MINISTRY OF EDUCATION AND SCIENCE OF THE RUSSIAN FEDERATION
Nizhny Novgorod State University of Architecture and Civil Engineering

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PRINCIPLES AND BASIS OF EFFICIENT AND ECOLOGICALLY BALANCED USE OF WATER RESOURCES IN KARST REGIONS

Second edition, revised, translated from Russian

Nizhny Novgorod
NNGASU
2012

ББК 26.3
К 55

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E.V. Koposov. Principles and basis of efficient and ecologically balanced use of water resources in karst regions [Text]: monograph / E.V. Koposov, S.E. Koposov; Nizhny Novgorod State University of Architecture and Civil Engineering. – N. Novgorod: NNGASU, 2012. – 185 p. ISBN 978-5-87941-860-6

The monograph evaluates the scale and dynamics of man-caused pollution of underground waters used for water supply in the areas with subterranean and surface karst forms that have become vertical “transit” conduits for the pollution to penetrate deep into the rock massif.
The authors collected and summarized numerous and unique materials on the study of this subject-matter by foreign and domestic scientists. The performed field and experimental investigations resulted in the development of complex methods of assessment of the extent of the underground water technogenic pollution.

The book is oriented on the specialists in the field of geoecology, water supply and sewage, hydrogeology and engineering geology, ecology and nature management, teachers, post-graduate and undergraduate students of the above mentioned subjects, as well as specialists of design organizations.

The monograph has been written on the results of the fundamental researches implemented within the framework of the assignment of the Ministry of Education and Science of the Russian Federation, register No. 5.5323.2011

ББК 26.3

ISBN 978-5-87941-860-6

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Preface

Urgency of the problem. Under the conditions of technogenesis underground waters have become the most important life-supporting factor for a man and for the society in general. The underground water extraction for water supply just in the Volga basin reaches 5,173.864 million m^3/year *(Naidenko, 2003)*.

Man-caused pollution of the underground waters is especially dangerous in karst regions, the total area of which in Russia constitutes about 20% of its entire area, and according to N.A. Gvozdetsky, a well-known karst expert, about on one third of the territory of our planet there exist real conditions for karst development. On the one hand, karst regions are characterized by a significant decrease of natural protectability of the underground hydrosphere; on the other hand, they contain considerable reserves of high quality fresh underground waters.

The karstified territories, where zones of a free flow (water exchange) between the zone of suspended water and the underlying aquifers occur due to the development of sinkholes and disruption of the geologic cross-section continuity, are the most vulnerable to industrial, domestic, agricultural and chemical waste landfills, as well as to other technogenic influences. Inevitably, it leads to deterioration of the underground water quality, to the change of its medical and biologic properties, i.e. general mineralization, pH, chemical composition, content of toxic microcomponents.

According to the Ministry of Natural Resources of Russia, about 370 million tons of solid wastes are disposed annually on 280,000 landfills. About 1,600 million tons of toxic wastes are stored in specially arranged disposal sites, including 178 million tons of nickel and its compounds, over 9 million tons of hexavalent chromium and its compounds, over 4 million tons of non-organic compounds of fluorine and other toxic substances. These landfills are immediate polluters of the underground waters, keeping in mind that about 40 per cent of them have not been equipped even with liners. When planning protective measures, quality improvement and rational management of water resources in the karst regions, one should pay a special attention to the study of conditions of their natural protection, migration of pollutants with regard to the recent and ancient sinkholes, identification of polluted areas and assessment of the pollution level under conditions of a continuously growing technogenic impact. The lack of methodology of a complex assessment of the underground water pollution in the karst regions, as well as effective measures of the underground water protection restrains the ecologically safe supplying of high quality fresh water to population, and as a result – socio-economic development of large regions in general. This explains the urgency of the problem and the necessity of its early solution.

The goal and tasks of the researches. The researches were aimed at the developing and applying methods of a complex evaluation of the man-caused pollution of the underground waters in the karst regions for the purpose of selecting ecologically safe locations of industrial enterprises, water intakes, wastewater treatment facilities, disposal sites of industrial, agricultural and domestic wastes, storehouses of chemical fertilizers, herbicides and pesticides, reduction of the existing man-induced loads on the underground hydrosphere, and the efficient management of the underground water resources.

The following tasks were to be accomplished to reach the above mentioned goal:

- analysis and generalization of the existing international and domestic experience in studying underground water pollution processes in the karst regions;
- analysis and typification of the geoecological conditions of the karstified territories in connection with the existing long-term functional specificity of the region (Nizhny Novgorod region);
- identification of the main existing and potential underground water polluters, their classification by the kind and composition of pollution;
- analysis and evaluation of the locations of the underground water polluters with regard to the degree of karst development;
- organization and fulfillment of experimental researches for identification of polluted water migration in the key areas;
- modeling processes of pollutants migration from the land surface into the fracture-karst waters;

forecasting possible development of the man-caused underground water pollution in the karst regions.

Chapter 1

ANALYSIS OF THE PRESENT STATE OF UNDERGROUND WATER QUALITY AND ITS USE IN KARST REGIONS

1.1 General characteristic of man-caused changes of the underground hydrosphere in karst regions

One of the main consequences of human activities and their impact on the environment is deterioration of the quality of underground waters due to pollution. First of all, it refers to the fresh underground waters used for drinking.

Pollution of the underground waters is a direct result of the environment contamination, particularly snow cover, rain precipitations, soils, surface waters. This relationship is reciprocal. For instance, acid rains are likely to increase cadmium and aluminum content in the underground waters. The atmospheric air pollution changes gradually the ground water hydrochemical composition even far away from the source of pollution. The underground water pollution processes should always be connected with snow and soil contamination.

The man-caused pollution of the underground waters manifests first of all in the increased mineralization, general hardness, temperature, content of chlorides, nitrates, organic compounds (especially hydrocarbon and chlorine-containing), heavy metals, and specific substances. This, in its turn, leads to the decrease of the oxygen content in the underground waters, the growth of microbiota, increase of the underground water biological pollution in general *(J. Frid, 1989; Goldberg, 1991)*.

The following important geoecological consequences of the underground water pollution should be mentioned: 1) increase of the underground water ion runoff; 2) increased pollution of the coastal shelf zone due to the discharge of polluted underground waters; 3) formation of local hydrochemical and temperature anomalies in the beds of rivers and lakes in the areas of polluted water discharge; 4) formation of a technogenic gas cloud in the zone of aeration over the surface of the polluted ground waters, especially over sinkholes, which may change agrochemical properties of soils and vegetation; 5) change of the geochemical composition of rocks due to sorption of pollutants; 6) conservation of bacteria in soils in the zone of aeration and in water saturated rocks due to sorption processes and secondary contamination of the underground waters due to desorption processes; 7) change of filtration characteristics of rocks, especially of clay rocks, under the impact of technogenic load that leads to the change of hydrodynamic conditions of aquifers *(Goldberg, 1984, 1990; Geoec. issl., 1994; Koposov, 2000, 2008)*.

Day ground-water aquifers in many respects determine ecological condition of landscapes, i.e. immediate well-being of people in every natural region of Russia, especially keeping in mind that in rural areas, small and medium-size cities they are used for domestic and industrial water supply. Ground waters, as a rule, are the first to be affected by the pollution; they are most vulnerable to industrial, building, mining, and transportation activities of a man. Nevertheless, unlike surface waters, the underground waters even of the day aquifers to a certain extent are protected from the direct pollution due to the sorption properties of rocks. The deeper fresh underground waters of artesian basins occur the better they are protected from the immediate technogenic impact. For this reason they are considered the main state reserves of reliable water supply sources.

Distribution of water resources on the territory of Russia permits to believe that water supply in many subjects of the Russian Federation may be provided by means of the underground waters. Today the underground water share in the total volume of communal and agricultural water supplying constitutes 57 per cent. The underground waters are the main source of water supply for rural settlements, small and medium-size cities. In large cities with population over 250 thousand people the underground water share reaches 30 per cent of the total water consumption *(Belyakov et al., 1997; Varmanyan, 1994)*.

The general underground water withdrawal and use for domestic purposes is continuously growing. Considerable quantities of the underground waters (about 5 to 6 million m^3/day) are pumped out of mines and quarries during mining operations. Though this water is polluted, and part of it is highly mineralized, after a proper treatment it may be used for production purposes. At present, anyhow, almost all pumped-out water is discharged into surface water bodies and various collectors, the fact that only intensifies the underground water pollution *(Geoecology: problems and solutions, 1991, Naidenko, 1995)*.

Thus, the dispersed extraction of the underground waters today may be considered quite a common and strong factor of a technogenic impact on the general water balance and regime of the underground waters that in some regions causes their lowering and pollution. This is especially noticeable on mining allotments, in the areas where natural conduits connecting underground and surface waters have been permanently damaged during artificial regulation of the underground and surface water runoff; in the areas of large construction dewatering; on the reclaimed lands *(Kotlov, 1978; Krainov, 1987; Koposov, 2000)*.

Today large quantities of the underground waters are extracted for drinking and industrial purposes, during dewatering of construction sites, quarries and mines. The share of the fracture-karst waters in the drinking water supply is quite considerable. N.A. Gvozdetsky (1972) identified three most important factors that determine the priority of the karst waters: 1) growing importance of the underground waters in water supplying due to the pollution of surface waters in industrial areas; 2) vast distribution of karst rocks on the territory of Russia; 3) useful fracture-karst water reserves in carbonate rocks exceed considerably underground water resources in other water-bearing complexes. A classic example of that is the Yuzhno-Gorkovskoe underground water field located on the south of the Nizhny Novgorod region and north of the

Republic of Mordovia, karstified limestone and dolomite rocks of which contain about 1.0 million m^3 /day of high quality drinking water.

The Nizhny Novgorod region in general is rich with underground water. It is widely used for domestic and technical purposes, for watering and medicinal purposes.

Fresh and low saline waters are of a special value. According to the forecast, expected reserves of these waters reach 8.7 million m^3/day. The claimed water demand in the region before 2005 was 1.3 million m^3/day. Procurement of the explored water reserves amounts to 200 per cent.

Reserves of the quality underground waters used for water supply in the cities vary over the region.

The most water-rich karstified territories are located in the south, south-west, and central parts of the region. The underground water is supplied from both individual wells and group water intakes. In all, there are about 10,000 production wells on the territory of the region. Their total volume amounts to 0.8-0.9 million m^3/day. Though there is a significant shortage of drinking water in some areas of the region, industrial enterprises use up to 30 per cent of it for technical purposes. For instance, in the city of Pavlovo this level reaches 39 per cent, in Nizhny Novgorod – about 29 per cent of total water consumption. As a result, the actual water consumption per capita in some districts is below the line.

The approved reserves are used for water supply in the cities of Vyksa, Kulebaki, Dzerzhinsk, Arzamas, Sarov, Bor, Gorodets, Sergach, Pilna, Pyra, Ilinogorsk.

According to the present hydrogeological conditions the underground waters on the great part of the karstified territories of the region are not protected from the surface pollution. In the areas with direct hydrological connections of rivers with karstifying rocks via sinkholes, the underground waters are subjected to pollution most of all (Fig. 1.1). Such areas are typical for the rivers of Tyosha, Seryozha, Satis, Sarovka, Pyana, Kishma, Kudma, Oka.

Deep erosion cuts, valleys of small and medium-size rivers in the areas of water intakes of the south and central parts of the Nizhny Novgorod region affect badly natural protectability of the underground hydrosphere (Fig. 1.2).

Operational imperfection of water intakes also leads to the pollution and depletion of the drinking quality underground waters. Infringements of the operation rules are numerous. They have been revealed during complex inspections of water intakes and potential polluters. In many cases the wells have no sanitary zones, inactive wells have not been timely liquidated, wellhead cementation is broken, quantities of extracted water are not recorded, the underground water quality is not monitored. At present there are more than 700 inactive wells in the Nizhny Novgorod region, which are to be eliminated (some of them restored) for they can serve as conduits through which contaminants can reach the exploited aquifers.

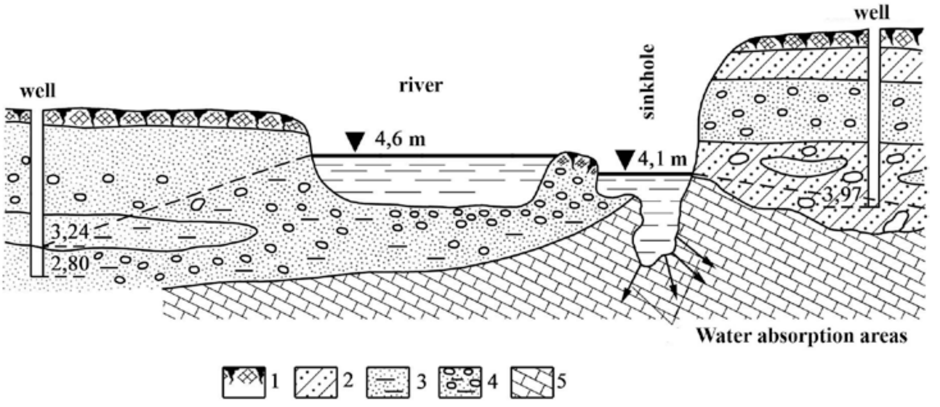


Fig. 1.1 Scheme of fracture-karst aquifer pollution with river waters via a sinkhole: 1 – vegetation layer; 2 – clay sand; 3 – sand; 4 – sand with pebble, water-bearing; 5 – limestone.

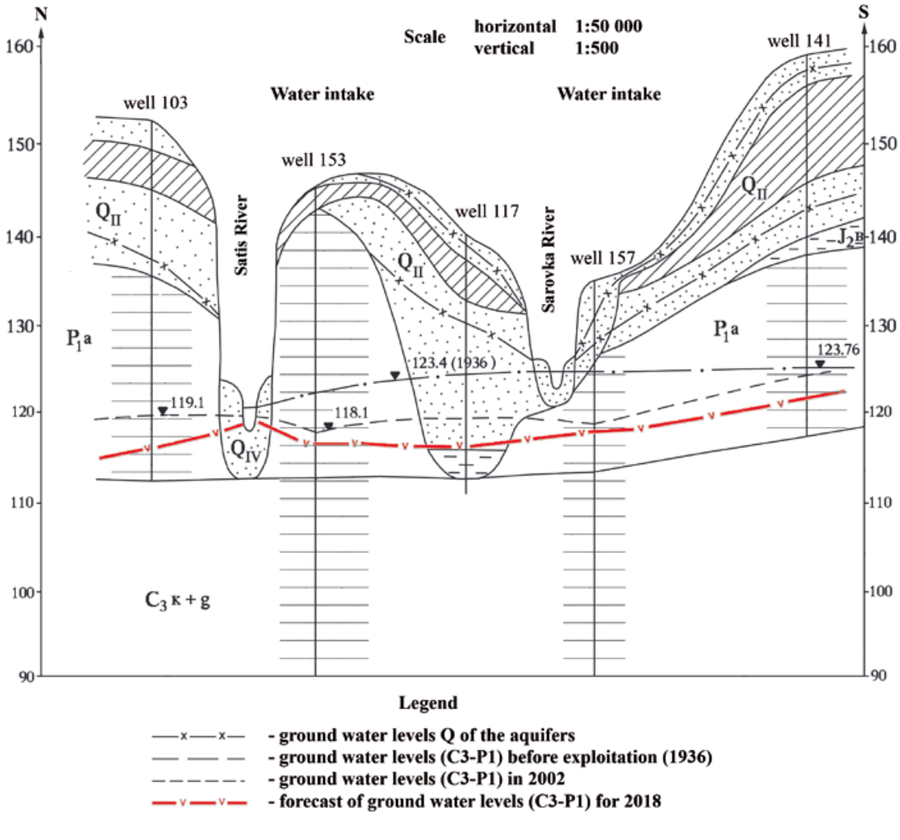


Fig. 1.2. Schematic hydrogeological cross-section along the line of operational water intakes

The maximum man-caused load falls on the central part of the Nizhny Novgorod region, where there are permanent sources of pollution: the city of Dzerzhinsk with a vast area of chemical pollution, which by the variety of contaminating elements can be compared with the periodic table; the cities of Balakhna and Pravdinsk, where wastes of the pulp and paper mill and the microwave equipment plant almost put the existing water intakes out of operation; the city of Nizhny Novgorod, particularly its industrial part, where such large plants as GAZ, Krasnoe Sormovo, Dvigatel Revolutsii, aircraft works are located. The spectrum of contaminating elements there ranges from a wide variety of heavy metals to almost a complete set of oil products.

The soil pollution caused by the operation of the Turtapsk pig-breeding farm threatens the underground water supplying in neighboring areas. The same situation exists in the settlements located in the zone of influence of the Iljinogorsk pig-breeding farm.

A long-term exploitation of aquifers may cause the underground water lowering and development of cones of depression, as well as deterioration of the underground water quality. The diameters of depressions vary from 0.3 km (the Reshetikha water intake) up to 15 km (water intakes of the Dzerzhinsk industrial area). For the whole period of the water intakes exploitation the depressions have developed to the depth ranging from 1.5 m (the Reshetikha water intake) to 25.7 m (water intake II of Dzerzhinsk). Some water parameters (concentration of sulphates – the Reshetikha water intake; concentration of iron and manganese – the Ivanovo water intake; hardness up to 10 mole/m^3, oxidability 5.1-6.5 mg O_2/dm^3, NH_4 – 0.4-0.8 mg/dm^3 – the Iljinogorsk and Reshetikha water intakes) exceed the sanitary norms. Due to the industrial contamination and existence of permanent sources of pollution (the wastewater collectors “Volosyanikha” and “Beloe more”, industrial waste disposal site, waste utilization shop, tar ponds, etc.) the change of water chemical composition is periodically reported in individual wells of the Dzerzhinsk water intake, namely the presence of cyanides, benzol and oil products.

The change of the hydrodynamic situation inside the karstifying rocks and the massif of the overlying sediments often causes an abrupt activation of karst processes, i.e. occurrence of sinkholes and deformation of buildings and structures on the land surface. The basic factors that cause karstification are fracturing, voidage, crashing of soluble rocks to pebble or powder and, as Kozhevnikova, 1984, and Kutepov, 1986, rightly underlined, mechanical destruction of karstified rock masses by high-velocity underground waters, karst cavern filler washing-out due to the change of filtration rate and direction, as well as due to the processes of rock softening and filtration deformations (Fig. 1.3) in the overlying formations *(Khomenko, 1986; Zlobina, 1986; Gaidin, 1987)*.

The man-caused karst activation was reported in the area of the water intakes of the

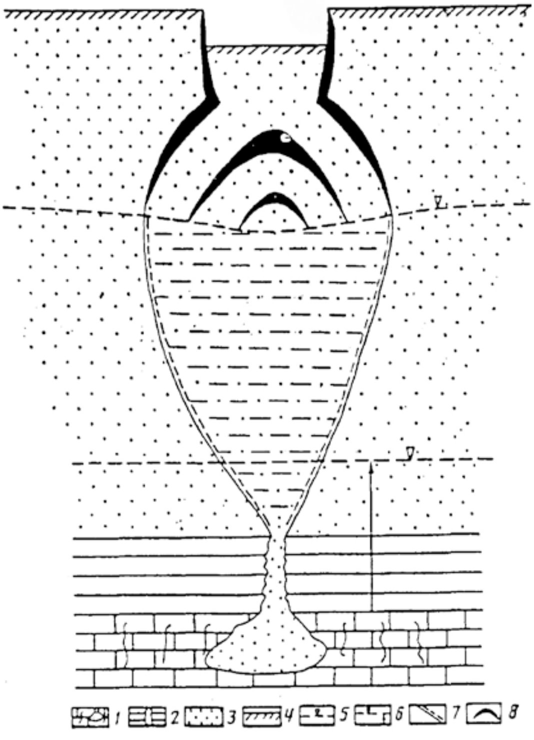


Fig. 1.3 Scheme of simultaneous processes of a complete filtration destruction of the structure of water-saturated sands and a sand collapse in the zone of aeration (by V.P. Khomenko):

1 – karstifying rocks with fractures and voids; 2 – tight rocks with broken continuity; 3 – sand rocks; 4 – ground surface; 5 – ground water level; 6 – pressure lift of fracture-karst waters; 7 – boundary of a filtration shift of the ground; 8 – voids of sand collapse in the zone of aeration.

industrial zone of Dzerzhinsk, where the water lowering in the exploited aquifer exceeded 20 m and the depression boundaries reached the city residential areas. Every year 5 to 6 karst-suffosion sinkholes form in the area of water intakes. Depressions and sinkholes have been also found in the area of the water intake wells of the city of Pervomaisk of Nizhny Novgorod region.

A long-term use of the underground waters on the territory of Moscow *(Kotlov, 1978; Kozhevnikova,1984; Kutepov, 1982; Kutepov, 1995)* has caused formation of a huge depression with the piezometric level lowering up to 80 m and activation of karst-suffosion processes that resulted in karst deformations and destruction of several buildings in the area of the Khoroshevskoe highway.

Numerous cases of pollution of the exploited aquifers, where water-bearing strata are formed of limestones and dolomites, are typical for many regions of Russia *(Borevsky, Khordikainen, Yazvin, 1976; Goldberg, 1991; Vartanyan et al.,1994; Koposov, Kaznov, 1996; Plotnikov, 1998)*.

In the Middle Volga area the south and central parts of the Nizhny Novgorod region may serve an example of this type of pollution (Biryukova, Chentsova, 1990; Koposov, Kaznov, 1996). While conducting field investigations of the karstified territories, the authors witnessed repeatedly gross violations of the environment protection regulations and ignorance of elementary rules during natural resources development by the representatives of the executive power as well as managers and specialists of various companies and organizations.

For instance, large sinkholes on the suburbs of Sosnovskoe settlement, Nizhny Novgorod region, where fracture-karst waters are the only source of water supply in the area, have been turned into reservoirs for waste POL discharge. Consequently, the main exploited aquifer was heavily polluted with oil products.

During field investigations numerous unauthorized dumps of solid municipal and food wastes were found in the area of the karst lake Yalchik in the Republic of Mari El. They create a constant risk of water bacteriological contamination. At the same time water supply of tourist camps, sports centres and rest homes in this area depends entirely on the fracture-karst waters.

In the result of an intensive extraction of the underground waters, directions of their flows and lines of their hydraulic watersheds may change, a risk of water suction from the underlying aquifers characterized by increased mineralization and different chemical composition appears (Fig. 1.4).

As a consequence, the exploited aquifer is contaminated with low-quality water and may become unfit for further use. This is the case of the intakes of the Pavlovo bus plant, villages of Bogorodsk district, water intakes of the Dzerzhinsk industrial zone. The same risk exists for the Teplovsky water intake in the Nizhny Novgorod region in the areas where sulphate rocks occur immediately under sands (Fig. 1.5).

During commercial production of shallow sulphate and carbonate fields, especially if the mining is connected with dewatering and water drainage, sinkholes and cases of fracture-karst water inrush are very frequent *(Abramov, Gazizov, Kostenko, 1976; Tychina, 1989)*.

For 30 years of the underground mining of the Bebyaevo gypsum field 38 sinkholes have formed (Fig. 1.6). In some areas of the field the work had to be permanently stopped due to the collapse of large volumes of clay material. During this period the adits and drifts of the Bebyaevo mine twice were entirely flooded by the fissure-karst waters due to the catastrophic inrushes. In some areas of the open pit development of carbonate rocks of the Budaevo, Gremyachevo, Smirnovsk, Ubezhitsy, Satis deposits up to 25 per cent of the useful rock mass were buried under the collapsed sand-clay formations. During the field investigations of the carbonate quarries the authors found out that in case of the open pit mining the underground waters were contaminated with mechanical particles and chemical compounds due to overburden washing-out, as well as with mineral oils, phenols, alkali and other contaminants associated with operation of boring, stripping, production and transportation equipment. Every year in the vicinity of the Budaevo field, where rocks are crushed by explosion, 2 to 3 sinkholes of depth from 0.5 to 2 meters appear on the neighboring karstified territories.

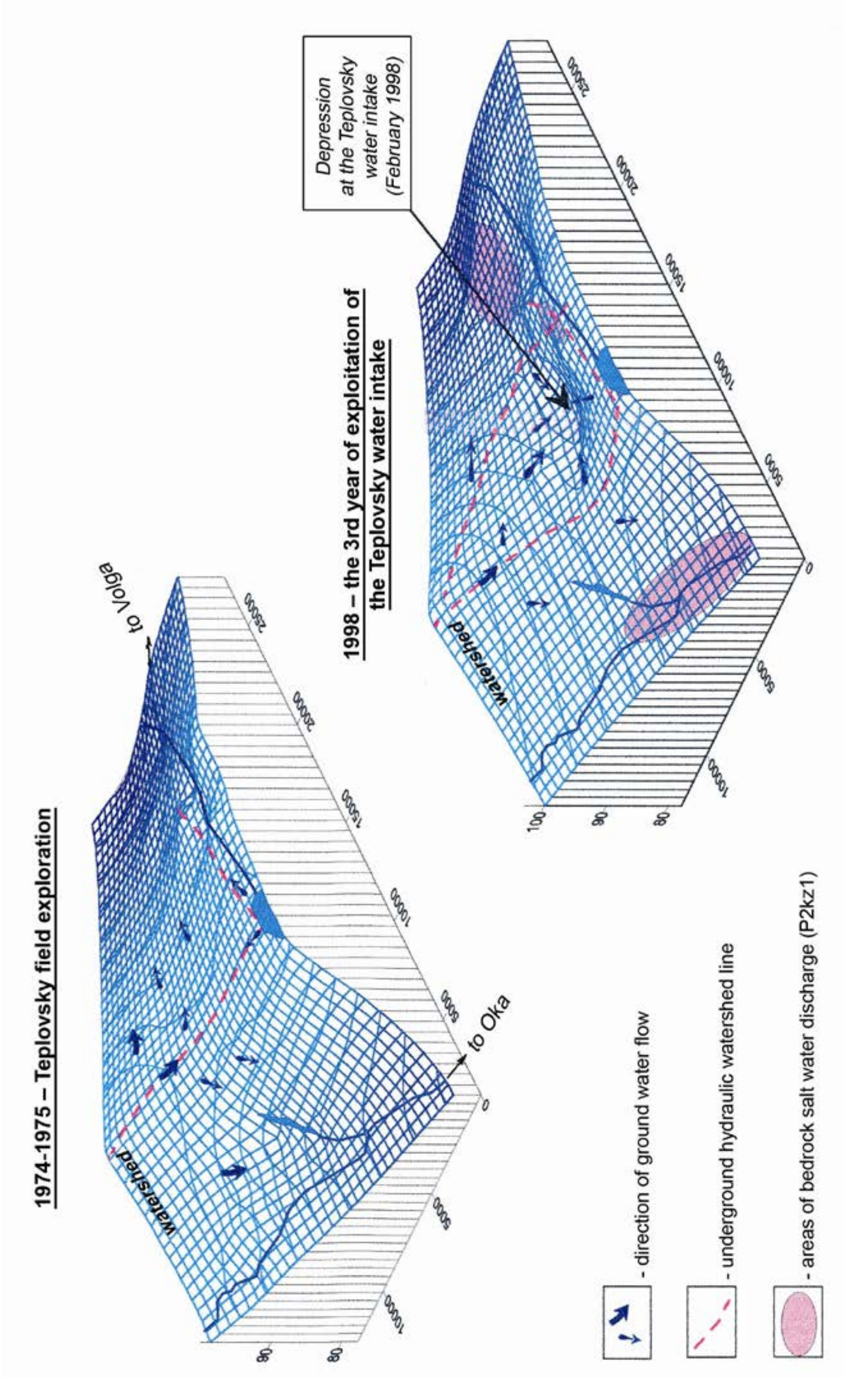


Fig. 1.4 Change of lines of the underground hydraulic watersheds in the course of the Teplovsky water intake exploitation

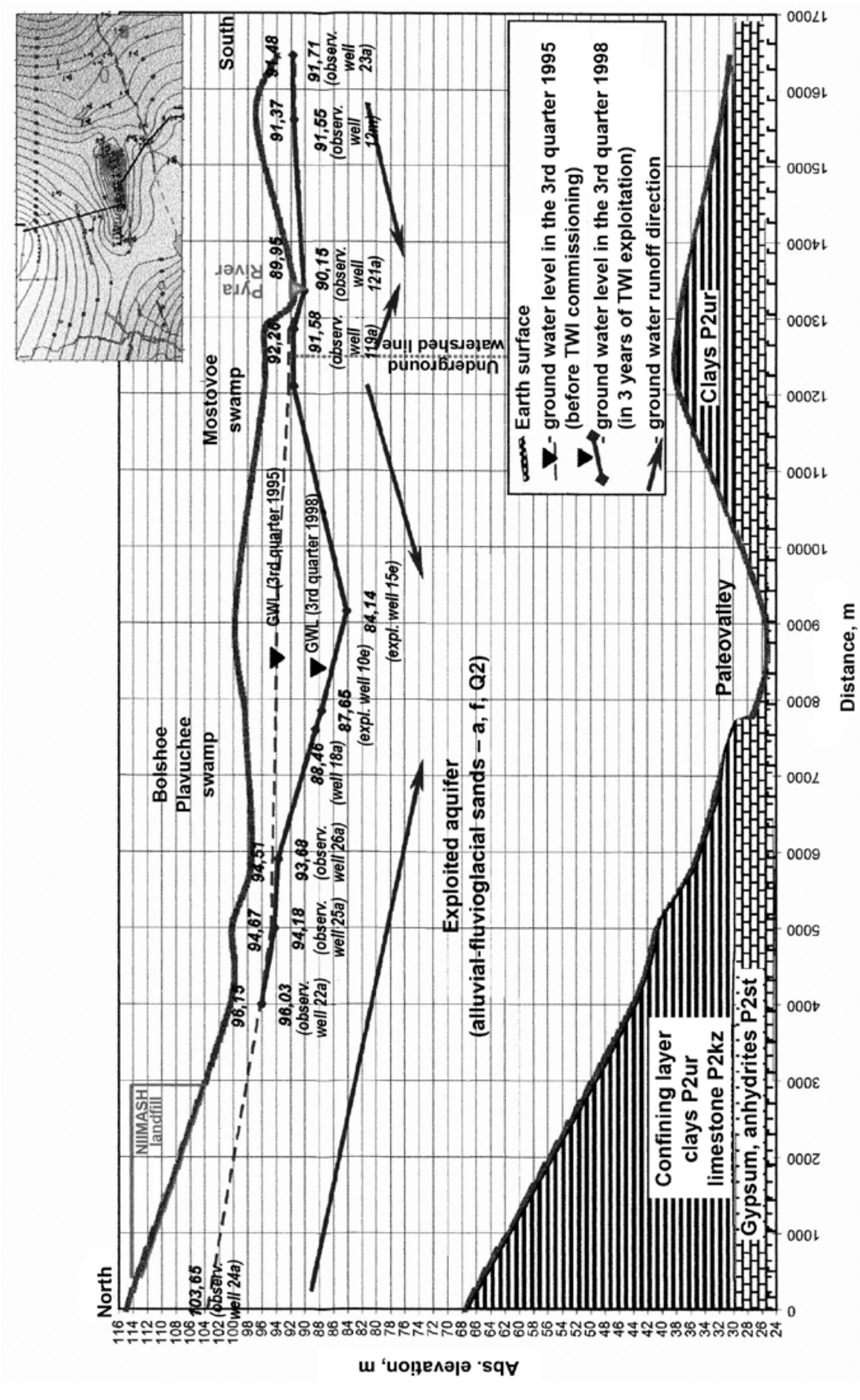
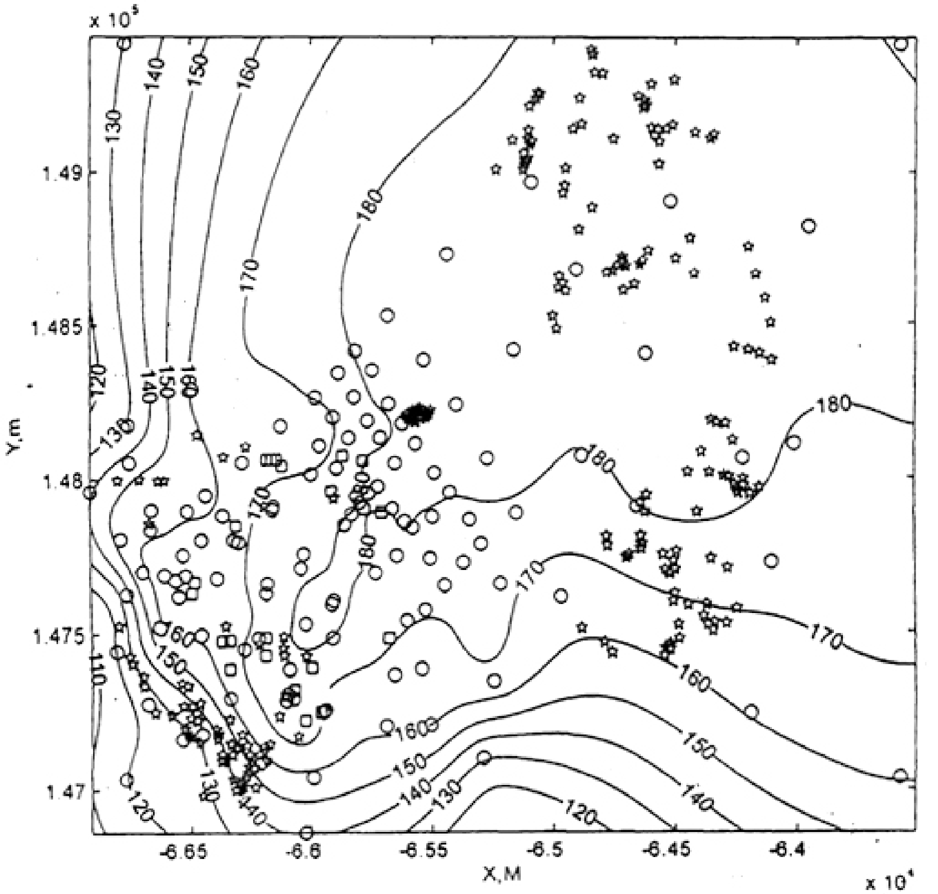


Fig. 1.5 The Volga paleovalley at the section of maximum overdeepening and carbonate rocks washing-out



Legend:
☐ - source; ○ - well; ★- sinkhole; ★ ★ - group of sinkholes; 180 – contour lines

Fig. 1.6 Relief map of the Bebyaevo gypsum deposit

1.2. Problems of arranging and exploiting waste disposal sites on the karstified territories

Every year more than 7 milliard tons of wastes are produced in the Russian Federation, less than 30 per cent of which are subjected to utilization. About 80 milliard tons of solid wastes have been accumulated on disposal sites on the territory of Russia *(Boravskaya et al., 2010)*. Concentration of toxic and hazardous wastes on the landfills amounting to 1.6 milliard tons is of a special concern. According to the State Committee of the Russian Federation on Statistics and Analysis (Goskomstat), since 1990 about 75 million tons of highly toxic wastes have been produced annually in Russia, only 18 per cent of which being processed and neutralized. By 2005 they exceeded 120 million tons. The unsatisfactory state of landfills, and often lack of them, creates emergency situations, when wastes are dumped directly on the land surface, into rivers, lakes, sinkholes and karst depressions *(Naidenko, Koposov, 2005)*. Today industrial and domestic wastes have become principle sources of the environmental pollution. In the areas of their storage changes in the underground water chemism, soil structure, water-physical and mechanical properties of soils take place, as well as pollution of air, soil and surface water *(Goldberg, 1995; Trufmanova, Galitskaya, 1999)*.

The urgency of the problem of storing and utilizing industrial and domestic wastes is connected not only with their constantly growing volumes. Up to now a whole number of issues related to the control and especially forecast of changes in various components of the environment in the areas of landfills has not been solved. The extent and character of the underground hydrosphere pollution as well as changes of rock properties depend largely on the stability of the geologic environment of a karst region as a whole to the technogenic influence and on the protectability of its individual components.

According to Article 51 of Federal Law No. 7-FZ dt. 10.01.2002 "About protection of the environment" industrial and domestic wastes are subject to collection, neutralization, transportation, storage and disposal. The conditions and methods thereof should be safe for the environment and regulated by the legislation of the Russian Federation. According to the Roskomstat, 6,000 industrial enterprises dispose more than 1,600 million tons of toxic wastes on their landfills. These disposal sites are immediate sources of underground water pollution *(Grozdova, 1987; Kaznov, Koposov, 1995; Gelashvili, Koposov, Laptev, 2008).*

Totally, more than 500 points of the underground water pollution have been registered on the karstified territories of Russia *(Belyakov, 1997; Koposov, 2000).* It is unlikely, that this figure gives a correct picture, for not all the polluters have been identified and studied yet. The underground waters were reported to contain nitrogen from 40 to 70 MPC; iron – 30 to 40 MPC; chlorides – 35 to 40 MPC; phenols, oil products – 5 to 7 MPC; strontium, aluminum – 5 to 6 MPC.

Every year the Nizhny Novgorod region produces over 1.6 million tons of industrial and domestic wastes, including those of hazard class 1 amounting to 0.2 thousand tons; of hazard classes 2 and 3 – 19.0 thousand tons; of hazard class 4 – 600.0 thousand tons; of hazard class 5 – 997.0 thousand tons.

In general the industrial and domestic wastes in the region by 2005 had exceeded 13.0 million tons. As before, the bulk of the disposed wastes (85 per cent) were various slimes and slags (hazard class 4) of power generating plants. The wastes are stored on 73 authorized and 17 unauthorized disposal sites, in 37 slime collectors, on specialized landfills built by the enterprises of Dzerzhinsk, Nizhny Novgorod, Vyksa, Balakhna and other cities.

Today more than 90 per cent of wastes from Nizhny Novgorod are taken to the disposal sites.

A principle disposal site of the municipal solid wastes (MSW) located on the territory of the Igumnovo forestry in its present state remains a source of pollution of soils, ground water and atmosphere (Fig. 1.7).

Fig. 1.7 Disposal site of municipal solid wastes in the Igumnovo forestry area

For the last ten years industrial wastes of hazard classes 2, 3 and 4 in the region have been disposed on the landfills constructed by the waste producers themselves. For instance, such landfills were built by JSC "Vyksa metallurgical works", the city of Vyksa; JSC "ZMZ", the city of Zavolzhie; JSC "Bor glass-works", the city of Bor. However, these departmental landfills are not sufficient to improve radically the situation with industrial waste disposal in the region. Therefore, very often wastes are dumped on the sites that do not meet the prescribed requirements, the fact that has a negative impact on the environment.

The MSW disposal on the specialized landfills also presents a problem. Many of them are overfilled. For example, the MSW landfill in Pavlovo has reached its critical state, however, industrial wastes of hazard classes 3 and 4 are continued to be dumped there along with the domestic wastes. The same is observed on the landfill of Arzamas. The municipal disposal sites of the cities of Kulebaki, Navashino, Chkalovsk are also overfilled, presenting a risk of soil and ground water pollution.

Fig. 1.8 The pond is filled with wastes to a depth of 2.5 m. The surface is covered with black oily liquid

Fig. 1.9 The north-east pond, filled to a depth of 2.8 m. There is a russet oily film on the surface.

Fig. 1.10 The central pond. The surface is covered with a thick brown film

Fig. 1.11 A damaged insulation layer in the form of a black film on the bank of an earth reservoir

Fig. 1.12 Unauthorized dump on the bank of the ponds

Fig. 1.13 Cracks in the earth slope of the pond bank. There is no insulation layer. The soil is heavily saturated with brown oily liquid

Fig. 1.14 Surface of the south pond covered with a thin oily film

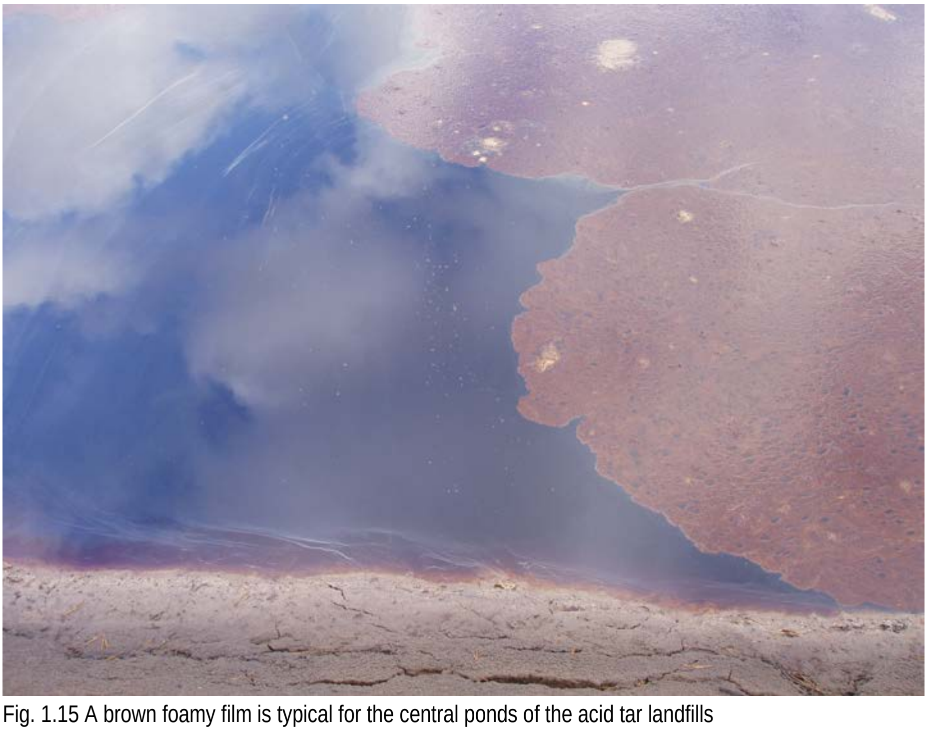


Fig. 1.15 A brown foamy film is typical for the central ponds of the acid tar landfills

Fig. 1.16 Crossover pipe between ponds with a badly damaged insulation layer

Fig.1.17 Area of polluted water spill-over

One of the priority tasks is utilization of acid tars. The tar ponds (earth reservoirs) of Dzerzhinsk contain 211,500 tons of acid tars – products of oil sulphuric acid purification – presenting risk of ground water pollution, particularly at the Teplovsky water intake of the city of Dzerzhinsk located 5 km north-west from the acid tar ponds (Fig. 1.8 to 1.17).

The filling of the tar ponds commenced in 1968. Additionally, in immediate proximity to the ponds a regional industrial waste disposal site was organized in 1974. The designed water-protective measures turned out to be insufficient. Proper service conditions at both sites were not observed, and liquid wastes leaked systematically from the earth reservoirs due to the damage of the continuity of the bottom and wall insulation, from time to time creating emergency situations. For example, in April 1978 about 13,000 tons of semi-liquid wastes leaked into the ground. Tar spill-overs from the ponds occurred repeatedly.

Fires on the solid waste disposal sites are reported all the time; an insulation film in many places is damaged by growing bushes and grass (Fig.1.18, 1.19).

Fig. 1.18 Former shop of industrial waste utilization

Pollution of the aquifer with oil products was first detected in 1976, later benzol and ammonium salts were found in it. A drastic increase of polluting substances was reported in 1979 following the leakage of semi-liquid ammonium sulphates with phenol and organic matters (the shop of industrial waste utilization).

The content of discrete components even now ranges in the following limits (wells 98, 100): mineralization 20.6 to 24.4 g/dm^3, sulphates 6.85 to 9.04 g/dm^3, chlorides 2.91 to 3.09 g/dm^3, oxidability up to 100.0 mg O_2/l.
Pollution with special components is recorded along the entire thickness of the water-bearing quaternary alluvial-fluvioglacial stratum. Cyanides, thiocyanates, benzol, phenol, formaldehyde, oil products, acetone were found in the water. The special components are widely dispersed and are found even in the areas with normal mineralization and sulphate and chloride background (wells 19, 21, 23, 29, 51[a]).

Ash-and-slime wastes in the Nizhny Novgorod region are produced mainly by the Igumnovo heat power plant located on the karstified territory in the valley of the Oka river (Fig. 1.20, 1.21).

Poultry farms in the Nizhny Novgorod region produce annually about 200 thousand tons of difficult for transportation and storage water-saturated wastes. The impossibility of their immediate use without preliminary disinfection and processing into appropriate forms of fertilizers leads to the wastes accumulation on limited territories (usually just near the poultry farms) in large quantities. The non-observance

Fig. 1.19 Non-operational industrial waste disposal site, where wastes are continued to be dumped daily

of the required rules during their storage causes air and soil pollution as well as change of soil composition. Harmful chemical components of the wastes contaminate surface and underground water sources affecting the environment and people's health.

Annual volume of the municipal solid wastes (MSW) in the Nizhny Novgorod region on 01.01.2005 exceeded 3.0 million m^3, including 1.5 million m^3 in Nizhny Novgorod itself. The MSW disposal is organized on 110 sites: 8 landfills, 64 authorized and 38 unauthorized dumps of a total area of 1,100 hectares. Most of the dumps do not meet norms developed for the MSW disposal. The issue of liquidation of the unauthorized dumps having negative influence on the environment should also be solved.

The majority of the dumps were constructed without design documentation. 65 dumps have no buffer area, or it does not meet the norms. Almost all of the dumps are not provided with a system of the ground water protection, the control over the ground water pollution is not performed, too.

The untreated domestic wastewaters from the settlements not provided with sewage systems are also transported to the MSW dumps. A proper waste compaction is not performed and interlayer insulation is not done at all landfills due to the lack of regular workers and appropriate waste compactors. Many dumps are not fenced-in and guarded; hence, they have spread over a vast territory.

