EMERGENCIES IN DRINKING WATER SOURCES

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ABSTRACT

The protection of drinking water resources against pollution is the common task of outstanding importance of the water management and environment protection sectors. To prevent water supply problems arising from the short-, and medium-term quality deterioration of resources caused by pollution incidents, it is vital to develop methods for monitoring the quality of the resources as well as methods for the monitoring and prediction of serious pollution events to protect water users. In the case of vulnerable drinking water resources establishment and maintenance of early warning monitoring system is important. Emergency treatment technologies are also needed by the waterworks to treat the water for periods when the quality of the raw water has temporarily deteriorated.

KEYWORDS

Water pollution, accidents, rivers, early warning, groundwater, bankside filtered water, drinking water, water treatment.

INTRODUCTION

The quality of the drinking water resources depends on biogeochemical factors in the aquifer and influenced by different pollutants from anthropogenic inputs. The different pollutants are discharged into the aquatic environment from chronic point sources - treated, or untreated municipal and industrial wastewaters -, and from non-point sources, particularly from agricultural lands and atmospheric fallout. Different accidental spills mainly from industrial, or transportation accidents may result in sudden increase of hazardous chemicals in the water resources. Such incidents directly affect the biotic compartment of the ecosystem and may create emergency situation at the water works using the affected water resource for drinking.
water production. To minimise the hazard to the public water supplies, it is important that the pollution incident is timely recognised, the situation evaluated and the necessary actions are taken in time such as summarised in Fig. 1.

In the field of the protection of drinking water resources, the objectives of the responsible water management authorities should coincide with those of the Specialist Organizations of the United Nations and, especially, the endeavors of the "International Drinking Water Supply and Sanitation Decade" programme of the World Health Organization.

**Fig. 1. Flow of actions in the case of emergency in drinking water supply**

For the protection of drinking water resources and to ensure safe drinking water supply, the following activities into four main themes are required:

1. Assessment of polluting impacts on drinking water resources.
2. Investigation into development of methods to provide early warning water quality monitoring system.
3. Investigation into development of methods to provide emergency technologies for drinking water treatment.
4. Study on the rehabilitation of polluted drinking water resources.
POLLUTION IMPACTS ON DRINKING WATER RESOURCES

The approach for assessment of the pollution impact on drinking water resources might be different in the case of subsurface and surface waters because temporal and spatial differences in the distribution and movement of the polluting substances in the aquifer.

Subsurface waters

Groundwater as sources of domestic water supply play a prominent role in many countries, where majority of the waterworks draw on some kind of groundwater, including phreatic groundwater, artesian water, bankside filtered water or water in karstic rocks. The hazards to these sources, due to pollution often affecting large areas, have shown a growing trend during the last decades. Because the quality of the bankside filtered water is highly dependent on the river water, it is discussed together with the surface waters.

Communal water supply schemes unaccompanied by appropriate sewerage, coupled with the increasing use of agrochemicals have caused large quantities of pollutants to find access to the soil and groundwater. As a consequence of these processes, the mostly phreatic aquifers close to the surface have become extensively polluted and unfit for domestic use without some kind of treatment. Progressing further downward and accelerated by the very abstractions themselves, these processes may entail quality deterioration in the deeper aquifers as well, thus jeopardizing valuable water resources and the well fields of the waterworks.

Owing to the high costs of eliminating completely the sources of pollution, current control practice consists of the establishment of hydrogeological protection areas, where pollutant infiltration is restricted by appropriate measures. These measures are, on the one hand, expensive (sewerage, water treatment) and may, on the other hand, influence substantially the land uses in the particular area. In the consideration of decisions on delineation and installation of the protective zones, allowance has to be made for the beneficial, or adverse impacts of the adsorption, dilution, chemical- and biological transformation and degradation processes taking place along the spreading pathways of pollution.

Methodological, computational and numerical models are needed by which the access of pollutants into the soil, the phreatic and subsequently into the deeper aquifers by infiltration, or the complex water budget of the unsaturated zone can be reproduced and simulated. They should also be capable of providing information about the horizontal propagation, mixing and dilution processes, together with those triggering transformation and degradation in the soil and in the groundwater.

