watercourses;
- Insufficient capacity of the distribution network considering consumption requirements;
- Terrorist attack at elements of the distribution network.

All the risks above may have a crucial impact on water distribution to end users, i.e. may result in a lack of water in the supply system for the population and national technical infrastructure.

Basic knowledge of the risks above according to the types of the manufacturing and operating facilities and an entire scale of other elements of the water supply system enables any water supply company to analyze the potential risk and to choose an optimal procedure to reduce the risk of occurrence of an unforeseen extraordinary event. Such a procedure must be stipulated in the Crisis Preparedness Plan of the given person, and at the same time, it must be interconnected with crisis plans of self-government regional units and communities.

Risk elimination

Occurrence of an extraordinary situation leading to a lack of water for the water supply system users cannot be excluded in water production and distribution. The probability of occurrence of such situations increases together with rising civilizational influences; their intensity and probability of origination are induced by a number of natural laws and rules, and also by the action of people and human activities in some cases. Considering that an extraordinary event cannot be fully excluded, any potential negative consequences should at least be eliminated to an acceptable level. The state develops a security system to eliminate the consequences of extraordinary events; such a system is composed of administrative authorities of the state, self-government planning bodies, armed and security services of the state, rescue brigades, emergency services, and legal and physical persons. In the Czech Republic, the security system is coordinated by the Integrated Rescue System, administered by the Fire Rescue Brigade of the Czech Republic.

In accordance with the above, basic spheres of measures to reduce the hazard of risks can be defined:

a) Under standard operating conditions:

- Create a mathematical model of the water mains network to design and analyze the states of operation;
- Design the water mains network with protective elements incorporated already in the technological solution;
- Build a monitoring and control system of the whole water mains network or a strategic part thereof;
- Use a suitable type of pipeline distributions and technological equipment;
- Optimize security and measuring elements in individual parts of the water mains network;
- Create basic scenarios in the crisis plan for handling operational accidents[12];
- Provide a logistic solution for substitute potable / utility water supplies;
- Prepare the methodology for operating water supply objects and water mains networks.

b) For extraordinary events and crisis situations:

- Ensure crisis planning, preparation of crisis preparedness plans of the water supply company;
- Determine critical elements in the technical infrastructure and their priorities in water supply;
- Ensure material and logistic preparation for extraordinary events, i.e. analyze the needs of material supplies, purchase and determine suitable locations of the supplies based on the importance and nature of the endangered object, and conclude agreements on lending technical equipment or on the form of help in crisis situations[6,12];
- Use a telemetric and control system for variant and emergency control of the water supply system.

The risk elimination analysis can also be schematically displayed as a structure of interconnected parts of the water supply system whose individual parts act on each other.

Monitoring and control of water supply processes

The ability to effectively monitor the entire process from water production to its delivery to the end consumer is an essential condition for handling the problem of water supply process control with success, provided that a sufficient technical and technological equipment of the water supply networks is available. Effective monitoring and ability to control, remotely if possible, establishes the preconditions to expect that the controlled system will be able to fulfil extraordinarily demanding conditions during crisis situations associated with the risk of a lack of water for the needs of the public, i.e. critical infrastructure. The possibility to predict an occurrence of an extraordinary event, and the technical equipment of a prompt response to any occurred negative operational state to reduce various types of primary and secondary damage, always depend on the result of the technical level of such monitoring. Modern telemetric systems must be used in this part of water supply process control [7,12].

Process to monitor water quality at the treatment plant

A considerable change in the quality of raw water, especially due to contamination with hazardous or extremely hazardous substances, may put the treatment plant out of service. The risk of unexpected putting out of service is reduced by online monitoring[12]:

- Monitoring of the quality of raw water fed from the source to the treatment plant including online information about the water inflow to the treatment plant in l.s-1;
- Complex monitoring of the treatment process of raw water to obtain potable water, see the figure below;
- Monitoring of output parameters of the flow, pressure and health safety level of potable water before its entering in the distribution system.

Monitoring of security and operating values in water towers

Water towers are another risk-bearing object of water supply in terms of the risk of violation. Not only an acute contamination of potable water from anthropogenic reasons is a threat, but water supply to the distribution system may also be endangered upon a more significant damage caused to the object and its technological equipment due to a violent act. At least the following information should be monitored remotely and evaluated in order to reduce the risk:

- Monitor the inflow and outflow of water from the water tower and evaluate its retention time and freshness;
- Monitor the temperature of the water, with subsequent management of its exchange;

- Evaluate the level of health safety of the water, with its additional chlorination control as appropriate;
- Control security elements ensuring protection against unauthorized entering in the object.

While water towers forming part of the distribution system do exhibit a high risk of being endangered, today they also offer a relatively easy and good-quality possibility of protection. The water mains network itself, especially its hydraulic efficacy, poses the highest risk in situations of a lack of water in sources for emergency supplies especially to persons of critical infrastructures and those of fire safety of buildings. Under certain conditions, it may, partially or completely, prevent water supply to water pipelines. In order to reduce this risk, not only the actual hydraulic parameters of the network should be available, but a possibility should also exist, based on the real situation, to change them in a simple manner during a crisis situation.