Fig. 1.20 Ash-and-slime wastes of the Igumnovo heat power plant on the karstified territory in the valley of the Oka river

The territory of the region is intersected by 4 technical corridors with 6 oil pipelines and 6 transfer stations. Two of them possess a large tank farm. Additionally, the oil-products pipeline “Gorky-Novki” crosses the territory of the region. Oil storage depots of the pipeline have been constructed almost in every administrative area of the region. Each storage depot has a capacity of 50,000 tons and a period of exploitation more than 30 years. This explains the widespread aureoles of oil pollution spotted on

Fig. 1.21 Municipal solid wastes are dumped along with the ash-and-slime wastes

the karstified territories. Tens of accidents related to the oil products spillage on the karstified territories of the Nizhny Novgorod region are reported every year.

Karst zoning of the territory of the Nizhny Novgorod region performed by the authors (Fig. 1.22) reveals that the man-caused loads and sources of pollution are located in the highly karstified areas, where the underground hydrosphere is subjected to the increased pollution.

Analysis of the usage of the karstified territories revealed that 60 per cent of the land resources in the Nizhny Novgorod region experience strong technogenic influence (Fig. 1.23).

The industrial and domestic waste landfills (dumps), storage ponds, tailing pits, filter beds, farming sewage ponds, oil-products storage depots located on the karstified territories present a serious problem.

According to the numerous publications by domestic and foreign researchers, an intensive pollution of the geological environment on the karstified territories takes place mainly in the areas of industrial sites having been exploited for a long time *(Goldberg, 1980; Vrba, 1984; Golubev, 1998; Vartanyan, 2000; Vakar, 2000; Anikeev, 2000; Belyaeva, 2001).* First of all it refers to the chemical enterprises *(Kovalyova et al., 1999; Lukyanchikov, 2000; Mironenko, Rumynin, 2002).*

In Germany such sites are called “Altlasten” (“old loads”) *(Eltsner, H, 1997).* Along with the change of the underground water chemism and pollution of air, soils, surface water

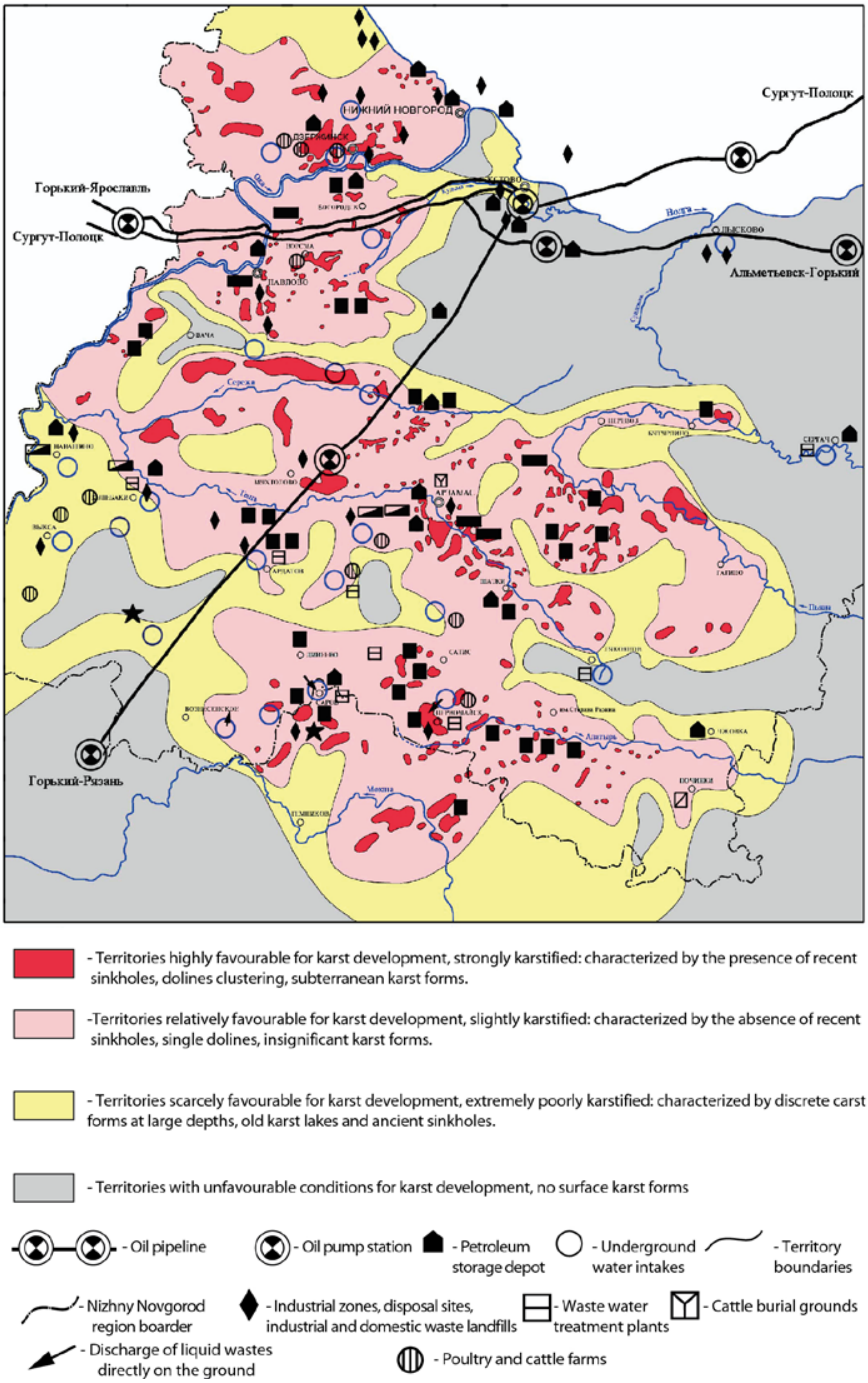


Fig. 1.22 Map of territory zoning according to the degree of karstification with the sources of pollution

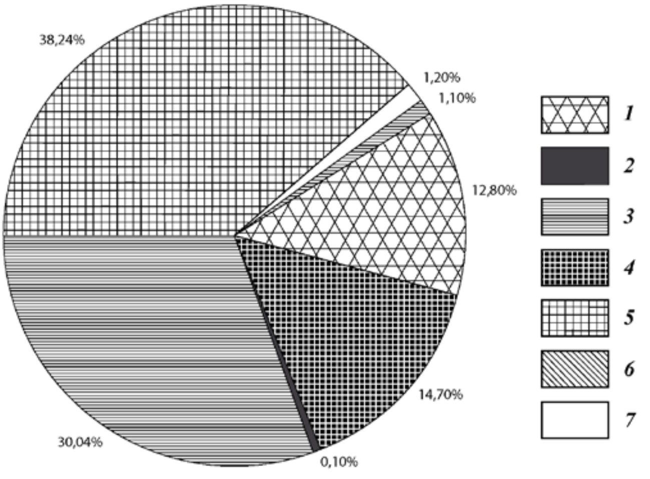


Fig. 1.23 Diagram of the karstified territories in the Nizhny Novgorod region used for construction and various kinds of economical activities: 1 – urban territories, suburbs, settlements, villages and industrial zones; 2 – railways, highways, gas and oil pipelines; 3- agriculture, waste landfills; 4 – exploited deposits, quarries, mines, adits, underground water intakes, including buffer zones, waterways; 5 – forests, reserves, recreation zones, gardens; 6- waterworks, dams, ponds, water reservoirs; 7 – unused or randomly used territories.

streams and water bodies at the locations of the waste landfills, changes of the soil water-physical and mechanical properties take place.

During designing, construction and exploitation of waste disposal sites on the karstified territories it is very important to assess permeability and sustainability of the capping above the soluble rocks. American researchers *(M. Ziqiang, E.C. Drumm, 1999)* have developed a simplified method of assessing the covering over caverns in limestone.

It includes assessment of the capping sustainability with regard to the following two possible kinds of damage: a) development of a cavern vault in the overlying rocks; b) soil plastic deformation and yielding in to limestone caverns (under the influence of pollution). This method permits to calculate the ultimate volume of wastes to be stored and, based on it, to control a technogenic load on a karstified area.

In 1999 while developing a geotechnical design of the foundation for wastewater treatment facilities located in a carbonate karst area in New Jersey, USA, Joseph A. Fisher and Joseph J. Fisher anticipated and prevented two dangerous cases of fracture-karst water pollution. First of all, the geotechnical design ensured early warning about a sinkhole formation under the wastewater treatment facilities by means of installed signaling devices; secondly, an ultimate diameter of a possible karst doline was calculated, and the foundation was reinforced additionally with a geotextile material.

According to E. Calvin Alexander, Andrew R. Kehren (1993), in 1992 the disregarding of the karst protection measures on the karstified territories led to the destruction of a wastewater treatment plant in one of the cities of Minnesota due to the development of a sinkhole. Consequently, 600 m^3 of wastewaters spilled into the karst rocks and polluted about 200 operational wells in a radius of 5 km from the damaged wastewater treatment facilities.

Emergency spillages of toxic chemicals on the karstified territories with shallow karst aquifers present a great danger for the population. Nikolas C. Crawford, Christi S. Ulmer (1993) were very convincing describing a case when a train crash in Lewisburg in Tennessee resulted in chloroform spillage into a fracture-karst aquifer, which put the underground water intake out of operation. The majority of the operating wells in the area had not been equipped with casing pipes, and trichloroethylene reached easily the aquifer.

Through the karst sinkholes located in the areas of industrial waste disposal sites or after emergency spillages hazardous chemicals penetrate into the voids of karst rocks, accumulate there and then after evaporation appear again on the surface. Nikolas C. Crawford (1984) described a case when in 1981 residents of 5 houses built in a karstified area in one of the US villages had to be evacuated when high explosive and toxic vapours rising from a karst void had accumulated inside the buildings to a dangerous level. In 1982 in the same area a karst void full of toxic chemicals – benzine and methyl chloride – was found, which evaporated under the karst void roof and then came to daylight. Specialists of the Environmental Protection Agency treated the concentrated vapours to the safe level, but in 1983 the same high explosive and toxic vapors again became a reason of evacuation of the inhabitants of 10 houses.

Waste dumping in sinkholes is another serious problem. D.W. Slifer, R.A. Erchul (1989) chose the coast of Virginia – a territory of an intensive carbonate karst development – to show how sensitive aquifers were to the waste dumping in the sinkholes. The investigations were carried out on the territory of two districts with total number of sinkholes reaching several thousand. Totally, there were found 260 unauthorized waste dumps. 75 per cent of them were located in the karstified areas. More than 23 per cent of the unauthorized dumps had been arranged in the sinkholes. At the same time about 90 per cent of the population in that area used water from wells and springs. In the result of the study, methods of selecting locations for waste disposal sites and a programme to increase population awareness about a danger of waste dumping in sinkholes were elaborated.

Waste disposal in abandoned quarries of carbonate rocks without special preliminary insulation is not less dangerous. According to A.J. Edwards, P.L. Smart (1989), in England and Wales there are 148 authorized disposal sites located on the territories of carbonate rocks, half of them have been located in the abandoned quarries. 66

disposal sites have the status “mixed”, 19 – “domestic”, 6 – “semi-inert” and 65 – “inert”. The majority of the “domestic” and “mixed” landfills are legal. But in many cases the quarries have no clay lining. At present the underground water pollution takes place mainly in the areas of the mixed and domestic waste disposal sites.

N. Bodhakar, B. Chatterjee (1993) described a case when in one of the Indian states an abandoned limestone quarry had been used for municipal waste disposal without preliminary insulation. Consequently, after a raining season all the wells in that area had been heavily polluted, and people who had used that water had to be hospitalized. Contaminants from the quarry were transported to the water intakes through the master karst fractures.

Every landfill in a certain period of time has to be closed. As Peter J. Hall, Andrew J. Meccasker (1995) wrote, the procedure of closing a landfill located on a karst territory included a whole complex of activities: analysis of microelements, measurement of piesometric parameters and specific resistivity, study of the area topography, monitoring of springs, establishment of a monitoring network, study of tracer movement dynamics, special treatment of the flushed zones in a landfill’s liner and sinkhole plugging. P. Hall, A. Meccasker developed this procedure for a municipal landfill of solid industrial wastes located on a karst territory at the centre of Missouri.

Construction and exploitation of waste disposal sites on the karst territories of Germany: Lower Saxsony, Sachsen-Anhalt, Thuringen, Hessen is also quite an urgent problem. According to H. Dullmann (1999), L. Muller (1999), K.H. Heitfekd, M. Heitfekd (2000), German researches, while selecting safe sites for landfills, pay particular attention to special detailed engineering-geological and hydrogeological surveys; they also pay attention to the arrangement of protective clay liners and barriers to prevent contamination of the geological environment.

Russian publications regarding designing, construction and exploitation of landfills on the karstified territories are very few *(Buchkin, 1988; Babak, 1991; Bogolyubov et al., 1997; Mamonova, Tolmachyov, 1997).* Available documents dedicated to the designing and exploitation of landfills under normal conditions describe patterns of pollution propagation, methods of studying the geological environment pollution, forecasts of the pollution spreading, organization of underground water monitoring in the areas of disposal sites. *(Gribanova, 1987; Orlov, Kuznetsov, 1988; Gribanova, Zaitsev, 1990; Delyatitsky, 1990; Goldberg, 1995; Bykov, 1997; Akparisova, Akulova, 1997; Trufmanova, Galitskaya, 1999).* In SNiP 2.01.28-85 “Landfills for neutralization and storage of toxic industrial wastes. General conditions for designing” in para 2.3. there is just a single sentence stating that it is prohibited to locate landfills in zones of active karst. At the same time the authors are aware of numerous cases of locating municipal and industrial waste disposal sites on the karstified territories in Kirov region, Vladimir region, Nizhny Novgorod region, Sverdlov region, the Republics of

Mari El, Tatarstan, Mordovia, Bashkortostan. Only on the territory of the Nizhny Novgorod region tens of cases of gross violations of the rules of industrial and domestic waste storage have been revealed for the last few years. For instance, JSC “Orgsteklo” uses depressions of karst origin in the industrial zone of Dzerzhinsk for dumping liquid and solid chemical wastes. Taking into account the fact that 29 administrative districts are located on the karstified territories of the Nizhny Novgorod region, we may speak about the fact of general pollution of the geological environment in the karst areas of the Nizhny Novgorod region.

Examples of a negative influence of the waste disposal sites located on the karstified territories of Dzerzhinsk on the geological environment were described by V.V. Tolmachyov and T.V. Mamonova (1997).

The study of Russian publications and current normative documents, e.g. SNiP 2.01.28-85, SP 11-105-97, SP 11-102-97, TSN 22-308-98 reveals that the State does not pay any serious attention to the issues of designing, construction and exploitation of industrial and domestic waste disposal sites on the karstified territories.

The impact of dumps and landfills located on the karst territories on the geological environment has been investigated in detail in the USA and Germany. Some US scientists recommend always to reinforce landfills’ beds with special geotechnical materials to ensure their adequate strength in case of a sinkhole occurrence, as well as to install special devices on a landfill’s bed to signal about the beginning of a sinking process *(A. Ficher, I. Ficher, 1999).*

German specialists believe that landfill construction on the karst terrains is a forced measure, and it should be approved only after detailed special engineering-geological and hydrogeological investigations of the sites and necessarily with arrangement of protective lining and barriers to prevent contaminants’ ingress into the underground hydrosphere *(Eltshner, 1997).*

Conclusions

1. The underground hydrosphere in the karstified areas is the most vulnerable component of the environment suffered from human activities.
2. The underground water pollution in the karst regions is closely connected with the pollution of the outdoor environment: snow cover, rainfalls, soils and surface water.
3. The man-caused pollution of the underground waters on the karstified territories manifests in increased mineralization, general hardness, temperature, content of chlorides, sulphates, organic compounds, heavy metals and specific substances, and their fast movement through karst sinkholes, fractures and conduits.
4. The importance of the fracture-karst waters in drinking water supply is growing: a) due to the increase of the karst water share in a water supply in view of the

growing pollution of surface waters in industrial areas; b) due to wide distribution of karstifying formations on the territory of Russia and on the planet as a whole; c) due to the fact that the fracture-karst water reserves in the karstified rocks exceed many times the underground water resources available in other water-bearing complexes.

5. Enormous quantities of the underground waters of drinking quality are concentrated in carbonate rocks on the territory of the Nizhny Novgorod region, which are poorly protected and sometimes unprotected at all from the surface pollution that requires introduction of a special “partial-load” mode of economical activity in the zones of their influence.
6. In large industrial regions of Russia and particularly in the Nizhny Novgorod region in the areas of cumulative underground water extraction under conditions of sinkhole development, zones of the most intensive water lowering in the fracture-karst water-bearing strata and concentration of polluted areas are registered.
7. The problem of safe disposal of industrial and domestic wastes on the karstified territories being highly sensitive to the man-caused impact has not been solved yet either in Russia or abroad.
8. For designing efficient measures of environmental protection from the influence of landfills in the karst regions, a wide complex of special researches and calculations should be conducted at the existing waste disposal sites, taking into account types of geologic-hydrogeologic conditions and possible mechanisms of sinkhole formation.

Chapter 2

PRINCIPLES AND METHODS OF STUDYING UNDERGROUND WATER POLLUTION PROCESSES IN THE KARST REGIONS

2.1. Basic ideas about processes and schemes of migration of underground waters under conditions of covered karst

The term “covered karst” is used when fractured soluble rocks are covered by insoluble sediments of different origin, e.g. continental and marine sandy-argillaceous sediments, fluvioglacial and alluvial formations.

Assessment, forecast and experimental study of the underground water pollution processes are based on the theory of a groundwater flow *(Bochever, Lapshin, Oradovskaya, 1979; Frid, 1981; Mironenko, Rumynin, 2002)*. Migration of chemical components in aquifers takes place along with convective, dispersion and diffusion processes complicated by the changes in the underground water physical-chemical properties and with interaction with water-bearing rocks *(Revich, 1982; Nosenko, 1986; Mironenko et al.,1998; Orfanidi, 2000; Pavlik, 2000)*.

A basic form of components migration in aquifers is their mechanical transfer by a hydraulic component, i.e. by means of *convection*. In homogeneous liquids this transport is “tied up” with a filtration flow of mean actual velocity $V_Д = V/n$ *(Mironenko et al., 1988)*, i.e. the intensity and trajectory of the solute motion during convection are controlled by the field of filtration velocities *(V)* and active porosity (fissuring, cavernosity) – *n*. Beside active (flow-through) pores, in the rocks there are always passive (dead) zones of filtration, which, as being saturated with a liquid due to the molecular diffusion processes, increase the total capacity of rocks vs. effective porosity alone. Convection is slowing down, and the design value *n* becomes dependant on the distance of transportation.

Migration tests proved *(Mironenko, Rumynin, 1988)* that at distances not less than tens to hundreds of meters the values of effective porosity are close to those of the absolute porosity minus the capacity of the isolated pores.

For the incoherent differences of porous (sand) rocks they lie in a comparatively narrow range n = 0.3-0.4; in cavernous fractured reservoirs the range of the *n*-parameter is much wider, though its absolute figures are significantly smaller: n = 0.0005-0.01. It means that, in all other things being equal, convection in fractured rocks is much more intensive than in porous rocks.

Various interconnected conduits and karst voids in a karstifying rock massif, confined in certain layers and oriented in certain directions, determine filtration anisotropy of the karstified rocks and control water motion along the branching karst systems. Since the velocity of a solute waterborne by a filtration flow $V_Д$, same as the filtration velocity *V*, is averaged within the limits of a representative volume, the transport by convection in homogeneous strata should be characterized by a sharp interface between displacing and displaced fluids without any mixing, the fact that indicates a frontal displacement of one fluid by the other. At the same time, at a plan filtration (in a homogeneous stratum) of two fluids of an equal density, the front of displacement is normal to the surface of stratification, and the deformation of the solutions' interface in plan depends entirely on the filtration flow structure.

Gravitational (density) convection depends on the density difference between original stratal fluids and technogenic (intruding) solutions. When filtration of homogeneous miscible fluids (for example, waters of different mineralization) is considered, an additional vertical constituent of a filtration velocity appears on the interface of the mineralized (density ρ_0) and fresh (density ρ^0) fluids:

$$\upsilon_\rho = k_z \Delta\rho \tag{2.1}$$

where $\Delta\rho = (\rho_0 - \rho^0)\rho^0$ is the density gradient; k_Z is the coefficient of vertical filtration. When the initial vertical relative difference of heads is insignificant as compared with the density gradient, the initial rate of dense wastewater sinking into an aquifer is:

$$\upsilon_{др} \approx \upsilon_\rho / n \tag{2.2}$$

At a frontal displacement of the fresh water by the mineralized solution, the density convection causes a deformation of the front of displacement: the heavy fluid moves faster along the subface of a stratum, while the interface motion near the roof is slowing, and the front inclines (for the light waste waters the picture is inverse). Under the conditions of intensive water intake in many karst regions, including the Middle Volga, karst depressions and sinkholes form "through hydrogeological windows" that disrupt natural insulation between the overlying aquifer and the fracture-karst waters due to the collapses of clay interlayers, providing for a fast propagation of heavy contaminated fluids into a kastifying rock massif (Fig. 2.1).

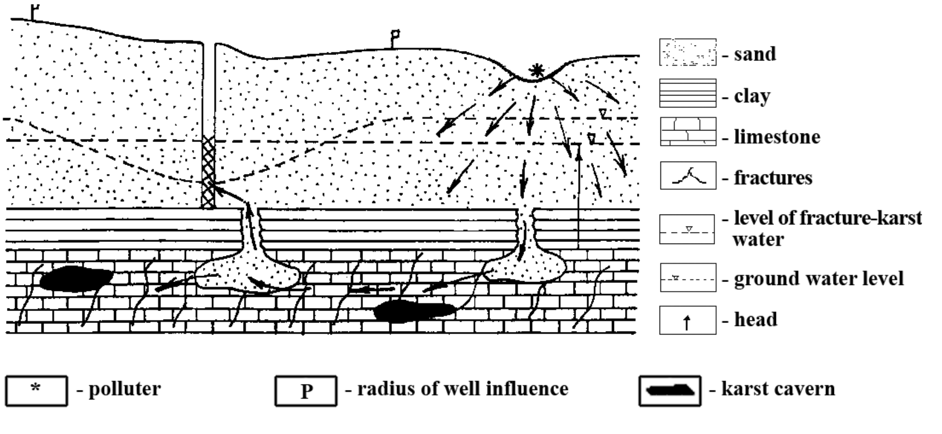


Fig. 2.1 Scheme of underground water pollution propagation with an operational water intake well in a karst region

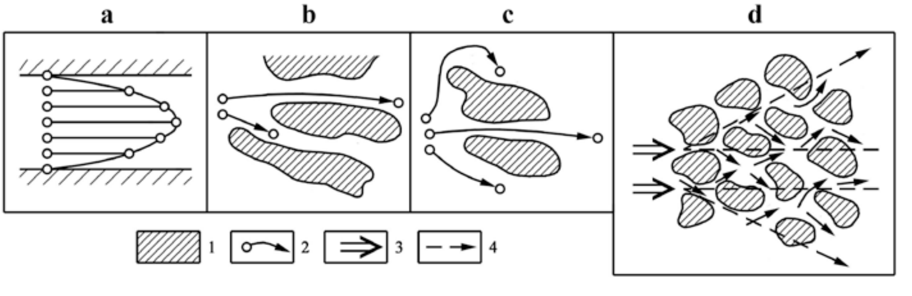
Diffusion substance transfer takes place due to the difference of chemical potentials of solutions, i.e. at the presence of a concentration gradient. Intensity of the process is regulated by the Fick's law of diffusion and depends, at all other things being equal, on the value of the molecular diffusion coefficient *(D_M)*. Typical D_M values in water saturated rocks are in the order of 10^{-5} m^2/day.

Velocity of the molecular diffusion transfer is low, and it should be taken into consideration only at low rates of filtration, first of all, during determination of mass transfer through the poorly permeable rocks (interlayers, porous blocks of fractured rocks). For example, during substance migration in heterogenic strata represented by the elements of different permeability (interlayers and clay lenses in sand formations, porous blocks and fractures) the molecular diffusion acts as a factor of concentration leveling providing for the substance outflow from the units of better permeability (via which the main convective transfer takes place) to the less permeable elements. As a result, it promotes a change of the general potential of mass transfer and formation of a transition zone with gradually varying concentration at the front of displacement of one fluid by the other. In clay formations diffusion may be supplemented by osmosis *(Roshal, 1980).*

Longitudinal hydrodispersion (mechanical diffusion) of a flow occurring due to a random distribution of velocities of discrete streams in pores and fractures causes formation of a transition zone with a gradually changing concentration on the interface between the displacing and displaced fluids. This process is characterized by the hydrodispersion coefficient D_υ that generally is a linear function of the filtration velocity:

$$D_\upsilon = \delta\upsilon, \quad (2.3)$$

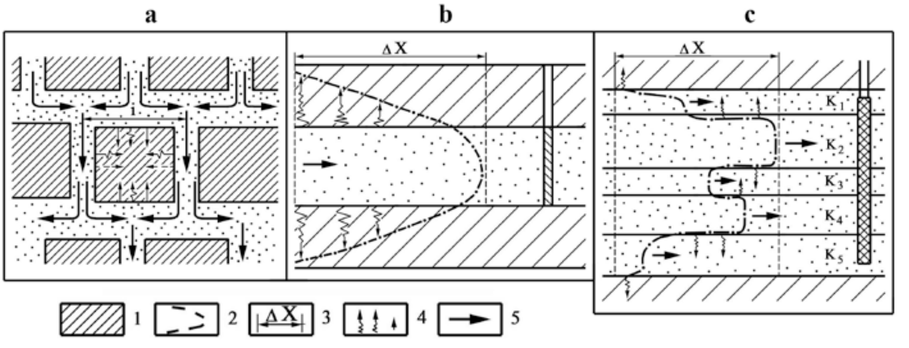
where δ is the constant of a longitudinal microdispersion reflecting the geometry of the disordered porous or fracture space of rocks; its values correlate with the sizes of the elementary components of a filtration rock (Fig. 2.2).



1 – rock grains; 2 – flow lines; 3 – flow general direction; 4 – contour of transverse dispersion

Fig. 2.2 Mechanisms of a microdispersion: *a* – unevenness of the field of velocities in a porous conduit; *b* – different velocities in different porous conduits; *c* – deformation of flow lines in porous space; *d* - transverse dispersion

For the porous rocks of relatively homogeneous granulometric composition the constant, according to the laboratory and small-scale field experiments *(Mironenko et al.,1998; Shestakov)*, varies from the decimal values to centimeters, which in many cases permits to ignore the longitudinal dispersion against the background of convection. In the fractured rocks, depending on the typical sizes of rock blocks, the microdispersion parameter changes in a much more wide range, i.e. from tens of centimeters to tens of meters, therefore, for the karst rocks it should be taken into account (Fig. 2.2, 2.3).



1 – blocks of rocks with dominant diffusion transfer; *2* – front of tracer solution motion; *3* – zone of microdispersion; *4* – directions of diffusion transfer; 5 – directions of local velocities of convective transfer.

Fig. 2.3 Mechanisms of a macrodispersion (by Mironenko): *a* – mass transfer in fractured porous formations, *b* – mass transfer between grain and clay rocks; *c* – layer transfer in a stratified layer of porous rocks.

The analogy in the forms of manifestation of the molecular diffusion and hydrodispersion permits to take them into consideration – in unidirectional processes – with the help of the total microdispersion coefficient *D* characterizing the general rate of dispersion of a substance at the front of transfer:

$$D = D_M + D_\upsilon = D_M + \delta\upsilon \qquad (2.4)$$

In a media of good permeability the diffusion transfer as compared with the hydrodispersion may not be taken into account at all. In clay rocks it is vice versa.

The concentration gradient existing in the directions orthogonal to the main flow causes a transverse dispersion, which may have great effect on mass transfer in any water-bearing complex. It is the most important factor providing for formation of large aureoles of dispersion as well as solute exchange between individual elements of filtration medium differentiated by the intensity of transit (for example, in the heterogeneous laminated strata) (Fig. 2.2, 2.3).

The experimental data prove that there is almost linear dependence between the transverse microdispersion coefficient D' ($D' \equiv D_\upsilon$ and $D' \equiv D_Z$ for the plan and profile mass transfer) and filtration velocity υ; however, the constant of the transverse microdispersion (δ') is about 10 to 20 times smaller than δ - values.

If the convective-dispersion transfer takes place in homogeneous (in terms of capacity and filtration properties) media, where the dispersion-diffusion mass transfer takes place on one elementary microlevel determined by the geometry of pores and fractures, then the process in general may be called microdispersion in a filtration flow.

Migration is accompanied by the processes of physical-chemical transformation of solutions in the water-bearing strata, which can control not only the general intensity of migration but also a deep metamorphization of the initial composition of solutions *(Driver, 1985; Lukner, Shestakov, 1986)*. With this regard the following processes may be identified: 1) processes of an interphase interaction taking place on the fluid - mineral skeleton interface, and 2) internal phase processes (reactions) running in a volume of porous fluid. Sorption, ion transfer, sedimentation (dilution), leaching belong to the former, while reactions of complex formation, destruction, radioactive decay belong to the latter.

2.2. Characteristic of main methods of studying underground water pollution processes on the karstified territories

Boring

The most reliable information about the condition of the underground waters on the karstified territories is obtained with the help of hydrogeological wells: exploratory, water-supply and observation. They serve as the main points of observation and evaluation, where water samples are taken for various kinds of analysis, researches and monitoring.

A special attention during the well boring is paid to the recovery of unbroken cores from sandy-argillaceous formations, base on which basic information about mechanisms of migration processes in the underground hydrosphere is received. By the core recovery, as well as by the character of fluid circulation and intervals of fluid loss, zones of increased fracturing and rock softening are identified.

Drilling methods and design of exploratory and observation wells should ensure minimum distortion of the permeability in the well filter zone. Examples of classic designs of observation wells for monitoring level and chemical regimes of the underground waters are given in Fig. 2.4, 2.5. Methods of borehole geophysics applied during the boring operations produce high quality and reliable results, especially on the stage of planning penetration tests.

Downhole geophysical methods

Geophysical methods of study are used to solve a large number of applied tasks related to the assessment of underground water condition during the boring and exploitation of wells at water intakes. The geophysical information permits to identify geological-lithologic cross-section of wells, to assess filtration properties of rocks,

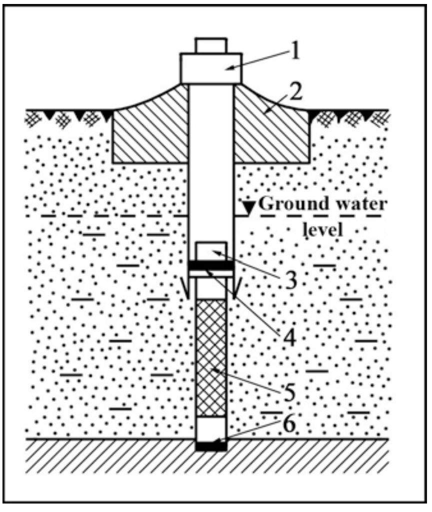


Fig. 2.4 Well design for stationary observations of ground water level fluctuations and changes of chemical composition: 1 – cap; 2 – embankment (clay); 3 – coupling; 4 – hempen gland; 5 – filter; 6 – plug

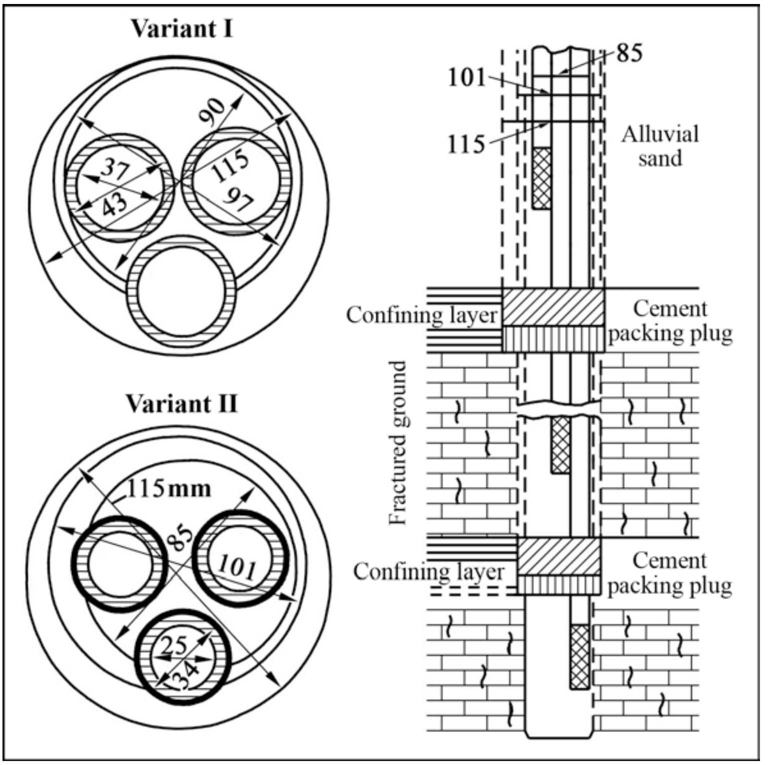


Fig. 2.5 Scheme of location of piezometers to observe water level fluctuations in three aquifers.
Variant I. Core barrels of diameter 43/47 mm are used as piezometers. Pumping out is performed through a bailing tube of diameter 29 mm with a step valve, and cleaning – with the help of a bailer of diameter 33 mm.
Variant II. Gas pipes of diameter 33.5/25 mm are used as piezometers. The pipes are welded together, pumping out is performed by a Letestu plunger of diameter 25 mm, and cleaning – by means of a force-pump.

direction and velocity of the underground water motion, chemical composition, zones of loss, intervals and integrity of the casing pipe cementing, and many other tasks *(Metody geofiz. v hydrogeol. i inzh. geol., 1984; Rekomen. po izuch. karsta geofyz. metod., 1986; Bogolyubov et al., 1997).*

Electric logging. Out of numerous methods of electric well-logging, resistivity profiling (RP) and self potential (SP) methods are the most in demand. They are used for subdividing geologic cross-sections into discrete strata as well as for selecting test intervals.

Permeable sands and sandstones in clay masses, as well as clay strata between sand and carbonate rocks are most distinct on the diagrams.

Rock resistivity depends largely on the electrolytic properties of water that fills pores and fractures in water-bearing rocks and confining layers. Saline water decreases drastically the electric resistivity.

Microprobing technique and well caliper logging give quite an accurate picture of the strata boundaries showing thin intermediate layers and zones of increased cavernosity and fracturing. These measurements ensure minimum distortion of the rock electric resistivity.

The degree of rock permeability is usually determined by a value of anomalies of the natural potentials.

In natural electric fields induced by filtration processes the SP value depends on the rate of filtration and fluid properties. As a rule, the more permeable strata show minimal SP anomalies.

This method can be used for water permeability assessment during water pumping out of or pouring into wells.

Well resistivimetry. A change of fluid resistivity in a borehole registered by means of well resistivimetry reflects the extent of hydrodynamic connections in the “stratum-well” system along a borehole. This method permits locating spots of fluid loss and inflow in a borehole, casing seal failure, washing solution/water interface in a well, and a number of other tasks.

Well resistivimetry may be applied to determine the underground water filtration rate in discrete layers in a single well, effective porosity, water yield, and coefficient of filtration of rocks during pumping-out. In addition to the detailed and accurate data on filtration properties obtained along a borehole cross-section, this method makes it possible to conduct investigations in the most difficult hydrogeological conditions.

Thermometry. Temperature conditions in a borehole affect many of well parameters measured by the geophysical methods. As the temperature rises, ion mobility increases, solution resistivity decreases, dynamics of the processes change. For continuous temperature measuring along a borehole, resistance thermometers are used; accurate measurements are taken with the help of the maximum thermometers and multi-zone temperature sensors.

The thermometric measurements alone or in combination with other methods permit to determine a temperature gradient, intervals of washing fluid loss, intervals of casing seal failure, zones of water inflow to a well.

Spinner survey. A method of spinner (downhole) survey is based on the measurements of the water mean velocity along a borehole during pumping-out or pouring-in operations, or during water flowing from one aquifer to another via a borehole. This is the most widely used geophysical method of hydrogeologic survey of karstified, fractured and resistant rocks. The measuring is performed by means of special propeller flowmeters or with the help of a resistivity meter in combination with a borehole surveying device and a downhole thermometer (Fig. 2.6).

Application of this method allows observation of changes in the rock water content along the length of a borehole, identification of water-rich fractured and karst zones for selecting test intervals and proper well designs.

These researches are crucial while drilling a sequence of formations of different permeability and different static heads overlying the roofing.

The spinner survey allows identification of the zones of loss during boring operations, loads on filters during pumping-out, as well as exact locations of casing seal failures.

Radioactivity logging. Radioactive methods of logging permit studying the geological and lithologic cross-sections mainly in combination with the electric methods of surveying. Their advantage is that they may be used for investigation of subcrops of cased wells, study and control of some physical phenomena in a stratum, in a cement ring and in a borehole based on the processes of the nuclear physics. The methods of radioactive logging may be applied not only for lithologic subdivision of rock cross-sections, but also for identification of aquifers and qualitative assessment of the permeability of water containing rock formations. During the boring of hydrogeologic wells a method of gamma-ray logging (GRL) is widely used. It is based on the gauging of natural gamma-activity of the rocks *(Dubinchuk et al., 1988)*.

The higher is the content of clay particles in a rock, the larger are the GRL values on a diagram. It means that intermediate lithologic differences – clay sands, limestone and marls may be identified by this method.

In this way aquifers represented by sands and clay sands are distinguished on the GRL diagrams by lower natural gamma ray values and slightly larger values of neutron gamma radiation. The less, in all other equal conditions, is the intensity of gamma radiation, the higher is the permeability of the rocks.

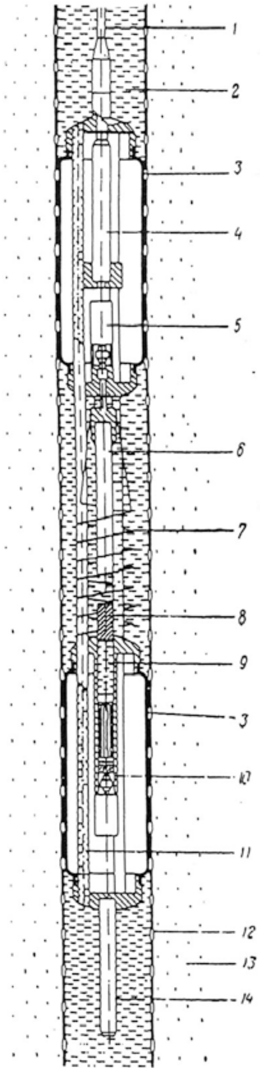


Fig. 2.6 Borehole surveying device for measuring rate of filtration: *1* – cable; *2* – underground water; *3* – rubber packer; *4* – scintillation detector No.1; *5* – coil motor; *6* – scintillation detector No.2; *7* – mixing coil; *8* – lead valve; *9* – tracer agent; *10* – injector; *11* – head leveling pipe (above and below the device); *12* – well filter; *13* – gravel; *14* - scintillation detector No.3

Application of the geophysical survey results to solve hydrogeological tasks requires an integrated approach to and deep knowledge of not only geophysical methods of surveying, but also geologic-lithologic and hydrogeological features of the region. Such an approach excludes ambiguous interpretations of the obtained data and gives not only qualitative, but also quantitative assessment of the properties of the rocks and hydrological conditions under study.

Surface geophysical methods

While conducting hydrogeological survey in karst regions, it is worthwhile to combine boring operations and other engineering-geological methods with certain methods of engineering geophysics *(Rukovod. po inzhen.-geol. izysk. v raionakh razv. karsta, 1995)* to identify:

- features of buried topography of karstified rocks in specific areas;
- location and shape of subterranean karst forms;
- degree of karstification and fracturing of discrete zones of a rock massif;
- boundaries of active filtration zones;
- locations of water inflow into wells;
- latent zones of underground water discharge;
- zones of concentrated infiltration on the karstified territories under increased technogenic loads.

To solve these tasks, geoelectric (electrical profiling, vertical electrical sounding, self potential survey, charged body method, etc.) as well as seismic methods of surveying are most frequently used; in some cases geomagnetics, gravimetry, acoustics are applied.

Geoelectric methods are based on the difference in the resistivity of rocks with different degree of porosity, karstification, water saturation, as well as on the existence of natural electric fields in the rocks induced by chemical, filtration and diffusion processes taking place therein, or on the artificial induction of such fields. Methods and technique of such investigations have been developed in detail *(Lyakhovitsky et al., 1989; Khmelevsky, Shevnin, 1992)*, and for karst areas as well.

The geoelectric methods in combination with other methods may single out lithologically heterogeneous elements of a rock massif, zones of increased karstification, water permeability, underground water mineralization (Fig. 2.7), identify conditions of karst development, directions of polluted water motion in subsurface water conduits, reveal subterranean karst forms.

Statistics show that among the geophysical methods used for the underground water pollution study the resistivity method, well-logging and electromagnetic methods are the most in demand *(Mazac, Kelly, Landa, 1987)* because of their comprehensiveness.

Seismic methods may also be used to solve the same range of tasks, but they are more complicated. Their advantage is that with their help the roof of slightly fractured distinctly less permeable bedrocks overlaid by massive unconsolidated sediments can be easily determined. The underground water mineralization in this case has no effect on the results of the study.

Zones of fracturing and karstification may be identified both in water saturated rocks and in dry rocks *(Method. geophys.v hydrogeol. i eng. geol., 1984)*.

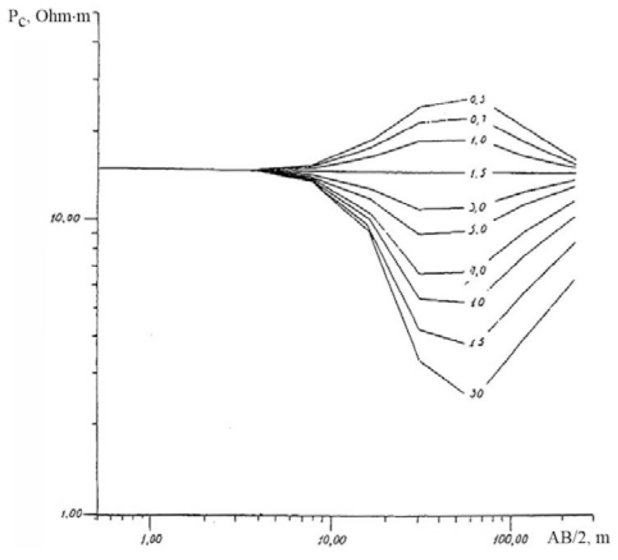


Fig. 2.7 VES curves at different water mineralization in a permeable stratum. Codes of the curves correspond to the values of mineralization in g/dm3

Near the village of Vorvan (Nizhny Novgorod region) a livestock farm is located in a karst area. At the request of the authors a seismic profiling was performed to identify the pattern of fracturing, direction of the karst process development and routes of the polluted water motion from the farm (Fig. 2.8).