Marking out the protection zone at land register level is not advisable in each situation, but compliance with the environmental protection regulations must be strictly enforced, such as:

- the sewage lagoon of a pig farm must be operated with the sealing specified in the authorization; the sealing effectiveness should be monitored,
- disposal of communal waste waters must be authorized under controlled conditions to minimise infiltration,
- no manure, wastes and chemicals must be stored under uncontrolled conditions,
- manure and fertilizers, as well as pesticides can be applied at reasonable rates with regard to the relevant guidelines,
• the deposition of hazardous wastes and any industrial activity conducive to the emission of such wastes must not be allowed.

Assessment of the pollution-sensitivity (vulnerability) of the representative area.

Pollution access to groundwater supplies could be estimated with information on:
– the geology of the area,
– the hydrological, seepage-hydraulic conditions,
– the type, amount, temporal and spatial distribution of the expected pollutants

Of these, the geology may be regarded practically constant, while more-or-less accurate estimates could only be made on the others. A number of methods have found application in international practice for mapping pollution sensitivity, which, in the majority of cases, go beyond the simple geological (thickness, rock type) representation of the protective cover overlying the particular aquifer.

Surface waters

Surface water intakes are outstandingly sensitive to river pollution incidents. Since the recharge of bankside filtered water resources is derived mostly from surface waters, protection activities of these resources should eventually be extended also to the rivers and their immediate catchments. In Hungary, for example, an unfavorable aspect for water management is that approximately 95% of the surface water resources originate from abroad. This condition creates a continuous potential risk for water users principally from the point of view of quality, but also of quantity. In particular, the safety of drinking water intakes is endangered, because the river systems entering Hungary are often subjected to accidental water pollution incidents. The total number of such accidental water pollution events yearly exceeds 150 all over the country, of which 15-20 % arose in upstream foreign countries. The polluted water travels down the rivers to Hungary. The operation of the surface water intake in Budapest Waterworks have been closed for a period of time in several cases during the last ten years because of water quality deterioration caused by accidental pollution events [Anon., 1992].

Research results indicated that bankside filtered drinking water resources are most vulnerable to toxic conservative substances that move along with the water, non-adsorbing radioactive substances of longer half-lives, certain organic - particularly refractory polar compounds - micropollutants, oil derivatives and also by small micro-organisms. At the time of the average water quality conditions in the Danube, the bankside filtered production wells supply good quality water, which meets the present drinking water standards. With the exception of accidental pollution events bankside filtration is, therefore, a safe and efficient way of producing good quality drinking water. During accidental pollution events the level of danger to the bankside filtered water resource depends on the duration of the accidental event, the time of travel, the type of the pollutant and on the management's operational strategy for abstraction from the production wells.

**EARLY WARNING WATER QUALITY MONITORING**

The establishment of an early warning water quality monitoring system to predict the effects on quality of accidental pollution events that might occur along rivers upstream of water intakes, or
bankside filtration wells, would provide timely information for the water users (first of all for waterworks) on the expected temporal and spatial quality changes, thereby increasing the protection and safety of potable supplies. Different UN organisations were active in preparing summary reports on the aspects of the accidental pollution of water bodies [WMO, 1992] and the early warning methodologies for surface and groundwater quality monitoring [GEMS/WATER, 1994].

There are different ways to observe/recognize water pollution accidents, such as (a) reports from polluters, (b) visual observation by environmental inspectors and public, and (c) signals from automatic water quality monitoring stations. The effectiveness of the different observing options depends on the type and form of the pollutants. The most reliable information could be obtained from the polluters, however, in many situations they are reluctant to report and/or giving false information. The visual observation is limited to directly - such as oil spills -, or indirectly - such as killed fishes - visually observable pollutants. The signals from automatic monitors are limited to target pollutants for which responsive sensor is installed, or to acute toxic pollutants detected by biomonitors. In either case, the establishment and operation/maintenance of such monitors is very costly.

One of the most vulnerable drinking water resource provides the raw water for the drinking water of Paris. Ensuring the early warning alarm to the water work, automatic water quality monitoring stations have been established in the river system providing the raw water, as well as at the water works [Journet, et al., 1987; Cognet et al., 1987]. Because of the high cost of the automatic sensors, the establishment of automatic sampling stations - collecting time-proportional discrete samples, e.g. hourly, and storing for 72 hours before discarding if pollution incident has not occurred - are under consideration in Hungary.