Monitoring distribution systems of potable water

Water mains network undoubtedly ranks among hazardous parts of the production and distribution system. As a rule, risks of secondary contamination of potable water occur in accidents and inconsistent observation of security principles and operational rules. The risk of uncontrolled spreading of potable water contamination can be reduced in particular by:

- Online monitoring and evaluation of the amount of water actually present in the distribution network, pressure zones, their sections, or monitoring zones;
- Monitoring, and remote control as appropriate, of the functionality of pressure regulating valves (night, day modes), repumping or pressure stations and other technological objects;
- Possibility of remote control of strategic fittings at feeders, backbone lines and selected points of the water supply distribution network.

Methodology for water supply system management in extraordinary situations

Currently, the use of a controlling system is on the rise to minimize the occurrence of extraordinary events, as a risk management process through controlling processes – "risk management" [8].

For the purpose of addressing problems in water supply management, in some specific cases it is suitable to combine FMEA (Failure Mode and Effect Analysis) method(ČSN EN 60812 [9]). with FMECA (Failure Mode, Effect and Criticality Analysis) method, which is focused on the severity and frequency of system failures.

Technical solution proposal for a risk recognition and control method

The final result very often depends on the control level of the entire distribution process and the possibility of promptly responding to a number of operational or extraordinary events, i.e. to minimize any occurred risks, maintain continuous water distribution in the required quantity and quality of the water.

When an extraordinary event or crisis situation occurs, the need of remote monitoring and control of the technology and of securing the objects against intentional damage is multiplied [10].

Virtually the only possibility that guarantees compliance with these requirements consists in installing and using telemetric systems for the control and monitoring of water supply processes. These systems must be used not

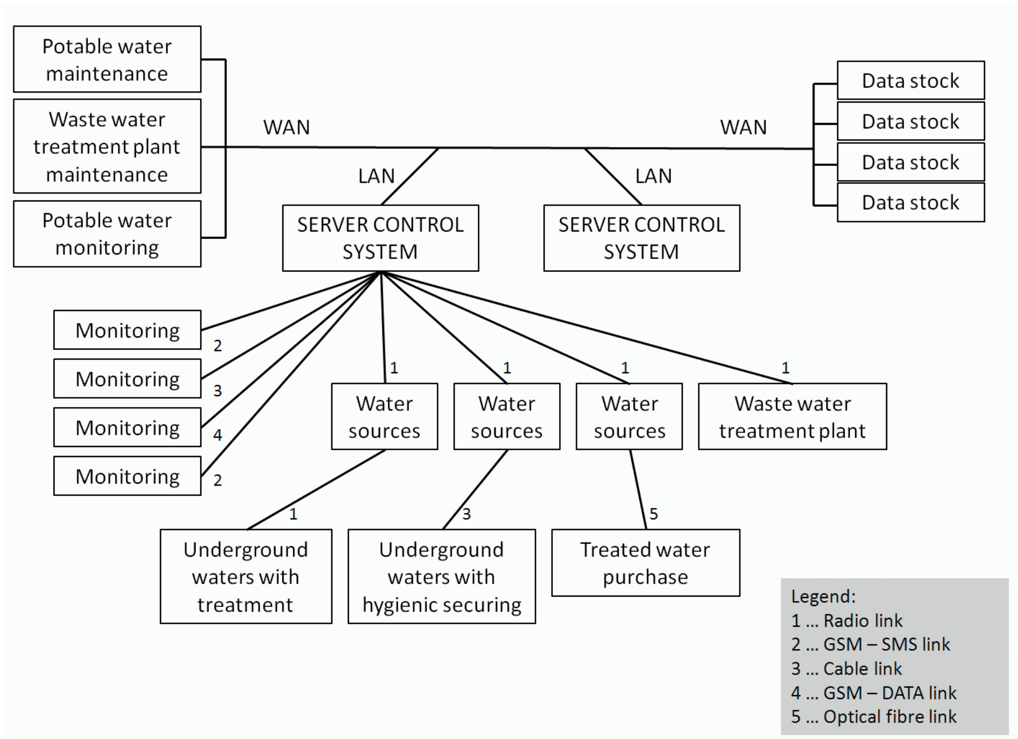

Fig. 2 Alternative diagram of system control of water production and distribution processes

Rys. 2 Alternatywny schemat systemu kontroli produkcji i dystrybucji wody only at the local technological objects themselves, but they must also support central remote access for the control of such objects on the level of a central water supply control centre, see Figure 2.

The structure of a telemetric system can be designed on three basic levels:

- Monitoring and control of operational, security and hydraulic values of water supply systems on the level of control implemented by operating companies through a control centre;
- Expert system of the water supply system control in extraordinary and crisis situations for the needs of the management of operating companies and crisis staffs;
- Information system for crisis planning of emergency water supplies in extraordinary situations for the needs of the state administration and self-government objects.

SCADA (Supervisory Control And Data Acquisition) type SW tools have been developed for the control of water supply systems. These tools support remote monitoring and control of water supply objects in real time. Schneider SCADA system, type SCADAExpert SCX6, has been applied for the needs of this solution.