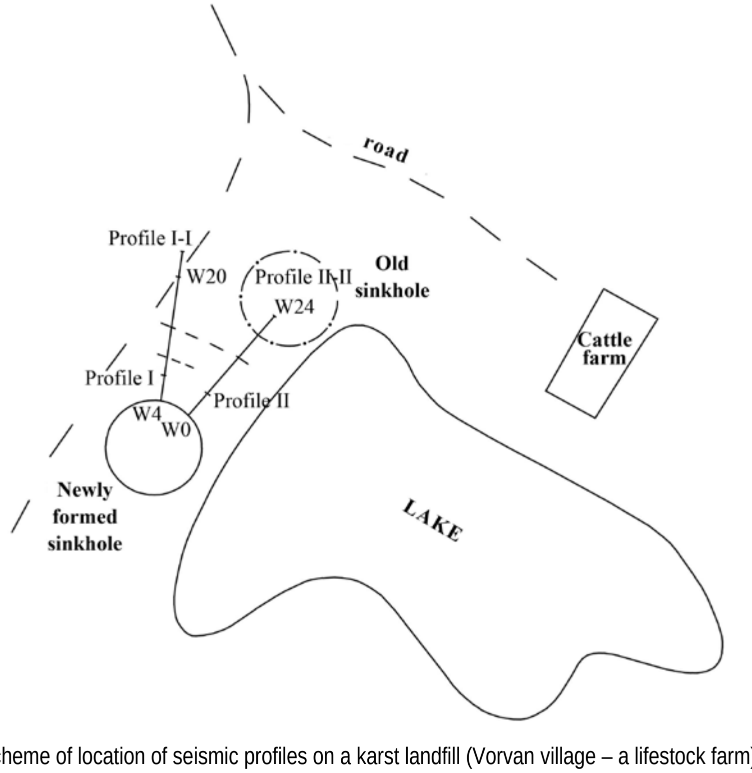


Fig. 2.8 Scheme of location of seismic profiles on a karst landfill (Vorvan village – a lifestock farm)

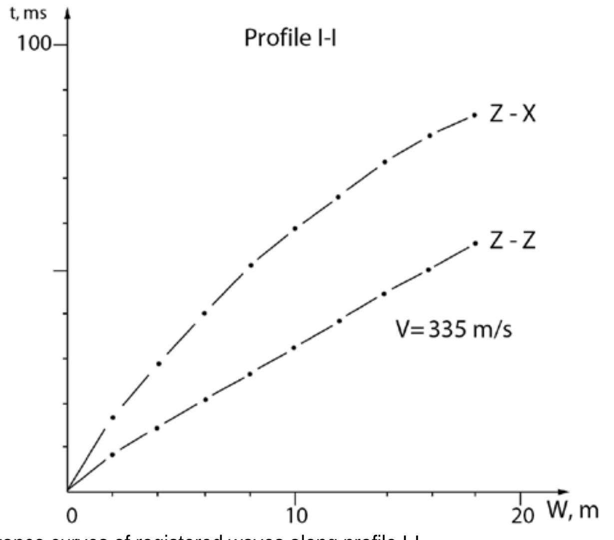


Fig. 2.9 Time-distance curves of registered waves along profile I-I

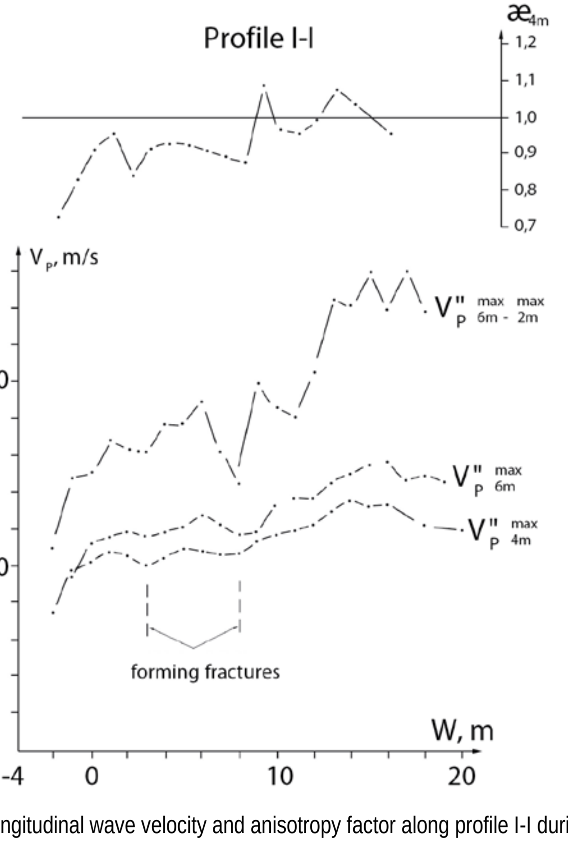


Fig. 2.10 Change of longitudinal wave velocity and anisotropy factor along profile I-I during observation at different geophone distances

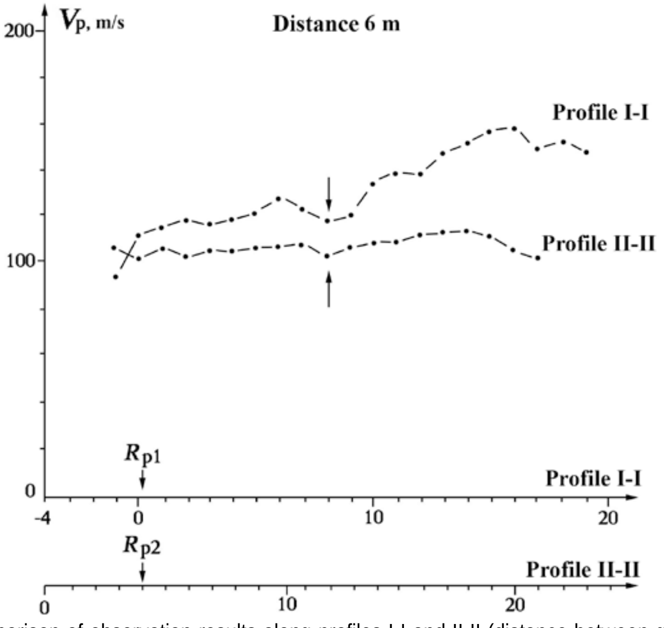


Fig. 2.11 Comparison of observation results along profiles I-I and II-II (distance between geophones is 6 m)

The researches permitted to identify zones of increased rock fracturing (Fig. 2.9 – 2.11) and organize their monitoring. In autumn 2004 a collapse sinkhole formed in that area. Water samples taken from the sinkhole showed a fivefold increase of nitrites and nitrates as compared with the MPC values.

Magnetometry and gravimetry methods are used during a karst study, when there is a difference in the magnetic properties of the karst void loose filler and the matrix, and in the case of large-size subterranean karst forms.

Under certain circumstances a combination of several geophysical methods gives good results.

Tracer methods

Tracer methods are widely used to study the dynamics of fracture-karst and filtration waters and changes of their chemical composition *(Goncharov, 1982)*. With their help the following tasks may be solved:

- identification of sources of recharge and the age of the underground waters;
- determination of subsurface flow direction and velocity, coefficients of filtration and permeability of aquifers;
- location of zones of concentrated infiltration in the areas of surface karst and identification of the nature of interrelation between these zones and main spots of pollution;
- identification of routes of concentrated filtration, etc.

The most frequently used tracers are various dyes (fluorescein, methylene-blue, rhodamine-B, uranin, eosin, eritrosin), electrolytes (sodium chloride, calcium chloride, ammonium chloride, lithium salts), stable and radioactive isotopes (T, D, ^{35}S, ^{131}I, ^{82}Br, ^{51}Cr, ^{60}Co, ^{86}Rb, ^{13}C, ^{14}C), dyed spores of lycopodium, fibre tracers made of coloured plastic.

The tracer methods are based on the injecting of a tracer into the test strata via boreholes and test pits in a studied area and determining the velocity of its transfer through the zone of aeration by a subsurface flow by the time of its appearance in the observation wells and pits or in a discharge zone.

To determine the permeability of homogeneous subsurface layers (upto a depth of 3 to 5 m) of sand-gravel and clay formations in the zone of aeration, a round sump of 35 to 50 cm in diameter and 15 to 20 cm deep is formed in a drain pit at a certain depth. In unconsolidated rocks the sump walls are reinforced by a metal cylinder 20 to 25 cm high. By filling the sump with water and keeping its level constant (10-15 cm), the rate of water infiltration through the sump bottom is determined. While adding water into a sump, rock washing-out and disturbance of its structure should be avoided. Fig. 2.12 shows graphs characterizing a change of a flow rate *Q* (l/min) and total volume *V* (l) of water infiltrated through the bottom of the sump during the test.
The flow rate curve in Fig. 2.12 is gradually flattening, as if the flow rate is becoming constant. But during the infiltration the water motion is always unstable, because it changes with time.

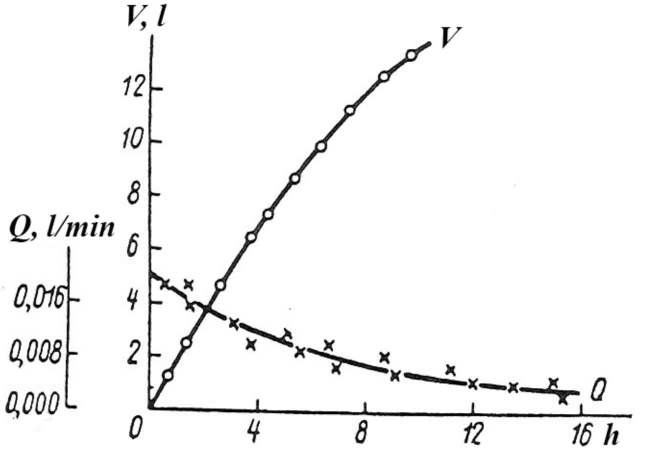
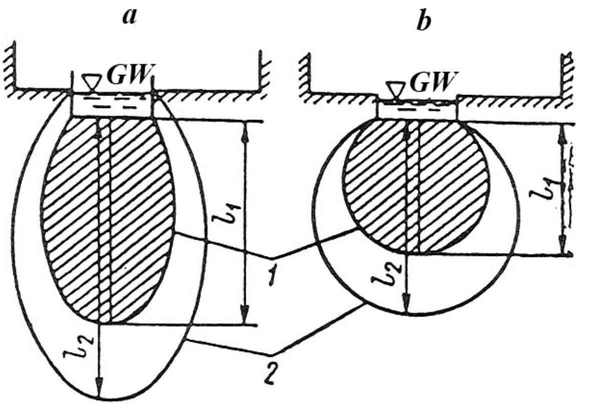


Fig. 2.12 Curves of the change of water flow rate *Q* and total volume *V* with time during rock infiltration tests



1 – wetting boundary in t_1, hours; 2 – same in t_2, hours
l_1, l_2 – depth of water infiltration – path of water infiltration in time t_1 and t_2

Fig. 2.13 Change of the shape and volume of the zone of rock wetting with time during water infiltration from a sump: *a* – sand rocks; *b* – clay rocks

As Fig. 2.13 shows, a zone of damping or, more precisely, actual saturation of the rocks forms underneath the sump bottom, the shape and size of which are controlled by the rock properties and duration of the infiltration tests.

Observation wells to track the tracer motion are located in a day aquifer, in the karstified limestone at a distance of 15 to 20 m and more from each other. A scheme applied to test the zone of aeration is called an "envelop" (Fig. 2.14).

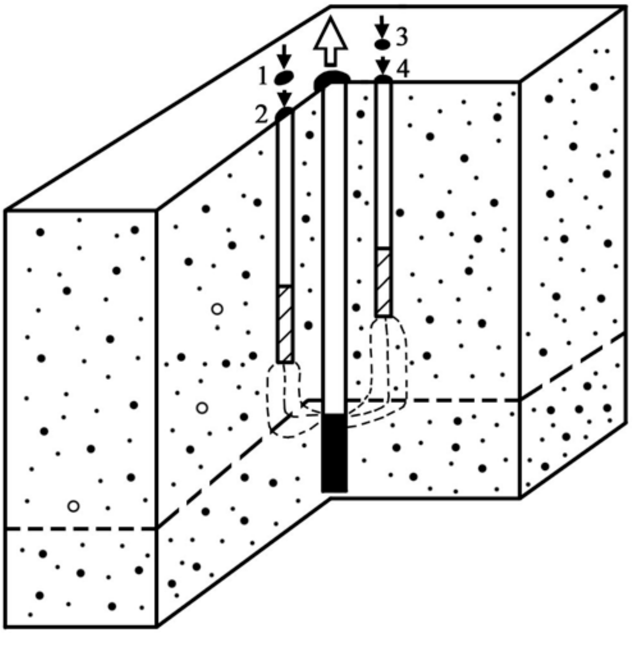
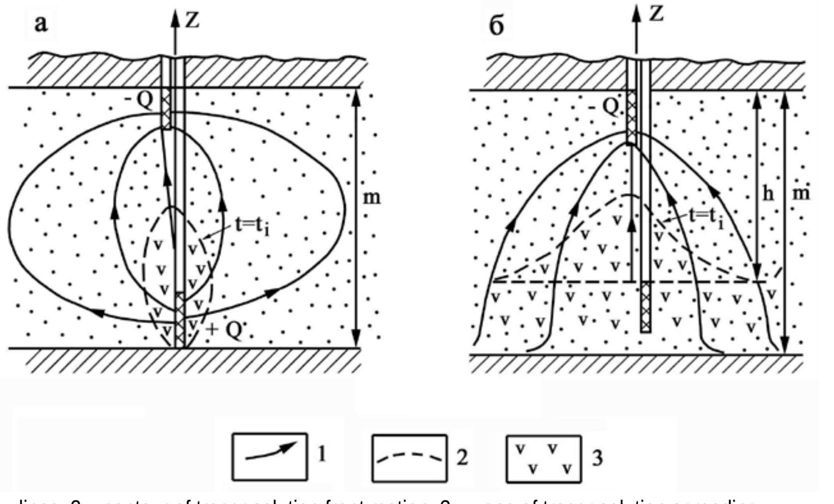


Fig. 2.14 "Envelop" scheme for testing the zone of aeration: 1-4 – tracer injection wells

Basic experimental schemes of tracer testing of the profile-anisotropy formations are: a) vertical doublet; b) "bottom salinization" (Fig. 2.15).



1 – flow lines; 2 – contour of tracer solution front motion; 3 – zone of tracer solution spreading

Fig. 2.15 Basic experimental schemes of tracer testing of the profile-anisotropy formations: (a – vertical doublet, b – "bottom salinization")

The tracer presence is detected by chemical, electrolytic and colorimetric methods:

- the chemical method identifies the tracer presence by the change of its concentration in water samples taken periodically at the observation points: time of the tracer transfer from the starting point to the observation point is measured either by its maximum concentration or by its occurrence;
- the electrolytic method measures the water electric conductivity with the help of resistivity meters, and the tracer presence in the observation points is checked by a maximum current in the circuit grounded via the well;
- the colorimetric method, based on the usage of various dyes, measures the time of tracer transfer with the help of a fluoroscope by the maximum intensity of the sample colouring.

The main drawback of using electrolytes and dyes as tracers is their relatively high concentrations that provide for the appearance of additional, and sometimes substantial errors connected with the changes of the physical and chemical properties of water and filtering medium: sorption losses, change of solution density, change of filtering ability of rocks, diffusion of tracers affecting accuracy of tests, etc.

Radioisotopic tracer technique used in different combinations and modification (in a single well, in observation wells, with one tracer, with two tracers) may be considered most promising to solve hydrogeologic tasks in karst regions.

In this method radioisotopes are used as tracers for water labeling. Their movement and concentration are tracked by the radiation intensity.

The advantages of the radioactive method are: higher sensitivity as compared with other methods, no impact on the filtration properties of loose fillers of karst voids and fractures, no need of water sampling to monitor filtration, a wide choice of available isotopes and a possibility to “label” large volumes of water. A radioactive isotope can be spotted even when it passes by the point of observation.

The drawbacks of the radioisotopic tracer technique are: relatively high cost of isotopes, special field equipment, skilled personnel specially trained to work with radioactive substances. The application of this method is to be approved by the health authorities and substantiated scientifically and economically.

To locate areas of lumped water leakage, special methods based on the use of natural tracers, i.e. radioactive isotopes that are always present in natural waters (radon 222, tritium and others) are widely used.

To search spots of local water leakage from landfill ponds, various methods, such as a method of “labeled cloud” (when a cloud of a radiotracer is introduced into a pond, which concentrates in the areas of increased infiltration at the bottom and is registered by submerged probes), fibre tracers (textile or plastic), disperse granulated materials (plastics, porous cement stones) of density 1±0.001, cellulose, bentonite and various emulsions may be also used.

2.3. Aspects of organizing special observations of the underground water pollution dynamics on the karstified territories

A system of underground water monitoring on the karst-free territories was developed quite long ago and described in detail in theoretical, experimental and methodological works of domestic and foreign researchers *(Altovsky, Konoplyantsev, 1954; Silin-Bekchurin, 1961; Konoplyantsev, Kovalevsky, Semyonov, 1963; Bochever, Oradovskaya, 1972; Shestakov, 1979; Goldberg, 1980, 1990; Krainov, Shvets, 1987; Mironenko, Rumynin, 1986, 1988, 2002; Fried, 1981; Luckner, 1989; Mercer, Coher, 1990 and many others).*

While planning observation activities on the karstified territories, first of all, it is necessary to do the following: 1) to study geological, hydrogeological and geomorphological conditions of karst development; karst distribution, nature and intensity, history and mechanism of its development; 2) to perform zoning of the territories according to the conditions of karst development, nature and degree of karstification in scale 1:5000 – 1:50000; assessment of the territory stability with regard to the sinkholes and karst depressions; 3) to study physical and mechanical properties of soils as well as hydrogeological conditions associated with karstification; to assess karst development under the influence of natural and technogenic factors and the feedback; 4) to identify the existing and potential polluters of the underground hydrosphere.

In this connection the authors, taking into consideration experience of the well-known Russian and foreign karst researchers *(Sokolov, 1962; Gvozdetsky, 1972; Chikishev, 1979; Iljin, 1984; Savarensky, 1990; Koposov, 1998; Yakuch, 1979; Melke, Kraemer, 1983 and many others),* have divided the entire system of special observations of the underground water pollution dynamics in the karst regions in several stages.

First stage – spade-work. At this stage archival and other materials about conditions of karst development, degree of rock karstification, distribution of surface karst, types and degree of man-caused loads with characteristic of existing and potential underground water polluters are collected, analyzed and generalized; aero- and satellite photos are interpreted, and the following special maps are plotted: a map of the area under survey, depicting technogenic objects; maps of the surface of the karstifying rocks and thickness of the overlying formations, differentiated according to the lithological types (permeable and distinctly less permeable soils); water-table and piezometric contours of aquifers; a hydrochemical, karstological map with plotted karst forms and lineaments. Based on these maps, a map of the preliminary zoning of the studied area by the conditions of karst development and degree of karstification with the plotted existing and potential underground hydrosphere polluters is drawn. Following the activities at the first stage and based on their results, a programme of field investigations is worked out, routes of karstologic surveys and locations of exploratory and observation wells are identified, aquifer sampling, pit and sinkhole filling-in are performed.

Second stage – field investigations. *The route karstologic survey* should solve the following specific tasks: study of the conditions and patterns of the karst forms distribution, their age, nature and intensity of development, identification of sources of technogenic impact on the underground hydrosphere and on the possible activation of the karst process. During the route karstologic survey the following should be described:

- geological, hydrogeological and geomorphological features of the territory under study;
- karst manifestations on the land surface (recent sinkholes, land subsidences, karst-erosion depressions, local sinking, large troughs, swallow holes, exposed karst caves, etc.);
- deformation of buildings and structures typical for karstified territories;
- hydrological and hydrogeological karst forms – closed reservoirs, areas of surface streams sinking, exsurgences, karst lakes, etc.;
- locations of technogenic impact, its nature, duration and intensity.

During the karstologic survey a special attention should be paid to water intakes, waterworks, water supply, gas and oil pipelines, other structures (artificial reservoirs, dams, foundation pits, landfills, etc.) from the standpoint of their influence on the development of karst and karst-suffosion processes as well as on the possible underground water pollution.

Materials obtained during the karstologic survey with the help of aero- and satellite photography revealing various karst forms, zones of increased dampness, lineament network, etc. should be crosschecked and compared with the results of the field investigations.

During the route investigations a detailed field description and mapping of all karst forms are fulfilled to collect enough initial data for their correct statistical processing. The description of sinkholes should include additionally the time of development of karst deformations and observations of phenomena occurred in the process of their formation.

Surface sensing and mapping of the areas where the number of karst forms exceeds 50 on a km^2 should be performed on larger scales from 1:5000 to 1:2000.

Geophysical survey. Surface and downhole geophysical methods are applied to solve the following specific tasks based on the results of the work implemented during the preliminary stage:

- study and identification of the lithologic composition of rocks in the karstified areas with evaluation of changeableness of physical-mechanical properties of rocks (karstifying and overlying) in the zones of sinkhole concentration;
- identification of tectonic features of the region, detection and study of ancient buried valleys, determination of underground water levels and flow directions;
- study of the buried karst topography, thickness, degree of fracturing and cavernosity of karstifying rock masses, characteristics of the overlying formations permeability;
- mapping of karst voids, decayed and soft zones;
- study of mineralization, velocity of polluted water motion in the fracture-karst and overlying aquifers.

A complex geological and geophysical structure is typical for the majority of karst areas in the Nizhny Novgorod region (i.e. non-horizontal boundaries of rock strata; shapes, sizes and depths of occurrence of local irregularities vary over wide limits; a wide variability of physical properties of soils within one lithologic difference).

To solve the above mentioned tasks, a complex of the following well-proved methods should be used: various modifications of downhole electrical survey and well-logging, seismic survey, gravimetrical prospecting, radiometric and other methods.

The results of the geophysical investigations permit to select most efficient locations for boreholes, open test pits, key sites for a detailed study of conditions and dynamics of the underground hydrosphere pollution development.

Boring and mining. In addition to the standard hydrogeologic wells, special wells for karst studying are drilled in the karst regions. Their purpose is to study conditions of karst development, nature and degree of karstification, to assess karst risk of the territories, directions of contaminants migration and rate of the underground water pollution in combination with geophysical, hydrogeological and other investigations. With their help the following tasks are solved:

1) identification of the geological structure of the territory;

2) study of the hydrogeological conditions;

3) study of the composition, state, properties of the karstifying rock massif, degree of fracturing, cavernosity and karstification of rocks (including localization of karst voids and decayed zones);

4) study of the composition, state and properties of the overlying formations (including localization and study of voids and soft zones in the overlying insoluble rocks and lenses of soft grounds filling sinkholes, depressions and other surface and buried karst forms);

5) sampling rocks and water for laboratory analysis;

6) implementation of experimental hydrogeological and geophysical works;

7) implementation of stationery (scheduled) observations of the process of the underground water pollution propagation;

8) identification of karst zones and their delineation by the degree of karstification and karst risk, as well as identification of zones of the underground water pollution.

In the zones of active karst development, identified by means of field observations and geophysical investigations, some discrete wells should be drilled through the entire thickness of karst active development and further deepened at least to 5 meters into the bedding rocks not affected by karst.

Design of the wells and technique of their boring should take into account difficult drilling conditions (zones of increased fracturing, weak and decayed formations, karst voids, zones of intensive flushing water loss); ensure the casing of a well at the zones of loose formations and karst voids, as well as provide for performing necessary geological and hydrogeological observations and special activities stipulated by the programme. A well should ensure maximum core recovery (in dense rocks – about 100 per cent, in loose, weak and fractured rocks – at least 80 per cent). Special measures should be taken to ensure core recovery of the karst void filler (often represented by loose rocks that can be easily washed-out and destroyed). The final diameter of wells is recommended to be not less than 91 mm.

Recovery, study and description of a core are performed according to the established rules.

Description of fractures should include the direction (vertical, horizontal, inclined with the angle of inclination), their relation to stratification, frequency of occurrence, character (potential, tight, open-joint). The width of fractures is measured. The shape of fractures (sinuous, branching, etc.), character of their walls and depositions thereon, composition, structure, texture and state of the filler, occurrence of secondary minerals (tiff, gypsum, etc.) are described. If a core is oriented, the azimuth of fractures' inclination is measured. When various types of fractures are revealed, each type is described separately with characteristic of its relative distribution.

During the drilling operations a special attention should be paid to the cases of sudden or easy sinking of a boring tool and abrupt flushing water loss.

Depth intervals at which sudden (or easy) sinking of a boring instrument occurred should be registered precisely, and its character (sudden, quick or slow sinking without rotation, under the load or without it, etc.) is to be described. Every such a case is to be registered in a shift report and in the boring journal, where the precise intervals of the boring instrument's crossing a karst void are logged.

For the reliable identification of voids, decayed and weak zones, timekeeping during the drilling operations is a must. The drilling rate should be observed and registered continuously and not only in the karstifying rocks, but also in the overlying formations.
In the course of drilling a hydrogeological survey is compulsory; it is performed to identify: intervals of different behavior of flushing water circulation (normal circulation, partial, significant or complete loss); for every aquifer – the depth of water appearance, and for every interval of water loss – water level recovery and stable water level should be fixed; water levels at the beginning and at the end of every shift are registered.

Hydrogeological survey. As a rule, to perform detailed hydrogeological researches, wells and open pits are set up in places of the concentrated surface and atmospheric water loss, near water intakes affecting the natural regime of the underground waters, as well as near hazardous from the ecological point of view industrial enterprises. Wells are distributed unevenly depending on the number of karst forms in the area and location of the sources of pollution.

Frequency of the underground water level measurements is based on the technogenic factors, but not less than 4 times a month. In the areas of large water supply facilities, regular and more frequent (at least 5 times a month) observations of water extraction and water level fluctuations are performed. Near large industrial complexes the frequency of measurements is connected with the reported cases of technological process violation: emergency discharge of concentrated waste waters, industrial water leakages, etc.

Along with the underground water level observations, detailed hydrochemical investigations are carried out. Their purpose is monitoring changes of the underground water chemical composition and mineralization caused by human activities. The frequency of water sampling depends on the technogenic factors.

Except for the standard chemical analysis, the content of specific chemical components is observed. Their presence is caused by the human activities, and they can increase considerably the aggressiveness of the underground waters with respect to the karstifying rocks. For example, in case of the sulphate karst, a special attention should be paid to the content of Na^+ and Cl^- ions in the underground waters, in case of the carbonate karst – to the presence of free CO^2.

Methods of processing the results are similar to those applied for the state monitoring of the underground waters.

During the pumping-out with the application of standard methods, coefficients of filtration of karstifying rocks, conductivity of layers, water yield of the karstified formations are determined. Besides, underlying beds, conduits between aquifers, hydrologic connections with the nearest surface water streams and reservoirs, water intake facilities, sources of pollution should be assessed. Measurements of the velocity of the fracture-karst underground waters and degree of their contamination are important for forecasting karst processes in the studied areas and for assessment of technogenic pollution propagation.

Field experimental work. According to the research programme, static, dynamic and vibration sounding, penetration survey and logging, field tests of soils in wells and mine tunnels as well as other types of work are carried out. The obtained data are used for: identification and delineation of soft zones of voids, i.e. surface and buried karst forms in the overlying rock massive; study of the conditions of natural occurrence of soils and underground waters; defining the permeability of the geological cross section, study of the rock roofing topography, forecasting possible zones of sinkhole formation.

Application of tracer methods is most effective on the highly karstified territories, particularly when dyes are injected into the recent sinkholes and swallow holes. Interesting results, as a rule, are obtained when dyes are injected into the observation wells located near the zones of discharge of the fracture-karst waters.

Third stage – laboratory and experimental work. Laboratory researches on the properties of ground masses in the karst regions include a wider spectrum of work as it is usually fulfilled under the normal conditions. Both the karstifying and overlying formations are studied according to a special programme.

Mineral and petrographic analyses and study of chemical composition of the rocks are performed to assess solubility of rocks under the underground water action with allowance to its man-caused contamination.

Chemical analysis of the underground waters is required to define changes in the chemical composition of the underground waters under the influence of natural and technogenic factors, to identify hydrochemical zones, to study interconnections between aquifers and the rate of contaminated water filtration. The basic methods of studying the hydrochemical characteristics are given in Table 2.1.

Table 2.1.

Methods of studying the "priority" hydrochemical indices of water quality

Characteristics and components	Method	Lower limit of content, mg/l
Ammonium ions and ammonia (NH_4, NH_3^+)	Photometry, spectrophotometry	0.05 0.001
Beryllium (Be)	Fluorimetry	0.000005
Hydrocarbonates (HCO_3)	Titrimetry, potentiometry	- 0.5
Iron (Fe)	Photometry	0.05
Cadmium (Cd)	Photometry, polarography	0.4-0.6 -
Potassium (K^+)	Plasma photometry	0.3
Calcium (Ca^{2+})	Titrimetry	0.4-0.6
Magnesium (Mg^{2+})	Titrimetry, photometry	0.4-0.6 -
Manganese (Mn)	Ditto	0.01
Copper (Cu)	Titrimetry, photometry, polarography	0.02 0.002 0.0005
Molybdenum (Mo)	Photometry	0.0025
Arsenic (As)	Ditto	0.01
Sodium (Na^+)	Plasma photometry	0.1
Oil and oil products	Gas chromatography, infrared spectrophotometry	0.01-0.62 0.05-0.1
Nitrates (NO_3^-)	Photometry	0.1
Nitrites (NO_2^-)	Ditto	0.007
Organoleptic properties (odour, colour, turbidity)	Ditto	-
Mercury (Hg)	flameless atomic absorption	0.0014
Lead (Pb)	Photometry, polarography	0.0005 0.00005
Total selenium (Se)	Fluorimetry	0.0001
Hydrogen sulfide and sulfides (H_2S, HS^-, S^{2-})	Photometry	0.05
Strontium (Sr)	Flame photometry	0.5-1.0
SS (anion-active)	Photometry	0.015

Sulfates	Gravimetry, titrimetry, turbidimetry	2.0
Solid residual	Gravimetry	-
Volatile phenols	Photometry	0.001
Phosphates, polyphosphates	Ditto	0.005
Fluorine (F)	Photometry, potentiometry	0.04-0.05 0.19
COD	Ditto	-
Permanganate oxidability	Titrimetry	0.4-0.5 mg O/l
Dichromate oxidation	ditto	2.0 mg O/l
Chlorides	Titrimetry	0.5
Organochlorine pesticides (DDT, aldrin, etc.)	Gas chromatography	0.001-0.003 mkg/l
pH	Photometry, electrometry	-
Eh	ditto	-

For clay, sand and fragmental rocks, standard laboratory researches of the physical-chemical properties are performed. When necessary, special laboratory analyses are carried out. The obtained data are used for assessing hydrogeological conditions of karst development (determination of the filtration coefficient, suffosion properties, washing of the filler out of voids and fractures, identification of routes of polluted water migration).

Experimental investigations, including computer simulation, are carried out when it is necessary to forecast directions of the polluted water motion under the influence of technogenic factors.

Hydrogeological simulation is used in the experimental researches of the filtration-gravity deformations taking place in aqueous soils overlying karst voids and fractures or places of disruption of confining layer continuity caused by karst processes and polluted water flows.

The simulation of changes of the natural-technogenic environment on the basis of a balance approach is obligatory in the areas adjacent to the groundwater intakes and industrial landfills.

Fourth stage – office studies. At this stage the results of the field, laboratory and experimental researches are processed, and data of certain observation periods are analyzed. If necessary, schemes of the observation networks and the programme of monitoring of certain components are reviewed. The efficiency of the research programme is evaluated in general. A forecast of the underground water pollution propagation is made. Suggestions on organization and implementation of the monitoring programme “Underground waters in karst regions and technogenesis” are developed on a local level.

Conclusions

1. Availability of various interconnected conduits and karst voids in the karstifying rock massif, confined in certain layers and oriented in certain directions, determines filtration anisotropy of karstified rocks and controls water motion along the branching karst systems.
2. Under the conditions of intensive water extraction in the sinkhole areas, fast propagation of heavy contaminated fluids inside the kastifying rock massif takes place due to the collapses of clay rocks separating the overlying aquifer from the fracture-karst waters.
3. Basic information required for studying specific conditions and estimating extent of technogenic pollution of the underground waters in the karst regions may be obtained only by implementing a complex of karstological, hydrogeological, geophysical, experimental and laboratory investigations.
4. Proceeding from the specific aspects of organization of special observations of the underground water pollution dynamics on the karstified territories, the authors have singled out 4 stages in the system of observations: a) preparatory; b) field; c) laboratory and experimental; d) office and analytical.

Chapter 3

METHODS OF ASSESSMENT OF UNDERGROUND WATER SENSITIVITY TO AND PROTECTION FROM TECHNOGENIC IMPACT IN THE KARST REGIONS

3.1 Description of the main types of cross sections of rock masses in the karst regions of the Middle Volga

Based on the analysis of the archival and other geoecologic materials, study and systematization of more than 3,200 well cores and over 700 chemical analyses of water and snow samples, fulfillment of special hydrogeological investigations including boring of observation wells, testing of aquifers, filling of open pits and wells at the industrial waste disposal sites of Dzerzhinsk in the zone of influence of the Teplovsky water intake, at the acid tar disposal site on the territory of JSC "Gorky metallurgical works", on the South-Gorky groundwater field, 9 basic types of cross sections of rock masses most typical for the karst regions of the Middle Volga have been defined (Fig. 3.1).

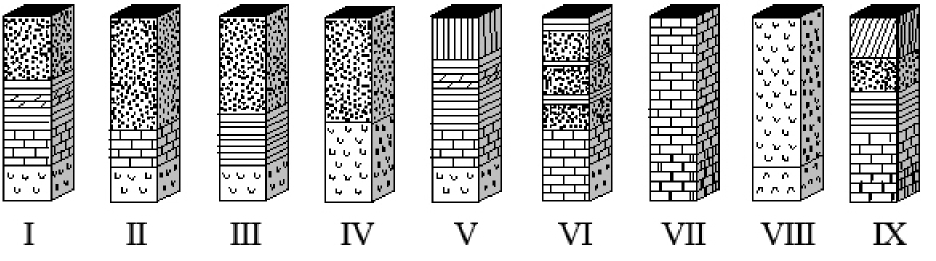


Fig. 3.1 Typical types of cross sections of rock masses in the karst regions of the Middle Volga: I-IX – types of cross sections

The defined types of rock cross sections have been united in 4 groups or kinds of media according to the degree of favourable conditions for karst development and contaminates' infiltration in to the ground and fracture-karst waters via the zone of aeration.

The first group (I, III, V, IX types of cross section) is characterized by the following conditions. The karstifying rocks are represented by gypsums and anhydrites, cavernous and heavily fractured limestone and dolomites. The soluble rocks are overlaid by argillo-calcareous insoluble sediments 20 to 25 m thick. The upper part of the section is formed of the interlaid strata of loamy soils and sands of different coarseness. The rock massif contains two aquifers: in the soluble rocks (fracture-karst water) and in the sand sediments (ground water). They are interlaid by poorly permeable marly clay formations. The fracture-karst water is characterized by head. This type of the karst development medium is low-sensitive or non-sensitive to the man-caused impacts. As a computer simulation of the areas of wastewater leakage proved, industrial aggressive waste waters had no direct effect on the karst process, i.e. there was no zone of aggressive waters with respect to the karstifying formations. During the underground water extraction, formation of the zone of aggressive waters under these circumstances has no impact on the present processes of karstification as well, provided the water extraction is organized from the upper aquifer and the aquifer's water table does not fall below the piezometric level of the fracture-karst waters. Conditions for the sinkholes formation in this type of a medium have been prepared for quite a prolonged period of time, and technogenesis has just completed this evolution process. Under these circumstances the state of modern ecosystems is related little with karst.

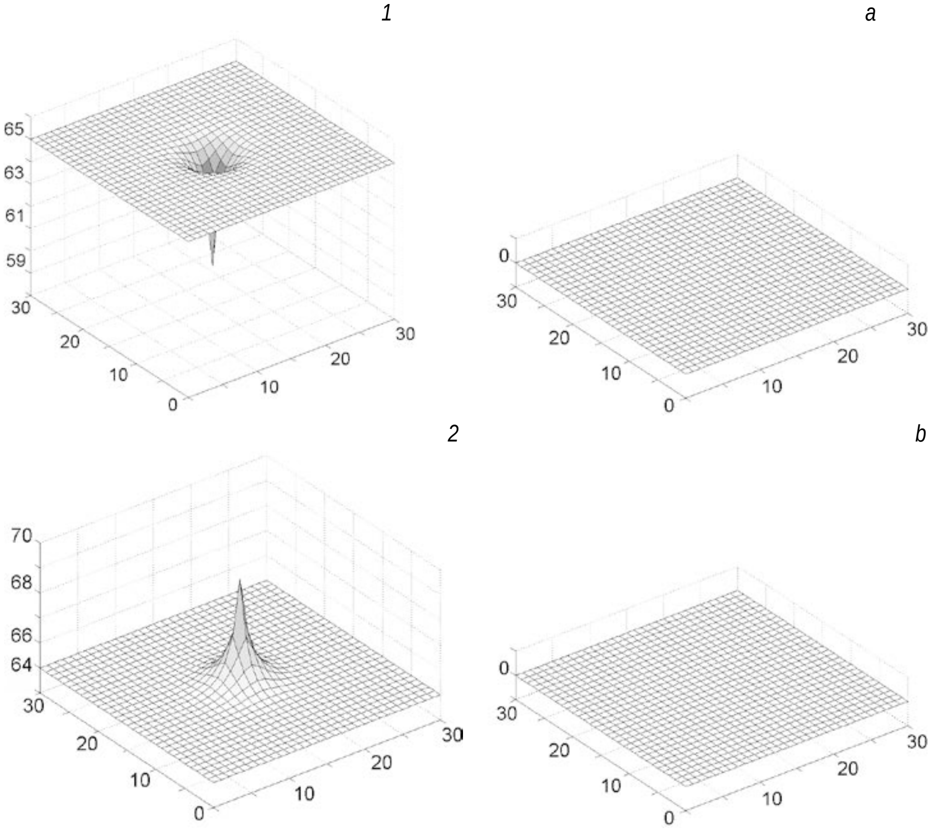


Fig. 3.2 Assessment of the impact of man-induced loads on the intensity of karst processes under conditions of the first type of the karst development medium: *1* – development of the cone of depression in the area of the underground water intake; *2* – formation of the underground water cupola in the area of domestic wastewater leakage and industrial wastewater discharge; *a)* formation of the zone of aggressive waters with respect to the karstifying rocks in the area of the underground water intake; *b)* formation of the zone of aggressive waters with respect to the karstifying rocks in the area of domestic wastewater leakage and industrial aggressive water discharge

The second type of the karst development medium (II, IV types of cross section) is characterized by the absence of a clay marl layer between the permeable sand formations and the karstifying carbonate-sulphate rocks. The aquifers have direct hydraulic connections between each other. They are not protected from any kind of contamination. This type of a medium is characterized by an increased sensitivity to the changes in the underground hydrosphere parameters: first of all it refers to the levels and chemical composition of the ground and fracture-karst waters, increase of velocities of water flows in the karstifying rocks and transfer of pollutants to considerable distances. Computer simulations of the conditions of the second type of

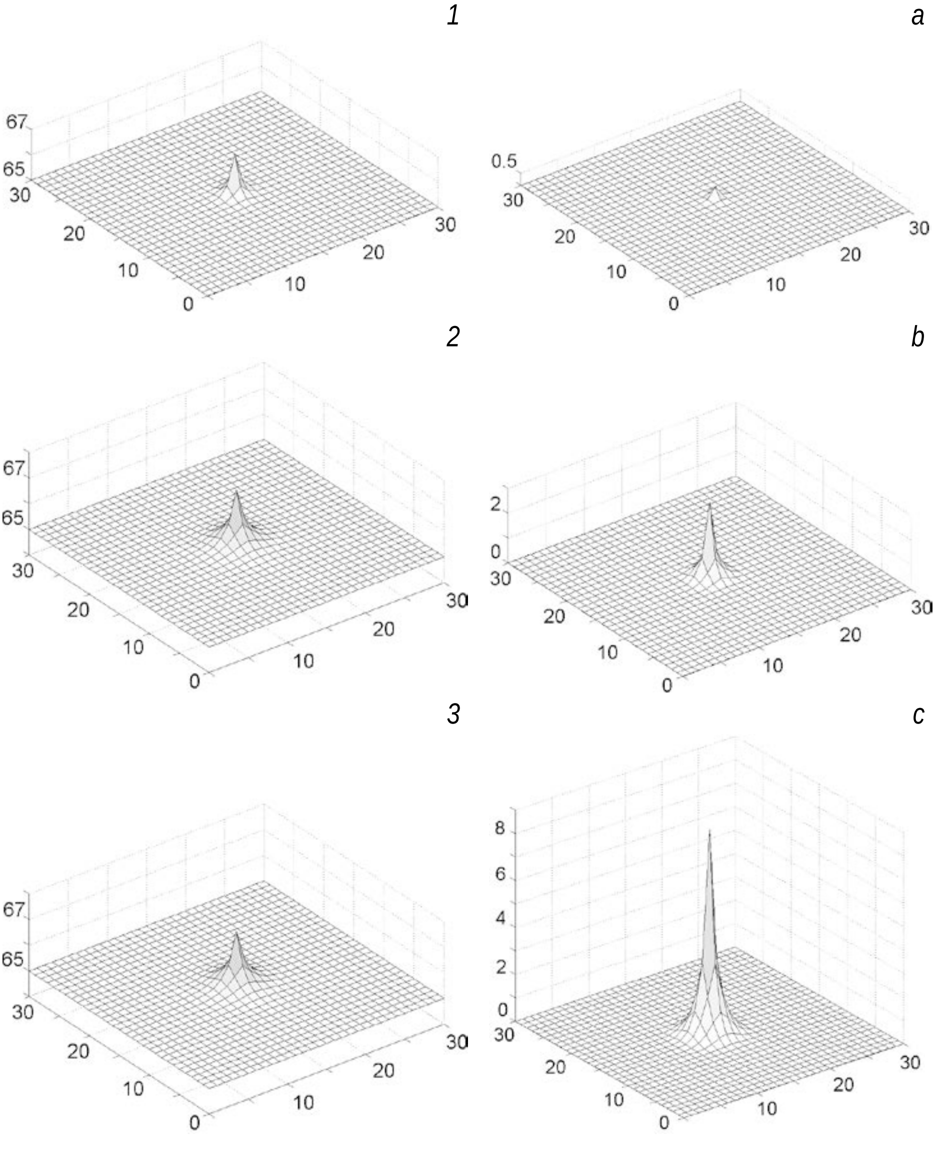


Fig. 3.3 Assessment of the impact of man-induced loads on the intensity of karst processes under conditions of the second type of the karst development medium in the areas of domestic wastewater leakage and industrial aggressive water discharge: *1, 2, 3* – stages of development of the underground water cupola; *a, b, c* – stages of formation of the zones of aggressive waters with respect to the karstifying rocks

the karst development medium have revealed a direct relation between the stages of development of sinkholes at certain quantities of water extraction and formation of zones of aggressive waters, as well as between the stages of development of underground water cupolas and stages of formation of zones of aggressive waters with respect to the karstifying rocks (Fig. 3.2, 3.3).

Under the conditions of intensive extraction of fracture-karst waters and, as a direct consequence of it, the catastrophic lowering of the ground water level, for this type of medium ecosystem changes are possible in a wide aspect from a zone of ecological risk to a zone of ecological disaster *(Vinogradov, 1984)*.

The third type of the karst development medium (VI type of cross section) by its parameters is an intermediate one between the first and the second media. Thin clay interlayers in the overlying strata do not guarantee protection of the ground and fracture-karst waters from the surface pollution. Anyhow, clay sediments available in the upper part of the section conditionally protect the underground waters from an easy ingress of contaminants permitting to take prompt preventive measures against water contamination during emergency discharges and spillages of liquid industrial wastes and oil products.

The fourth type of the karst development medium (VII, VIII types of cross section) is characterized by an increased sensitivity to the man-caused impact. The karstifying formations (limestone, gypsum) occur directly on the surface and respond immediately to the hydrodynamic and hydrochemical changes. This type of medium is less common and characterized by an abrupt activation of karst-suffosion processes leading to the formation of surface depressions, local sinks and sinkholes. Ecosystem changes are possible in a wide range – from a zone of ecological risk to a zone of ecological disaster.

It should be noted that one of the most important conditions of forecasting the karst process development and underground water pollution propagation is the determination of an actual extent of the rock subterranean karstification, i.e. the presence of karst voids, their parameters, degree of filling with collapsed or drifted materials, depth of voids, types of rocks confining voids, etc. In Nizhny Novgorod the authors have conducted complex researches to assess the subterranean karstification of the city territory located on the lower bank of the river (called “zarechnaya” part or Zarechie) and typify hydrodynamic conditions of the relationship between the ground and fracture-karst waters.

On the entire territory under study there exist necessary and sufficient conditions for the ground and fracture-karst waters interaction. On the east riverside territory an upward filtration prevails meaning that the piezometric levels are higher than the ground water levels. This filtration is promoted by the existence of “hydrogeological windows” – places of erosion of the Lower Tatarian strata.

In the west part of the territory the direction of filtration is downward, i.e. the ground water levels are higher than the piezometric ones.

The interface of the fields of filtration that runs along water-table contour + 70 m is not static. Season fluctuations of the ground water levels in a long term cause the displacement of the interface within the aquifer's space, i.e. when the ground water level rises, the area of discharge of the fracture-karst waters reduces.

The ground water table has a shape of a radial flow spreading in the directions of the main drains in the area of the Oka and Volga rivers. The absolute elevations of the water surface come down from 78 m at the watershed to 67 m at the riverbank lines. The shape of the water surface is complicated by the anthropogenic factors. The most dramatic disturbances of the natural gydrogeological environment are observed at the sites of large industrial enterprises (Sormovo machine plant, GAZ plant, the underground line, etc.) and large heat stations (Avtozavodskaya and Sormovskaya heat stations).

As a rule, at the locations of large industrial enterprises, technological processes of which are connected with water losses, local cupolas of various heights form over the ground water table. Good examples of that are the territories of the Avtozavodskaya and Sormovskaya heat stations.

On the territory of the Sormovskaya heat station the water table is deformed due to the formation of a local cupola of an area of 1.5 km^2 with a radius of 700 m. The cupola is asymmetric, which is explained by the proximity of a drainage area (the Volga bed). The cupola is more than 4 m high.

A similar cupola has formed on the territory of the Avtozavodskaya heat station. The cupola is less than 2 m high being practically the same in area, as compared with the Sormovskaya heat station, which is explained by the quick spreading of the leaked industrial waters along the stratum (at the site of the Avtozavodskaya heat station filtration properties of the rocks are much better than those at the site of the Sormovskaya heat station).

The fracture-karst waters of the Lower Kazanian strata form a stream directed towards the main drains of the region – the Oka and Volga rivers. On the territory of Zavolzhie (the Volga lowlands) it is a flat-parallel flow having no hydraulic connections with the Volga tributaries. The absolute elevations of the stratum piezometric surface gradually come down from 120 m at the watershed to 60-70 m at the Volga riverside. On the territory of the "zarechnaya" part of Nizhny Novgorod the absolute elevation of the piezometric level is about 70 m. The piezometric surface is in the form of a radially spreading stream.

The confining layer separating the ground waters of alluvial deposits from the fracture-karst waters is formed of marly clay strata of the Upper Perm age.

The ground waters of the upper part of the flow confined mainly in the fine-grained and very fine-grained sands, often dust sands, are alkalescent with pH ranging, on average, between 7.2 and 7.4 in the south and central parts of Zarechie. Though in some areas (territories of industrial enterprises: JSC GAZ and others) it reaches 8.0-8.2 meaning that the ground waters become alkaline. In the west part of Zarechie (an area of swamps and garden-plots) and on the territory of the north Volga riverside, where the Sormovo shipyard and Sormovskaya heat station are located, the subacid and acid ground waters are widely spread. The pH value in the Volga floodplain decreases to 6.35-6.1. In the swamp area the pH value is relatively stable and constitutes, on average, 6.5.