In international, transboundary river basins, establishment of an early warning alarm system is needed, at least for communication, without specifying the observing options. Because of the importance of the Rhine as source of drinking water, an early warning system has been developed and operated [Anon., 1987]. This system involves operation of several automatic water quality monitors. An Accident Emergency Warning System has been established in the Danube river basin [Hartong et al., 1994], however, the establishment of automatic monitors is under consideration.

**EMERGENCY TECHNOLOGIES FOR DRINKING WATER TREATMENT**

Because of the usually good water quality of the bankside filtered water, no special water treatment methods should be applied by the waterworks at these resources. Some of the waterworks had to apply technologies for removing iron and manganese. This, however, was not due to poor water quality of the recharge from the river, but to the oxidation-reduction conditions prevailing in the channel bed, in the filter zone and to the inappropriate siting of the production wells. Most of the waterworks, therefore, are not equipped with the necessary treatment techniques for supplying water of drinking water quality during periods of accidental pollution events. Even more vulnerable are surface water intakes which do not have the benefit of bankside filtration. The sources of unexpected water pollution and creation of emergency situation at water works are summarized in Table 1. These circumstances necessitate the study of control strategies that could, in the case of accidental pollution events lasting for a few days, assure the supply of safe drinking water to the population served by the water distribution network.
Table 1. Sources and creation of chronic impact and emergency situation.

<table>
<thead>
<tr>
<th>Chronic impact</th>
<th>Emergency situation</th>
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<tbody>
<tr>
<td>wastewaters:</td>
<td></td>
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<tr>
<td>treated domestic</td>
<td>Failures at treatment plants</td>
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<tr>
<td>industrial effluents</td>
<td></td>
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<tr>
<td>solid/hazardous wastes:</td>
<td></td>
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<tr>
<td>treated and secured</td>
<td>Unsecured disposal of wastes</td>
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<tr>
<td>waste disposals</td>
<td>Illegal disposals</td>
</tr>
<tr>
<td>industrial effluents</td>
<td>Industrial accidents</td>
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<tr>
<td>treated domestic</td>
<td></td>
</tr>
<tr>
<td>treated and secured</td>
<td>Military activities</td>
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<tr>
<td>waste disposals</td>
<td>Accidents during transportation of hazardous materials</td>
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<tr>
<td>agricultural wastes:</td>
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<tr>
<td>sustainable use of agrochemicals</td>
<td>Overdose/miss-use of agrochemicals</td>
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<tr>
<td>(fertilizers, pesticides)</td>
<td></td>
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<tr>
<td>safe disposal of manure</td>
<td>Uncontrolled disposal of manure</td>
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</table>

Development of the emergency water treatment technologies

The development of emergency drinking water treatment technologies for waterworks, which are applicable for periods of temporary water quality deterioration, usually is based primarily on the existing treatment facilities and consisting of complex multi-function treatment procedures. For this development the following is needed:

− identification of potential contaminants;
− treatment technologies for the removal of potential contaminants;
− design of multi-function treatment technologies.

The term emergency water treatment technology means technologies applied to raw waters from different sources for removing contaminants (mostly micro-pollutants) that occur temporarily in the water. Thus, iron and manganese removal are not included in these technologies, but the removal of nitrate or ammonium-ion are considered emergency technologies, as these contaminants show up not continuously, but temporarily.

Identification of potential contaminant. The groups in which contaminants likely to occur were determined and divided into inorganic and organic micro-pollutants. The most important inorganic pollutants were grouped into two categories: nitrogenous inorganic substances (ammonium, nitrite, nitrate, etc.) and toxic heavy metals (mercury, cadmium, nickel, lead, copper, zinc, chromium). Of the inorganic pollutants, ammonium-ion get into the water of the wells mainly from the river, while nitrate and nitrite-ions infiltrate from the background zone. Compounds belonging to the second group of inorganic micro pollutants (toxic heavy metal compounds), might originate from either the river or the background zone. Of the organic pollutants that can reach the water in bankside filtration wells, mineral oil and derivatives, phenols and phenol derivatives, detergents, PAH compounds, chlorinated hydrocarbons (PCB, THM), organic metal complexes, complex forming organic substances, humus, lignin and dissolved excreta are the most common.
Treatment technologies for the removal of potential contaminants. The basic idea of selecting and elaborating emergency treatment technologies is that technologies based on physico-chemical, or chemical processes should be used exclusively, since the technologies would have to be operative within a few days of notification of the accidental pollution. This speed cannot be reliably matched by biological technologies.