Based on application of the given methodology and using the data of the designed SW system, it is actually possible to quickly and operatively respond to any occurred hazard or development of a security situation, with continued water supply.

Using a thus designed system, the planning authority of state administration or self-government of cities and communities, or an operator of any water mains for public needs, can analyze at any determined moment and place whether the development of information and phenomena is kept in an acceptable range or whether it is no more acceptable for ensuring water supply to the consumers.

In order to achieve a high level of effectiveness and the required operational effect of the water supply system, the establisher should have clear information as early as in the pre-project phase what requirements should be complied with by the water supply system, what is expected from the technological equipment, and in what modes it may or will operate. Such plans must also include the definition of requirements for the telemetric system.

Conclusion

Nowadays, water supply system control is no more an issue of sufficient intuition and practical experience as used to be the case in previous decades. Optimal control requires an entirely different type of approach to evaluation of water management problems, including the use of computing-based monitoring and control equipment. This need is given not only by the increasing numbers of users who consume potable water from the public water mains network, but especially by demands coming from customers of the technical infrastructure with a high level of the technical equipment used, existentially dependent on hydrodynamic parameters of the supplied water. The task of telemetric systems in the operation of any water supply system in extraordinary situations such as the floods in 1997 and 2002 is irreplaceable. While the operation of small distribution systems can be handled manually under standard conditions, the absence of telemetric systems in extraordinary and crisis situations, particularly in middle-sized and large cities, always causes considerable material and moral damage.

As far as persons of critical infrastructure are concerned in times of a crisis, lack of water may lead to a concatenation of problems and even to a collapse of services and medical facilities.

Such risks can be minimized by timely recognition of weak points of the water supply production and distribution system and by their elimination through crisis planning. The paper indicates how this problem should be approached, and how any water supply company can prepare itself for handling extraordinary, large-extent events. Any resulting lack of water is not only a problem of the owner or operator of the water mains, but it has a very severe impact on the whole society and its infrastructure, and therefore it must be an integral part not only of crisis management of national technical infrastructure, but also of the broader environmental management of the society.

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Analiza systemu zarządzania kryzysowego dostaw wody

Większość mieszkańców Europy zależy dziś od dostaw wody pitnej głównie z systemu wodociągów publicznych. Ryzyko wystąpienia sytuacji nadzwyczajnej, powstającej kiedy przekroczone są możliwości zadowalającego rozwiązania awaryjnego zaopatrzenia w wodę wszystkich klientów, rośnie wraz z rosnącą liczbą mieszkańców, którzy polegają głównie na dostawach wody ze źródeł centralnych. W szczególności zagrożone są podmioty

infrastruktury krytycznej, co zależy całkowicie od ich charakteru i technologii, których używają do bezpośrednich dostaw wody pod ciśnieniem z sieci wodociągowej; na przykład usługi medyczne i produkcji żywności, ale także niektóre obiekty infrastruktury publicznej i bezpieczeństwa pożarowego na rozległych obszarach zabudowanych. W celu zminimalizowania opisanego ryzyka musimy być świadomi zarówno słabych jak i silnych stron i właściwości istniejącego systemu używając analizy ryzyka i przy zastosowaniu technik diagnostycznych i komputerowych, w tym przyjmowania odpowiednich środków zapobiegawczych. Warunki i możliwości są różne w poszczególnych 28 państwach członkowskich UE. W Czechach magistrale wodociągowe zaopatrują w wodę pitną około 93% mieszkańców. W 2012 roku zafakturowano 481 milionów m^3 wody pitnej dostarczanej przez wodociągi publiczne, a wartość dostarczającej infrastruktury wodociągowej osiągnęła 1.000 CZK miliardów [1]. Prawie 2000 osób prawnych jest zaangażowanych w produkcję wody pitnej i jej dystrybucję do użytkowników - mieszkańców i elementów technicznych infrastruktury krytycznej; jednak decyzyjną rolę odgrywa ok. 120 osób prawnych w Czeskim systemie dostaw wody [1]. Określone strategiczne znaczenie sieci wodociągowej musi być powiązane nie tylko ochroną prawną, ale także ochroną systemów zaopatrywania w wodę w praktyce. Z tego powodu infrastruktura wodociągowa jest klasyfikowana jako jeden z zasadniczych elementów infrastruktury krytycznej. Biorąc pod uwagę, że ryzyku przerwania dostaw wody pitnej z przyczyn naturalnych lub antropogenicznych nie można zapobiec, negatywne skutki dla konsumentów, powinny co najmniej być zminimalizowane.

W artykule omówiono, jak to złożone zadanie może zostać rozwiązane na podstawie rzeczywistych warunków instalacji wodociągowych i jak zapewnić, przynajmniej dla odbiorców strategicznych, minimalną ilość wody w sytuacjach kryzysowych.

Słowa kluczowe: system zaopatrzenia w wodę, źródła wody, skuteczność hydrauliczna, zanieczyszczenie, wypadek, analiza ryzyka, monitorowanie i zarządzanie