The ground water mineralization distributes over the territory of the city quite unexpectedly. It is a well-known fact that there is quite a number of large underground water polluters located in the "zarechnaya" part of Nizhny Novgorod. These are mainly industrial enterprises and sites of surface and subsurface disposal of industrial and domestic wastes. However, according to the hydrochemical analysis, the background value of the ground water mineralization constitutes 0.4 g/dm^3. To the east and north from isoline 0.4 g/dm^3 the ground water mineralization increases slightly in the direction of the Oka and Volga beds, and just in one borehole in the "Strelka" area (well 90) it comes up to 0.678 g/dm^3. In the central and west parts of the territory the ground water mineralization is less than 0.4 g/dm^3.

The abnormally high mineralization value of the ground waters of the upper zone of the flow is observed on the territories of the Avtozavodskaya and Sormovskaya heat stations, where water soluble salts used in the technological process are stored directly on the ground.

On the whole territory the content of ion SO_4 is less than 200 mg/dm^3. The background content of sulphates is in the range from 111 to 128 mg/dm^3. The exceeding of the background content of sulphates is reported on the entire territory of JSC GAZ, Avtozavodskaya heat station and the floodplain, where the GAZ industrial facilities and a landfill are located.

Thus, regardless the fact that there are large sources of industrial and domestic pollution on the territory of the "zarechnaya" part of Nizhny Novgorod, the ground waters of the upper zone of the ground flow may be considered fresh, low saline, alkalescent, subacid, showing no sulphate aggressivity with respect to the concrete of standard density (with the exception of discrete areas on the territory of JSC GAZ), i.e. the selected ingredients (mineralization, SO_4, pH) may not be reckoned among the indices of industrial contamination of the given territory, that makes identification of the areas of the fracture-karst water discharge easier. The following circumstance should be noted – the analysis of the chemical composition of the ground waters on the entire territory has revealed that the ground waters of fluvial sediments being of low mineralization have increased content of chlorides, nitrates, nitrites, oxidability, ferrous and ferric iron, that points to the fact that the ground waters are contaminated and unsuitable for the household use.

The hydrochemical analysis of the ground waters of the lower part of the flow shows a different water composition. The central part of the region is characterized by subacid ground waters of pH ranging from 6.8 to 6.0. On the rest of the territory ground waters are subacid and alkaline.

Compared to the upper zone of the flow, the mineralization of the ground waters of the low zone increases sharply. Mineralization isoline 1 g/dm^3 delineates a considerable area of Zarechie, including central and south regions. The highest ground water mineralization was registered in well 3 (the GAZ plant district) accounting to 15.28 mg/dm^3. On the riversides (the floodplain, I and II above-floodplain terraces) the ground water mineralization is less than 1 g/dm^3, but still high enough – exceeding 0.7-0.8 g/dm^3.

The areas of the highest mineralization, as a rule, are characterized by a high content of sulphates – over 200 mg/dm^3. The background content of sulphates ranges from 0.3 to 0.5 mg/dm^3; in the GAZ plant area the content of sulphates reaches its maximum value of 3,126.4 mg/ dm^3.

By comparing the map of water-table contours with the hydrochemical map, it becomes evident that the highest ground water mineralization and the highest content of sulphates are registered in the areas of the fracture-karst waters possible discharge into the fluvial sediments. As a rule, the ground waters in these areas are alkaline and alkalescent.

3.2. Typification of technogenic sources of pollution of the underground hydrosphere

The underground waters are a very sensitive indicator of the environmental technogenic changes. The underground hydrosphere has been changing especially fast in the last century under the man's direct and indirect impact. The natural regime of almost all the elements of the underground hydrosphere has been disturbed, i.e. conditions of recharge, run-off, discharge, levels, heads, velocity, chemical composition and temperature of the underground waters *(Trofimov, Korolyov, Gerasimova, 1995)*.

According to the types of man-caused changes of the underground water quality, contamination is subdivided into *(Goldberg, 1990, 1995; Mironenko, Rumynin, 2002)*:

1) chemical;
2) thermal;
3) bacterial;
4) radioactive.

Based on the functional features of the enterprises-polluters, the following sources of the underground water pollution are distinguished: industrial, mining and oil-producing, agricultural, domestic and radioactive.

Each of the singled out types of the sources of pollution are further classified according to the contaminants: chloroorganic compounds, polychlorobiphenyls, sulphates, chlorides, oil products, phenols, heavy metals, nitrites, nitrates, etc. *(Gribanova, 1995; Delyatitsky, 1990; Koposov, 2000).*

Based on the topological features, sources of pollution are divided into *(Koposov, Kaznov, 1996; Krainov, Sobolev, 2000)*:

a) local or point (a well, a pit);
b) linear (a channel, a river);
c) areal (a slime disposal site, a landfill, etc.).

According to the degree of a hydrodynamic influence on the underground waters, sources of pollution are differentiated into:

a) hydrodynamic active;
b) hydrodynamic passive – depending on the changes caused thereby in the structure of an initial flow.

Typical regimes of influence of the sources of pollution with time are:

a) continuous;
b) discrete (cyclic);
c) conditionally immediate.

According to the physical and chemical conversion and interaction of contaminants (solutions) with underground waters and rocks, the migrants are subdivided into:

a) physically and chemically neutral – tracers;
b) liable to physical and chemical and/or microbiological transformations and interactions, but incapable to cause any essential change of the initial density and viscosity of the underground waters (physically neutral waste waters);
c) affecting considerably density and viscosity of the underground waters (heavy or light waste waters).

3.3. Basic types and sources of the underground water pollution with characteristics of contaminants by the example of the karstified territories of the Nizhny Novgorod region

As a result of studying, analyzing and generalizing archival and other materials, interpreting air photographs, implementing field, experimental and laboratory researches, the authors have defined the following types of the underground water pollution widely distributed on the karstified territories of the Nizhny Novgorod region: industrial, domestic, oil, agricultural and, to a lesser degree, mining (see Fig. 1.22).

Main sites of the industrial pollution are concentrated on the karstified territories of large industrial centers of the Nizhny Novgorod region: Dzerzhinsk, the “zarechaya” part of Nizhny Novgorod, Balakhna, Arzamas, Pavlovo, Vyksa, Kulebaki, Ardatov, Pervomaisk.

The industrial area located within the limits of the cities of Balakhna – Dzerzhinsk – Nizhny Novgorod has been studied more thoroughly. An active karst process of sinkhole development (5 to 6 sinkholes per year) is observed in this area, where the main production and human resources are concentrated producing large volumes of industrial and domestic wastes accordingly; where large centralized underground water intakes have been used for many years for domestic and industrial water supply with formation of depressions of the main exploited surface aquifer. The entire territory of the industrial area under survey is located on the contemporary and buried valleys of the Oka and Volga rivers and characterized by a good permeability of the upper zone of the geological cross section, represented by the Quaternary alluvial sands of various coarseness and thickness ranging from 22-29 to 80.0 m in the areas of the buried valleys. The alluvial sands contain the main exploited aquifer, which is practically unprotected from the surface pollution, having direct hydraulic connections with the fracture-karst waters in the places of washout and increased fracturing of the Tatarian marly clay sediments (P_2t) as well as in the areas of sinkholes and karst lakes.

Based on the results of the fulfilled investigations and analysis of materials of previous researchers (*Iljin, Safronova et al., 1971; Tychina, Maksimova, Glushneva, 1988; Gantov et al., 1995; Tolmachyov, Tseneva, 2000),* it has been found that only in the east part of Dzerzhinsk, according to the catalogue of the Committee for environment protection of the Dzerzhinsk administration, there are 14 landfills of industrial and domestic wastes (Fig. 3.4).

Almost all landfills are not equipped with special protective structures to prevent contaminants’ penetration into the ground. Not a single landfill has protective structures to withstand karst-suffosion deformations. It should be also noted that during landfill designing the engineering-geological survey was not performed in a proper way. It refers even to the waste landfills of hazard class III and IV, which constitute 50 per cent of the total number of waste disposal sites *(Tolmachyov, Mamonova, 1997)*.

The detailed technical characteristics of the landfills are given in Table 3.1.

The majority of the investigated landfills were constructed more than 20 years ago, and three of them have been in operation for more than 80 years. According to the fulfilled investigations, landfills of more than 20 years of age have aureoles of pollution exceeding significantly boundaries of their buffer zones. Two landfills are used for disposing wastes from Nizhny Novgorod. Based on the long-term researches carried out by JSC "Protivokarstovaya i beregovaya zaschita" on the territory of Dzerzhinsk, the east industrial zone was found to be karst-affected most of all (Fig. 3.5).

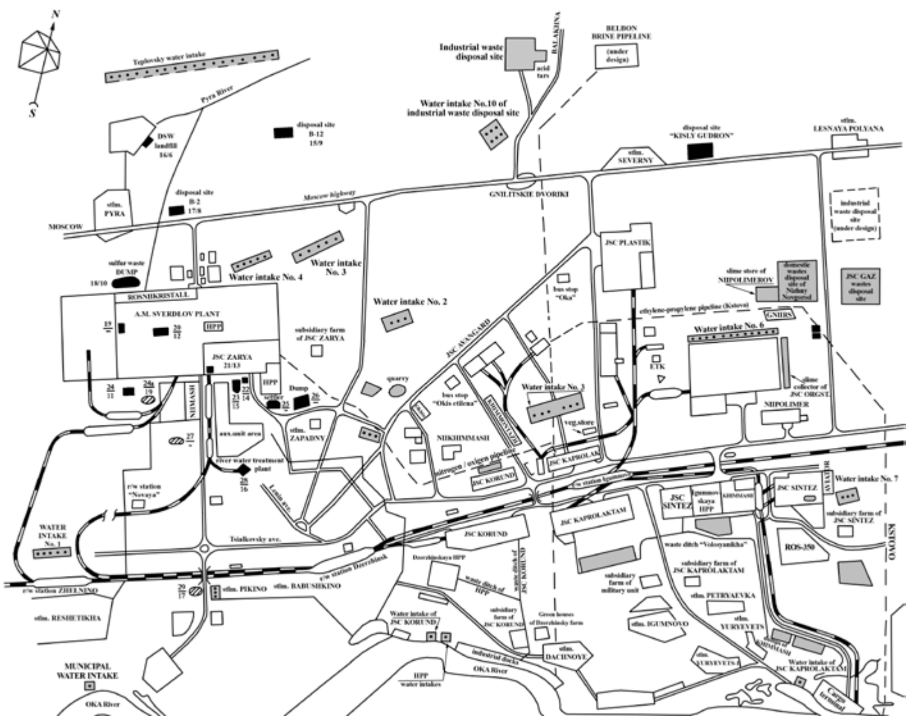


Fig. 3.4 Map of location of industrial and domestic waste landfills on the territory of Dzerzhinsk

Analysis of subterranean karstification and recent sinkholes, deformation of buildings and structures caused by karst-suffosion processes permits stating that, from the standpoint of building norms SNiP 2.01.28-85 "Landfills for neutralization and storage of toxic industrial wastes. General conditions for designing" and TSN 22-308-98 NN, almost all landfills are located in the zone of "active" karst (Fig. 3.5), i.e. in defiance of the above mentioned normative documents.

The largest risk of sinkhole development exists at the industrial waste landfill of JSC "Korund" with an intensity of sinkhole formation (λ) ranging from 0.48 to 1.0 sinkhole a year per 1 km^2 (II category of stability), with a maximum number of sinkholes (> 50) and increased density of a lineament network connected with the belts of deep tectonic fractures.

Landfills 2, 3, 4, 10, 11, 12 (Fig. 3.5) are located on the territory characterized by stability category III (λ ranging from 0.09 to 0.24) and development of sinkholes and surface subsidences.

The rest of the landfills are located on the territory characterized by stability categories IV and V with respect to the sinkhole development. The intensity of sinkhole formation (λ) constitutes 0.01 - 0.02 sinkhole a year per 1 km^2.

Construction of landfills in the areas of "active" karst with unprotected ground and fracture-karst waters leads to a direct ingress of contaminants to aquifers and formation of vast zones of the underground water pollution.

Under natural conditions waters on the studied territory are mainly hydrocarbonate calcium with total mineralization ranging from 0.1 to 0.3 g/dm^3. Because of the wastes, chemical composition of the ground waters is chloride-, calcium- and sodium-dominant. Mineralization in the areas of pollution increases tens and hundreds of times along with the increased oxidability. Characteristics of main contaminants of the underground waters in the areas of industrial waste landfills of the east territory of Dzerzhinsk are given in Table 3.2.

The content of special components of pollution in the alluvial aquifer exceeds permissible norms and at some landfills reaches extremely dangerous concentrations. Four large aureoles of pollution existing in the area of JSC "Orgsteklo" associate with industrial waste landfills, slime collectors and a settling pond.

The following special components of industrial pollution of organic origin were found in the wells: acetone, benzol, methanol, oil products, phenol, formaldehyde and cyanides. The content of contaminants in the water reaches an extremely dangerous level of pollution exceeding the MPC values 103-105 times.

As the stream of ground waters moves towards the main drain of the Oka river, concentrations of special components reduce, while the content of sulphates and chlorides "furnished" by the slime collectors and other polluters increases.

The lithologic structure and thickness of the alluvial strata in the area of landfills contribute considerably to the mechanism of contaminants' ingress to the east aquifer.

The thickness of the alluvial strata changes from 20 m in the area of landfill 7 to 55 m in the area of landfill 1.

The upper zone is formed of dust and fine sands and characterized by a low water yield and low filtration properties. Its thickness is about 15-20 m and the coefficient of filtration is in the range of 1.0 and 6.4 m/day.

The lower layer 5-10 m thick is formed of medium and coarse-grain sands with inclusions of pebble and gravel of different sizes.

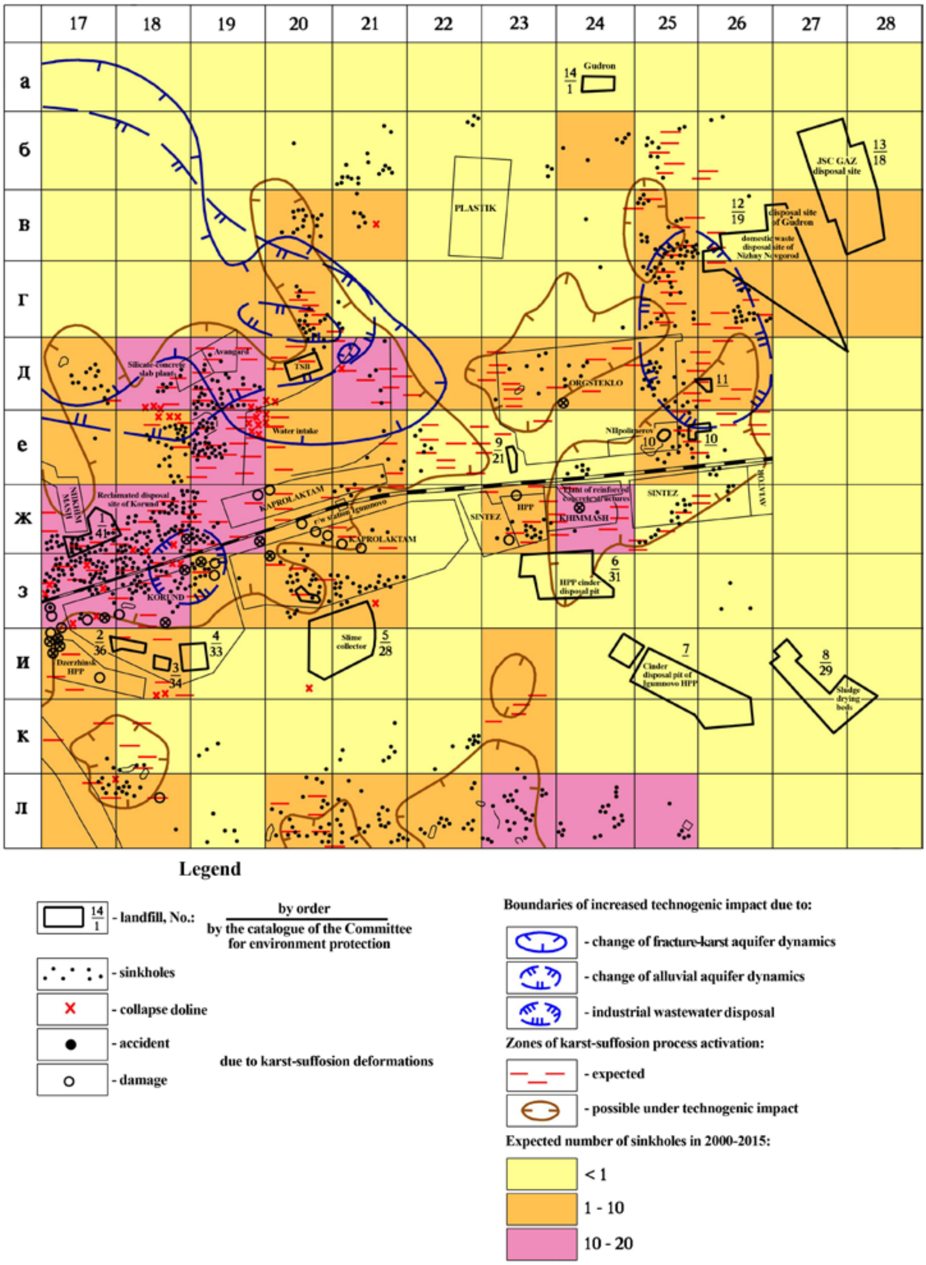


Fig. 3.5 Karst risk schematic diagram of the territory of the Dzerzhinsk east industrial zone and locations of waste landfills (JSC “Protivokarstovaya i beregovaya zaschita”)

Table 3.2

Characteristics of underground waters in the area of industrial waste landfills located on the karstified territory of the east district of Dzerzhinsk

Land-fill Nos. on the map	Well No., a.e. of well-head, m	Groundwater level (unconfined): Level depth (summer low level) max	Groundwater level (unconfined): Level depth (summer low level) min	Groundwater level (unconfined): Level change, m	Well No., a.e. of well-head, m	Level of fissure-karst waters (artesian): Level depth (summer low level) max	Level of fissure-karst waters (artesian): Level depth (summer low level) min	Level of fissure-karst waters (artesian): Level change, m	Chemical composition of ground waters: pH	Ground waters: Oxid-ability	Ground waters: Organic pollutants	Ground waters: Minera-lization	Ground waters: Type of water	Chemical composition of fissure-karst waters: pH	Fissure-karst waters: Oxid-ability	Fissure-karst waters: Organic pollutants	Fissure-karst waters: Minera lization	Fissure-karst waters: Type of water	Location with respect to sinkholes, formed in groundwaters	Location with respect to sinkholes, formed in fracture-karst waters
1/41	601/88.23	10.01	7.77	+2.24	604/88.25	13.33	7.89	+5.44	7.2	4.32	Formaldehyde-0.09 Oil products-1.0	0.327	Cl-Na				~4	SO_4-Ca	In zone of influence	In zone of influence
	728/88.94	14.35	10.1	+4.25																
2/36	5/78.94	6.86	5.46	+1.40	5a/78.76	9.53	7.95	+1.58				2.5-3.0	Cl-Ca				~2-3	SO_4-Ca	Out of zone of influence	Out of zone of influence
3/34	34/76.73	2.27	1.60	+0.67	34a/76.72	2.27	1.52	+0.75				~3.5	Cl-Ca	7.25	5.12	Formaldehyde-0.05	0.831	SO_4-Na	-«-	In zone of influence
4/33	35/76.30	3.29	0.26	+3.03	35a/76.56	3.13	0.69	+2.44				~3	Cl-Ca	6.04	2.2	Not determined	1.939	SO_4-Na	-«-	-«-
5/28	3/74.13	2.07	0.20	+1.87	3a/74.19	7.60	5.38	+2.22	6.4	22.6	Oil products-1.0	4.6	Cl-Ca	6.55	10.08	Benzol-0.25, Phenol-0.008, Cyanides-0.116	3.244	Cl-Ca	-«-	Out of zone of influence
6/31		10.41	8.26	+2.15	3a/77.24	6.40	4.24	+2.16					HCO_3-SO_4-Ca-Na	6.3		Formaldehyde-0.27	4.2	SO_4-Na		
	67/76.47				5a/73.09	2.17	0.59	+1.59	7.25	9.92	Ammonia	1.3		8.3		Oil products-1.4 Acetone-0.38, Phenol-0.05, Oil products-0.8	1.2	HCO_3-Na	-«-	-«-
7/-	78/3/74.6	7.75	6.29	+1.46									HCO_3-Na					SO_4-Ca	-«-	-«-
8/28	n.a./~73	~9	~7.5	+ ~3									HCO_3-Na					SO_4-Ca	-«-	-«-
9/21	751/89.45	10.95	9.49	+1.41	751a/89.45	9.99	8.44	+1.45	8.4	41.6	Phenol-0.05, Methanol-0.84 Oil products-0.6 Cyanides-0.355	1.607	HCO_3-Na	7.86	9.28	Oil products-0.6 Acetone-0.4 Cyanides-0.388	1.407	SO_4-Ca	Out of zone of influence	Out of zone of influence
	n.a./~90	~12.5	~11	+1.5	640a/92.23	13.39	12.03	+1.36												

To be continued

Table 3.2. Continuation

Land-fill Nos. on the map	Well No., a.e. of well-head, m	Groundwater level (unconfined): Level depth (summer low level) max	min	Level change, m	Well No., a.e. of well-head, m	Level of fissure-karst waters (artesian): Level depth (summer low level) max	min	Level change, m	Chemical composition of ground waters: pH	Oxid-ability	Organic pollutants	Minera-lization	Type of water	Chemical composition of fissure-karst waters: pH	Oxid-ability	Organic pollutants	Mineral ization	Type of water	Location with respect to sinkholes formed: in groundwaters	in fracture-karst waters
10/-	126/82.33	4.73	3.39	+1.34	126a/81.95	4.16	3.00	+1.16	6.85	128.8	Benzol-0.49, Phenol-1.15, Formaldehyde-0.085	7.505	Cl-Na	5.3	> 100	Acetone-2.5, Benzol-0.08, Phenol-13.18, Cyanides-0.28	6,546	Cl-Na	In zone of influence	In zone of influence
	101/83.63	5.85	4.60	+1.25	101a/83.63	5.89	4.79	+1.10	7.98	576.0	Acetone-3.0, Benzol-0.6, Methanol-42, Phenol-36.3	5.324	Cl-Na							
	70/83.78	5.69	5.07	+0.62		~6	~5	+1	3.87	1232	Acetone-75.2, Benzol-3.2, Methanol-620, Phenol-105, Cyanides-0.57	34.128	SO_4-Na	8.15	6.5	Phenol-1.2, Cyanides-0.075, Oil products-2.3, Methanol-0.56	1.3	SO_4-Ca		
11/-	Same as 10				SG-1/83.28	3.88	3.27	+0.61			Benzol-0.6, Phenol-36.3, Formaldehyde-0.085	7.505	Cl-Na	6.45	104	Oil products-0.9, Cyanides-0.09	5.097	Cl-Na	-«-	-«-
					SG-2/83.65	4.83	3.82	+1.01	7.98	576.0	Methanol-0.42, Acetone-23.0									
					SG-3/82.99	2.5	1.95	+0.65												
12/19	n.a./~88	~6.5	~4.5	~ +2									HCO_3-Ca					SO_4-Ca	Out of zone of influence	Out of zone of influence
13/18	n.a./~86	~6	~4	~ +2															-«-	-«-
14/1	61/87.36	3.8	1.51	+2.25	61a/87.29	3.93	1.084	+2.05	6.6	5.3	Cyanides-0.375, Oil products-2.2, Methanol-0.44	0.89	HCO_3-Ca	7.45	3.52	Cyanides-0.05, Oil products-1.2 Methanol-0.5	0.7	SO_4-Ca	Out of zone of influence	Out of zone of influence
	84/86.35	4.87	2.13	+2.74	86/86.35	7.76	4.86	+2.90												

Because of the sand granulometric composition this layer is characterized by a higher water yield and better filtration properties. Its coefficient of filtration ranges between 3 and 14 m/day.

The given values of the filtration coefficient provide for a high permeability of the zone of aeration.

The Permian deposits underlying the sand masses should not be considered a good barrier to protect the fracture-karst aquifer from contamination. These deposits are heavily fractured and highly soluble having numerous fracture-suffosion voids.

The fracture-karst aquifer is confined in the karstified rocks of the Sakmarian gypsum-anhydrite strata and the crudely fractured karstified Kazanian carbonate rocks. The permeability of the rocks varies considerably, and their filtration coefficients are different, too. The filtration coefficient of about 20 m/day may be considered typical. The output of production wells reaches 140 m^3/day. The fracture-karst waters are mainly sulphate calcium with mineralization ranging from 0.5 to 3.5 g/dm^3 in the areas out of the zones of pollution. They are recharged by the waters of the Quaternary deposits and discharge back to the Quaternary deposits. The zone of the fracture-karst water discharge is adjacent to the Oka river, and it spreads from 1 to 2 km in width.

Industrial wastes contribute greatly to the mineralization and chemical composition of the fracture-karst waters. However, the pollution does not cause so much the increase of mineralization (up to 5-10 g/dm^3) and oxidability (tenfold) but changes the fracture-karst water composition (to chloride) and provides for the appearance of specific components, many of which are spotted sporadically (landfills 1 to 11, 14). As in the case with the ground waters, the fracture-karst aquifer is polluted by a wide spectrum of contaminants. Their main "suppliers" are the liquid and solid industrial wastes. The industrial waste waters varying widely in chemical composition and having a high content of toxic components play an important role in this process. The east group of the landfills remains highly polluted due to the presence of phenol, benzol, oil products, formaldehyde, methanol, acetone and cyanides. Their content in the water exceeds the MPC values tens and hundreds times.

Thus, the chemical composition of the fracture-karst waters depends considerably on the pollution processes widely spread on the territory of the landfills under study.

According to the regional center for geological environment monitoring "Volgageologia", having been conducting stationary observations of the background chemical regime of the underground waters on the territory of the Nizhny Novgorod region for many years, drastic changes of the quality of subsurface waters are also observed on the "zarechnaya' part of Nizhny Novgorod. The similarity of the geological and hydrogeological conditions of the territory as well as conditions for karst

Table 3.3

Characteristics of underground waters in the identified areas of pollution on the “zarechnaya” territory of Nizhny Novgorod (as on 01.01.2005)

Location of pollution site	Polluter and its departmental affiliation or reason of pollution	Date of pollution recording	Polluted aquifer (name, index, area), km²	Contaminants (type of pollution)	Class of hazard	Concentration of pollutants (C), mg/dm³		Degree of pollution C/MPC		Remarks
						from	to	from	to	
Nizhny Novgorod, Avtozavodsky district	Slime collectors and oil tanks of heat station of JSC GAZ	2002	Middle-Upper-Quaternary alluvial stratum (aQ_{II-III}); 0.06	Iron Vanadium (industrial)	3 3	1.20 0.21	8.30 3.40	4.00 2.10	27.60 34.00	Observation network at two objects of 4 and 5 wells. Water protection zone of the Oka river
Nizhny Novgorod, Kanavinsky district, Internatsionalnaya street (water intake)	JSC “Melinvest”	2004	Lower Urzhumian terrigenous water-bearing complex, Lower Kazanian carbonate water-bearing series (P_2ur_1, P_2kz_1); n.a.	Oil products (industrial)	5	-	0.27	-	0.27	2 running wells, 1 standby well; 652 m³/day –industrial water supply
Nizhny Novgorod, Leninsky district, Vorotynskaya street (water intake)	JSC “Brewery “Volga”	2002	Sakmarian – Lower Kazanian carbonate water-bearing series ($Ps-kz_1$); n.a.	Ammonia (nitrogen content) (communal)	3	1.95	2.05	0.98	1.03	3 running wells, 2 suspended wells; 863 m³/day –industrial water supply
Nizhny Novgorod, Leninsky district, Motalny lane (water intake)	JSC Flax-scutching mill “Tekhnotkan”	2004	Lower Kazanian carbonate water-bearing series (P_2kz_1); n.a.	Oil products (industrial)	5	-	0.24	-	2.40	1 running well, 2 standby wells, 1.4 m³/day –industrial water supply
Nizhny Novgorod, Moskovsky district	Storage pond of JSC “Nizhegorodsky Mashinostroitelny Zavod”	1999	Upper Quaternary modern alluvial stratum (aQ_{III-IV}); 0.2	Oil products Copper Nickel Chromium Iron Manganese Titanium Barium Strontium Ammonia COD O_2 (industrial)	5 3 3 3 3 3 3 2 2 3 5 5	0.19 1.25 0.12 0.90 0.35 0.30 0.20 1.10 - - 18.00 5.90	67.10 1.70 0.19 1.50 4.86 2.13 1.60 1.50 8.40 2.50 340.0 0 54.50	1.90 1.25 1.20 1.80 1.16 3.00 2.00 11.00 - - 1.80 1.18	67.10 1.70 1.90 3.00 16.20 21.30 16.00 15.00 1.20 1.25 34.00 10.00	Observation network of 3 wells

To be continued

Table 3.3 Continuation

Location of pollution site	Polluter and its departmental affiliation or reason of pollution	Date of pollution recording	Polluted aquifer (name, index, area), km²	Contaminants (type of pollution)	Class of hazard	Concentration of pollutants (C), mg/dm³		Degree of pollution C/MPC		Remarks
						from	to	from	to	
Nizhny Novgorod, Moskovsky district, settl. Orlovskie Dvoriki, (water intake of zonal center of dog-breeding)	Nizhny Novgorod – Moscow highway	2004	Upper Quaternary modern alluvial aquifer (aQ_{III-IV}); n.a.	Oil products (of different origin)	5	-	0.58	-	5	1 running well; 12.5 m³/day – household water supply, industrial water supply
Nizhny Novgorod, Sormovsky district	Snow disposal site of company “Dorozhnik”	2000	Upper Quaternary alluvial stratum (aQ_{III}); 8.0	Oil products Manganese Iron (communal)	5 3 3	0.17 0.13 5.50	1.53 1.30 109.00	1.70 1.30 18.30	15.30 13.00 363.30	Observation network of 9 well, channel, lake
Nizhny Novgorod, Sormovsky and Moskovsky districts	Sormovskaya heat station, Sormovskaya petroleum storage depot, Burnakovskie lakes	1954	Upper Quaternary alluvial stratum (aQ_{III}); 0.5	Oil products (industrial)	5	4.80	14	48	141	Observation network of 2 wells, lakes, Volga river, water protection zone of the Volga river
Nizhny Novgorod, Sormovsky district, Bazarnaya sq., (water intake)	JSC “Sormovskaya konditerskaya fabrika”	2004	Upper Quaternary modern alluvial aquifer (aQ_{III-IV}); n.a.	Oil products (industrial)	5	-	0.13	-	0.13	1 running well; 60 m³/day –industrial water supply
Nizhny Novgorod, Sormovsky district, 2a Novosovetskaya street, (water intake)	JSC “Khleb”	2004	Upper Quaternary modern alluvial aquifer (aQ_{III-IV}); n.a.	Oil products (industrial)	5	-	0.23	-	2.3	1 standby well; 3.3 m³/day –industrial water supply
Nizhny Novgorod, Sormovsky district, Fedoseenko street, (water intake)	JSC “Ekos”	2004	Upper Quaternary modern alluvial aquifer (aQ_{III-IV}); n.a.	Oil products (of different origin)	5	-	0.32	-	3.2	1 standby well; 3.5 m³/day –industrial water supply
Nizhny Novgorod, Sormovsky district, Fedoseenko street, (water intake)	Enterprise “Volgastalkonstruktsiya	2004	Upper Quaternary modern alluvial aquifer (aQ_{III-IV}); n.a.	Oil products (of different origin)	5	-	0.92	-	9.2	1 running well; 2.5 m³/day –industrial water supply
Nizhny Novgorod, Sormovsky district, Dizelnaya street, (water intake)	JSC “Silikatny zavod No.1”	2004	Pliocene Quaternary alluvial aquifer (N_2 – aQ); n.a.	Oil products (industrial)	5	-	0.46	-	4.6	1 running well, 1 standby well; 122.2 m³/day – household water supply

development with the conditions attributed to the territory of Dzerzhisk shows congeniality of a number of contaminants (Table 3.3). Most likely it may be connected with the corresponding specific activities of the enterprises-polluters.

3.4 Assessment of underground water protectability

By protectability of the underground waters from contamination is meant the presence of overlying deposits, primarily poorly permeable ones, above an aquifer, which prevent contaminants' transfer from the land surface to the underground waters *(Goldberg, Gazda, 1984; Alekseev, 1989)*. Thus, by assessing the protectability of the underground waters, one should proceed from the consideration of their natural factors *(Eliseev, Gladkovskaya, 1989)*. This constitutes a qualitative assessment of the conditions of protectability. A quantitative assessment is based on the natural and technogenic factors *(Goldberg, 1991; Grozdova, 1998)*.

The basic natural factors are: the presence of distinctly less permeable formations in a cross section of rocks; depth of the underground water occurrence; thickness, lithology and filtration properties of rocks (first of all distinctly less permeable rocks) overlying an aquifer; absorption properties of rocks; correlation of water levels of the aquifer under study and the overlying aquifer.

The distinctly less permeable formations are deposits the coefficient of filtration of which is less than 0.1-0.05 m/day. These values are usually intrinsic to loamy sands, clayey sands and light loams; clay loams and clays have even lower coefficients of filtration *(Lukner, Shestakov, 1986)*.

The technogenic factors are: conditions of contaminants storage on the land surface and a mechanism of contaminants ingress to the underground waters which depends on these conditions, specific properties of contaminants, their migration abilities, interaction with rocks, decay time or chemical stability *(Belitsky, 1976; Galitsyn, 1985; Borevsky, 1994; Balakhonov, 1998; Geoekol. kartograf., 1998; Grinevsky, 2000; Belousova, 2003)*.

3.4.1 Qualitative assessment of ground water protectability

The qualitative assessment is based on a point total that takes into consideration all hydrogeological parameters of the rock mass overlying the aquifer (with reference to the ground water stratum) and on determining distinctive hydrogeological indices, including the correlation of water levels (with respect to the pressure aquifer). The qualitative assessment can also be carried out on the basis of the quantities of waters infiltrated into the underground waters by means of zoning the territory according to the intensity of infiltration. It is obvious, that where the inflow is higher the protectability is lower.

The assessment of protectability (qualitative and quantitative) is mainly of comparative, relative character. But in the case of particular contaminants, decay time or sorption ability of which is known, the protectability assessment may by absolute. Comparing the time of filtration with the decay time of a specific contaminant, one may say if it reaches the ground water level during the time of its decay or not, and hence, either the underground waters are protected from this contaminant or not. Such detailed quantitative assessments of the protectability are useful to be performed locally and with respect to the contaminants with known decay time and sorption ability. For this purpose the time of percolation may be used. With respect to neutral conservative ingredients (such as chlorine) the decay of the influent contaminated waters and their dilution by the underground waters to the MPC level or any other specified level of pollution may be used for the protectability assessment. In general, the quantitative assessment is performed according to the time of percolation.

The qualitative assessment of the ground water protectability is carried out on the basis of four values: depth of the ground water level occurrence (thickness of the zone of aeration); structure and lithology of the rocks of the zone of aeration (depth of the ground water level occurrence); thickness of poorly permeable deposits in the cross section of the zone of aeration; filtration properties of the rocks of the zone of aeration, primarily of the poorly permeable deposits.

The ground waters are most unprotected under the conditions when the zone of aeration is formed of permeable sediments, and there are no layers of poorly permeable rocks in its cross section. Though the ground waters protectability is increased with depth, the effect of this factor is much lower than the presence of poorly permeable deposits in the cross section *(Demin, 2000; Zagovenkova, 1998)*.

The qualitative assessment of the ground water natural protectability may be performed on the basis of the assigned categories of protectability. The categories differ from each other by the point total, which depends on the depth of the ground water level occurrence, thickness of the poorly permeable deposits and their lithology (filtration properties of the deposits depend directly on their lithology). The larger is the point total the higher is the category of protectability. The points corresponding to different depths of the ground water level occurrence, thicknesses and lithology of the poorly permeable deposits are assigned on the basis of the time during which contaminants from the land surface reach the ground water level.

The time of percolation t_1 through the zone of aeration formed of the permeable rocks ($k \approx 2$ m/day) of a thickness of 10 m is taken as reference. The time of percolation t_2 through the zone of aeration 20 m thick formed of similar rocks is about twice as much ($t_2 \approx 2t_1$); through the zone of aeration of a thickness of 30 m – three times as much ($t_3 \approx 3t_1$), and so on.

The thickness of the zone of aeration varies usually from 3 to 30 m, very rarely exceeding 40-50 m. Therefore, five gradations of the ground water level depths are identified: up to 10 m, from 10 to 20 m, from 20 to 30 m, from 30 to 40 m, and over 40 m. Each subsequent gradation differs from the preceding one, on average, by 10 m. The first gradation of the minimal depth of the ground water level occurrence (H<10 m) with the time of percolation t_1 corresponds to 1 point; the second gradation with the depth of the ground water level (10<H<20 m) and the time of percolation about twice as much ($t_2 \approx 2t_1$) corresponds to 2 points; the third gradation – to 3 points, the fourth – 4 points, and the fifth – 5 points.

The thickness of the poorly permeable deposits in a cross section of the zone of aeration is subdivided into 11 gradations: up to 2 m, from 2 to 4 m, from 4 to 6 m, …, from 18 to 20 m, and over 20 m. . Each subsequent gradation differs from the preceding one, on average, by 2 m. According to the lithology and percolating capacity the poorly permeable deposits are subdivided into three groups: group *a* – loamy sands, light loams ($k \approx$ 0.1 to 0.01 m/day), group *b* (intermediate between *a* and *c*) – a mixture of rocks of groups *a* and *c* ($k \approx$ 0.014 to 0.001 m/day), group c – heavy loams and clays (*k* is less than 0.001 m/day). Gradations of the thickness of the poorly permeable deposits in a cross section of the zone of aeration and their corresponding points are given in Table 3.4

Table 3.4

Gradations of thickness of poorly permeable deposits of the zone of aeration and their corresponding points

Gradation number	Thickness of deposits m_0, m	Group of deposits		
		a	b	c
1	<2	1	1	2
2	$2<m_0<4$	2	3	4
3	$4<m_0<6$	3	4	6
4	$6<m_0<8$	4	6	8
5	$8<m_0<10$	5	7	10
6	$10<m_0<12$	6	9	12
7	$12<m_0<14$	7	10	14
8	$14<m_0<16$	8	12	16
9	$16<m_0<18$	9	13	18
10	$18<m_0<20$	10	15	20
11	>20	12	18	25

The point total, which depends on the gradation of the ground water depth of occurrence, thickness of the poorly permeable deposits and their lithology, defines the ground water protectability expressed by the protectability index ε. According to the point total, six categories of the ground water protectability are specified (Table 3.5).

Table 3.5

Categories of groundwater protectability (according to the point total)

Protectability category	I	II	III	IV	V	VI
Protectability index ε	<5	$5<\varepsilon<10$	$5<\varepsilon<10$	$5<\varepsilon<10$	$5<\varepsilon<10$	>25

The most unfavourable conditions of protectability correspond to category I, the most favourable conditions – to category VI.

3.4.2. Qualitative assessment of pressure water protectability

Analysis of the water protectability of the exploited artesian aquifer, the first from the land surface, shows that contaminants can be transferred into it from above, i.e. from the overlying aquifer, waters of which are polluted for this reason or other. In many cases such an overlying aquifer turns out to be a ground water aquifer.

The assessment of the pressure water protectability may be performed on the basis of the following indices:

1) aquifuge thickness;
2) aquifuge lithology;
3) aquifuge filtration and migration parameters;
4) correlation of water levels of the aquifer under study and the overlying aquifer.

Contaminants are waterborne from the overlying aquifer to the pressure waters through the aquifuge by convection, due to a molecular diffusion or a combination of both. The pollution of the pressure waters takes place mainly by means of the convective transfer, as its scope under the conditions of active water exchange many times higher than that of the diffusion transfer.

The level correlation of the pressure aquifer and the overlying aquifer is important for the assessment of the pressure water protectability, for it controls the pollutants' ingress to the pressure aquifer.

Denoting the overlying aquifer level by H_1 and that of the underlying pressure aquifer by H_2, three conditions for the assessment of the pressure water protectability may be defined: 1) $H_2 > H_1$, 2) $H_2 \approx H_1$, 3) $H_2 < H_1$. In the first case, i.e. when the levels of the pressure aquifer under study are higher than the levels of the overlying aquifer at the presence of an aquifuge adequate in area and thick enough to withstand this level difference, the pressure aquifer with high degree of probability may be considered protected from any kind of pollution as long as the condition $H_2 > H_1$ is maintained. With this level correlation, when the vertical flow gradient is directed upwards (a positive gradient), the ingress of contaminants from the overlying aquifer to the underlying one by means of convection is not possible. The transfer of contaminants to the lower aquifer under these circumstances can take place only by means of molecular diffusion. But the diffusion transfer will be hampered, because the gradient of concentration, that controls the process of diffusion, in this case is opposite to the vertical pressure gradient (they are directed towards each other). Therefore, these hydrogeological conditions provide for the highest degree of protectability of the pressure waters from the polluted water inflow from the overlying aquifer.

A less favourable hydrogeological situation is when the levels of the underlying and overlying aquifers coincide ($H_2 \approx H_1$). In this case the vertical pressure gradient, directed upwards and preventing contaminants transfer from above does not exist. But at the same time there is no downward pressure gradient (negative gradient) also, which controls contaminants transfer through the aquifuge from above. The ingress of contaminants from the overlying aquifer to the pressure aquifer is possible in this case by means of diffusion, which is not hindered under these circumstances by the positive pressure gradient.

The most unfavourable hydrogeological conditions are when the levels of the pressure aquifer are lower than the levels of the overlying aquifer ($H_2 < H_1$). In this case the vertical pressure gradient is directed downwards forming hydrogeological conditions for the contaminated water flow to run from the overlying aquifer to the underlying pressure aquifer. The contaminants transfer in this case takes place by means of a joint action of the convection and diffusion oriented in one direction.

Thus, the pressure water protectability depends greatly on the correlation of water levels, which creates conditions for and nature of the contaminants transfer to the pressure aquifer.

Anyhow, regardless its importance, this index cannot be considered the only one to be used for the assessment of the pressure aquifer protectability. In fact, the correlation of the underground water levels can change with time in the course of exploitation. So, if initially levels of an exploited aquifer were higher than a level of the ground waters, and the pressure aquifer was protected from the contaminated ground waters, than later on due to the underground water extraction the correlation of the levels may become quite opposite, creating conditions for the ground water flow to run to the pressure aquifer. The protectability of the latter will decrease drastically. Consequently, if the correlation of the levels can change with time, the protectability of the pressure aquifer can also be time variable.

The aquifuge thickness may be considered as a basic, and quite stable and reliable, index of the pressure water protectability assessment. Other important factors are lithology of waterproof rocks, their filtration properties, and the above mentioned correlation of the underground water levels.

In the areas of fresh underground water occurrence, confining layers are represented mainly by clay rocks, sometime marls and carbonate deposits. The clay confining layers are believed to be the most reliable aquifuges, but it is not always so. Screening properties of the confining layers may differ depending on the type of clay minerals: a confining layer is the most reliable when montmorillonite prevails in its composition. In the least reliable confining layer caolin is predominant.

The qualitative assessment of the pressure water protectability is based on the thickness of the confining layer or on the ratio of its thickness to its filtration coefficient, as well as on the correlation of the underground water levels.

The following gradations of an aquifuge thickness (m_o) are specified:

I – $m_o < 5$;

II – $5 < m_o \leq 10$ m;

III – $10 < m_o \leq 20$ m;

IV – $20 < m_o \leq 30$ m;

V – $30 < m_o \leq 50$ m;

VI - $m_o > 50$ m.

The protectability assessment based on these gradations is comparative, i.e. protectability II is assumed to be better than I, and III - better than II, etc.

Based on a combination of these two indices - m_o and the level correlation (H_2 of the pressure aquifer under study and H_1 of the overlying aquifer) the following main groups of the pressure water protectability may be defined:

I – (protected) – pressure waters are overlain by a confining layer adequate in area and having no discontinuity at $m_o > 10$ m and $H_2 > H_1$;

II – (conditionally protected) - pressure waters are overlain by a confining layer adequate in area and having no discontinuity at (a) 5 m < m_o < 10 m and $H_2 > H_1$, and (b) $m_o > 10$ m and $H_2 \leq H_1$;

III – (unprotected) – a confining layer is thin: (a) $m_o < 5$ and $H_2 \leq H_1$ or (b) a confining layer is inadequate in area and has discontinuities (lithologic “windows”, zones of developed fractures, faults), $H_2 <> H_1$.

In group I, the protectability of the pressure waters is ensured by a large thickness of a confining layer and such hydrogeologic conditions, under which the ingress of polluted waters from above is not possible. Within group I the protectability varies depending on the confining layer thickness and the difference of water levels.

It should be noted that if a confining layer is adequate in area but has discontinuities, than even at $H_2 > H_1$ the pressure aquifer cannot be considered protected.

Having analyzed the data of different wells: exploratory, production, observation and test, as well as aerial photographs, the authors have plotted a map of the underground water protectability on the territory of the Nizhny Novgorod region (Fig. 3.6), contouring areas of “active” karst development.

The obtained information has revealed that territories with a high degree of the underground water protection turned out to be quite vulnerable to the surface pollution due to numerous sinkholes, collapse dolines, karst lakes, depression cones, sinking streams. In view of this, while zoning the karst territories with respect to the degree of the underground water protectability, the authors have added one more category: a territory of increased vulnerability to the surface pollution because of disruption of the lithologic cross section continuity by numerous collapse dolines, sinkholes, depressions and other forms of surface and subterranean karst.

The implemented zoning of karst territories with respect to the underground water protectability subjected to the existing technogenic loads was used as a basis for elaborating recommendations on site selection for construction of ecologically dangerous landfills of toxic industrial wastes on the territory of the Nizhny Novgorod region.