Another factor that affects the character of a feasible solution at a given waterworks is whether it has technological units available for certain water treatment technologies or not. Depending on hydro-geological conditions many waterworks, based on bankside filtered water resources, have to apply iron and manganese removal technologies. In such waterworks the possibility of applying emergency technologies is different from those where no technology except disinfection is applied.

For removing ammonium ion, break-point chlorination was suggested. Activated carbon adsorption was proposed as a means of removing the chloramines thus generated. Selective ion-exchange was recommended for removing nitrate-ions, or granulated activated carbon might be also applied - to a limited extent - for the removal of nitrate-ions.

The traditional methods of solid-liquid phase separation (coagulation, flocculation, sand filtration) seem to be suitable for removing most of the toxic heavy metals. In the case of certain heavy metals (e.g. cadmium and nickel) these procedures are of limited efficiency only, when the pH is close to neutral. The above method can be efficiently applied for the removal of toxic heavy metal ions in the pH range of 9.0-10.0. For the removal of chromium, in the form of Chromium/VI/ compounds, a solid-liquid phase separation technology was elaborated, with a redox process forming the first stage. This would be followed by conventional solid-liquid phase separation methods for removing chromium compounds from the water.

Adsorption methods are recommended for the removal of organic pollutants. The overwhelming majority of organic substances that are likely to occur as accidental pollutants can be efficiently removed by activated carbon. For removing volatile organic substances, intensive aeration of the water provides a good and inexpensive solution.

Applying the various water treatment technologies in an appropriate sequence, or grouping such technologies, multi-function technology systems can be formed, and recommended for application. These systems can remove far more polluting substances than would be possible by applying the various technologies, either individually, or not in the most appropriate sequence.

Methods of multi-function treatment technologies. Multi-function technologies have been elaborated to the end that an existing technological unit could be utilised (with certain modifications and temporary extensions) for the removal of the most likely components of groups of polluting substances. The main processes for removing pollutants, expected to occur during accidental pollution events, are as follows:

- Aeration (removal of volatile substances),
- Solid-liquid phase separation (removal of solids, or, by precipitation, solidified substances)
- Absorption (removal of most of the organic, and some of the inorganic constituents).

The technology of solid-liquid phase separation relies on single-, or multi-layer filters contained in a pressure vessel while adsorption is provided in a container filled with granulated activated
carbon. In the case of the simultaneous occurrence of a combination of contaminants, the above mentioned two containers can be used in sequence.

The emergency treatment techniques proposed would, normally, be used only infrequently. They would not, therefore, be very cost-effective. If, however, the units were utilised to treat the normal run-off water and the water so treated were to be recharged in the background zone, a sufficiently large reserve might be accumulated that the passage of a slug of pollution might not adversely affect the yield of the production wells.

**REHABILITATION OF POLLUTED DRINKING WATER RESOURCES**

Different approaches should be followed for rehabilitation of the polluted drinking water resources in the case of surface waters and subsurface waters. In surface waters, the dissolved polluting substances are relatively fast transported by the water body along the river, except in lakes and reservoirs, the particulate matter associated pollutants may accumulate in the bottom sediment. In subsurface waters, partitioning of the pollutants between the soil and water is controlled by physical and chemical processes, and the migration of the dissolved substances is relatively slow.

Rehabilitation of polluted rivers is usually achieved by reduction of point and diffuse pollutant inputs, and the effectiveness is indicated by significant improvement of the water quality in the river system. The quality of the river Rhine, known as one of the most polluted river in Europe during the 50’s, 60’s and 70’s, showed significant improvement in the 80’s and 90’s as a result of the pollution reduction programme [Hellmann, 1993].

