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Review:

Groundwater protection: What can we learn from Germany?

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Abstract: For drinking water security the German waterworks proceed on a comprehensive concept, i.e., the protection of all the regions from the recharge area to the client. It includes the protection of the recharge area by a precautionary management, a safe water treatment, a strict maintenance of the water distribution network, continuous control and an intensive training of staff. Groundwater protection zones together with effective regulations and control play a very important role. Three protection zones with different restrictions in land-use are distinguished. Water in reservoirs and lakes is also protected by Surface Water Protection Zones. Within the surrounding area the land-use is controlled, too. Special treatment is necessary if acidification happens caused by acid rain, or eutrophication caused by the inflow of sewage. Very important is the collaboration between waterworks and the farmers cultivating land in the recharge area in order to execute water-protecting ecological farming with the aim to reduce the application of fertilizers and plant protection agents. Probable financial losses have to be compensated by the waterworks.

Key words: Drinking water security, Germany, Groundwater protection zone, Water protection
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INTRODUCTION

The growth in population, improved hygiene, changing habits of consumption, as well as the extreme extension of the industrial production and the increasing irrigation in agriculture resulted globally in an enormous rise of the demand of water during the last decades and this demand is still rising (Prinz and Malik, 2003). Worldwide, there are quantitative as well as qualitative problems concerning the water resources. Quantitative problems are caused by local and even regional overuse of surface- and groundwater, climatic change, and reduction of precipitation and melting water from glaciers. Qualitative problems are caused by contamination, mainly, of surface water, but also of shallow groundwater.

In order to protect the quality of water resources, the effective operation of sewage treatment plants, the reduction of applications of toxic substances, fertilizers, plant protective agents and chemicals, and the establishment of water protection zones are necessary.

The current water situation in China can be listed as follows (Zhang *et al*., 2001; Deng *et al*., 2002): (1) The water demand is outstripping the resources in many urban areas; (2) Many urban regions and water environments are at risk of contamination caused by climate change and population growth; (3) Water pollution (inorganic and organic pollution, point and non-point source pollution) in main river systems is becoming more and more serious; (4) The eutrophication in the main lakes is rather serious; (5) Besides water saving technologies, currently the most important task for the urban water supply is to adopt a modern and efficient water quality management.

GROUNDWATER AS A WATER RESOURCE

As an essential part of the hydrologic cycle, groundwater is involved in many natural processes, which is a geo-technical factor conditioning soil and rock behavior. It is important for sustaining spring discharges, streams, river base-flow, lakes, wetlands, and aquatic communities. The use of groundwater has significantly increased in recent decades due to its wide-spread occurrence, good quality, high reliability during droughts, and modest development costs. Industry and agriculture, particularly the irrigation systems, strongly depend on groundwater.

In many areas including several mega-cities, groundwater is the most important and safest source of drinking water. For example: (1) In the countries of the European Union, groundwater provides nearly 70% of the piped water supply and 80% of the drinking water; (2) In Baden-Württemberg, Germany, 75% of the water supply originates from groundwater; (3) In the USA, 50% of the population relies on groundwater as its primary source of drinking water; (4) In China, 20% of the urban water supply originates from groundwater, in Northern China 72%, in Northwestern China 66%, while 80% of the Chinese cities have water resource problems.

GROUNDWATER CONTAMINATION

Different substances behave in different ways in the subsurface water (Balke, 2003; Balke amd Zhu, 2003). Salts are more or less soluble in water and move together with the groundwater in flow direction. Heavy metals are only soluble in water at low pH values and precipitate at neutral and basic pH values as hydroxides. Hydrocarbons such as gasoline, diesel, kerosene, light fuel oil, etc. float on the groundwater surface because of their low specific gravities, and a small portion of hydrocarbons is dissolved and moves with the groundwater flow. Above the contaminated areas, gaseous hydrocarbons are contained in the interspaces of the unsaturated zone, escaping slowly into the atmosphere. Halogenated hydrocarbons such as trichloroethylene (C_2HCl_3), dichloromethane (CH_2Cl_2), etc., percolate the unsaturated zone as well as aquifers more or less vertically, due to their high specific gravities. Finally, lenses of halogenated hydrocarbons in phase are accumulated on the bottom of the aquifer. A new group of contaminants with increasing concentration are pharmaceuticals, such as hormones, vitamins, enzymes, beta-blocker, psycho pharmacological medicine, antiepileptic drugs, antibiotics, disinfectants, etc., but also including cosmetics and perfumes. Pharmaceuticals and their metabolites are released from sewage treatment plants, pharmaceutical industry, leaky sewers, and waste deposits. They are very persistent and will be enriched in the course of time. From a site of contamination a plume of contaminated groundwater is formed in the aquifer which may extend for a few kilometres.

Because of huge amount of contaminants that may pollute groundwater resources, an efficient control of waste, sewage and the recharge areas of drinking water wells is necessary. But in practice, poor or lacking control has led to uncontrolled aquifer exploitation and groundwater contamination. Groundwater quality degradation is recorded in many countries in various occasions, e.g., as downward and upward influx of water of poor quality into exploited aquifers, as irrigation return flow or discharge of pollutants from point and diffuse pollution sources into shallow aquifers, or as saltwater intrusion into coastal aquifers. Groundwater contamination is worldwide a serious problem for social life, public health, economic development and ecological environment.