3.5 Methodological fundamentals of assessment of underground water interconnection on the karstified territories

To define the probability of aquifers’ interconnection on karst territories, one should first specify the required and sufficient conditions for this process.

The first necessary condition for the adjacent aquifers’ interconnection is the separating confining layer permeability; the second one is the correlation of the levels (piezometric levels) of the adjacent aquifers that controls direction and velocity of the underground water flow.

The change of the underground water chemical composition may serve as a confirmation of the existence of the underground water flow through the poorly permeable strata (provided chemical compositions of the adjacent aquifers are different).

3.5.1. Main factors determining rock permeability

Permeability (or water permeability) of rocks is their ability to allow water to pass through them under pressure. In a wider sense, by the rock permeability a water motion through pores and voids not only by gravity, but also by other kinds of moisture transfer – capillary, film, vaporous and electroosmotic – is meant. Being an extremely important property of rocks, the permeability depends on their porosity and voidage, on the properties of filtered liquids and hydrogeologic conditions (presence of pressure).

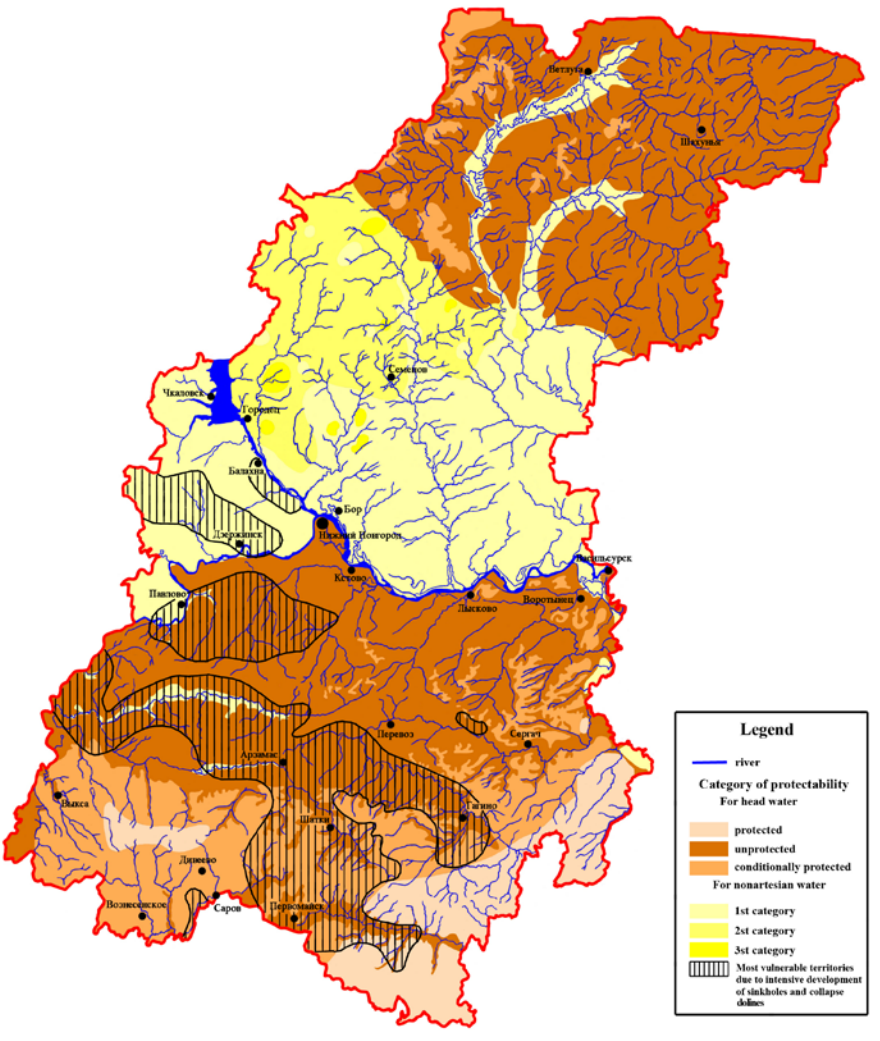


Fig. 3.6 Map of the underground water protectability of Nizhny Novgorod region with allowance for the karstification factor

In any rock there may be identified a volume of a mineral part and a volume of pores and voids filled completely or partially with water, air and gases. The voidage or porosity determines the relative volume of all voids and pores in a rock. The term “voidage” (“porousness” by F.P. Savarensky) is referred to all kinds of voids, regardless of their size and shape.

Describing porosity, different authors specify different maximum sizes of microvoids. For example, V.D. Lomtadze determines rock porosity as a relative volume of voids of a capillary size (pore diameter < 1 mm, fracture width < 0.25 mm) and a subcapillary size (pore diameter < 0.0002 mm, fracture width < 0.0001 mm). E.E. Kerkis (1948) recommended to use the term “porosity” only with respect to the relatively small voids (up to 5 mm in diameter) of the same sizes and oriented in different directions.

In this work by the term “voidage” the relative volume of all the voids and pores irrespective of their shape and size is implied; by the term “porosity”, according to V.D. Lomtadze, the relative volume of voids of capillary and subcapillary sizes is meant.

The necessity to differentiate the terms “voidage” and “porosity” is caused by the fact that in a rock massif the porosity is distributed relatively uniformly, and it does not usually affect the integrity of rocks (basically hard rocks). But the voidage disrupts the rock integrity, discrete and conjugated fractures disintegrate a rock massif into separate blocks, change hydrologic properties of rocks (water-absorbing ability, water yield, water permeability), deteriorate their strength and deformation properties.

By type of voids, rocks are subdivided into:

- porous clastic incoherent;
- porous clastic coherent;
- fractured;
- karstified and cavernous.

According to Sh.K. Gimatudinov, the porosity in the clastic rocks is differentiated into:

- complete or absolute (porosity factor), equal to the volume of all the pores (open and isolated, nonconjugated);
- open, equal to the volume of all open conjugated pores;
- effective, equal to the volume of the porous space through which water moves.

Incoherent clastic rocks contain relatively little bound water, their complete porosity is almost the same as open porosity and equals their water yield. The effective porosity is equal to the open porosity minus the relative volume of the “dead zones” of stagnant water and the volume of bound water. But in the opinion of E.E. Kerkis, this concept is in a way indefinite, because the transition to the dead zones and films of bound water is gradual. Besides, the dead water in pores and the film water are not entirely still *(Kerkis E.E., 1948)*.

According to their origin, pores and voids in the rocks are subdivided into primary (syngenetic), formed simultaneously with the rocks, and secondary (epigenetic), formed afterwards, in the following geologic period during rock transformation.

The primary are pores and voids that occur between grains of fragmental rocks; bedding joints and lithogenous fractures; fractures of primary cleavage in cooling-down igneous rocks; caverns and voids appeared during the cooling-down of effusion rocks accompanied by gas emission. The secondary voids and fractures often occur in places of the primary ones. For example, caverns can form in the sections of fine lithogenous fractures.

Porosity is the most important feature of the sedimentary fragmental rocks, which is formed by the intergranular voids. In igneous and metamorphic rocks, the porosity is formed mainly by microcracks. The rock porosity is not a constant value. It depends not only on the conditions of rock formation, but also on the action of lengthy and complex physic-geologic processes on the rocks caused by endogenous and exogenous factors. In the course of such an action the porosity and voidage of the rocks may either decrease, sometimes almost to zero, or increase.

Weathering plays not the least role in the formation of the rock permeability. At physical weathering the rock permeability usually increases. In hard rocks it can reach a thousand darcy. However, in the course of weathering fine materials that form in large quantities fill up pores and voids decreasing the rock permeability. Chemical weathering is usually most active in the zone of aeration, but it takes place in the entire zone of water circulation diminishing with depth. The thickness of a weathering crust, according to B.B. Polynov (1950), can reach 50 m.

The rock porosity and voidage are subject to change due to rock dissolution by the underground waters. The most soluble rocks are halite and sylvite, gypsum and anhydrite. Tiff and dolomite are less soluble. Dissolubility of halite at a temperature of fresh water of 10°C constitutes 320 g/dm^3, anhydrite – 1.93 g/dm^3, tiff – 15 g/dm^3. At a concentration of NaCl in water ranging from 130 to 180 g/dm^3, solubility of $CaCO_3$ is more than three times higher; the solubility of $CaCO_3$ increases also with the increase of the content of free CO_2.

The rate of the rock dissolution depends on the temperature, dissolubility, hydrogeologic factor (intensity of water circulation, a character of water motion), and a character of the rock surface. Formation of joints is especially important for the rock permeability.

An interface at which the vector of displacement is disrupted is called a joint *(Shatsky, 1945; Shultz, 1964)*. A total of joints constitutes the rock mass fracturing. The rock fractures are differentiated according to geometry, morphology, genesis, age and mechanism of formation. The rock fracturing was studied by M.V. Ratz, V.V. Belousov, S.S.Shultz, S.N. Chernyshov, N.I. Kriger, L.I. Neishtadt, E.M. Smekhov, A.E. Mikhailov, M.V. Gzovsky, M.N. Polyansky, L.D. Knoring, A.S. Novikova, E.N. Permyakov and other researchers. We will focus on a genetic systematization of the joints. I.P. Kushnaryov and L.I. Lukin (1960) specify three basic types of joints in the rocks: petrogenetic, tectonic and exogenous. Interfaces formed in the process of intensive plastic deformations, better known as “cleavage”, are singled out in a separate group.

The petrogenetic joints form under the action of internal energy of sediments (rocks), in many cases due to the shrinkage of a solid phase. Therefore, within the limits of a uniform layer or a rock massif the pattern of the primary petrogenetic joints remains relatively the same.

The lithogenous joints in sedimentary rocks form usually in the layers thickness of which is small in comparison with their area, and the character of joints depends entirely on the composition, structure and texture of the rocks.

The tectonic movement is one of the main reasons of occurrence of joints in the rocks. The tectonic fractures are subdivided into two groups – planetary or general and local. N.S. Shatsky (1945) while stating that all dislocations on the platforms had been caused by general stresses in the earth’s crust, noted that jointing in the sedimentary rocks of the Russian Platform had developed not only in the areas of placanticlines (dislocated parts of the platform), but also in almost horizontal layers on the syneclise flanks.

The general *(Barenblatt, 1961, 1963)* or planetary *(Shultz, 1964)* fractures, forming the background of the sedimentary rock jointing, are widely distributed over the platform constituting two mutually transverse systems: orthogonal (N-S-, E-W-oriented) and diagonal (NE-SW-, NW-SE-oriented). The conjugated joints are not confined in any particular structure, but are observed in the rocks of the entire sedimentary cover, their orientation is constant; but the density decreases in the upward direction. At the same time dependence of the joint density on the thickness of the strata they pass is clearly observed. The tectonic fractures are more apparent in the dense rocks, where they are usually normal to stratification.

The local joints are subdivided into fault- and fold-related fractures. Discontinuity (disjunction) of rocks is accompanied by the fault-related fractures with flank displacement with respect to a fault fracture. A fault fracture, as a rule, is accompanied by subparallel and “feathering” fractures creating zones of increased permeability in the rocks. But when a master fracture is filled with poorly permeable fragmental rocks, the surrounding fractured zone has a higher permeability.

The fold-related fractures are small fractures formed due to folding and associated, as a rule, with the primary joints. On an anticline roof these fractures are normal to the bedding and have maximum opening and increased conductivity; on the flanks of the structures, fractures develop due to the displacement along the stratification planes, they are parallel to the bedding and have small opening and low permeability *(Romm, 1966)*.

The permeability of the tectonic fractures depends on the age of the orogenic processes: the more ancient is the period of tectonic movement the lower is the conductivity of the fractures of tectonic zones, “cured” in the course of the geologic history of a region.

The general features of the tectonic fractures are:

- considerable depth and length; the fractures pass through the whole series of strata of different rock composition;
- consistency of orientation of both discrete fractures and fracture systems in specific directions;
- even, smooth walls of contraction fissures, and uneven, rough, torn walls of tension cracks.

The fractures of the first type, as a rule, are tight, while those of the second type are open. The fractures of the second type are either open-joint, or filled with secondary minerals or other inclusions. E.N. Permyakov underlines that differences in the wall appearance between the contraction and tension fractures can reduce considerably in the course of time due to the weathering processes. Anyhow, during field investigations he encounted slickensided surfaces on the walls of contraction fractures formed during considerably ancient geologic epochs. Regardless of this fact, the walls of the fractures still remained very even, strong enough, and just slightly ironshot, though the rock itself was highly cavernous just one centimeter away from a fracture wall. Such a resistance to the weathering and leaching may be explained in this particular case by the considerable consolidation of the rock in a narrow zone alongside the fracture at the moment of contraction and sliding. The permeability of the fractured strata depends largely on their composition. Seamy nonlaminated hard rocks, mechanical breakage of which produces small quantities of disperse materials capable to mud the fractures, have the highest degree of permeability. The permeability of laminar rocks (gypsum, anhydrite, rock salt, clay, marl, etc.) is low, because the fractures in these rocks are tight even at small depths. Conductivity of the fractured rock masses reduces sharply if fractures are filled with the secondary minerals and fine poorly permeable rocks (clay, marl, etc.).

The tectonic fractures subjected to the exogenous processes near the land surface undergo changes. The change of the rock stress in the course of the river valley development leads to formation of fractures in the bank and bottom soils that in their turn increase the permeability of the sediments.

The weathering fractures, unlike the tectonic ones, are not deep and often filled with the products of weathering – fine detrital deposits.

The artificial fractures form in the rocks in the result of engineering activities. Explosion fractures affect permeability most of all. These fractures, like other exogenous fractures, develop along the planes of weakness that exist in the rock massif. The explosion fractures cause the spreading and concentration of the already existing conjugated fractures; in a zone adjacent to the charge placement the rock crushing takes place irrespective of the previously existed systems of fractures.

The cleavage fractures are characterized by the low permeability that is close to zero. The filtration characteristic of the underground water laminar motion is expressed by the coefficient of filtration k, which is assumed as a velocity of filtration at a pressure gradient equal to 1, and the coefficient of permeability k_0, which describes more accurately the properties of the filtrated liquid. The relationship of the two coefficients may be expressed as follows:

$$k_o = k\frac{\eta}{\lambda} = k\frac{\vartheta}{g} \qquad (3.1)$$

where η and ϑ are the absolute and kinematic coefficients of viscosity; γ is the volume weight; ρ is the liquid density; g is the force of gravity.

The dependence of the permeability on the geometry of a pore medium was studied in detail by M.V. Shestakov (1979). For the rocks with the skeletal specific surface area *S* the coefficient of filtration (k) is equal to:

$$k = \frac{g\chi n^3}{2\vartheta S^2} \qquad (3.2)$$

where χ is the coefficient of pore tortuosity, n is the rock porosity.

The available formulas of calculation of the filtration coefficient on the basis of a granulometric composition have a limited application due to the difficulty to take into account specific features of the natural structure and composition of the rocks.

It is a well-known fact, that the rock permeability is not defined by the total porosity and voidage, but the total conductivity of the interconnected conduits, pores and voids. At a laminar water flow in a uniform system of similar fractures the coefficient of permeability (k) of fractured rocks may be calculated according to E.S. Romm's formula (1966):

$$k_o = An_T\,\delta_T, \qquad (3.3)$$

where A is the numeric coefficient dependable on the mutual orientation of fractures. When the fractures are oriented uniformly, A=1; at a chaotic orientation A=0.5; n_T is the fracturing; δ_T is the width of a flat fracture.

The permeability of loose clastic rocks depends on the density of their structure. As the experience reveals, at the rock consolidation the coefficient of filtration reduces linearly with the reduction of the coefficient of porosity.

The Darcy's law is the basic law of the underground water filtration in the rocks that describes the relationship between the laminar water flow and the pressure drop. The law is not applicable to the underground water motion in highly permeable rocks because of a sharp increase of filtration velocities and the flow regime transformation into turbulence, as well as in distinctly less permeable rocks with low velocities of filtration.

The detailed analysis of all the researches carried out in order to determine the upper limit of application of the Darcy's law in a porous medium was presented in V.N. Schelkachyov's work (1949). His observations show that the water flow even in the coarse-grained rocks continues to be laminar, and just in the gravel-stone and seamy hard rock formations a turbulent regime of filtration can occur, i.e. under the conditions that are rarely encountered in a hydrogeologic practice.

The lower limit of application of the Darcy's law is of much more interest from the practical point of view.

Following the Darcy's law, at the pressure gradients observed under natural conditions the underground water motion in fractures is mainly laminar. Natural flows have become turbulent when the width of fractures exceeds 1.5-2 mm, as well as at the fracture widths ranging from 0.05 to 0.1 cm under the conditions of hydrogeologic experiments. E.E Kerkis (1948) deduced a formula to determine the critical gradient $J_{кр}$. for an ideal model of fractured rocks characterized by three systems of mutually perpendicular evenly spaced similar fractures:

$$J_{\text{кр}} = \frac{4S\gamma}{kl} \cdot N_{\text{кр}}, \tag{3.4}$$

where S is the coefficient of tortuosity (the ratio of the actual fracture length to its corresponding straight-line section, usually $1 \le S \le 2$); γ is the density of water; k is the coefficient of filtration; l is the length of the filtration path; $N_{кр}$ is the Reynolds number.

For S =1.5, γ =0.01 st, $N_{кр}$=50, at l between 0.1 and 10 m, $J_{кр}$.values vary from 30 to $3 \cdot 10^{-4}$, when k (at 10ºC) ranges from 1 to 1000 m/day and the coefficient of permeability from 1.33 to 1330 darcy.

The critical gradients of seamy rocks in reality are lower than those calculated for the ideal model with the help of formula (3.4). It may be explained by the fact that with the growth of the pressure gradient deviations from the Darcy's law start initially in the large-size fractures and then proceed to the thin fractures. According to E.E. Kerkis, in karst conduits even of relatively small diameter the Darcy's law is valid only for low water flow velocities and small pressure gradients. For instance, at a water velocity ranging from 0.8 to 80 cm/s and a fracture radius between 0.1 and 10 cm the critical gradient, i.e. the pressure gradient at which a laminar water flow changes to turbulent, lies within the limits from 0.65 to $6.6 \cdot 10^{-7}$, and the coefficient of permeability changes from 123 to $1.2 \cdot 10^{-6}$ cm/s accordingly. Since karst fractures, conduits and voids under the natural conditions are filled partially with loose material or secondary minerals reducing their cross-section area, the actual values of critical gradients are higher than the above mentioned.

Nonlinear dependences of the filtration rate on the pressure gradient were studied by many authors and addressed in detail in the works of Shultz S.S., 1964, Kerkis E.E., 1948, Minsky E.M., 1958, Ratz M.V., 1970. The transition of the law of filtration from a linear dependence to nonlinear at the increase of the pressure gradient is different in different types of rocks: in loose and fractured rocks the transition is mainly gradual and slow, in karstified rocks (with unfilled karst conduits) it is sharp.

3.5.2 Regional patterns of distribution of filtering properties of poorly permeable deposits in Nizhny Novgorod region

Sedimentary rocks in the Nizhny Novgorod region differ in age, lithology, structure, hydrogeologic properties and filtration parameters (Fig. 3.7).

Based on the commonality of the hydrogeologic properties and parameters, the following rock complexes have been defined on the studied territory:

1. Sandshale complex represented by Cenozoic fragmental porous unconsolidated rocks (Quaternary, Neogene, Paleogene) of the alluvial, glacial, alluvial-fluvioglacial and fluvioglacial genesis. These are mainly sands of different coarseness with layers of clay sand, loam and clay.
2. Lower Triassic and Tatarian marl clay complex represented mainly by fractured marls, clays with layers of siltstone, sands, sandstone, conglomerates, dolomites, gypsum and anhydrite.
3. Lower Kazanian carbonate complex formed mainly of fractured, sometimes karstified limestone and dolomites.
4. Lower Permian gypsum-anhydrite complex represented by the monotonic seamy masses of gypsum and anhydrites, the upper part of its cross section is formed of dolomites with random layers of clay.
5. Lower Permian, Carboniferous and Devonian terrigenous-carbonate complex. These are mainly fractured limestones and dolomites interlain by terrigenic rocks.

The Cenozoic Lower Kazanian deposits and the terrigenous-carbonate complex of the Lower Permian, Carboniferous and Devonian rocks are water-bearing and water permeable. These deposits confine region-related aquifers, and they are distinguished by a high water content and permeability.

The Lower Triassic and Tatarian deposits and Lower Permian gypsum-anhydrite rock masses constitute poorly permeable layers that divide the pressure water system of

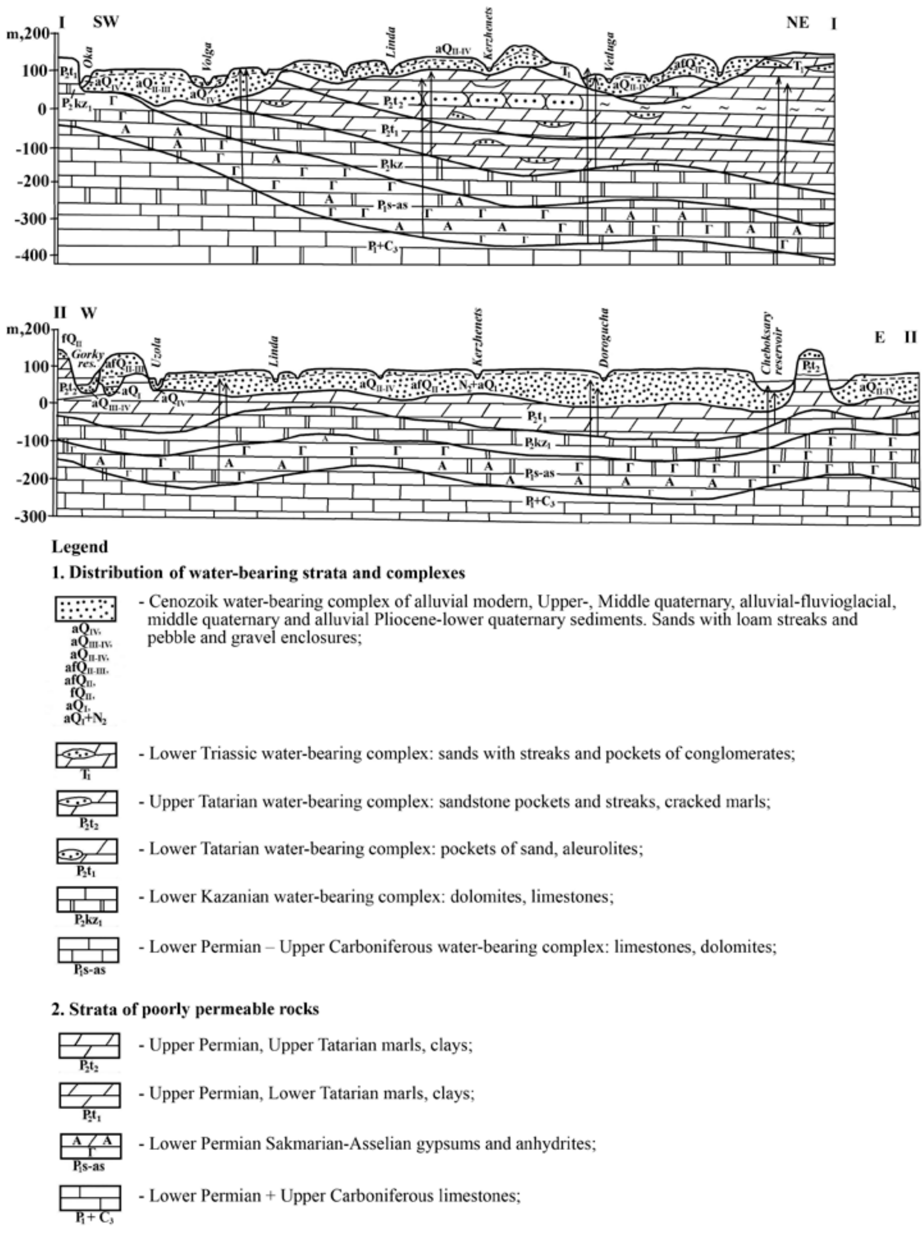


Fig. 3.7 Schematic diagrams of hydrogeologic cross sections

the sedimentary rock masses into relatively independent aquifers and water-bearing complexes.

Let us consider structural features of the poorly permeable layers.

The Lower Triassic and Tatarian marl clay deposits separate ground waters of the Cenozoic water-bearing complex and the Lower Kazanian pressure aquifer.

A distinguishing feature of the lithologic structure of this poorly permeable interlayer is the increased sanding of the rocks observed in its cross section on the watersheds and watershed slopes in the areas, where deposits are represented by the Lower Triassic and Upper and Lower Tatarian rocks. It refers especially to the upper part of the cross section, where thick layers of sand, sandstone and conglomerates are present. In the upper and middle reaches of the Volga left-bank tributaries the sanding diminishes. In their lower reaches, in the Volga valley, in the lower reaches of the Oka river, where the Lower Triassic and Upper Tatarian deposits are not present, and the Lower Tatarian deposits are represented mainly by gypseous clays and marls, the streaks of sand, sandstone and conglomerates have a secondary significance.

The surveys carried out during the construction of bridges across the Oka and Volga rivers at Nizhny Novgorod revealed that the Tatarian rock masses in the river-beds were characterized by the increased fracturing. Branching cracks of size upto 20-30 mm, sometimes 40 mm, in clays, sandstones and marls were filled with gypsum of a cross-fibrous structure (Fig. 3.8). Discrete fractures damped out (thinned out) quickly to microfractures; within one layer highly fractured rocks changed over to rocks with tight fractures and even to solid rocks. It was also pointed out that fractures filled with selenit traversed inclusions of rounded contractions of gypsum in the rock mass as well.

The fracturing of the Upper Permian Tatarian rocks is clearly visible in the river steeps, walls of quarries and excavation pits; it is registered in cores during drilling operations and observed along the entire cross section.

In the upper part of the cross section the fractures are open, having films of iron and manganese oxides on their faces. In the middle and lower parts of the cross section blind fractures prevail, easily revealing at a slight strike on the rock; these are tight fractures, usually filled with palygorskite, anhydrite, gypsum, selenit, sometimes clay. The fracture faces are also covered with manganese and iron oxides; their orientation varies, but a system of vertical fractures is more distinct. Genetically, these are weathering fractures (located basically in the upper part of the cross section and on the slopes) as well as bedding and tectonic fractures.

Judging from the descriptions of the cores of numerous wells drilled during geologic and hydrogeologic surveys, the fracturing of the Tatarian rock messes is maximal on the crests of anticlines, where their thickness diminishes.

The fracturing is typical for Lower Triassic deposits, too. Found mainly in the north part of the studied territory, the rocks of this age are disintegrated by numerous fractures, predominantly weathering, bedding and tectonic. The fracturing diminishes with depth. As in the case of the sedimentary cover of the Russian Platform, the Lower Triassic rocks are characterized by two mutually perpendicular systems of tectonic fractures: orthogonal (N-S-, E-W-oriented) and diagonal (NE-SW-, NW-SE-oriented). The maximal fracturing and bedding dislocation in the Lower Triassic deposits are

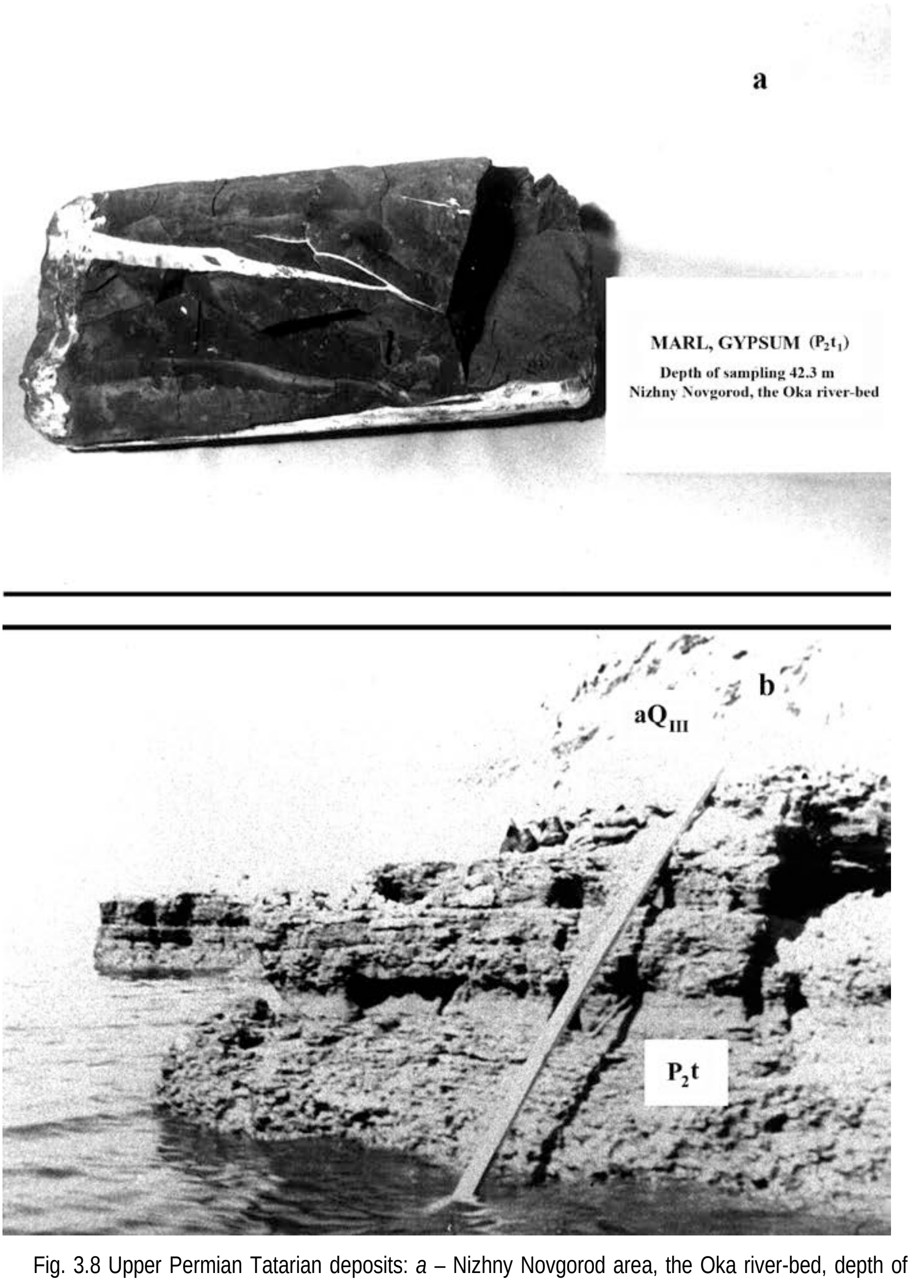


Fig. 3.8 Upper Permian Tatarian deposits: *a* – Nizhny Novgorod area, the Oka river-bed, depth of sampling is 42.3 m; *b* – rock exposure at the settlement of Sokolskoe, the Gorky reservoir

observed in the Volga valley, upstream of Gorodets, in the area of the well-known Puchezh-Katun dislocations, where the rocks are heavily fractured, rumpled and folded.

The ubiquitous fracturing along with the increased sanding of the Lower Triassic and Upper Permian deposits creates conditions for the rock mass permeability.

The permeability of the Lower Triassic and Upper Permian marl clay deposits was determined by means of a balance method (Fig. 3.9). Mean values of the coefficient of filtration of the poorly permeable deposits vary in area (from $n \cdot 10^{-3}$ to $n \cdot 10^{-5}$ m/day). Rocks with the increased coefficients of filtration of $n \cdot 10^{-3}$ m/day appear in the Volga valley upstream of Gorodets, in the lower reaches of the Uzola river (south from the Gorodetsko-Koverninskaya tectonic zone), in the country between the Linda and Kerzhenets rivers, in the upper reaches and right-bank areas of the Vetluga river, as well as in the left-bank areas of the Volga river between the lower reaches of the Kerzhenets and Vetluga rivers.

The highest values of the coefficient of filtration upto $5.6 \cdot 10^{-3}$ - $9.6 \cdot 10^{-3}$ m/day are registered in the right-bank areas of the Vetluga river. Relatively high coefficients of filtration of $3.6 \cdot 10^{-3}$ - $5.3 \cdot 10^{-3}$ m/day are observed in the deposits near the Gorodetsko-Koverninskaya tectonic zone, where dislocations of the rock bedding are registered everywhere.

The rest of the territory, that is the Volga valley downstream of Balakhna, the Oka valley, the valleys of the Volga left-bank tributaries, as well as a vast swamped territory between the Kerzhenets and Vetluga rivers are characterized by the coefficient of filtration $n \cdot 10^{-4}$ m/day; and just discrete sections of the watersheds (relatively small in area) and the Volga valley at the city of Novocheboksarsk have the permeability that does not exceed $5.6 \cdot 10^{-5}$ - $8.6 \cdot 10^{-5}$ m/day. Such a distribution of the rock permeability, when the most permeable zones are located mainly on the watersheds, may be explained by the fact that the permeability of the marl clay rocks depends primarily on the degree of their sanding.

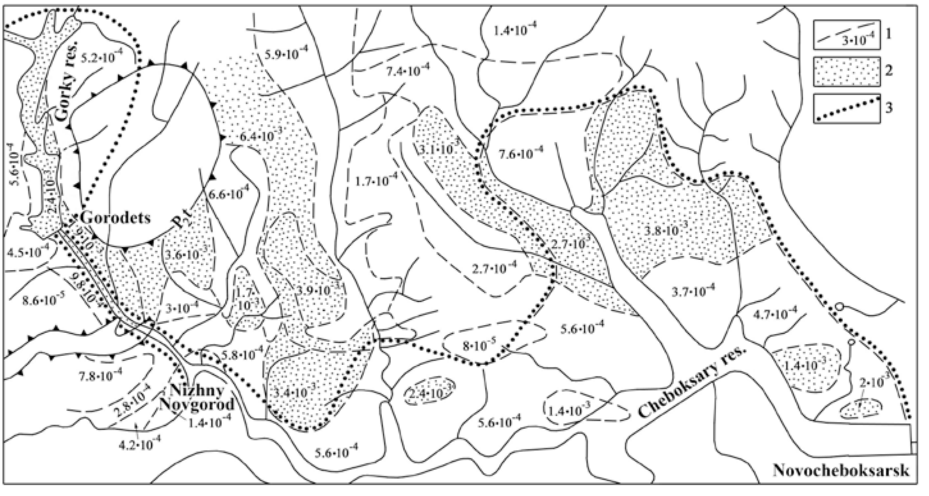


Fig. 3.9 Schematic diagram of the permeability of the Upper Permian Tatarian deposits on the territory adjacent to the Gorky and Cheboksarsk reservoirs: *1* – boundaries of districts and mean values of the coefficient of filtration of the deposits (k_0 m/day); *2* – areas with the value k_0 $n \cdot 10^{-3}$ m/day; *3* – boundary of the groundwater backup zone

On the watersheds, though the rocks are fractured to a lesser degree, the cross section of the Tatarian deposits are represented by a full range of the Upper and Lower Tatarian strata characterized by the highest degree of sanding.

As the sanding of the cross section diminishes, and clays, marl clays and marls in it (in the valleys of the Volga and its tributaries) become dominant, the permeability of rocks reduces.

The increased permeability of the marl clay deposits in the Volga valley upstream of Balakhna is explained, apart from the high degree of sanding, by the increased tectonic disintegration of the rock masses in this area as compared with the rest territory of the valley.

In the north part of the studied territory (the upper reaches of the Volga tributaries) the permeability of the marl clay deposits decreases due to the presence of the Lower Triassic deposits in the cross section. In the left-bank areas of the Volga and near the city of Yurievets the coefficient of filtration constitutes only $8.6 \cdot 10^{-5}$ m/day; in the upper reaches of the rivers of Kerzhenets, Vetluga and Rutka it is slightly higher – $1.4 \cdot 10^{-4}$ m/day.

The rocks of the Sakmarian Asselian deposits are rather monotone masses of gypsums and anhydrites interlain by dolomites, often gypseous dolomites. The rocks are fractured. The fractures are both open and tight, filled with anhydrite, gypsum, marl, clay. In the anhydrite layers (Fig. 3.10) bedding fractures were found. During well drilling a breakthrough of a boring tool was often observed, caverns and karst voids were registered.

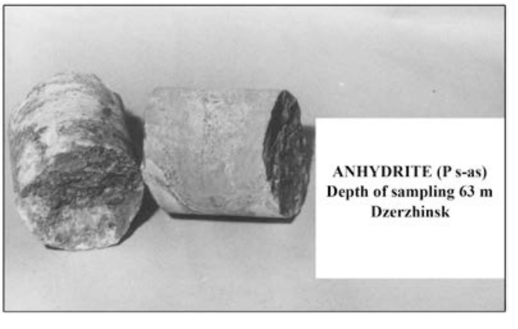


Fig. 3.10 Lower Permian anhydrite, the city of Dzerzhinsk, sampling depth is 63 m

The orientation of fractures varies; the vertical fractures are more noticeable. With an apparent chaotic character of the orientation, two mutually perpendicular systems of tectonic fractures, typical, as mentioned above, for all the rocks of the sedimentary cover of the Russian Platform, are distinguished: orthogonal and diagonal. The maximal dislocation is on the crests of anticlines with a lesser disturbance on the sides.

Open porosity of gypsums and anhydrites within the limits of the anticline high (Kstovo district) in the average is less than 1%, the permeability is under 0.1 md. When the gypsums and anhydrites are interlaid with dolomites, an increase of the open porosity up to 4.6% and the permeability up to 1.35 md is observed. The increase of the permeability and porosity is also observed in the gypsums of macrocrystalline structure. In the dolomite rocks the open porosity varies in a wide range from 0.1 to 21.4% and permeability – from less than 0.1 to 17.5 md, which is connected with the structural features of the rock and the presence of microfractures.

The balance calculations permitted to identify regional patterns of distribution of the permeability of the gypsum-anhydrite strata. If the permeability of the upper layer of the poorly permeable marl clay to a greater degree is determined by the lithologic non-uniformity of the rocks and to a lesser degree by the fracturing, then the permeability of the lithologically uniform gypsum-anhydrite section is determined mainly by the tectonic fracturing.

The rock fracturing diminishes naturally from the Volga valley to the watersheds, in the same direction the coefficient of filtration of the rocks decreases (Fig. 3.11).

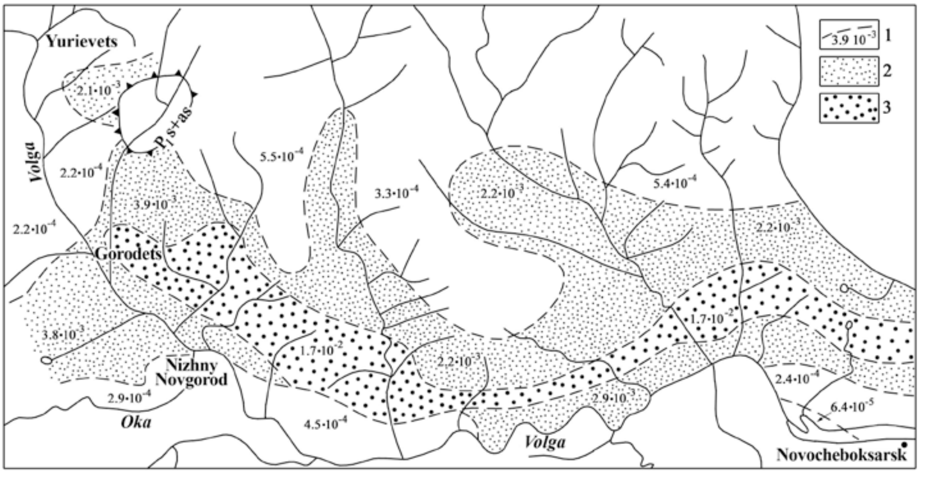


Fig. 3.11 Schematic diagram of the permeability of the Lower Permian Sakmarian Asselian deposits (P_1s-as) on the territory of Nizhny Novgorod region: *1* – boundaries of districts and mean values of the coefficient of filtration of deposits (k_0 m/day); *2* – areas with the value k_0 $n \cdot 10^{-3}$ m/day; *3* – areas with the value k_0 $n \cdot 10^{-2}$ m/day

A strip of the most permeable deposits with the value of the coefficient of filtration $n \cdot 10^{-2}$ m/day (from $1.1 \cdot 10^{-2}$ to $4.6 \cdot 10^{-2}$ m/day), i.e. water permeable deposits (k > 0.001 m/day), from 5 to 20-25 km wide and about 250 km long stretches to the left-bank areas of the Volga parallel to its bed from Novocheboksarsk to Gorodets, coinciding in plan with the Volga paleovalley. Sufficiently high values of the coefficients of filtration of the gypsum-anhydrite deposits ($n \cdot 10^{-3}$ m/day) are observed in the Volga bed and its right-bank valley upstream from Nizhny Novgorod to Gorodets, in the middle reaches of the Uzola river, in the country between the Uzola and Linda rivers, geographically adjacent to the Gorodetsko-Koverniskaya tectonic zone, in the middle reaches of the rivers of Kerzhenets, Vetluga and Rutka. These areas stretch lengthwise the river valleys, the coefficients of filtration of the rocks range from $1.2\cdot10^{-3}$ m/day in the Uzola valley to $2.2\cdot10^{-3}$ m/day in the valleys of the Kerzhenets, Vetluga and Rutka rivers. On the watersheds a natural decrease of the rock permeability is registered: the values of the coefficients of filtration go down to $1\cdot10^{-4}$ m/day, and on higher areas they are only $(5\text{-}5.9)\cdot10^{-5}$ m/day.

The picture of the regional distribution of the rock mass permeability in the Volga valley south from the strip of the permeable rocks is a little bit different. Downstream from Nizhny Novgorod in the Volga bed, in the floodplain, in the areas of the 1st above-floodplain terrace the permeability of the gypsum-anhydrite deposits first reduces, in the lower reaches of the Kerzhenets river the coefficient of filtration constitutes $(3\text{-}7.7)\cdot10^{-4}$ m/day, downstream from the Kerzhenets inflow it increases to $n\cdot10^{-3}$ m/day, varying from $1.1\cdot10^{-3}$ to $8.5\cdot10^{-3}$ m/day, and only at Novocheboksarsk it goes down again to $2.4\cdot10^{-4}$ – $6.4\cdot10^{-5}$ m/day.

Upstream from Gorodets the permeability of the gypsum-anhydrite deposits is relatively uniform, the coefficients of filtration vary from $(3.9\text{-}5.6)\cdot10^{-4}$ m/day in the Volga valley to $(1.9\text{-}2.1)\cdot10^{-4}$ m/day on the watersheds, and only in the immediate vicinity of the border of deposits' thinning on the Volga left-bank territories the coefficient of filtration increases up to $2.1\cdot10^{-3}$ m/day.

Thus, the permeability of the gypsum-anhydrite deposits depends on the tectonic structure of the studied territory. The most permeable sections, in spite of the deposits' uneven thickness ranging, on average, from 100 to 140-150 m, are located in the most fractured zones – river valleys and Gorodetsko-Koverninskaya tectonic zone. Location of the strip of the permeable deposits with the coefficients of filtration $n\cdot10^{-2}$ m/day in the areas of the paleovalleys filled up with the Lower Quaternary and Upper Neogene alluvial deposits indicates that the processes of the territory geologic development, formation of fractures and permeability of deposits are directly related and correlated.

The nature and degree of the permeability of the poorly permeable Upper Permian and Lower Permian rock masses depends on their structure.

Plastic deformations, high compressibility and water capacity along with the low permeability are typical for the Upper Permian marl clay rocks, where the clay rocks are dominant.

The gypsum-anhydrite deposits also possess plastic properties. It is a well-known fact, that at depths exceeding 250-300 m fractures in such rocks, as a rule, are tight. But in the Volga valley and in the lower reaches of its left-bank tributaries the depth of the top of the gypsum-anhydrite deposits ranges between 40 and 160 m, and in the lower reaches of the Oka river their roof underlies the Quaternary alluvial deposits, i.e. it lies at the depths where the plastic properties of the sulphate rocks are not sufficiently distinct, and the fracturing has become the main factor determining the rock permeability.

The decrease of the gypsum-anhydrite deposits' permeability observed under natural conditions on the watersheds is connected not only with the diminishing of the tectonic fractures therein, but also with the fact that as the deposits deepen in the north-east direction, the thickness of the overlying formations in the upper reaches of the Volga tributaries increases to 440-460 m. At these depths rocks become almost watertight. Based on the calculations, the coefficient of filtration here does not exceed $n \cdot 10^{-5}$ m/day.

On the whole, the Lower Permian gypsum-anhydrite rock masses are more permeable as compared with the Upper Permian marl clay section in the areas of the Volga valley, the valleys of the Volga left-bank tributaries, in the Gorodetsko-Koverninskaya tectonic zone. In these areas the values of the coefficient of filtration of the lower poorly permeable cross section are on 1-2 orders higher than those of the upper cross section. On the watersheds the inverse relation is observed. And only in the country between the rivers of Kerzhenets and Vetluga both sections show sufficiently low values of the coefficient of filtration $n \cdot 10^{-4}$ m/day. On the rest watershed territory the permeability of the Upper Permian deposits is on one order lower than that of the Lower Permian gypsum-anhydrite deposits.

3.5.3. Permeability of Permian marl clay deposits on the "zarechnaya" territory of Nizhny Novgorod

The "zarechnaya" territory of Nizhny Novgorod is typical for all Middle Volga regions in terms of natural conditions and man-caused impact. Active karst processes taking place in different areas of the city make it necessary to investigate this phenomenon in detail. Therefore, the "zarechnaya" territory of Nizhny Novgorod may be considered a model for studying patterns of the ground and fracture-karst water relationship.