Rehabilitation of the polluted subsurface waters - groundwaters - may include two approaches: (a) pumping out and treatment of the groundwater, and (b) geohydrological isolation of the polluted aquifer. In any situation, it is important to clean-up the contaminated site - soil - to minimise the future leaching of the contaminants to the water resource [van Veen and Weenk, 1994].

**CONCLUSIONS**

Safe drinking water supplies require actions to be taken for the protection of the drinking water resources which might be contaminated by acute - accidental - and/or chronic pollution.

In the case of subsurface aquifers: (a) numerical seepage-hydraulic and transport models are useful tools to determine protection zones of well-fields, and (b) the protection zones and ranges should be determined by the access time. The principle of reconsidered protection allows the existence of those pollution sources which can not be liquidated economically and their pollution impact does not endanger water abstraction to continue.

In the case of surface waters and bankside filtered waters: (a) the methods discussed to increase the safety of supply and the protection of drinking water resources (hydro-geological and transport models of the filtration zone, the early warning water quality monitoring system and the emergency drinking water treatment methods) should be implemented in practice at the waterworks and by the authorities concerned, and (b) hydro-geological protection zones of the bank-filtered water resources should be extended to the river itself, whose water ensures the recharge of these resources.
Data on accidental river pollution incidents showed that water users - especially waterworks operating along rivers - were endangered and restricted several times every year because of the temporary quality deterioration of the surface water resources, therefore, it is important to operate an early warning water quality monitoring system along the rivers. The warning from this system can protect all water users, but especially the waterworks by providing them with warnings in due time about pollution incidents.

The hydro-geological and water quality transport model-systems developed for the filtration zone of the selected area of drinking water resources could be used for prediction the effects of pollution both in the parent river and in the landward background zone. Such models can be used for aiding the design and selection of technical control measures against polluting effects. They will also be beneficial for operational management in its decision-making, therefore, optimal operations schedule of the bankside filtered wells should be elaborated for accidental pollution incidents, in order to minimise the risks. This should be done with due concern to the duration of the pollution event and to the time of travel to the wells.

The protection of the drinking water resources should be solved in such a way to ensure (in addition to the safety of drinking water production) the employment and well-being of the inhabitants, the maintenance of agricultural and forestry activities, and recreational land uses. The contamination of the production wells from the off-river background zones should be intensively investigated to determine its effects on the quality of the water produced by the bankside wells. Possible means of preventing this type of pollution should also be investigated.

The application of emergency drinking water technology could assist waterworks to maintain supply during the period of temporary deterioration of water resources caused by accidental pollution. Most waterworks do not have the capability at present to apply emergency treatment technology. Waterworks should be made to install the necessary equipment to put into operation temporary emergency technologies when needed, especially in cases where they utilize surface water sources (rivers) because they are especially vulnerable to accidental pollution incidents:

- Applicable emergency technologies should be considered to remove organic and inorganic micropollutants for small and medium-size waterworks;
- In the case of favorable hydro-geo-chemical conditions, the small and medium size waterworks should be made independent of the parent river for a few days with groundwater recharge in the landward background zone and with the establishment of new production wells that draw on these resources;
- In the case of shorter (one-two days) accidental pollution events, an appropriate solution can be provided by establishing sufficiently large clean water storage capacity at the waterworks. When the clean water storage capacity of the waterworks is only 15-25% of the daily quantity supplied, it is inadequate. Investment in this field would prove useful, not only in the case of accidental pollution events, but also at low river flows, when bankside filtered production wells operate with capacities much below their average.

Public and professional interests are increasingly focussed on the methods of rehabilitation of contaminated drinking water resources, therefore:

- Research and development work into the rehabilitation of contaminated groundwater resources should be continued in order to develop methods of protecting drinking water
resources;

• efforts should be made to develop rapid and reliable methods for human-toxicological investigations for the determination of public health effects of specific pollutants in water;

• the protection areas of the waterworks should be determined and planned with due regard to the presently effective stricter quality requirements and the likely quality of potential recharge from the off-river background zone.

Waterworks along international rivers are often endangered by transboundary water pollution incidents. The safety of drinking water supply in such regions could be improved by applying the method of the early warning water quality monitoring system in practice.

REFERENCES