Therefore, it is an imperative aim to introduce innovative and safe methods of water protection, such as efficient water catchment management and remediation of contaminated water resources, and application of new water recycling systems and methods for the protection of existing water resources.

GROUNDWATER PROTECTION ZONES

In order to protect the quality of water resources and to reduce the application of toxic substances, fertilizers, plant protective agents, chemicals, etc., within groundwater recharge areas, the delimitation of water protection zones is necessary (Balke *et al*., 2000; Balke and Griebler, 2003). Groundwater protection zones make the control of possible water pollution from the source to the well.

Groundwater protection zones in unconsolidated sediments

Within water protection zones the protection of water resources takes priority over all other competing interests of land use. Several restrictions in land use can prevent the contaminants from entering the aquifer by seepage from the Earth's surface. In this way, the introduction of harmful and noxious substances into the aquifer can be stopped, and the water resources can be conserved in the long run. Above all, agricultural activities and installations of infrastructures are affected by those restrictions. In Germany thousands of water protections zones have been delimited within the last decades; in Baden-Württemberg, Germany, e.g., more than 25% of the land surface is water protection zones (Schmidt and Balke, 1980; 1985).

According to the kind and locality of a contamination and the hydrogeological conditions of the subsurface in the catchment area, pollutants need different time courses to reach a well or spring. Along the way, the pollutants are exposed especially to the processes of dilution, fixation and decay. Therefore, an area where groundwater is protected against contamination can be subdivided into three sectors: (1) Protection zone I: remedial action zone, Sector I; (2) Protection zone II: attenuation zone, Sector II; (3) Protection zone III: well field management zone, Sector III.

These protection zones are sectors of different significance and function in order to avoid possible pollution with regard to the natures of various pollutants within the aquifer. On the base of the planned water discharge of the well, the hydrogeological situation (flow direction and flow velocity of the groundwater, hydraulic conductivity and transmissivity of the aquifer, etc.) within the recharge area, and the amount of the annual natural and artificial groundwater recharge, the size of the protection zones can be designed (Fig.1). For the calculations a special formula or a computer programmes is applied.

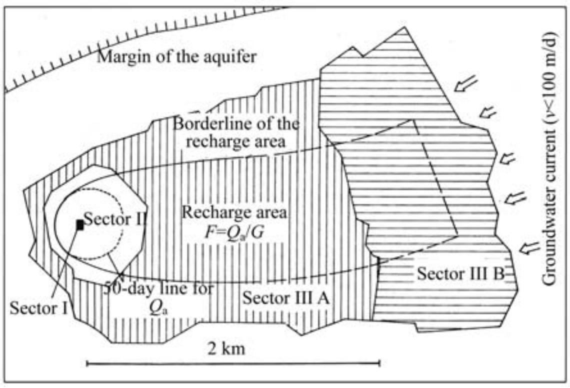

Fig.1 Groundwater protection zones for a well exploiting an unconsolidated aquifer
G is the amount of annual groundwater recharge; F is the recharge area; Q_a is the mean amount of annual discharge (Geological Survey of Baden-Wüerttemberg, 1991)

Protection zone III protects a well from serious endangering, particularly from non-degradable or heavily degradable chemicals and radioactive pollutants (Zhu *et al*., 2007). In order to obtain a protection effect by decay and adsorption of contaminants and dilution by seeping rain water, Protection zone III extends over the hydrological and hydrogeological recharge area of a well or spring. Protection zone III can be further subdivided into Protection zones III A and III B, if its longitudinal extent amounts to more than 2 km.

In Protection zone III the following is forbidden: (1) seepage of wastewater, (2) factories such as oil refineries, metal plants and chemical plants without sufficient protection measures, (3) nuclear power plants, (4) storage or disposal of water endangering substances, (5) long-distance pipelines for water endangering substances, (6) large-scale animal husbandry, (7) settlements, hospitals, plants without safe waste water removal, (8) reloading and trading of fuel oil, diesel and other water endangering and radioactive substances, (9) airfields, (10) exercises of armed forces, (11) refuse dumps and garbage deposits, (12) sewage and waste water treatment plants, (13) transport of manure and feces, (14) drillings for exploration or exploitation of crude oil, natural gas, carbonic acid, mineral water, salt and radioactive substances.

Protection zone II guarantees the protection of a well or spring from pollutions, particularly caused, besides other chemicals, by various microorganisms such as bacteria, germs, viruses, etc. which are noxious to human beings. According to previous investigations, in Protection zone II most of the microorganisms introduced into the groundwater are eliminated after 50 d by dying off, decay, adsorption, etc. The "50-day-line"—the borderline of Protection zone II—is the connection of all sites within an aquifer from which the groundwater needs to be held for 50 d until it arrives at the well or spring. However, because of scientific uncertainties and political decisions, in various countries different elimination periods (20, 50, 100 d, etc.) are taken as a basis for the delineation of Protection zone II.