The ground waters of the Middle Quaternary alluvial aquifer and the fracture-karst underground waters are separated by a layer of poorly permeable marl clay deposits. Their thickness varies considerably over the territory due to the erosion of the pre-Quaternary deposits. Though the "background" elevation of the roof of the Lower Tatarian deposits remains higher than +50.0 m, there exist wide washout depressions with flat slopes (Fig. 3.12). The slopes of the most shallow depressions reach elevations +46.0 m; depressions within the interval of abs. elevations from 50.0 m to 46.0 m cover the largest area. In fact, these wide causer-like depressions are distributed over the entire "zarechnaya" territory from the Avtozavodsky to the Sormovsky district. Here and there they are separated by narrow isthmuses, where the top of the pre-Quaternary deposits rises up to 50.0-54.0 m of the abs. elevation, sometimes not exceeding 48.0 m.

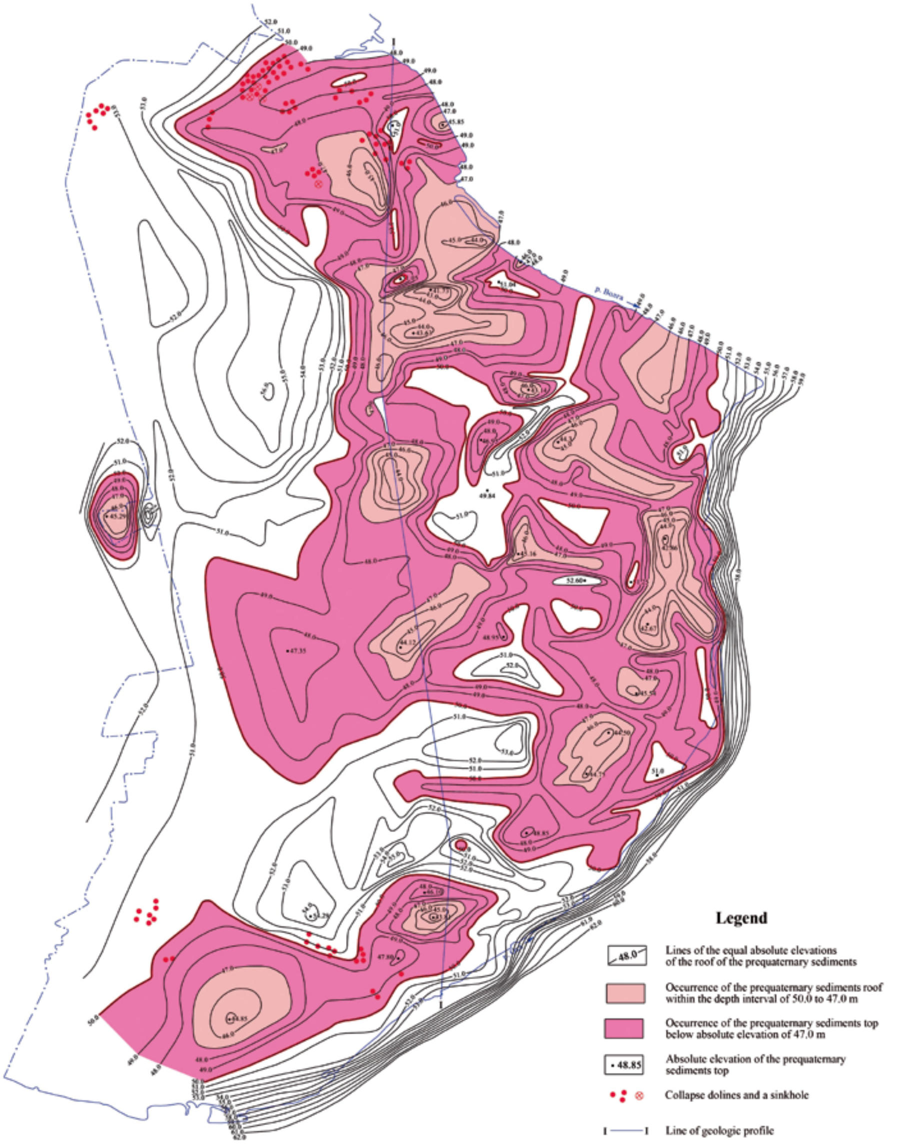


Fig. 3.12 Schematic map of the roofing of pre-Quaternary deposits of the “zarechnaya” territory of Nizhny Novgorod.

As it is evident from the cross section, the Lower Tatarian deposits are mainly marl clay fractured rocks with subordinated seams of sand, sandstone and siltstone. Close to the Volga river the clays with marl give place to siltstones with seams of sand, the marl clay layer being subordinate. The interlayer of the Lower Tatarian deposits becomes water permeable, because the coefficient of filtration of siltstone is as high as 0.5-1.5 m/day, and in spite of the considerable thickness of the Lower Tatarian deposits amounting to 13.5 m, there exist conditions for the active water exchange between the adjacent aquifers.

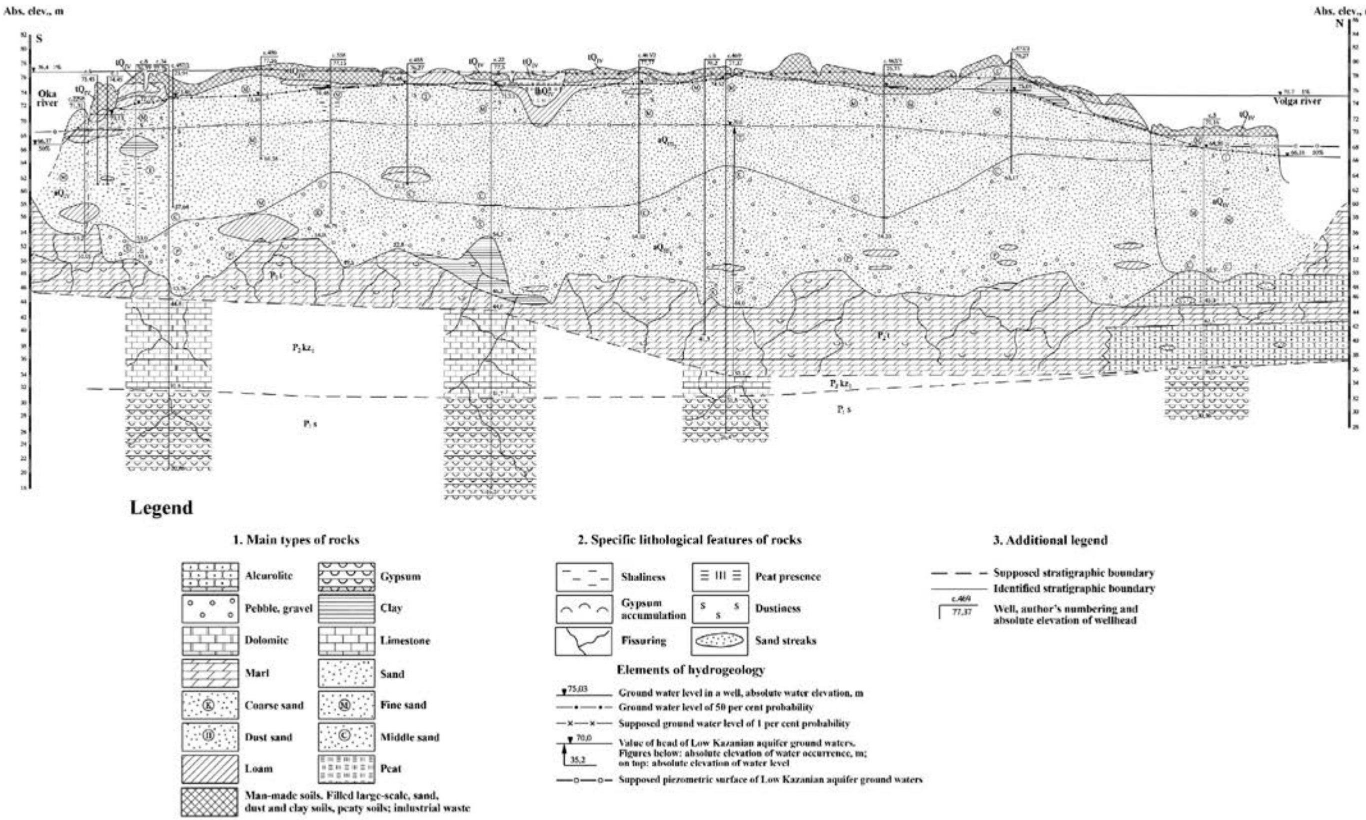


Fig. 3.13 Geologic-hydrogeologic section of the “zarechnaya” territory of Nizhny Novgorod along line I-I.

Against the background of the wide causer-like depressions in the roof of the pre-Quaternary deposits, deeper dissolution sinkholes (collapse dolines) with steep slopes and relatively small diameter are distinguished. They are located parallel to the modern beds of the Oka and Volga rivers in the form of a discontinuous series at a distance of about 1.5 km from them. At the maximum depth of the erosion cut (from the abs. elevation +50.0 m as reference) ranging from 6.5 to 4.9 m, the depth of the sinkholes constitutes on average 1.5-2.5 m.

The maximum reduction of the thickness of the Lower Tatarian deposits is registered in the Avtozavodsky district, in the west part of Zarechie (mainly a waterlogged territory outside the built-up areas), in the Sormovsky district. The above territories are the places of “hydrogeologic windows”, where the most active water exchange between the adjacent aquifers, i.e. the ground waters and fracture-karst pressure waters takes place. It should be noted that the presence of the “hydrogeologic windows” is explained not only by the reduction of the thickness of the poorly permeable rocks (sometime their absence), but also by the facial variation of the deposits. Fig. 3.13 clearly demonstrates this statement.

Mechanisms of formation of the permeability of the layers separating the water-bearing strata are common for all vast Volga regions, including the “zarechnaya” part of Nizhny Novgorod.

Investigations performed by the authors have proved that there is a water exchange between the adjacent aquifers and water-bearing complexes through the poorly permeable Tatarian deposits (the investigations were carried out on the territory of Nizhny Novgorod region, including areas of the Gorkovskoe and Cheboksarskoe reservoirs).

Fig. 3.9 shows mean values of filtration of the Tatarian deposits on the territory along the Volga river from Gorodets to Novocheboksarsk. According to the schematic diagram, the permeability of the deposits on the “zarechnaya” territory of Nizhny Novgorod is as follows:

- on the Oka streamside, including areas of housing and industrial development $k_ф = 1.4 \cdot 10^{-4}$ m/day;
- on the territory of the GAZ automobile plant $k_ф = 4.2 \cdot 10^{-4}$ m/day;
- in the west part of Zarechie (mainly watershed swamp areas) and on the Volga streamside (the Sormovsky district) $k_ф = 2.8 \cdot 10^{-4}$ m/day.

Thus, necessary conditions for the interconnection of the ground and fracture-karst waters are available on the entire “zarechnaya” territory of Nizhny Novgorod, which can be judged by the permeability of the Lower Tatarian marl clay deposits separating the adjacent aquifers.

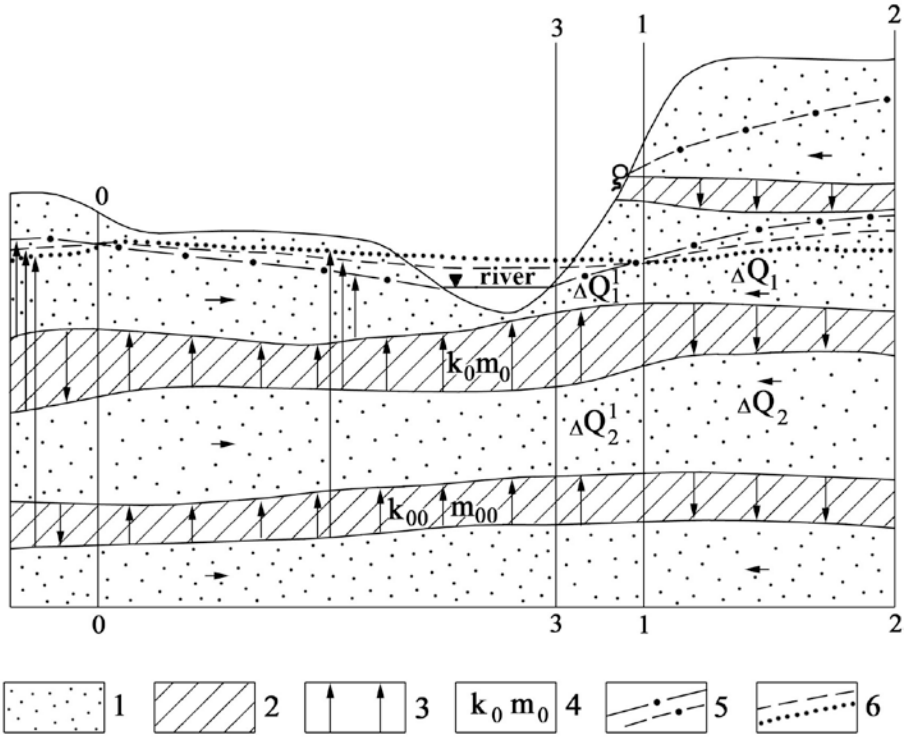


Fig. 3.14 Schematic diagram of the underground water motion according to A.N. Myatiev: *1* – permeable deposits; *2* – poorly permeable deposits; *3* – direction of the underground water filtration; *4* – coefficient of filtration (k_0) and thickness (m_0) of the poorly permeable layer; *5* – ground water levels; *6* – underground water piezometric levels

One of the necessary conditions for the water exchange between the adjacent aquifers is the correlation of their levels.

According to the researches fulfilled by A.N. Myatiev, V.A. Vsevolzhsky and others, under natural conditions watershed areas are regions of the underground water recharge (Fig. 3.14).

Its level (piezometric level) decreases with depth that, in combination with the permeability of the intermediate layers, creates a vertical flow of the underground waters through these layers in a downward direction. In the areas of the river valleys a vertical flow in an upward direction takes place due to the increase of the level (piezometric level) with depth, i.e. the river valleys are the areas of the underground water discharge.

With the advent of the water reservoirs, areas of the underground water discharge located under the erosion cut of the hydrographic medium have reduced due to the ground water backup. The reservoir basins and the adjacent territories (within the limits of the influence of a steady backup) have changed over from the areas of discharge to the areas of pressure water recharge, i.e. the levels of the latter have became lower than those of the reservoirs and backed-up ground waters.

The same patterns are typical for the “zarechnaya” territory of Nizhny Novgorod. The ground waters are backed up due to the Cheboksarskoe reservoir. The maximum level lift (more than 2 m) is observed in the streamside areas. Reduction of the backing is registered at the west suburbs of the city, in the area of high bogs. The entire “zarechnaya” territory of Nizhny Novgorod is subject to the backing created by the Cheboksarskoe reservoir.

The ground water level lift on the territory of Zarechie is connected with several factors, including the backup created by the Cheboksarskoe reservoir. First of all, these are technogenic losses of water by industries (JSC “GAZ”, JSC “GMZ”, large industrial enterprises of Sormovsky and Kanavinsky districts, heat power stations, etc.), water leakage at private gardens, a barrage effect of the subway tunnel, etc.

It should be noted that along with the technogenic recharge the ground waters are subject to the technogenic discharge, too (pumping out on the subway section in the Avtozavodsky district; drainage for wetlands drying-out). But the volume of the discharge is incommensurably less than that of the technogenic recharge.

Thus, a complicated complex of natural and technogenic factors maintain the abnormally high levels of the ground waters on the entire “zarechnaya” territory of Nizhny Novgorod.

According to the available data, the piezometric surface of the fracture-karst waters of the Lower Kazanian deposits constitutes a radially spreading flow directed from the watershed (the west part of the territory) to the rivers of Oka and Volga. On the watershed the abs. elevations of the piezometric levels are 70.5 m, in the modern beds of the Oka and Volga they descend to 65.0 m.

The comparison of the ground water levels of the 50% probability with the elevations of the piezometric surface of the fracture-karst waters revealed that the ground water surface on the entire territory is higher than the piezometric surface of the fracture-karst waters.

On the watershed this difference exceeds 7.0-9.0 m; in the Volga bed it decreases to 1.16 m, in the Oka bed it constitutes 1.37 m.

Thus, on the “zarechnaya” territory of Nizhny Novgorod there exist necessary and sufficient conditions for a constant flow of the ground waters into the Permian fracture-karst waters. The flow is provided for by the following factors:

- the permeability of the Lower Tatarian marl clay deposits separating the adjacent aquifers;
- the correlation of the levels of the ground waters and the piezometric levels of the fracture-karst waters; the excess of the ground water levels over the

piezometric levels ranges between 9.0 m on the watershed and 1.16-1.37 m in the beds of the Volga and Oka.

3.5.4 Methods of quantitative assessment of the underground water flow from adjacent aquifers

Balance method of calculation of ground water recharge and discharge. The quantitative assessment of discrete constituents of the aquifer hydrologic balance during identification of factors and sources of ground water recharge and discharge is a complicated hydrogeologic task, for it requires special high-cost researches.

The suggested method of balance calculations of the groundwater sources and values of recharge (or discharge) is universal; it does not require special hydrogeologic researches as it is based on the previously performed hydrogeologic and engineering-geologic surveys and on the data obtained during operation monitoring.

The balance method of calculation is based on the determination of the change of the groundwater flow discharge. It takes into consideration not only the recharge of the underground flow on the basis of natural factors (infiltration of atmospheric precipitations, surface run-off absorption, discharge from adjacent aquifers and water-bearing complexes), but also the anthropogenic impact caused by leakages in water supply pipelines, process water losses (at heat and power stations, large industrial enterprises), backwaters of reservoirs, water pumping-out, etc.

As it is well known, a natural discharge of a ground flow at a uniform thickness of an aquifer is calculated with the following formula:

$$Q = K\,H \cdot B \cdot I\,, \tag{3.5}$$

where K is the coefficient of filtration, m/day; H is the mean thickness of the aquifer, m; B is the flow width, m; I is the flow slope.

The groundwater balance in any cross section of the flow is defined as a relation of the recharge and discharge:

$$\Delta Q = Q_1 - Q_2\,, \tag{3.6}$$

where ΔQ is the change of the flow discharge (balance), m^3/day; Q_1 is the groundwater recharge, m^3/day; Q_2 is the groundwater discharge in the layer, m^3/day.

In a general case the recharge of the groundwater balance on the urban underflooded territories is the sum of the layer inflow ($Q_{пр}$), infiltration of atmospheric precipitations ($Q_{ос}$), surface run-off absorption provided channels, lakes and other water bodies are available on the urban territory ($Q_{ст}$), discharge of the underground waters from the adjacent aquifers and water-bearing complexes ($Q_в$), losses of water supply pipelines, industrial wastewater discharge into relief depressions and absorption wells, emergency spillages of process water, water pumping out of wells ($Q_п$). The discharge of the groundwater balance consists of the layer outflow ($Q_{от}$), evaporation ($Q_{ис}$), the outflow to the adjacent aquifers and water-bearing complexes ($Q_{см}$).

Thus, the equation of the groundwater balance takes the form:

$$\Delta Q = (Q_{пр} + Q_{ос} + Q_{ст} + Q_{в} + Q_{п}) - (Q_{от} + Q_{ис} + Q_{см}) \qquad (3.7)$$

The positive balance (+ΔQ) of the ground waters indicates that the territory is underflooded due to the rising of their level.

But in the urban built-up areas, especially at the sites where foundation soils have low filtration properties, the underflooding can occur even without direct sources (i.e. process water and wastewater discharge, accidents on water supply pipelines, etc.). It is just enough to change conditions of the groundwater outflow in the layer, when $Q_{пр} > Q_{от}$, and the aquifer's levels start rising everywhere because its balance has been disturbed.

The balance of the ground waters on the urban territories changes also due to the reduction of the recharge natural constituent – infiltration of atmospheric precipitations. Asphalt and concrete pavements, residential and industrial buildings creating watertight barriers for the precipitations and storm sewage – all this factors decrease the infiltration. Soil loosening during construction, on the contrary, increases the atmospheric precipitations infiltration.

Difficulty (reduction) of the groundwater outflow is caused by the liquidation of natural drains due to ravine filling, creation of vast pile fields during construction of multi-story residential and industrial buildings, territory leveling, positioning buildings normally to the direction of the groundwater flow, etc. These factors have a maximum effect under the conditions of low seepage (loess soils, dust and clayey sands, loams and loamy sands).

The positive groundwater balance leads to the formation of a technogenic aquifer and on the last stage, when the groundwater levels reach critical elevations – to the territory *underflooding*.

The method of balance calculations allows defining the *source* and the *volume* of water loss on the underflooded territories.

The essence of the method is as follows. A map of hydrogeologic zoning is drawn for the underflooded territories, on which the groundwater contours or piezometric contours of the pressure aquifer and the value of water conductivity (KH, m^2/day) are plotted based on the data of the engineering-geologic survey performed on the stage of designing.

Because of the complexity of its water-table contours (piezometric contours) the aquifer field of filtration is divided into hydrodynamic blocks and subblocks, within which relatively uniform hydrodynamic conditions are observed (Fig. 3.15).

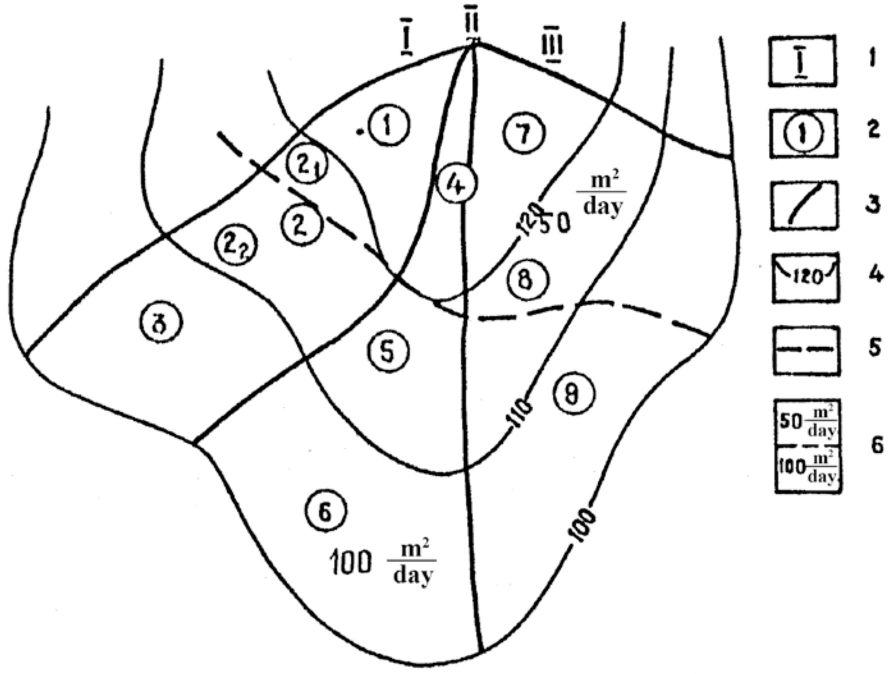


Fig. 3.15 Schematic diagram of the balance calculation of the underground water recharge and discharge: *1* – block number; *2* – subblock number; *3* – line of the flow, side boundary of a block; *4* –water-table contour, upper and lower boundaries of subbocks; *5* – boundaries of the areas of different water conductivity; *6* – value of the coefficient of water conductivity (KH, m²/day).

Characteristic lines of the flows serve the side boundaries of the blocks and subblocks, water-table contours (piezometric contours) form the upper and lower boundaries. The upper boundary of a subblock at the same time is the boundary of its recharge, and the lower one is the boundary of its discharge.

The watershed lines, being zero-discharge boundaries, serve the upper boundary of the blocks and first subblocks. At a constant discharge in any i-subblock $Q_{pi} = Q_{ni}$, where Q_{pi} + Q_{ni} is accordingly the recharge of the flow through the boundaries of discharge as well as the recharge of the i-subblock.

If there is an additional source of recharge in the i-subblock of the area F m², the flow discharge through the discharge boundaries is defined as follows:

$$Q_{pi} = Q_{ni} + W_i \cdot F_i \,, \tag{3.8}$$

where W_i is the module of the balance recharge in the i-subblock, m³/day·m².

The W_i-value is positive at the block recharge and negative at its discharge.

The module of the balance recharge (discharge) is calculated with the formula:

$$W_i = \frac{Q_{pi} - Q_{ni}}{F_i}\,. \tag{3.9}$$

In every subblock along with the balance recharge module the module of natural discharge can be calculated:

$$M_i = \frac{Q_{pi} - Q_{ni}}{2F_i}\,. \tag{3.10}$$

When territories are characterized by complicated hydrogeologic conditions, the subblocks may be further divided into smaller sections of a uniform structure (for example, when the KH value varies sharply within one subblock). Then the total discharge on the boundaries of a subblock is calculated with the formula:

$$Q = \sum K_i H_i \sum J_i B_i\,, \tag{3.11}$$

where KH is the coefficient of water conductivity; B is the flow width, m; i is the number of the section with the constant value J.

The sizes of blocks and subblocks are defined based on the specific features of the standard surface of the aquifer and the required precision of plotting. For a system of the interrelated subblocks located downstream between two flow lines:

$$Q_{ni} = Q_{pi-1}; \tag{3.12}$$

$$Q_{pi} = Q_{ni+1}\,, \tag{3.13}$$

where $Q_{pi\text{-}1}$ is the discharge on the discharge boundary of the i-1 subblock; Q_{ni+1} is the discharge on the recharge boundary of the i+1 subblock. The block (i-1) is located upstream and the block (i+1) downstream from the calculated i-subblock.

Taking into account the fact that the discharges in the subblocks are interrelated according to equations (3.12) and (3.13), the balance calculations can be performed for every block, permitting to describe the dynamics of the aquifer balance recharge along the flow and determine the total discharge (recharge) on the territory of a given area.

Based on the data of the balance calculations the maps of the recharge (discharge) balance and modules of natural discharge of the underground waters are drawn.

When a more detailed assessment of the underground water recharge or discharge is required in some discrete areas, the blocks and subblocks can be minimized to the elementary cells and flow strips.

To calculate the underground water recharge and discharge of by the balance method, the following data are required: I – the value of the groundwater table hydraulic slope;

K – the coefficient of filtration of the aquiferous rocks, m/day; H – the mean thickness of the aquiferous rocks, m; B – the width of the flow, m.

To define the above mentioned calculated parameters of the aquifer, the following special geologic-hydrogeologic maps have been drawn for the “zarechnaya” territory of Nizhny Novgorod:

- a map of water contour of 50% probability, scale 1:25000;
- a schematic map of the roofing of the pre-Quaternary deposits, scale 1:25000;
- a map of the thickness of the groundwater aquifer of 50% probability, scale 1:25000.

The map of the groundwater aquifer thickness was plotted graphically by superposing the map of the groundwater contour of 50% probability and the schematic map of the roofing of the pre-Quaternary deposits. The areas with the mean value of the aquifer thickness were singled out on the map to be used as a basis for the balance calculations.

The analysis of the geological structure of the “zarechnaya” territory of Nizhny Novgorod revealed that the alluvial masses consisted of two layers. Since filtration properties of the alluvial deposits had been studied sufficiently well, it was easy to calculate the mean value of the filtration coefficient, which was 9 m/day. This value was used during the balance calculations for the “zarechnaya” territory of Nizhny Novgorod, i.e. K = 9 m/day for all hydrodynamic blocks.

As mentioned above, the balance calculations were performed on the basis of the map of the groundwater contour of 50% probability. The hydrodynamic field of the ground waters was divided into IX blocks by drawing the most characteristic lines of the flow. Each hydrodynamic block was subdivided, in its turn, into subblocks formed by the adjacent hydroisohypses (on the top and bottom) and by the flow lines (on the sides). When the hydrogeologic parameters within one subblock were uniform, its balance was determined by calculating the groundwater discharge at its upper and lower boundaries.

When the parameters varied, i.e. were not uniform (for example, the aquifer thickness or flow slopes changed sharply), the subblocks were subdivided into smaller cells (Fig. 3.16).

The slope of the flow (I) within a subblock or a cell was calculated as a ratio of the difference between the elevations of the upper and lower groundwater contours to the length of filtration (distance between the water contours).

The balance method of calculations of the groundwater recharge and discharge gives just the value of the flow increase or decrease in the hydrodynamic block, subblock and cell. The analysis of natural conditions and possible man-induced loads on the aquifer can answer the question about the reason of the flow change.

Based on the analysis of the natural conditions of the "zarechnaya" territory of Nizhny Novgorod, as well as the technogenic impact on the ground waters, basic possible sources of the groundwater recharge and discharge have been identified.

It should be noted that the groundwater hydrodynamic calculations were performed based on the map of the groundwater contour of 50% probability plotted for a summer low water flow (on August 31) during the dry period, when there was no infiltration of atmospheric precipitations, and the layer water discharge into the main drains of the Oka and Volga rivers was dominant. Therefore, the natural recharge of the aquifer owing to the infiltration of precipitations was excluded. Groundwater evaporation from the aquifer surface was also not taken into consideration. The basic entries of the groundwater balance on the "zarechnaya" territory of Nizhny Novgorod were the following:

I. Inflow (Recharge)

1. Natural factors:
   a) Groundwater inflow from the watershed;
   b) Filtration from the surface water bodies (lakes, swamps).
2. Technogenic factors:
   a) Process water loss at various industries (plants, heat stations, etc.), leakages on water supply pipelines;
   b) Waste water filtration from small tributaries of the Oka and Volga;
   c) Watering in collective gardens;
   d) A barrage effect of the Nizhny Novgorod subway tunnel.

II. Outflow (Discharge)

1. Natural factors:
   a) Natural groundwater outflow in the layer. Discharge into the Oka, Volga and their tributaries;
   b) Outflow into fractured and karst Lower Kazanian rocks.
2. Technogenic factors:
   a) Groundwater drainage in water-logged areas;
   b) Groundwater pumping out on the Avtozavodsky district section of the subway;
   c) Water intake wells (unwatering boreholes).

The hydrogeologic calculations of the groundwater balance performed for the summer low waters (levels of the 50% probability) (Table 3.6) show that their recharge and discharge on the "zarechnaya" territory of Nizhny Novgorod are almost equal: the total inflow is 50,102 m^3/day, outflow – 49,648 m^3/day, imbalance constitutes + 454 m^3/day

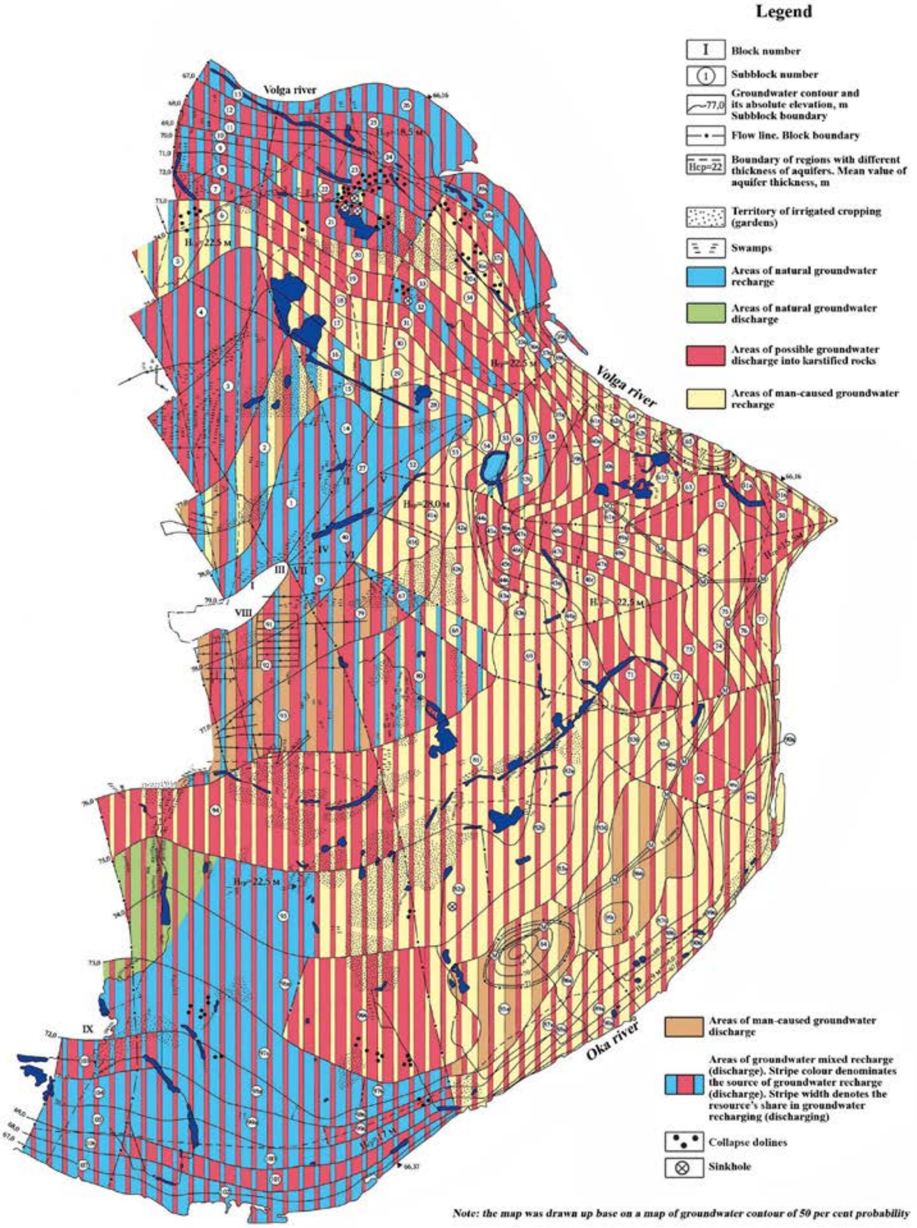


Fig. 3.16 Map of zoning the "zarechnaya" territory of Nizhny Novgorod according to the groundwater recharge and discharge

(0.9% of the inflow). The inflow-outflow equality speaks for a dynamic stability of the aquifer. Though the groundwater levels on the underflooded territory of Zarechie are abnormally high, they do not rise further. The dynamic equilibrium of the groundwater inflow and outflow in the layer is ensured by a region-related natural factor: the groundwater outflow into the fracture-karst Lower Kazanian aquifer through the layers of poorly permeable Lower Tatarian deposits. The outflow into the fractured and karstified Lower Kazanian deposits is a regional background, against which all other hydrogeologic phenomena take place.

The significance of the outflow existing due to a number of natural and technogenic reasons (permeability of the confining layers, correlation of the levels of the adjacent aquifers, high groundwater levels due to the Cheboksarskoe reservoir backwaters, as well as man-caused leakages in industrial and residential areas) is very high. The groundwater outflow into the fractured and karstified rocks influences (changes) the values of all the constituents of the water balance. So, on the territories of large industrial enterprises, technological processes of which are connected with the loss of large quantities of water, the ingress of polluted waters into the ground waters, according to the calculations, is insufficient. The “loss” of the technogenic waters is explained by their outflow to the underlying fractured and karstified rocks. This phenomenon is observed almost everywhere.

Areas of the groundwater vertical flow prevailence, according to the schematic map of the roofing of the pre-Quaternary deposits (see Fig.3.12), are associated with the hydrogeologic “windows”, i.e. areas of erosion of the roof of the fractured marl clay deposits, and with the areas, where the thickness of the Lower Tatarian deposits is represented by the permeable rocks – siltstones with sand bands.

Fig. 3.16 shows areas of the groundwater prevailing discharge into the fractured and karstified Lower Kazanian rocks.

The vertical outflow of the ground waters prevails primarily in the streamside areas of the Oka and Volga. The width of the discharge strip, running parallel to the modern beds of the Oka and Volga, reaches 2.5 km.

The modules of groundwater discharge in these areas vary in a wide range, which, in our opinion, is an evidence of a heterogeneous permeability of the confining layer. On average, the modules of discharge in the Volga area range between 36.0 and 80.5 $m^3/day \cdot km^2$, however, on the Volga flood-plain the value of the groundwater discharge into the pre-Quaternary deposits reaches 658 $m^3/day \cdot km^2$.

The modules of the groundwater discharge into the pre-Quaternary deposits in the Oka area vary from 53.4 to 206.8 $m^3/day \cdot km^2$. Like in the Volga area, the highest values of the modules are registered on the flood-plain, partially on the first above-

Table 3.6

Groundwater balance on the “zarechnaya” territory of Nizhny Novgorod
(conditions of 50% probability)

Inflow ($Q_{\text{п}}$, m^3/day)		Outflow ($Q_{\text{р}}$, m^3/day)		Imbalance, m^3/day
Inflow item	Inflow value	Outflow item	Outflow value	
Natural recharge $+\Delta Q$e	11,785	Natural discharge (into karst and pre-Quaternary fractured rocks) - ΔQe	14,703	+ 454 (0.9 % of inflow)
Technogenic recharge $+\Delta Q$тех	38,317	Technogenic discharge - ΔQтех	2,109	
		Natural discharge into the Oka - ΔQe		
		Natural discharge into the Volga - ΔQe	10,487	
Total	50,102	- ΔQe	49,648	
Recharge model $+W = \frac{+\Delta Q}{F}$, where F is the calculation area, km^2	226.3 m^3/day·km^2 (2.6 l/s km^2)	Discharge model $-W = \frac{-\Delta Q}{F}$	224.2 m^3/day·km^2 (2.6 l/s km^2)	

floodplain terrace. The next strip of the prevailing groundwater discharge into the pre-Quaternary deposits stretches in the west part of the territory of Zarechie, including the territory of the Avtozavodsky district, and covers the territory from the Volga to the Oka. It should be noted that some subblocks of the prevailing groundwater discharge into the fractured and karstified rocks coincide with the areas of collapse dolines and sinkholes location (Sormovsky and Avtozavodsky districts). The modules of the groundwater discharge within the limits of this strip from 1.5 to 4.5 km wide, unlike the streamside areas, are of smaller values. On the watershed they range, on average, from 4.08 to 16.3 m^3/day·km^2, closer to the Volga they increase to 104 m^3/day·km^2, to the Oka – up to 51.6 m^3/day·km^2.

According to the balance calculations, the *total* (aggregated) value of the groundwater outflow into the fractured and karstified Lower Kazanian deposits constitutes 14,703 m^3/day.

The *natural* recharge of the ground waters in the low-water period constitutes only 23.5% of the total recharge. The main sources of the groundwater recharge in the low-water period remain natural lakes and swamps that accumulate atmospheric precipitations and give them gradually away to the ground waters by means of filtration through the bottom sediments.

The areas of concentrated, mainly natural recharge are located in the west part of the territory, on the watershed, where an intensive development of swamps takes place, as well as on the territory of the Oka flood-plain and the first above-floodplain terrace (the Avtozavodsky district). As a rule, places of the groundwater natural recharge are located out of the residential and industrial areas. The groundwater natural recharge takes place along with the vertical outflow in the layer.

In the absence of the influence of the technogenic factors, the module of the groundwater natural recharge is rather high, ranging between 30.4 and 90.2 $m^3/day \cdot km^2$. Drain gutters reduce it to 1.9 – 14.4 $m^3/day \cdot km^2$. In the absence of the drains the module of the natural recharge reaches 309.3 $m^3/day \cdot km^2$.

According to the balance calculations, the total value of the groundwater natural recharge in the low-water period constitutes 11,785 m^3/day. The inflow from the watershed equals 475 m^3/day.

The groundwater technogenic recharge prevails within the boundaries of the residential and industrial areas. The inflow of large quantities of process water on the territories of large industrial enterprises and heat stations; leakages from water supply pipelines; filtration from small rivers used for industrial wastewater disposal; inflow from large massifs of numerous individual gardens; barrage effect of the subway tunnel, etc. – all these create an aggregated strong constant technogenic factor of influence on the ground waters. The large volume of the groundwater technogenic recharge, reaching 38,317 m^3/day, constitutes 76.5% of the total ground water recharge. The concentrated man-caused inflow deforms the groundwater table. Discrete local domes form against the background of a radially spreading ground flow (Sormovskaya and Avtozavodskaya heat power stations), water contours acquire a complicated and unusual shape; slopes of the groundwater table change. Most of all, the groundwater table is deformed in the areas of large industrial enterprises (Sormovo shipyard, JSC GAZ and others).

Small rivers – tributaries of the Oka and Volga – are especially important for the groundwater recharge; anyhow, as mentioned above, almost all of them have been turned into the industrial wastewater disposal sites. Their beds are piled with garbage.

The balance calculations have proved that all lakes and swamps of Zarechie feed the ground waters. It refers also to large lakes of Sormovsky, Kanavinsky, Leninsky, Avtozavodsky districts, including the Shuvalovsky channel. It runs parallel to the contour of the abs. elevation 75.0 m, which deviates from it in the south-west direction in the form of an elongated tongue. The flow lines drawn for this area on the map of isohypses show that the ground waters are recharged from the channel; it means that the channel is one of the sources of the groundwater recharge (Fig. 3.17).

The balance calculations show also that the Rzhavka river feeds the ground waters along its entire length (on its open-bed section). The water-table contours from the Rzhavka head to its entry disperse in the form of a spreading stream. The area of the

Rzhavka river influx to the ground waters constitutes 20.6 km^2, the total filtration rate is 2,084 m^3/day (24.1 l/s).

Analysis of the balance calculations gives grounds to state that the Vjunitsa river drains the ground waters only in its upper reaches, and feeds them in its middle and lower reaches. The Gnilichka river – the tributary of the Vjunitsa – is also a source of the groundwater recharge.

The natural discharge of the ground waters into the fractured and karstified rocks was discussed earlier. Just as a reminder, the aggregated value of the vertical outflow of the layer constitutes 14,703 m^3/day or 29.6% of the total discharge; the outflow takes place everywhere over the layer.

The technogenic discharge of the ground waters occurs in local, relatively small areas. Drain gutters on the marshlands of the watershed reduce the natural recharge of the aquifer.

The reduction of the groundwater discharge takes place on the section of the subway in the Avtozavodsky district. Due to the constant pumping-out of the ground waters a depression sink has formed in the shape of an elongated oval. The length of its perimeter is 5,355 m, the groundwater outflow on its outer contour is 419.5 m^3/day.

The reduction of the groundwater discharge is also possible due to the operation of other drain holes and water-supply wells. Reliable data on the location of such wells and their output are not available.

The aggregated value of the groundwater technogenic discharge is equal to 2,109 m^3/day or 4.2% of the total groundwater discharge.

The natural discharge of the ground waters into the Oka and Volga takes place directly on the banks; the aggregated value of this balance item equals 22,349 and 10,487 m^3/day accordingly. As it is evident from the above figures, the value of the groundwater natural discharge into the Oka is two times higher than that into the Volga, which is explained by the fact that the Oka bank in the “zarechnaya” area is longer.

The share of the discharge into the Oka constitutes 45% of the total groundwater discharge, and that into the Volga – 21%.

Conclusions

1. According to the availability of favourable conditions for the karst development and contaminants ingress into the ground and fracture-karst waters through the zone of aeration, 9 basic types of rock mass cross sections were defined and described for the karst territories of the Middle Volga, which were grouped by the authors into 4 media of karst development.

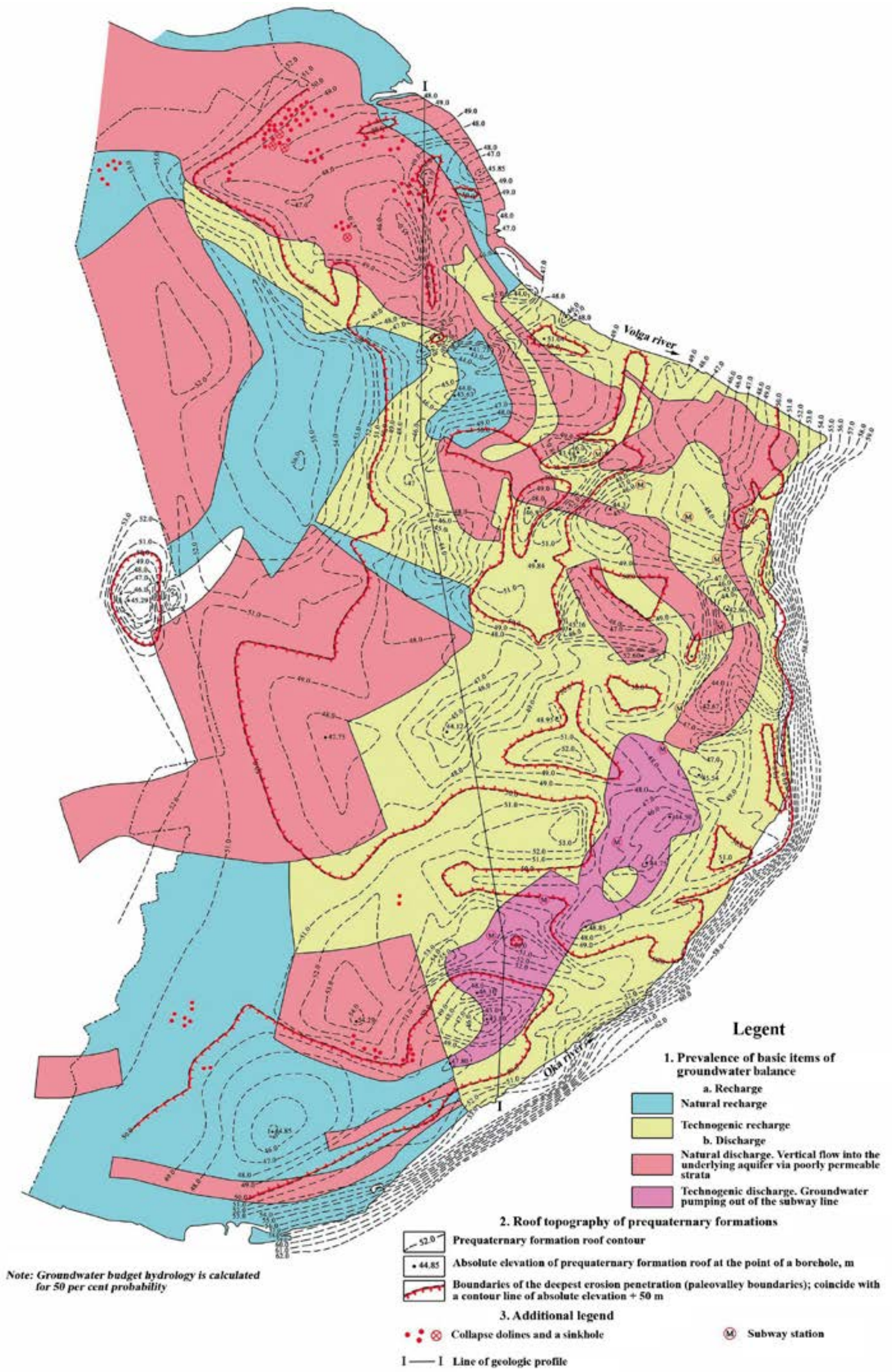


Fig. 3.17 Schematic map of the groundwater balance on the “zarechnaya” territory of Nizhny Novgorod

2. Typification of technogenic sources of pollution of the underground hydrosphere by the nature of the man-caused changes of the underground water quality was performed based on the functional features of the enterprises-polluters, typological characteristics, degree of hydrodynamic impact, mode of action of polluters with time, possibility of physical and chemical transformations and contaminants interaction with the underground waters and rocks.