Protection zone II is situated within Protection zone III and protects especially against noxious microorganisms. Besides the restrictions suggested for Protection zone III, Protection zone II also has the following additional prohibitions: (1) buildings for commercial and agricultural use, (2) roads and railway, (3) parking places and petrol stations, (4) camping and sports grounds, (5) cemeteries, (6) open pits, cuts and quarries, (7) blastings, (8) intensive grazing and crowds of cattle, (9) over-fertilizing, (10) open storage and improper use of mineral fertilizers, (11) private gardens and commercial horticulture, (12) storage of fuel oil and diesel, (13) drain ditches, (14) fishponds.

Protection zone I protects the direct vicinity of a well or spring against any kind of contamination and destruction. In Germany, it encircles the water source at all sides at a distance of at least 10 m. The area should be surrounded by a stable fence. In groundwater of Protection zone I, the restrictions of Protection zones III and II are also applied. In addition, the following is not allowed in Protection zone I: (1) unauthorized entry, (2) any kind of agricultural or other usages.

Groundwater protection zones in consolidated rocks

It is also possible to delimitate groundwater protection zones in consolidated rocks such as sandstone and limestone, but in most cases it is more difficult. The groundwater flows through joints and fissures that follow certain directions according to the tectonic history of the rocks. In broader fissures the groundwater flow velocity can be much higher than that in unconsolidated rocks. Especially in karstified limestone that contains large open channels and caves, the groundwater may have flow velocities up to a few kilometres per hour. Therefore, the recharge area can be located several kilometres away from the extraction well. The flow velocity and the flow direction of the groundwater normally are carried out by tracer tests. It also has to be considered that water, possibly the contaminated one, can flow from the earth's surface into the aquifer where jointed zones or dolines and sinkholes in karstified limestone, enable a fast seepage. Regarding these facts, it is understandable that the protected area is irregularly covered with protection zones (Fig.2).

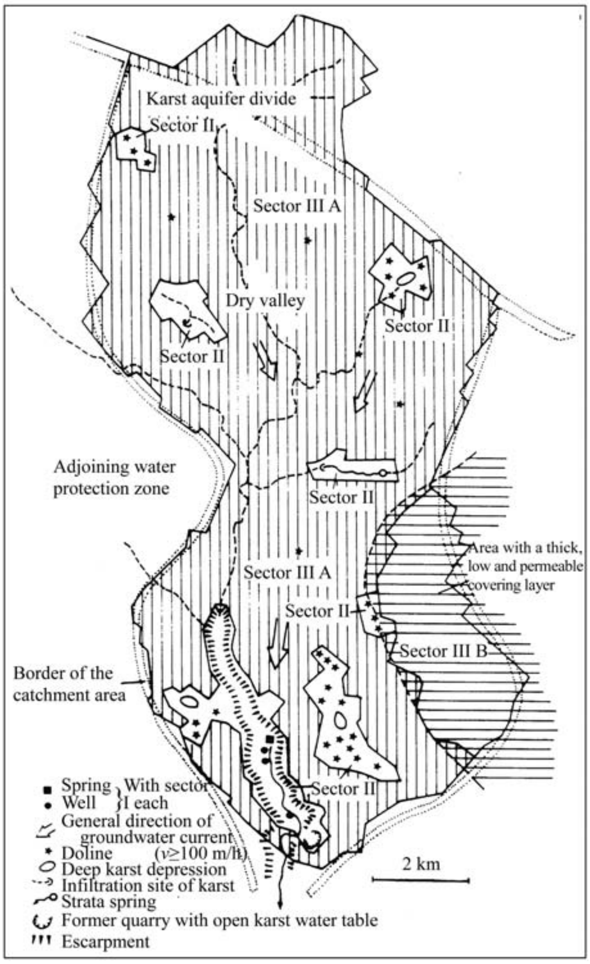

Fig.2 Groundwater protection zones in karstified limestone (Geologisches Landesamt Baden-Wuerttemberg, 1991)

WATER PROTECTION ZONES FOR SURFACE WATER

There are also regulations for the delimitation of water protection zones for surface water along the banks of rivers, lakes and reservoirs, and the prohibitions include the following: (1) camping, (2) bathing, (3) washing, (4) shipping and sailing, (5) fishing, (6) car washing.

WATER PROTECTION BY SUSTAINABLE ECOLOGICAL FARMING

Some water supply authorities in Germany came to an agreement with farmers cultivating in the vicinity of their wells. As farming is mostly a source of water pollution, especially by the application of fertilizers (such as nitrate, phosphate and ammonia), pesticides and plant protective agents, the water authorities convinced the farmers to change from conventional to ecological farming by using exclusively natural fertilizers and by reducing the number of animals to only 2 cows per ha meadow. A strict control of these regulations secures that these regulations are met. Farmers who realize a shortage of their income or have high investment cost are financially compensated by the water authorities. It has been shown that the payment to the farmers is much cheaper for the water authorities than the cost that they would have to afford for water treatment.

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