3. Main types and sources of the underground water pollution were identified and the characteristic of contaminants was given by the example of the most typical karstified territories of the Nizhny Novgorod region (Dzerzhinsk and “zarechnaya” territory of Nizhny Novgorod).

4. A direct relation between the formation of vast areas of the underground water pollution and location of industrial waste landfills and dumps in the zones of “active karst” was illustrated.

5. With the help of the developed methods the natural protectability of the underground waters from contamination on the territory of Nizhny Novgorod region was assessed. The territory zoning by the degree of protectability with the allowance to the intensity of karst manifestation and directions of karst development was performed.

6. Interconnection of ground waters with the adjacent aquifer of the pressure fracture-karst waters was proved. It is provided for by two factors:

- permeability of the marl clay interlayer;
- correlation of the levels of the ground waters and piezometric levels of the fracture-karst waters. It was found out that the groundwater levels everywhere, with the exception of narrow riverside areas, located higher than the piezometric levels of the adjacent confined aquifer. The existence of the groundwater flow into the fractured and karstified Lower Kazanian rocks was confirmed by the change of the chemical composition of the ground waters at their contact with the pre-Quaternary underlying rocks, as well as by the balance calculations of the underground water recharge and discharge on the given territory.

7. The hydrogeologic calculations of the groundwater balance performed in the summer low-water period (levels of a 50% probability) have revealed that the groundwater recharge and discharge on the “zarechnaya” territory of Nizhny Novgorod are almost equal: the total value of inflow (recharge) constitutes 50,102 m^3/day, outflow – 49,648 m^3/day, imbalance is +454 m^3/day (0.9% of the outflow). The value of recharge is slightly higher than the value of discharge.

The equality of the inflow and outflow of the ground waters points to the aquifer dynamic stability. Under the existing conditions of the groundwater recharge and discharge, the aquifer levels in the low-water period retain stability, though remaining abnormally high, that leads to the underflooding of the entire territory of Zarechie. The groundwater level stability, in its turn, provides for the stability of the process of underflooding.

The dynamic equilibrium of the groundwater recharge and discharge is ensured by the stability of the balance items: values of natural and technogenous recharge and discharge and to a great extent by a constant regional factor – the groundwater outflow to the adjacent aquifer of the fracture-karst Kazanian deposits through the permeable interlaying strata.

8. Areas of the prevailing groundwater vertical outflow coincide with the hydrogeologic “windows” in the roof of the pre-Quaternary marl clay deposits. An intensive outflow of the ground waters (against the background of the technogenic recharge) is observed in the Oka and Volga riverside areas. The width of the discharge strip reaches 2.5 km; the zone of discharge runs parallel to the modern beds of the Oka and Volga.

9. An active groundwater outflow prevails in the west part of Zarechie against the background of the natural and technogenous recharge. The strip from 1.5 to 4.5 km wide of the groundwater discharge into the fractured and karstified rocks stretches from the Volga to the Oka (from north to south), coinciding with the area of the most corroded rocks of the interlaying aquifuge. The areas of the dominant groundwater discharge into the pre-Quaternary deposits almost coincide with the areas of active surface karst development.

Chapter 4

ASSESSMENT OF THE EXTENT OF THE MAN-CAUSED UNDERGROUND WATER POLLUTION AND STUDY OF MECHANISMS OF ITS PROPAGATION

4.1. Structure of the information support of the assessment of the man-caused underground water pollution in the karst regions

For the Nizhny Novgorod region the authors have developed a scheme of information support for the geoecological assessment of the man-caused pollution of the underground waters in the karst regions.

All available data about the territory under study were divided into three levels (Fig. 4.1). The first level includes 10 factological blocks, eight of which are presented in the form of cartographic models. The 1st block describes the reserves and functional usage of the karstified territories. The 2nd block contains information about the distribution of surface, subterranean and buried karst forms on the studied territory and their main parameters. The 3rd block reflects morphologic-structural conditions, types of karstifying rocks, their state, depth of occurrence, specific features of the surface of the karstifying rock masses, characteristic and thickness of the overlying deposits (Fig. 4.2, 4.3). The 4th block contains karst age parameters, inherited features of its development, direction of the collapse karst development in space and with time (Fig. 4.4). The 5th block describes conditions of the surface and underground waters interconnection, zones of recharge and discharge, shows the dependence of the karst development on erosion and longitudinal profile drift as well as on the balance of river systems (Fig. 4.5). The 6th block evaluates the natural protectability of the ground and fracture-karst waters from different kinds of contamination and characterizes features of the zone of aeration.

The 7th block gives the main parameters of exploitation of the aquifers and water-bearing complexes, their geochemical characteristic and forecast variants of the chemical and level regime of the exploited underground waters. The 8th block contains information about the types of man-caused impacts and loads and gives characteristic of changes of the natural and technogenic environment connected therewith. The 9th block includes the computer simulation of the variants of development of the underground water pollution under the conditions of the covered karst based on solid models. The 10th block contains typification of karst deformations, collapse mechanisms and ecological risks from waste disposal on the karstified territories.

The second level is based on the information collected at the first level and presents the evaluation and analytical basis for typification of the natural-technogenic environment by the degree of its sensitivity to the man-induced loads.

On the third level a synthesis of the evaluation data takes place, and a final map of the geoecological zoning of the studied territory is drawn with the assessment of the underground hydrosphere pollution.

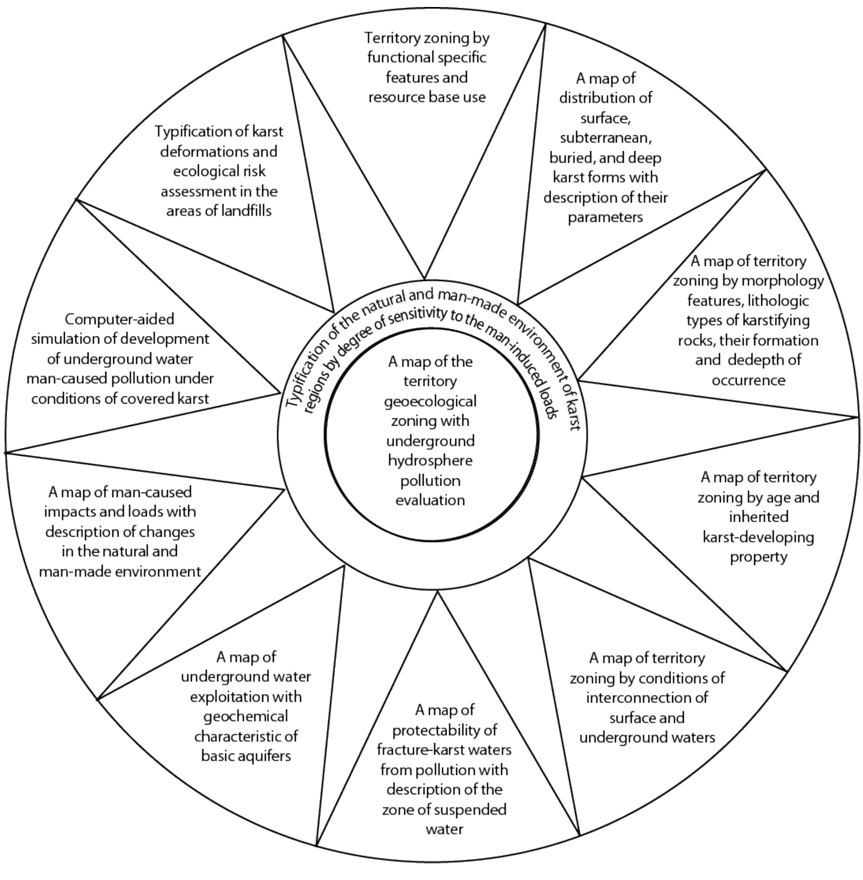
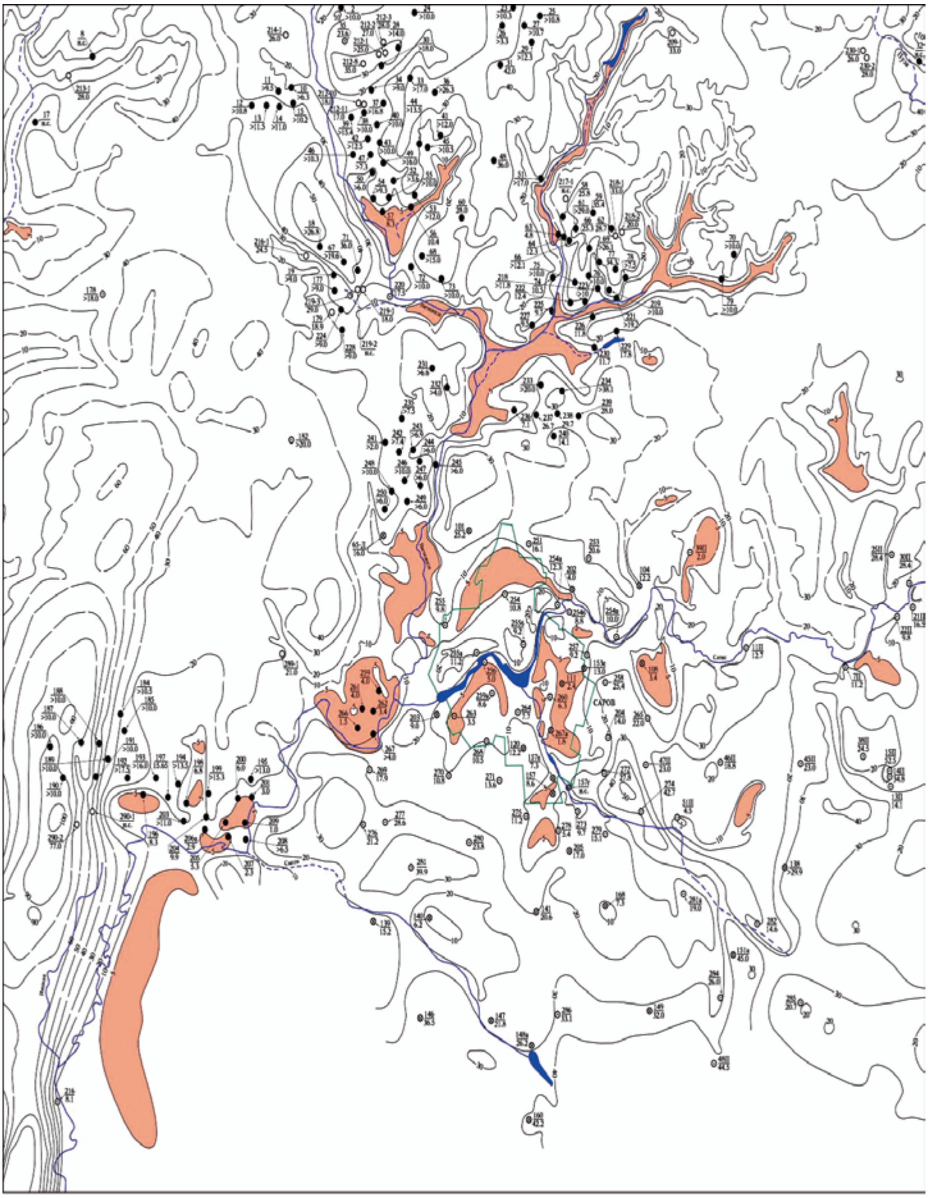


Fig. 4.1 Scheme of information support of geoecological assessment of the man-caused pollution of underground waters in karst regions



Legend

- Survey borehole
- Prospecting borehole
- Secured borehole
- Operating borehole
- Minerals exploration borehole

$\frac{718}{9.7}$ - Numerator is the well number in the catalogue; denominator is the thickness of the supracarbonate deposits; the sign ">" in front of the denominator shows that the thickness of the supracarbonate deposits is larger than indicated (the carbonate deposits have not been reached by the particular borehole)

Thickness isolines of the supracarbonate deposits:

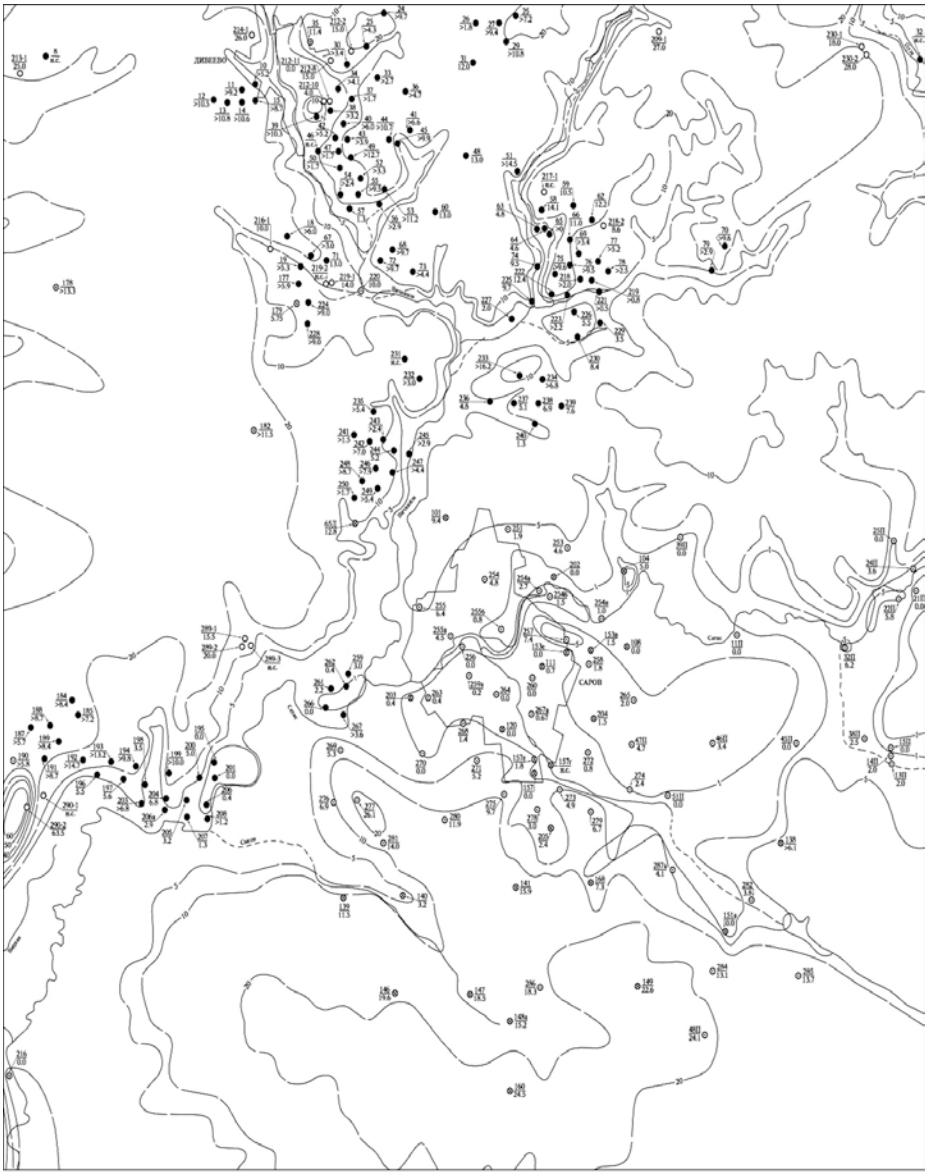
a) identified

b) supposed

Note: the isolines are drawn in every10 m; additionally an isoline of the thickness of 5 m is plotted

- Sharp change of the supracarbonate deposit thickness

Fig. 4.2 Map of thickness of supra-carbonate deposits



Legend

- ⊙ - Survey borehole
- ⊙ - Prospecting borehole
- ⊗ - Secured borehole
- ○ - Operating borehole
- ● - Minerals exploration borehole

⊙ $\frac{718}{9.7}$ - Numerator is the well number in the catalogue; denominator is the thickness of the supracarbonate deposits; the sign ">" in front of the denominator shows that the thickness of the supracarbonate deposits is larger than indicated (the carbonate deposits have not been reached by the particular borehole)

Thickness isolines of the supracarbonate deposits:

- a) identified
- b) supposed

Note: the isolines are drawn in every10 m; additionally an isoline of the thickness of 5 m is plotted

- Sharp change of the supracarbonate deposit thickness

Fig. 4.3. Map of thickness of poorly permeable supra-carbonate deposits

Fig. 4.4 Map of distribution of surface karst forms for the last 300,000 years in the lower reaches of the Oka: *1* –contour of the ancient valley of the Kishma (more than 300 thousand years old); *2* – recent erosion cuts; *3* – zone of distribution of surface karst forms 70 thousand years of age; *4* - zone of distribution of surface karst forms 30-35 thousand years of age; 5 - zone of distribution of surface karst forms for the last10 thousand years

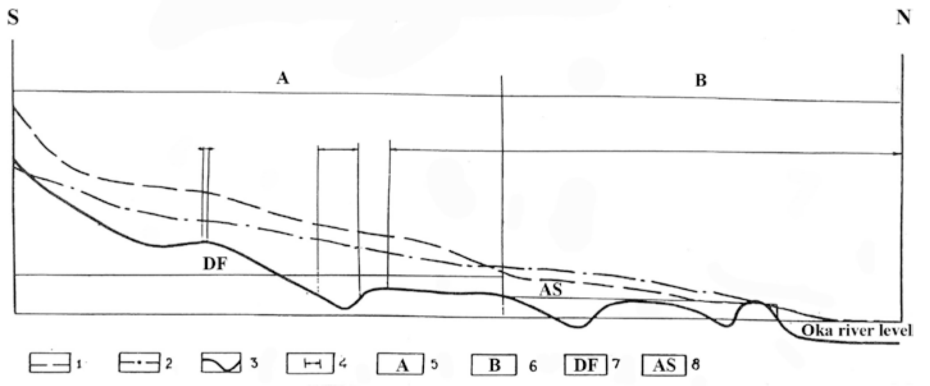


Fig. 4.5 Scheme of correlation of the Kishma longitudinal profile, fracture-karst water level and the surface of the karstifying rocks: *1* – Kishma longitudinal profile; *2* – steady level of fracture-karst waters; *3* – surface of karstifying rocks; *4* – areas of development of surface karst forms; *5* – zone of the absence of the surface water flow; *6* – zone of surface water flow; 7 – downward filtration; 8 – artesian sources

4.2. Main regional patterns of karst development and distribution of recent karst forms

Karst forms in the studied region are characterized by a wide morphological variety and amazing sizes. In this area one can meet forms from small saucer-like sinkholes to vast deep depressions, powerful vauclusion springs and sinking streams, collapse dolines of small to gigantic sizes, reaching hundreds of meter in diameter and tens of meters in depth, large karst lakes.

In general, the region under study is one of the most original and dynamic regions in terms of the development of covered sulphate, sulphate-carbonate and carbonate types of karst on the Russian Platform. According to the morphologic-genetic features of the classification developed by N.A. Gvozdetsky (1972), A.V. Stupishin (1967), A.G. Chikishev (1979), E.V. Koposov (1986), karst forms are subdivided into surface, subterranean and buried.

Surface karst forms. Surface karst forms are interconnected genetically, and they determine the morphology of the relief. The authors single out discrete sinkholes and karst lakes, fields of sinkholes, karst valley-shaped sinks (broad gullies, ravines and dry valleys), karst hollows and karst depressions.

Sinkholes and karst lakes. Sinkholes belong mainly to a collapse type, and only in the valleys of the rivers of Tyosha, Seryozha, Chyornaya and Moksha, where the overlying deposits are represented by sand formations with sinking streams, a distinct type of karst-suffosion sinkholes is registered.

Sizes and shapes of the collapse sinkholes vary. The sinkholes of 8-15 m in diameter and 3-6 m deep prevail. The morphologic appearance of the collapse sinkholes depends on their age. Recent sinkholes have a cylindrical shape, especially if they formed in the loess-like loams (Fig. 4.6). The majority of collapse sinkholes in the studied region are of this shape. If the top of the cross section is formed of argillaceous-silt-marly deposits, a collapse sinkhole is pitcher-shaped, and in sand formations it is mainly basin- and cone-shaped (Fig. 4.7).

Along with the middle-size forms there are huge collapse sinkholes in the right-bank areas of the Lower Oka associated with the upper reaches of ravines and gullies. They usually appear in the places of coalescence of several ravine offsets. Their sizes reach 100 meters in diameter with a depth of 20 to 30 meters. As a rule, at once they are filled up with fracture-karst waters, becoming lakes. The Boldyrevsky and Grudtsynsky collapse sinkholes in the Nizhny Novgorod region and the Temnikovsky collapse sinkhole in Mordovia may serve examples of such giant collapse sinkholes.

Karst lakes are connected genetically with large sinkholes, and usually formed by a coalescence of several collapse sinkholes. The Vorsmenskoe lake is an example of such a lake consisting of six collapse sinkholes 12 to 15 m deep with powerful underwater sources. The same is referred to the Svyatoe lake, into which karst waters discharge in the form of strong vauclusion springs (Fig. 4.8). The water source of the latter is so powerful, that the surface of that part of the lake does not freeze even in the most severe winters. Large reserves of fresh water are stored in the karst lakes formed by karst sinkholes near Staraya Pustyn in the valley of the Seryozha river. In the well-known and described in the literature Vadskoe lake (on the south of Nizhny Novgorod region) the fracture-karst waters discharge in the form of a powerful vauclusion spring, which allows the local population to use the lake for fishery and recreation.

The karst lakes are usually “margined” with sinkholes; especially they are numerous on the sides of the Vorsmenskoe and Svyatoe lakes. Recent sinkholes are reported to be related exactly to the littoral zones. Thus, 8 collapse sinkholes have formed on the sides of the Svyatoe lake for the last 16 years.

Fields of sinkholes. Collapse sinkholes are rarely met singly. More often they are located in clusters, groups of the total area usually not exceeding 1 to 2 km^2. In the karst literature they are described as “fields of sinkholes” *(Savarensky, 1990)*. On the studied territory the fields of sinkholes are widely developed, especially near the villages of Korovino and Kishimskoe, the settlements of Ababkovo and Cherneevo, where the number of sinkholes exceeds 200. Large karst fields, in terms of area and number, are registered in the valleys of the rivers of Chyornaya, Seryozha, Tyosha, Kishma, Alatyr, Moksha and Satis. The density of sinkholes within discrete fields is so high, that the balks between them remain just in the form of small ribs.

Fig. 4.6 Cylindrical sinkhole on the outskirts of the city of Pavlovo

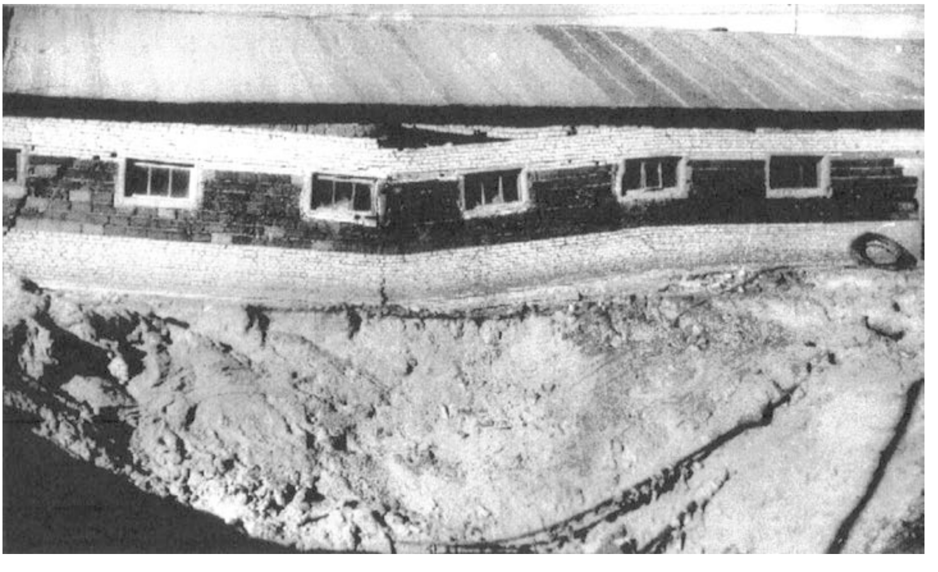


Fig.4.7 Collapse sinkhole on the territory of the Dzerzhinskaya heat and power station (diameter 26 m, depth 5.5 m)

To study karst forms and their distribution in low-populated regions, the authors used aerial photographs of the territories of different years and scale.

That made it easier not only to perform karst mapping, but also to identify specific patterns of its distribution and dynamics of the karst process in general.

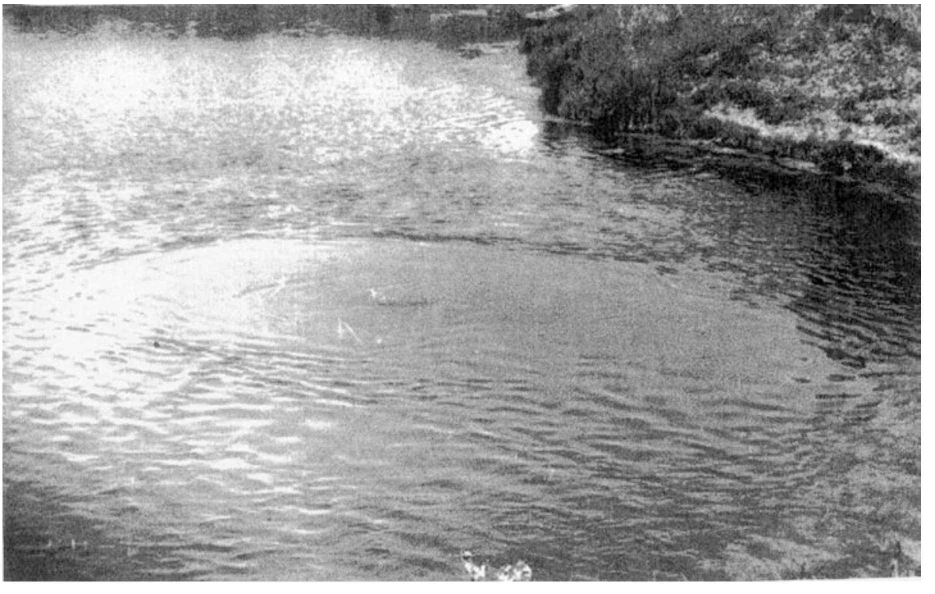


Fig. 4.8 Discharge of fracture-karst waters in the form of a strong vauclusion spring.

Karst broad gullies, ravines and dry valleys. These forms represent river-oriented valley-shaped depressions with karstified bottom and slopes. A karst ravine differs from a broad gully by more steep and exposed slopes, i.e. a broad gully is its next phase of formation. Dry valleys are large waterless valleys up to several kilometers long with swallow holes and sinkhole at the bottom.

On the territory under study the karst broad gullies and dry valleys are more frequent. By the elevation of their bottom with respect to the fracture-karst water level in the region the karst broad gullies are considered suspended constituting zones of surface water absorption. There are also discrete large broad gullies with the karst aquifer resurgences at the bottom. Examples of the first type are: a well-developed system of the Ubezhische gullies in the valley of the Chyornaya river, Boldyrevsko-Grudtsinsky and Solonsky broad gullies, branching gullies near the village of Cherneevo. The karst broad gullies spread mainly in the north-west and north-east directions; more rarely they are latitude- or meridian-oriented, that, in our opinion, is explained by the prevailing orientation of the tectonic fissuring in the karstifying rocks. The length of the gullies reaches 5 to 6 km at a width of from tens to hundreds meters.

Dry valleys and sinking streams are well developed in the region. Actually, the valleys of the rivers of Kishma, Chyornaya, Surin, Alatyr and Satis on vast territories, mainly in their upper and middle reaches, do not have a permanent surface stream. It exists only in the periods of heavy rains and spring floods, when swallow holes are not capable to drain all surface waters into the massif.

Dry areas of the valleys stretch from 5 to 10 km. The absence or presence of a stream is connected with a longitudinal profile drift of the river, its elevation with respect to the Oka level (the regional basis of erosion) and piezometric level of the fracture-karst waters. Thus, the river of Kishma springing at the bottom of a dry valley on the eastern outskirts of the village of Kolpenka very soon descends in to the bedrocks. At the settlement of Bogdanovo its flow is about 40 l/s. Downstream from the settlement the river cuts into the Lower Tatarian argillaceous-silt gypseous bedrocks increasing water infiltration and karst development in the valley. As a result, the surface stream disappears and resurgences again only at the village of Vorvan. Near this village karst waters come to daylight, i.e. the Kishma longitudinal profile crosses the curve of the piezometric levels of karst waters (see Fig. 4.5). After that point the Kishma runs as a common surface stream up to its outlet.

Karst hollows. Karst hollows are usually the result of a coalescence of several sinkholes; they usually constitute closed surface subsidences over 200 meters in diameter and about 10 meters deep, sometimes much deeper. The karst hollows are characterized by an irregular multicone bottom constituting a specific rib relief (Fig. 4.9). The appearance of the karst hollows is controlled by the erosion processes; as a result they are often cut through by gullies. On the studied territory the Vorsmenskaya erosion-karst hollow is the largest and most relief-pronounced of about 30 km^2 in diameter with the depth, on average, of 15 to 20 m (in discrete areas reaching 30 to 40 m). In the hollow two karst lakes: the Vorsmenskoe and Svyatoe are located, as well as sinking streams Surin and Klyuchik and three broad gullies. In general, the Vorsmenskaya hollow by its large scale may be considered an analogue of a Yugoslavian polje, though differing by some morphologic and genetic features.

Fig. 4.9 Specific karst relief, the right bank of the Oka river (Nizhny Novgorod region)

The Korovinsko-Yasenetskaya and Cherneevskaya hollows are smaller, but they have all the features of the described above Vorsmenskaya erosion-karst hollow.

Karst depressions. This is the highest form in the surface karst genetic hierarchy on the studied territory, being an analogue of the longitudinal riverside depressions described by D.S. Sokolov (1962). The Gomzovsko-Ubezhitskaya, Kishminskaya and Tyoshe-Seryozhinskaya erosion-karst depressions may be pointed out.

The Kishminskaya erosion-karst depression includes the middle and lower reaches of the Kishma basin of the total area of about 120 km^2 with sinking streams, erosion-karst hollows, broad gullies, fields of sinkholes, karst lakes. The depression has formed in the result of the erosion and karst processes. Numerous springs in the lower section of the Kishma valley and in karst lakes form a permanent surface stream, while the upper part of the valley is waterless. The karst-erosion ratio changes in the course of the karst topography evolution.

The depression broadens in discrete areas due to recent erosion cuts, through which karst spreads into the watersheds. Chemical composition of the karst springs is characterized as sulphate-calcium, which proves that intensive karstifying processes take place within the boundaries of the erosion-karst depression.

The Gomzovsko-Ubezhitskaya depression is smaller, located mainly in the basin of the Chyornaya river; its area does not exceed 40 km^2. A clearly defined erosion-karst outlier of the karstifying sulphate-carbonate rocks is registered within its boundaries. Sinkholes, sinking springs and rarely recent collapse dolines are concentrated in the valley of the Chyornaya river, in the karst ravines and broad gullies. On the whole, the morphologic appearance of the surface karst forms (saucer-shaped forms prevail) in the Gomzovsko-Ubezhitskaya erosion-karst depression speaks for their ancient age.

Subterranean karst forms. Karst fractures, caverns, voids and zones of broken rocks belong to the subterranean karst forms on the studied territory. Karst forms of this type are concealed by the overlying strata almost on the entire territory; being difficult for studying. Information about the degree of karstification of the carbonate and sulphate rocks has been collected during the investigation of the Ubezhitsky, Pavlovsky, Satissky, Budaevsky, Annenkovsky, Gremyachevsky, Filinsky quarries, the Bebyaevsky mine, as well as on the basis of the data of the karst exploratory wells.

A considerable disintegration of the karstifying rocks, a wide variety of voids and karst conduits in terms of size and degree of filling were registered in every investigated quarry.

Many facts on the subterranean karstification were obtained during special site investigations on the territories of the cities of Pavlovo, Vorsma, Nizhny Novgorod, Arzamas, Pervomaisk, Balakhna, Vyksa and others. Hundreds of boreholes were drilled in the karstifying rocks to a depth of 15-20 m min., permitting to evaluate the karst risk of each construction site and recommend appropriate preventive measures against possible karst activation due to technogenesis. Since the late 60s much has been done in this respect by A.N. Iljin (1978, 1981, 1984), I.A. Savarensky (1977, 1987), A.A. Safronova (1983), V.G. Remizov (1984), E.V. Koposov (1987).

Buried karst forms. Ancient karst forms completely filled up and practically unexpressed in the modern relief belong to the buried karst forms. Among the surface forms these are mainly sinkholes and hollows, while the subterranean forms are mainly the filled-up karst voids located deep in the karstifying rocks. Identification of the buried forms is a difficult matter. At the lower strata of the soluble rocks these forms may be encountered only by chance. Therefore, they are usually spotted incidentally during fulfillment of other tasks. For example, V.I. Ignatjev (1952) discovered ancient buried collapse sinkholes older than 100,000 years during a geologic survey in the lower reaches of the Oka river (see Fig. 4.10).

Using the available methods of interpretation of the surface karst forms on the valley territories *(Sadov, 1995)*, the authors have identified buried karst sinkholes in the valleys of the rivers of Chyornaya, Kishma, Moksha, Alatyr, at the villages of Korovino, Vorvan, Ababkovo. The identification of the buried forms is important, for it permits identification of the most ancient sites of distribution of the collapse karst sinkholes.

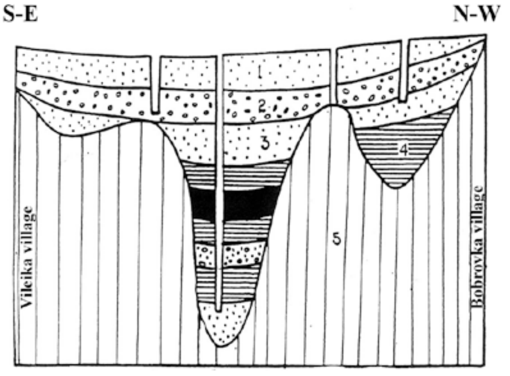


Fig. 4.10 Ancient buried collapse sinkholes (according to V.I. Ignatjev, 1952): *1* – above-floodplain sands; *2* – moraine; *3* – submoraine sands; *4* – clay with peat and sand interlayers; *5* – karstifying rocks

As wrote A.B. Stupishin (1967), not only the valley-related type of karst is developed on the studied territory, though the surface forms are concentrated mainly in the valley of the rivers of Seryozha, Tyosha, Satis, Alatyr, Kudma and Kishma. By the example of the Kishma basin, the right-hand tributary of the Oka river, the authors have shown that the karst process has “climbed up” high on the watersheds gradually following recent erosion cuts and forming the upper zone of karst forms (see Fig. 4.11).

The middle zone of the karst forms distribution is related to the toe of the valley-side slope of the Kishma river and is observed along the slope in the interval of elevations between 25 and 35 m above the river-bed. In this zone the highest number of recent karst collapse sinkholes is reported, which are notable for their significant, though slightly smaller diameters and depths as compared with those of the upper zone. Areas of the underground water resurgences are registered in the cross section of the valley-side slope. The Northern Dvina water-bearing complex is drained almost in all places. These waters together with the ground waters and waters of atmospheric precipitations are absorbed by the underlying layers, and through the fractured zones they reach the karstifying rocks. Thus, on the slopes of the river valley conditions for a continuous vertical water circulation and constant ingress of contaminants into the massif are formed that provides for an active karst development and dynamic pollution distribution in the middle zone. Similar phenomena of the underground water discharge from the overlying deposits were described by A.N. Iljin (1984) in the valleys of the rivers of Tyosha, Seryozha, Kutra and Kuzoma.

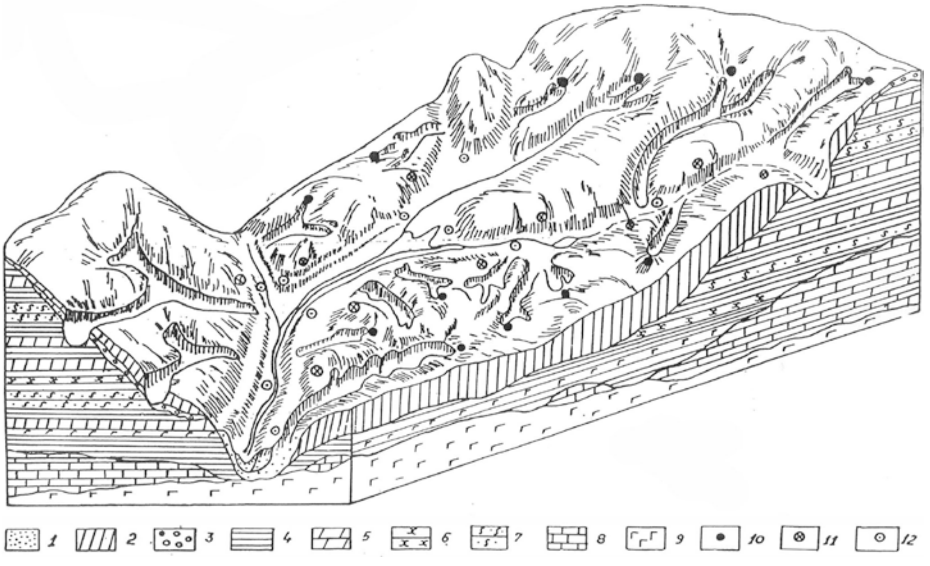


Fig. 4.11 Block map of the Kishma basin structure and distribution of recent karst forms: *1* – sand; *2* – loam; *3* – moraine; *4* – clay; *5* – marl; *6* – sandstone; 7 – siltstone; *8* – limestone; *9* – gypsum. Karst sinkhole distribution: *10* – upper zone; *11* – middle zone; *12* – lower zone

The lower zone of surface karst includes the floodplain, the first and the second above-floodplain terraces. This is the most karstified territory. The density of collapse sinkholes in discrete areas reaches 300 per 1 km^2. Almost all morphologic types of sinkholes: from cylinder-shaped to basin-shaped are available, which points out to the different age of the karst forms. Their sizes vary significantly: from 8 to 15 m in diameter and from 2 to 3 m deep. Broad gullies, dry valleys and erosion-karst hollows are typical for this zone.

The increased concentration of sinkholes is often observed in the area of the terraces and valley-side slope conjugation, which can be explained by the increased surface water vertical circulation to the karstifying rocks in these places the increased number of karst sinkholes in the areas marginal to the outfalls of ravines, gullies and streams running to the valley, as it is so at the villages of Ababkovo and Vorvan, in our opinion, is quite natural. The outfalls are the sites of the surface water maximum discharge into the massif that causes karst development and agricultural pollution in these areas. The increased concentration of the surface karst forms is registered in the areas of local tectonic structures, where the raised karstifying rocks are formed of limestones, dolomites and gypsums. In these areas the karstifying crudely fractured rocks either crop out, or are overlain by a thin sedimentary mantle of 2 to 5 m thickness, and subjected to a strong action of atmospheric and melt waters, which is reflected in the formation of numerous surface karst forms.

Deep collapse karst lakes form, so to speak, “through” disruptions (from the land surface to the karstifying rocks) that affect sharply strength properties of the rocks in the massif. Stability of the areas marginal to the lake slopes diminishes due to the formation of subsidence fractures. Besides, the discharge of the underground waters of various aquifers takes place on the lake slopes. Such a hydraulic connection even further reduces the stability of the slope-adjacent areas of the massif. Researches performed by V.M. Kutepov (1986, 1989) revealed that non-uniform changes of the natural stress of the rock massive are observed in such areas.

4.3. Main types of the mechanism of propagation of underground water technogenic pollution in the regions of covered karst

The problem of studying mechanisms of pollutants’ penetration deep into the massif of karstified rocks and their transfer to large distances from the sources of pollution has been of interest of many researchers, mainly abroad. Thus, German researcher B. Beck offered a simplified model of the mechanism of pollution of ground waters used for drinking water supply for covered karst, when the karstifying rocks are overlain by a thick layer of non-soluble rocks, and sinkholes and collapse dolines with their swallow holes go deep into the karstifying massif (Fig. 4.12). Any analogue in the Russian literature has not been found.

Based on the performed researches, the authors have singled out 4 main types of mechanisms of the groundwater technogenic pollution propagation in the areas of covered karst in the Nizhny Novgorod region. The first type – surface pollution does not penetrate into the fracture-karst stratum due to the presence of a thick clay aquifuge (m > 25 m, coefficient of filtration 0.001 m/day). Experimental studies at a waste disposal site in the Balakhna district for 7 years have shown a steady propagation of the industrial pollution in the direction of the Volga over the surface of the clay aquifuge (Fig. 4.13).

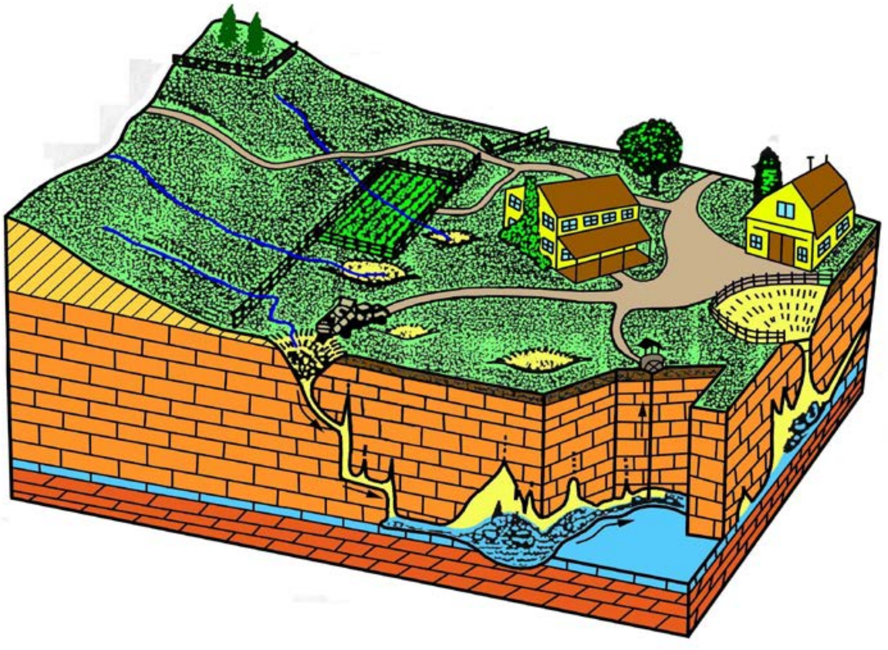


Fig. 4.12 Mechanism of ground-water pollution under karst conditions (B. Beck, 1993)

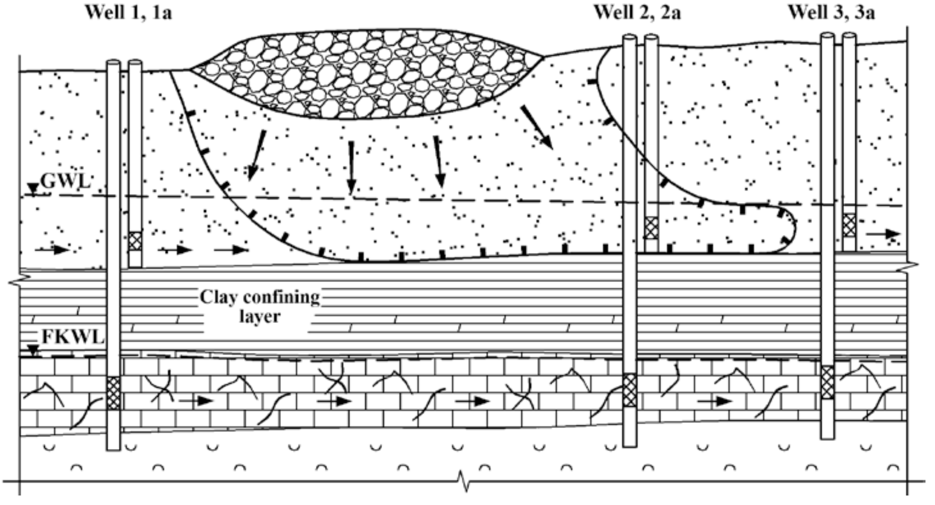


Fig. 4.13 Propagation of groundwater pollution in the areas of waste disposal with an intact clay aquifuge overlying karstifying rocks

The observation wells with a filter installed in the fracture-karst aquifer have not registered the presence of specific pollutants in the confined aquifer for the entire period.

The second type – the technogenic pollution propagates in the areas of waste disposal due to the discontinuity of the clay aquifuge caused by collapse sinkholes and vertical fractures. The void roof collapses, and contaminants move downwards through the sinkhole shaft. Via the hydrogeologic "windows" contaminants reach the fractured zone of the karstifying rocks, and then they are transferred at long distances by the fracture-karst waters (Fig. 4.14).

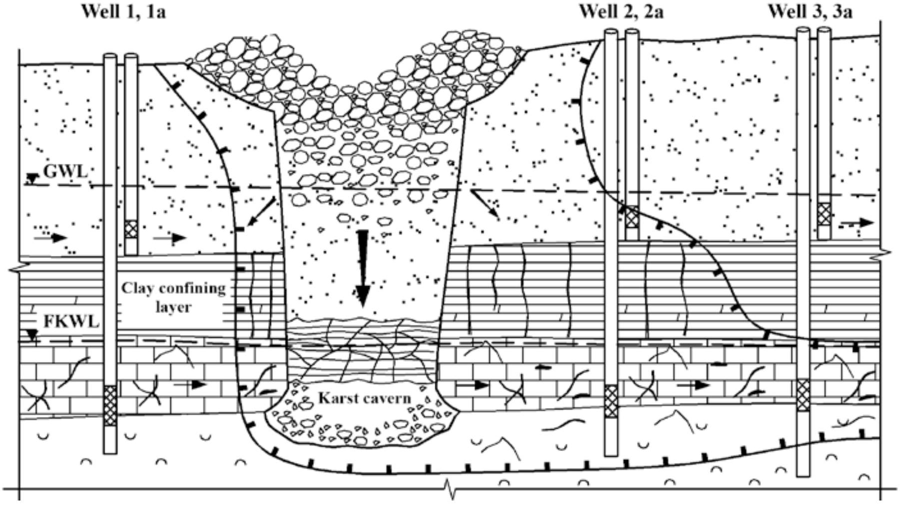


Fig. 4.14 Propagation of groundwater pollution in the areas of waste disposal, when the continuity of the clay aquifuge overlying the karstifying rocks is disrupted by a void roof collapse.

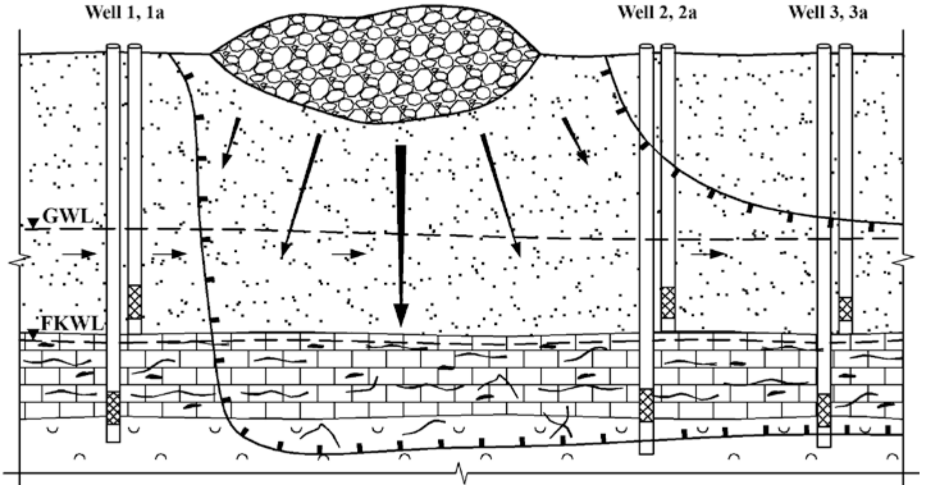


Fig. 4.15 Propagation of groundwater pollution in the areas of waste disposal, when there is no clay aquifuge overlying karstifying rocks

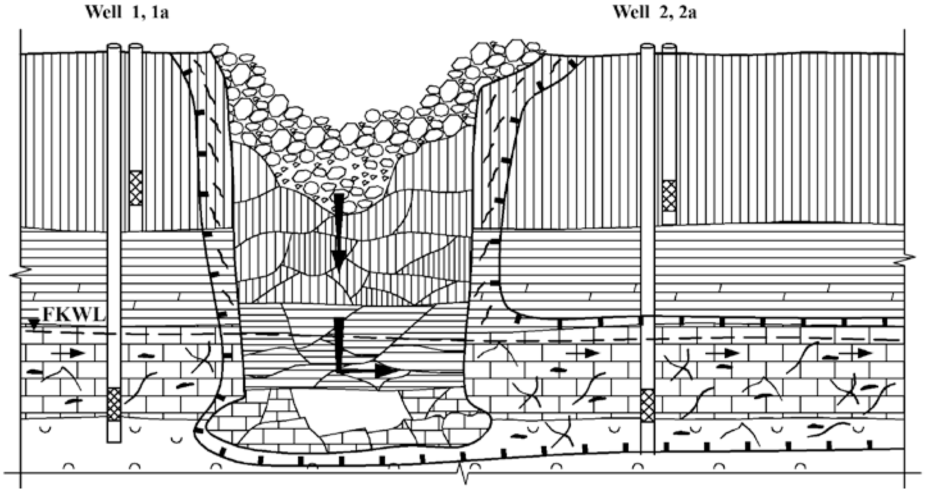
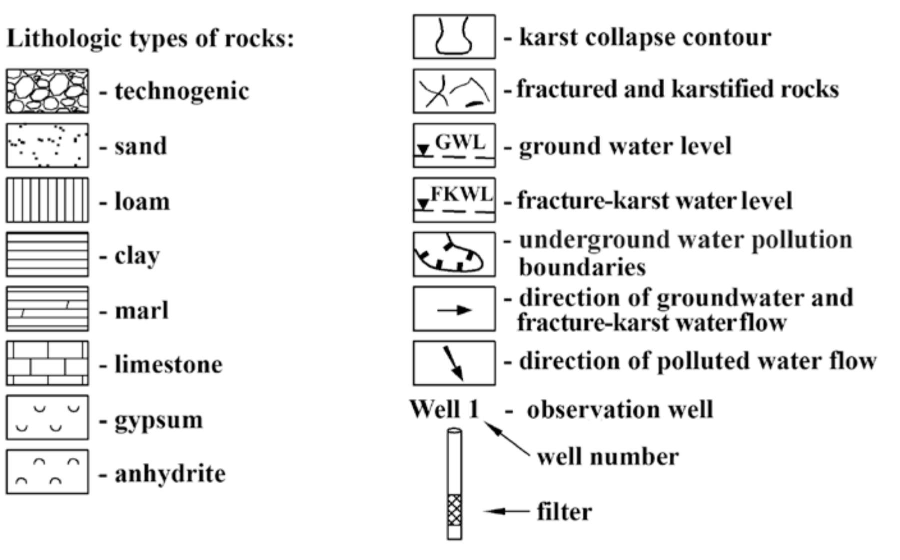


Fig. 4.16 Propagation of groundwater pollution in the areas of waste disposal in places of collapse sinkholes, where the zone of aeration is formed of loamy deposits, and karstifying rocks are overlain by a clay aquifuge.

Legend for Figures 4.12 to 4.16



A network of observation wells on the landfills and waste dumps on the “zarechnaya” territory of Nizhny Novgorod, in Dzerzhinsk and Iljinogorsk located in the river valleys confirms that this type of mechanism of the groundwater technogenic pollution propagation is widely developed in the areas of active karst.

The third type is a characteristic feature of the zones of complete washing-out of non-permeable clay deposits above the karstifying rocks. The aquifers of the ground and fracture-karst waters are interconnected. Surface contaminants penetrate easily into both aquifers (Fig. 4.15). It is typical for the recent and buried valleys in the areas of the cities of Dzerzhinsk, Arzamas, Vorsma, Pervomaisk, Sarov, and the Yuzhno-Gorkovskoe and Teplovskoe underground-water fields.

The fourth type is related to the watershed areas, where the karstifying rocks are overlain by a thick layer of poorly permeable loamy and clayey deposits, and under the normal conditions the fracture-karst waters are protected from the surface pollution. Collapse dolines and sinkholes that occur in the waste disposal areas disrupt the aquifuge creating conditions for the contaminants penetration into the massif. The contamination is of a local character, taking place in the upper part of the cross section and a linear zone of the fracture-karst water-bearing stratum (Fig. 4.16).

4.4 Assessment of the extent of the underground water pollution

The extent of the underground water pollution should be assessed on the basis of studying water condition in the areas of the sources of pollution.

According to the experience of the previous researches *(Goldberg, 1984, 1990; Gavich, 1985; Gribanova, 1987, 1995; Mironenko, Rumynin, 2002)*, at the locations of the sources of pollution the scope of pollution, its intensity and the rate of contaminated water motion along the stratum are to be identified.

The isoline of general mineralization 1 g/dm^3, or the MPC boundary of the characteristic polluting component typical for the given conditions may be assumed as the *boundary of a zone of pollution*. If the change of the underground waters is caused by several contaminants, the zone of pollution is contoured both by the isoline of mineralization 1 g/dm^3 and MPC boundaries of these components.

The isoline of general mineralization 1 g/dm^3 as a boundary of the zone of pollution is chosen because of the fact that fresh underground waters are characterized by mineralization less than 1 g/dm^3, while contaminated waters, as a rule, have higher mineralization. Moreover, according to the sanitary standards, general mineralization of 1 g/dm^3 is the maximum permissible value specified for the waters of drinking quality (SaNPiN 2.1.4.559-96).

On the hydrochemical map of the exploited Middle Quaternary-Present alluvial water-bearing stratum in the area of Dzerzhinsk, drawn by the authors, the pollution is assessed not only by the mineralization isolines, but also by the types of water with prevailing anions: chlorides and sulphates (Fig. 4.17).

In a number of cases, when the general mineralization of polluted waters is low, and by this feature they differ little from fresh or slightly saline underground waters, the zone of pollution is identified by a typical contaminant.

Zones of pollution in poorly explored regions with a small number of observation wells are defined by the wells with the highest content of contaminants and by the wells, wherein artificial pollutants not typical for the underground waters of a given region have been found, even though their content is lower than the MPC values.

The zone of pollution in the area of a landfill of JSC "Orgsteklo", the city of Dzerzhinsk, was identified quite accurately by means of geophysical methods, specifically, by the VES method *(Tolmachyov, Tseneva, 2000)*. The field investigations revealed geoelectrical anomalies (Fig. 4.18).

Geoelectrical cross sections plotted on the basis of the specific resistivities showed the zones of pollution on the territory of a large landfill in plan and in section (Fig. 4.19, Fig. 4.20) related to the ancient karst sinkholes.

Dimensions of a zone of pollution is assessed by its area: length and width *(Grozdova, 1987; Goldberg, 1990; Mironenko, Rumynin, 2002)*.

An area of a zone of pollution formed under the influence of one polluter is determined by the area contoured by the isolines of general mineralization 1 g/dm^3 and MPC value of individual components. In case of several polluters, when between discrete areas of pollution there are areas of clean underground waters (but they are smaller or close to the sizes of contaminated zones), the sum of polluted water areas and clean water areas located between them should be assumed as a zone of the underground water pollution.

The intensity of the underground water pollution is determined by:

1) the value of mean mineralization in the zone of pollution contoured by the isoline of general mineralization 1 g/dm^3;
2) the mean concentration of individual components within the MPC contours.

The mean general mineralization and mean concentration of discrete components are determined as weighted mean values of the area *("Izuchen. zagryazn.", 1990; Tyutyunova, 1987)*.

The mean general mineralization within the zone of pollution defining intensity of the underground water pollution is equal to:

$$M = \frac{M_1 \cdot F_1 + M_2 \cdot F_2 + M_3 \cdot F_3 + ...M_n \cdot F_n}{F_1 + F_2 + F_3 + ...F_n} \quad (4.1)$$

The mean concentration of pollution (C) inside the zone was determined with the following formula:

$$C = \frac{C_1 \cdot F_1 + C_2 \cdot F_2 + C_3 \cdot F_3 + ...C_n \cdot F_n}{F_1 + F_2 + F_3 + ...F_n} \quad (4.2)$$

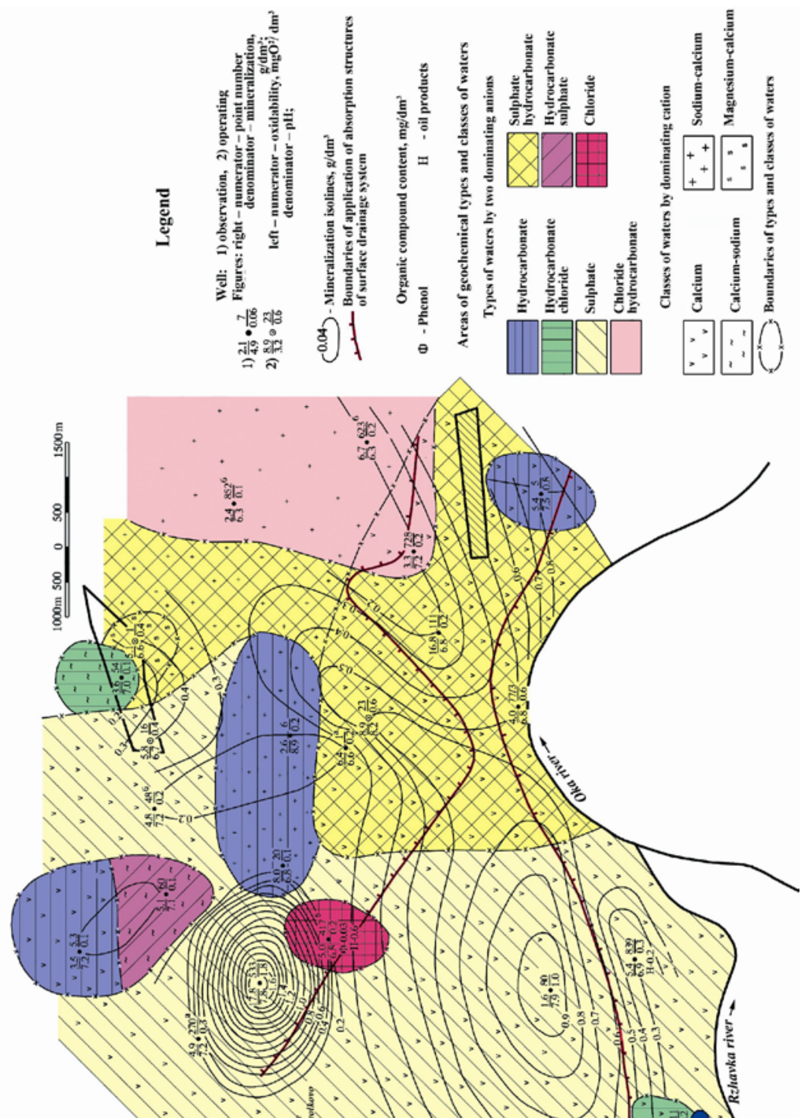
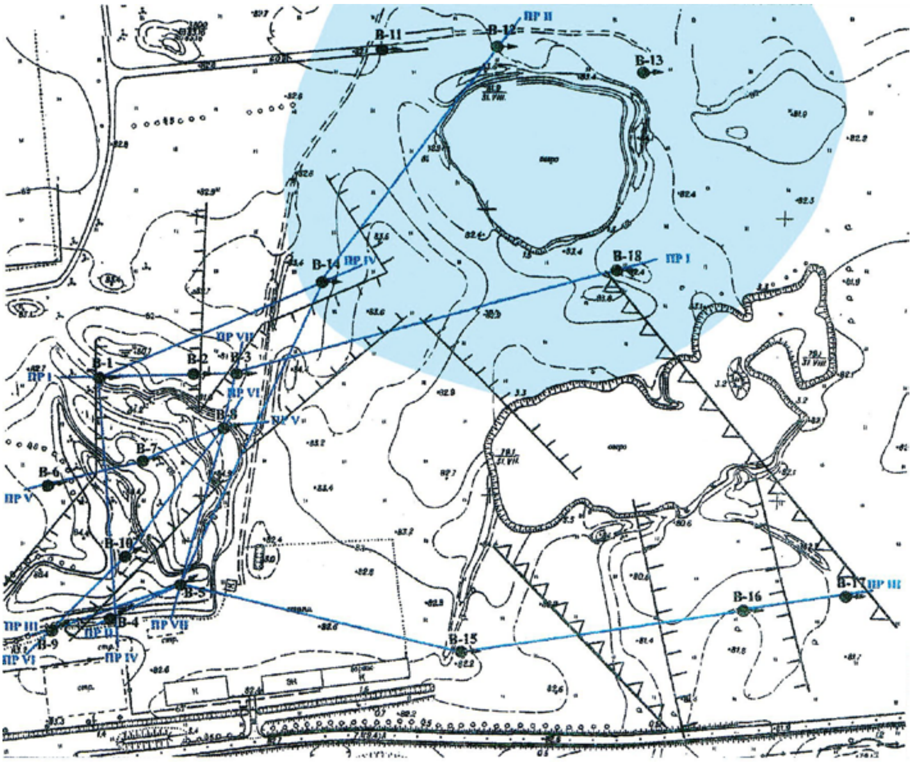


Fig. 4.17 Distribution of geochemical types and classes of water in the exploited Middle Quaternary-Present alluvial water-bearing stratum in the area of Dzerzhinsk



Legend

- point of electrical measurement, its number and direction of feeding electrode spread:
  a) in section
  b) in plan
- geoelectric section line
- location of geoelectric layer boundaries and value of specific resistance
- numerator – specific resistivity; denominator - anisotropy factor
- dominating direction of conductivity (fissures)
- boundary of subvertical anisotropy (conductivity) zone in sand-clay strata
- karstified areas in gypsum-dolomite strata
- cruelly karstified areas in gypsum-dolomite strata with specific resistance less than 100 Ohm•m
- solid (slightly cracked) gypsum-dolomite strata
- polluted areas according to electric survey
- zone of underground water increased mineralization
- region of overdeepening in gypsums

Fig. 4.18 Map of geoelectrical anomalies of the JSC “Orgsteklo” landfill area (scale 1:2000)

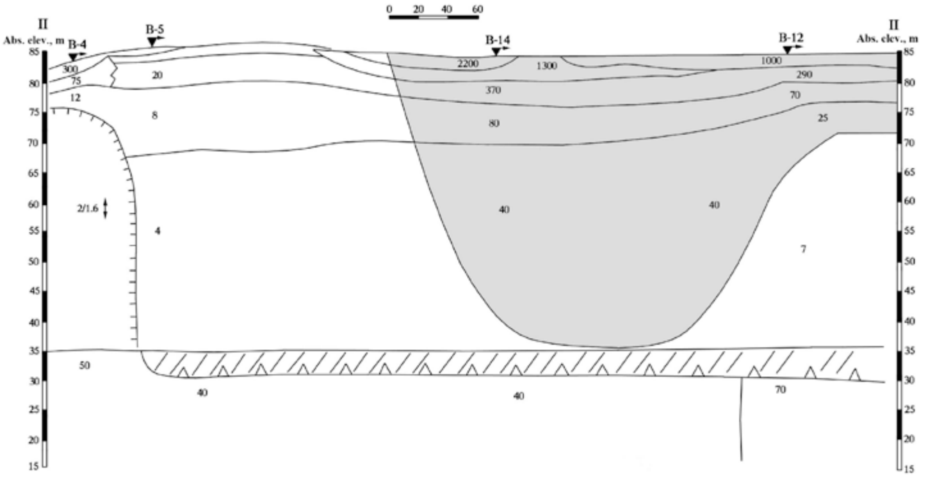


Fig. 4.19 Geoelectrical section II-II (landfill of JSC “Orgsteklo”)

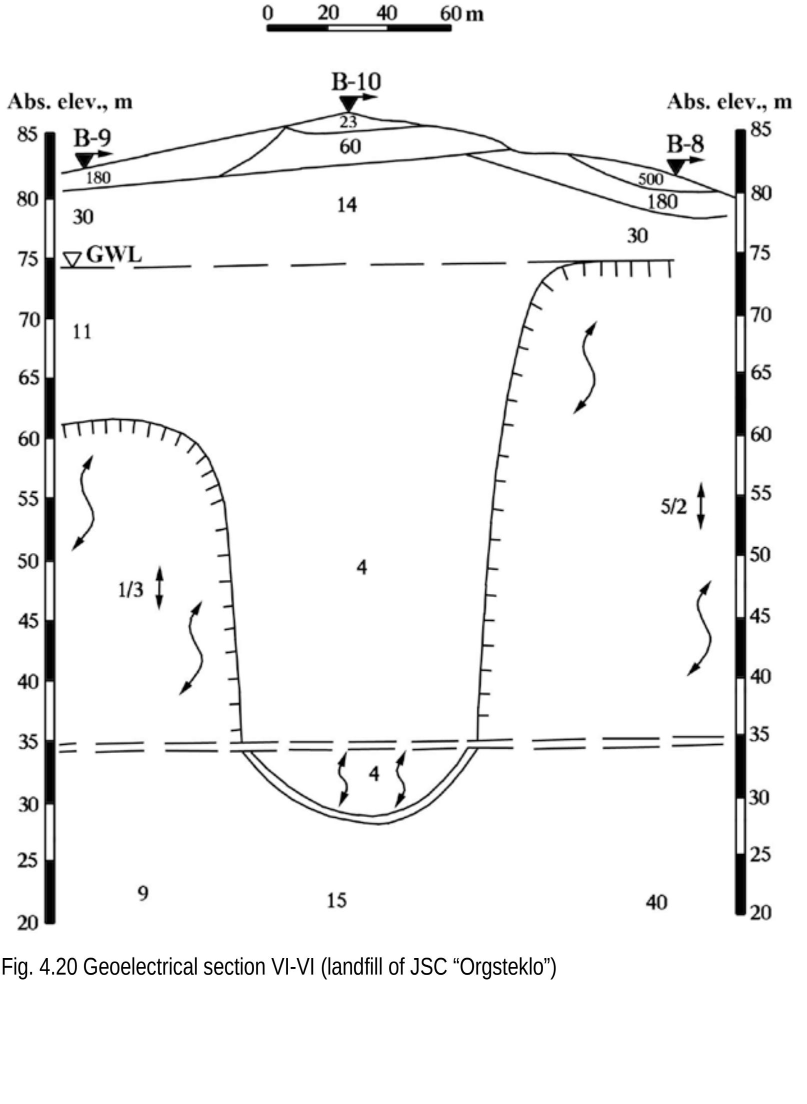


Fig. 4.20 Geoelectrical section VI-VI (landfill of JSC “Orgsteklo”)

This approach initially was proposed by well-known Russian scientists Goldberg, 1984, 1990 and Tyutyunova, 1987.

To make the analysis and interpretation of the data easier, the intensity of the underground water pollution in a discrete point may be characterized in relative values and determined as a relation of the absolute value of the pollutant concentration (C^1) to its MPC value:

$$C = \frac{C^1}{MPC} \tag{4.3}$$

The karstified territories are most sensitive to the snow cover pollution. Large masses of snow accumulate in sinkholes and other land subsidences during a winter season, where pollutants concentrate. In spring with melt water they penetrate into the underground waters through the disintegrated soil masses.

Information about air-borne contaminants is especially important for the areas located in immediate proximity to large industrial centers, as well as for planning centralized underground-water intakes, designing buffer zone of water intakes, studying pollution and directions of its propagation.

A schematic map of snow cover contamination with oil products, drawn for the city of Dzerzhinsk before the Teplovsky water intake commissioning (Fig. 4.21), and a hydrochemical map on scale 1:50000, plotted by the authors on the results of a snow cover survey of the city of Dzerzhinsk as on 01.03.2004 (Fig. 4.22), may serve good examples.

Based on the data of exploratory drilling, wind rose analysis, snow survey results and information about locations of potential and existing polluters, a network of observation wells has been drilled for monitoring changes of the natural-technogenic environment in the areas of existing water intakes and quality of drinking water. The network of the observation wells in the area of the Teplovsky water intake, the registered useful underground water resources of which were evaluated to 1,560 thousand m^3/day, is depicted on the map of water-table contours of the exploited Quaternary aquifer (Fig. 4.23). The schematic map shows sulphate concentrations in the water of the exploited aquifer and sources of the underground water pollution.

Abnormal concentrations of sulphates as on 2004 did not locate in the zone of influence of the Teplovsky water intake, but at that time it did not operate at full capacity. Therefore, systematic monitoring of the level and chemical regimes of the underground waters at the Teplovskoe field should be continued in order to prevent its contamination.

Analysis of the observation data obtained in the area of the Teplovskoe underground water field and study of the works of previous researchers have revealed that the zone

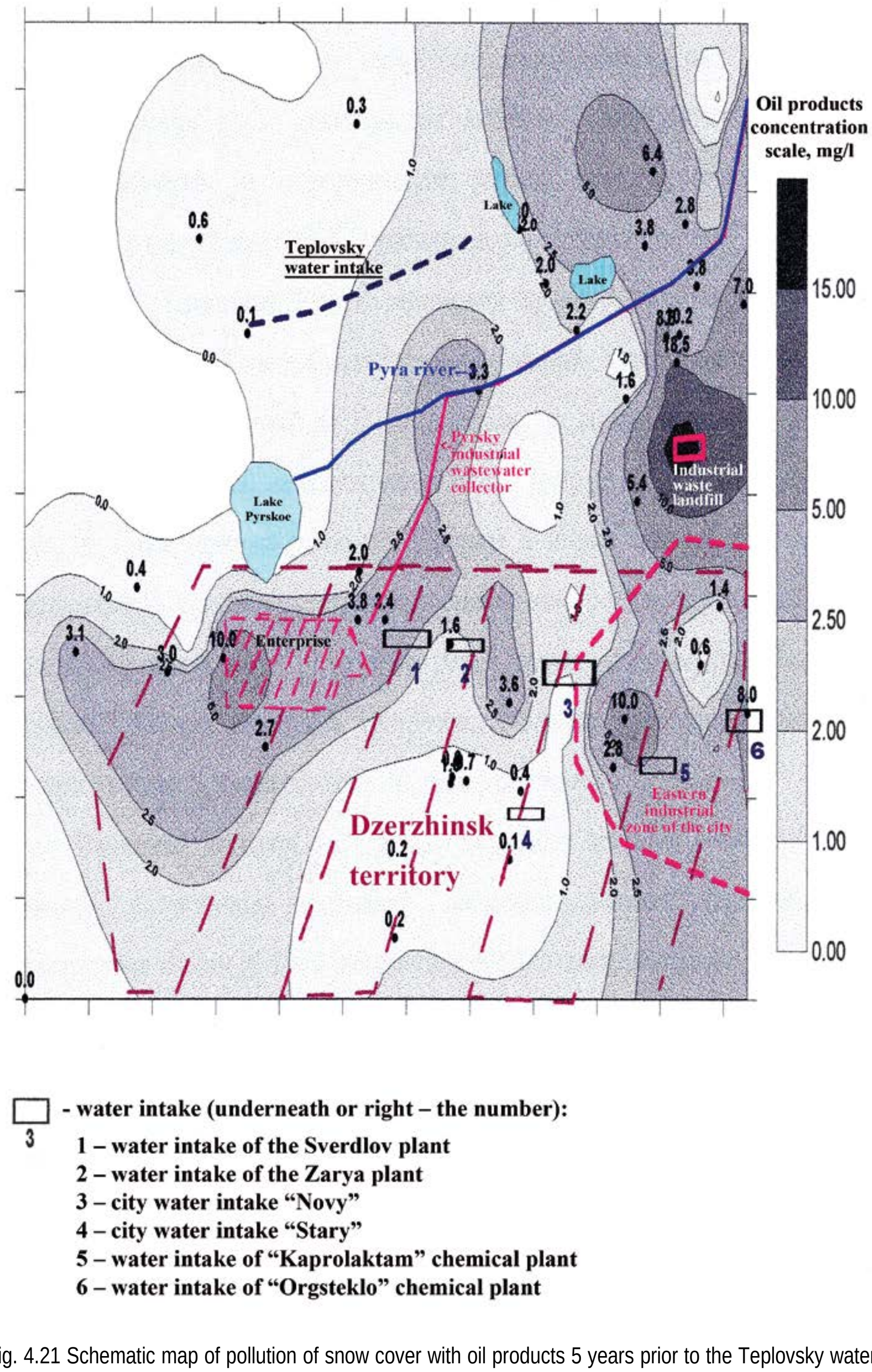


Fig. 4.21 Schematic map of pollution of snow cover with oil products 5 years prior to the Teplovsky water intake commissioning (drawn on the basis of a snow survey performed by Nizhny Novgorod KGIGP).

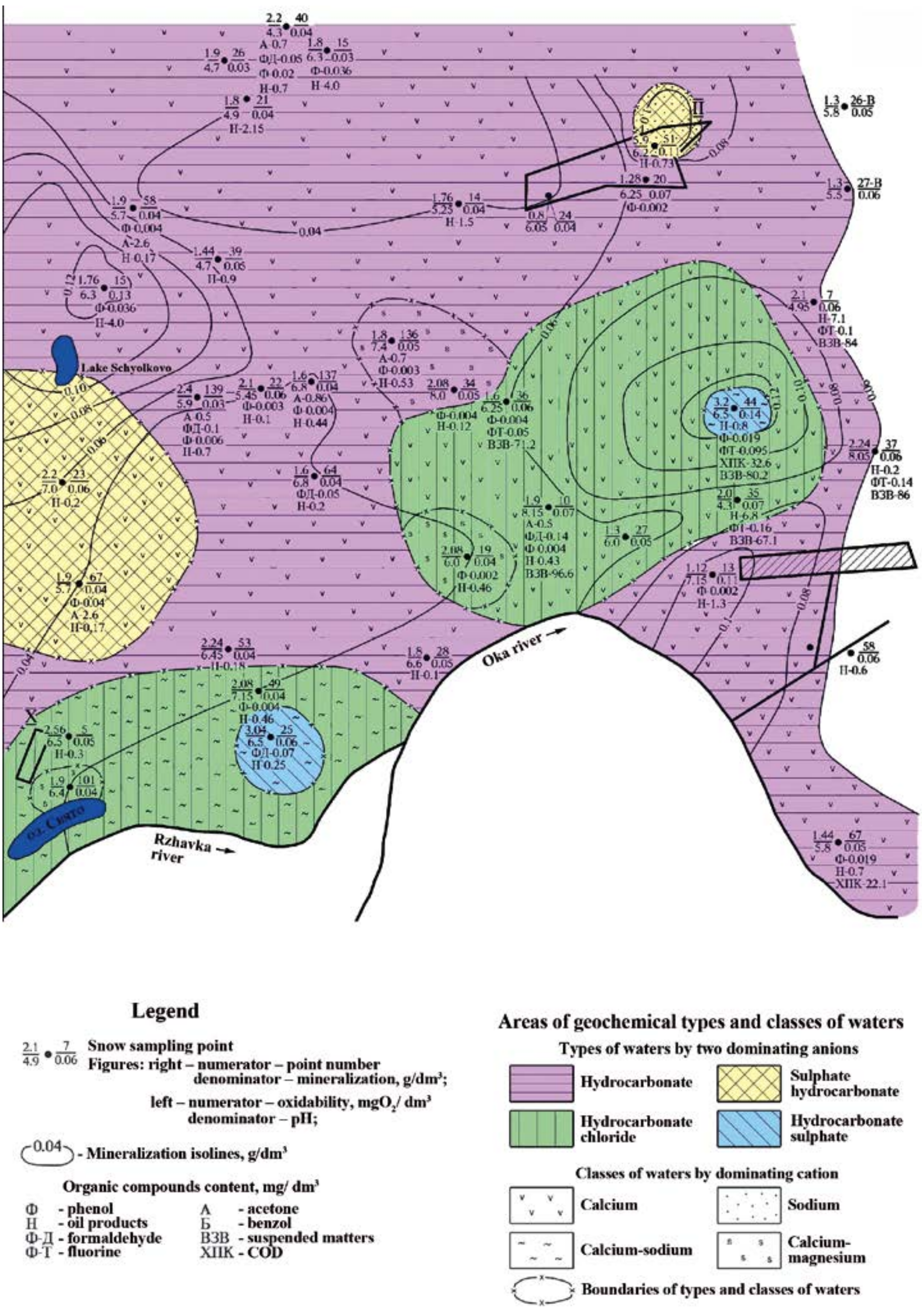


Fig. 4.22 Hydrochemical map based on the results of the snow cover survey of the residential area of Dzerzhinsk (scale 1:50000)

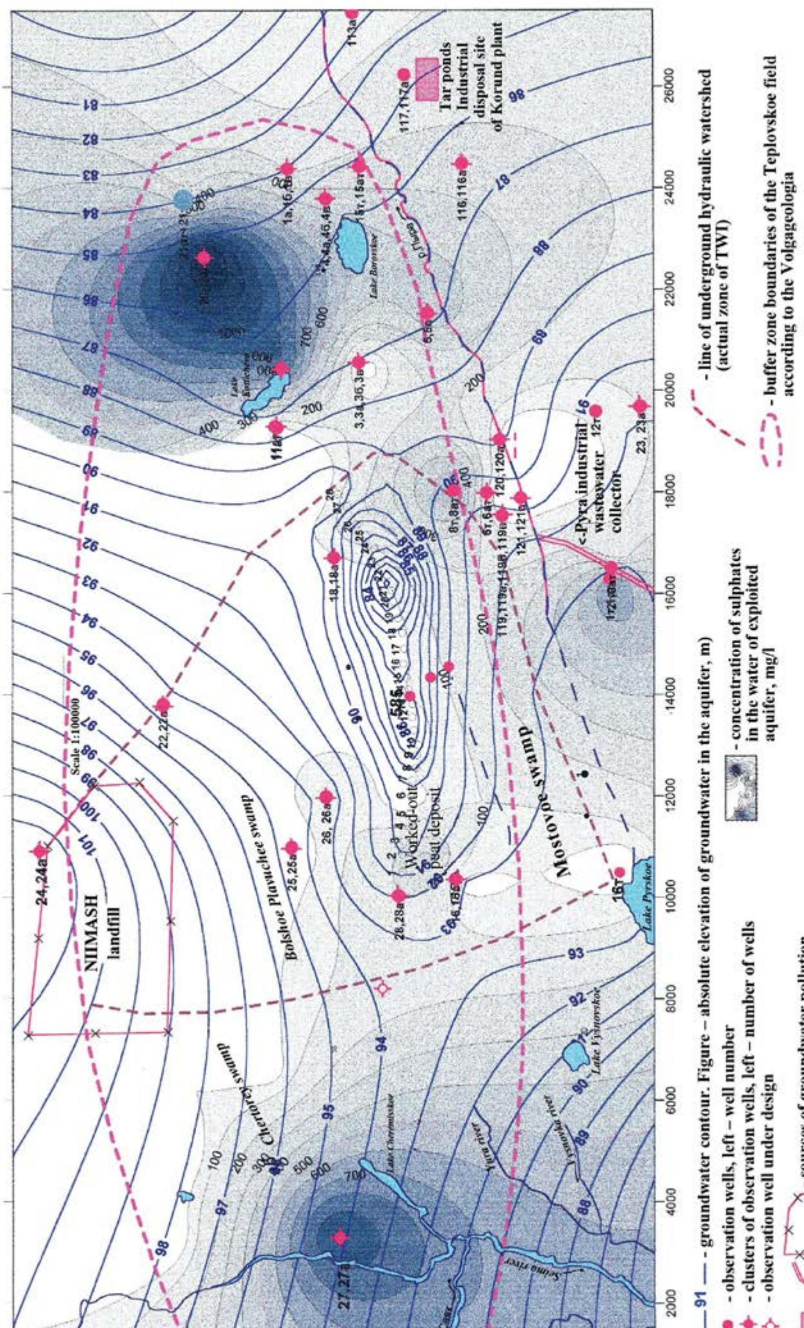


Fig. 4.23 Scheme of location of observation wells in the area of the Teplovskoe field

of increased mineralization always spreads, if during the water intake exploitation the water is extracted in quantities less than 100,000 m^3/day, (Fig. 4.24 and Fig. 4.25).

In the buffer zone of the water field and in its marginal areas special components, namely benzol, phenol, formaldehyde, cyanides and oil products are sporadically spotted in the underground waters of the exploited aquifer (Fig. 4.26).

The former shop of waste utilization and the acid tar ponds constitute a vast and longstanding hotbed of the underground water pollution in the area of the buried ancient valley of the Volga. According to the data of the observation wells drilled in the studied area, the zone of the ground-water pollution contoured by the isoline of general mineralization 1 g/dm^3 is characterized by an area of 5.8 km^2, length of 4 km and mean relative mineralization 2.2; the zone of sulphate pollution within the MPC contour (0.05 g/dm^3) is of an area of 7.3 km^2, length 4.2 km and mean relative concentration 2.8; the zone of chloride pollution within the MPC contour (0.35 g/dm^3) is characterized by an area of 1.45 km^2, radius 1.4 km and mean relative concentration 1.9.

The pollution halo is related to the shop of waste utilization and tar ponds. The maximum values of individual components at present reach (in wells 98, 100): mineralization 20.6 to 24.4 g/dm^3, sulphate content 6.85 to 9.04 g/dm^3, chloride content 2.91 to 3.09 g/dm^3, oxidability up to 100.0 mg O_2/l.

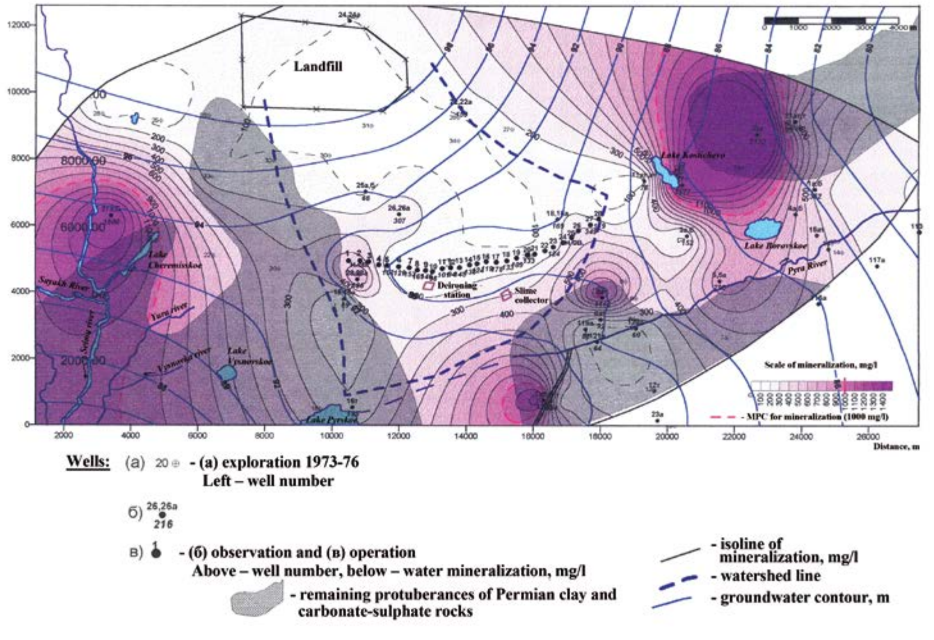


Fig. 4.24 Schematic map of mineralization of the ground-waters of the Middle Quaternary alluvial-fluvioglacial aquifer in the area of the Teplovsky water intake (based on the exploratory survey of 1998-2001, scale 1:100000)

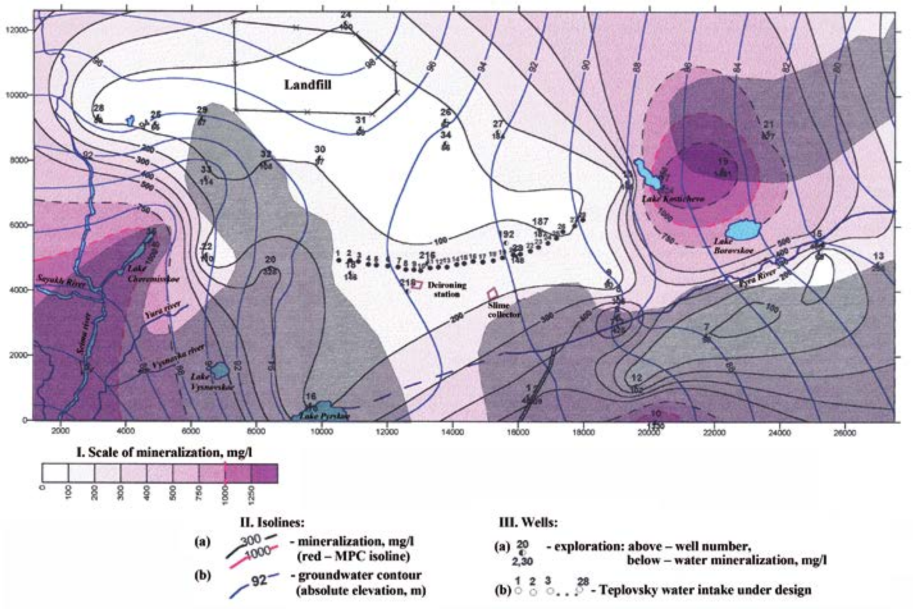


Fig. 4.25 Schematic map of mineralization of ground waters of Quaternary alluvial-fluvioglacial aquifer in the area of the Teplovsky water intake (based on the exploratory survey of 1974-1976, scale 1:100000)

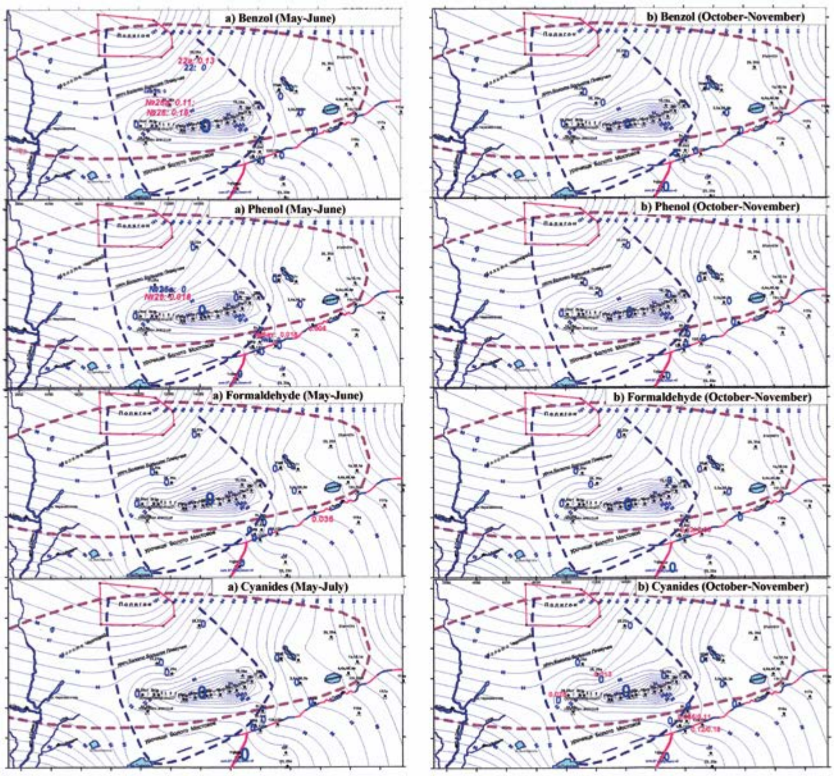


Fig. 4.26 Pollution of the underground waters of the Quaternary alluvial-fluvioglacial aquifer with special components as on 2003 (scale 1:100000)

For tar disposal 9 ponds of dimensions 150-200 mm x 40-50 m and 3.5 m deep were constructed. Almost all the ponds are filled with acid tars up to 2.5 – 3.0 m. More than once the ponds were overfilled with snowmelt floods, and the liquid wastes spilled over on to the relief. Some of the ponds have been used for slag dumping. Others are in emergency state, because the protection film on their slopes and floor has worn out. On the surface it is almost impossible to determine, where contaminated waters leak into the ground. For this purpose the authors used modern radar equipment – the georadar "Zond 12C" (Fig. 4.27)

Fig. 4.27 Georadar "Zond 12C"

10 longwise and crosswise profiles of tar ponds were performed (Fig. 4.28, 4.29) based on which radargrams were drawn and zones of polluted water flow were identified (4.30).

A tracer – fluorescein – was injected into the observation wells, 50 litres each, according to a known method *(Goncharov, 1982)*. Four wells were selected in two areas: downstream of the tar ponds (at a distance of 50 m from the last pond) and at a distance of 40 m north from the nearest pond. The direction of the ground-water flow was determined with the help of the map of water-table contours. The distance between the first pair of wells was 32 m; that between the second pair was 5.1 m (Fig. 4.31, 4.32). Observations were performed every 4 hours. The first traces of the emerald-green colour in water sampling were registered in a well of the second pair in 44 hours, i.e. the velocity of the tracer motion through the aqueous sands constituted 11.5 cm per hour or 2.76 m/day. Fluorescein was not found in the first pair of wells. The observations were carried out during 19 days. After that the experiment had to be stopped for technical reasons.

The same experiment was performed in the area of the karst active development in the east industrial zone of Dzerzhinsk. A hole 2.5 m deep was drilled in a sinkhole. The ground-water level was registered at a depth of 3.4 m. 100 litres of a fluorescein solution were poured into the hole. In the karst lake located downstream at a distance of 18 m fluorescein was spotted in 26 days, i.e. the velocity of its motion was in the average 0.7 m/day.

Fig. 4.28 Georadar tar ponds longwise profiling

Fig. 4.29 Georadar tar pond crosswise profiling

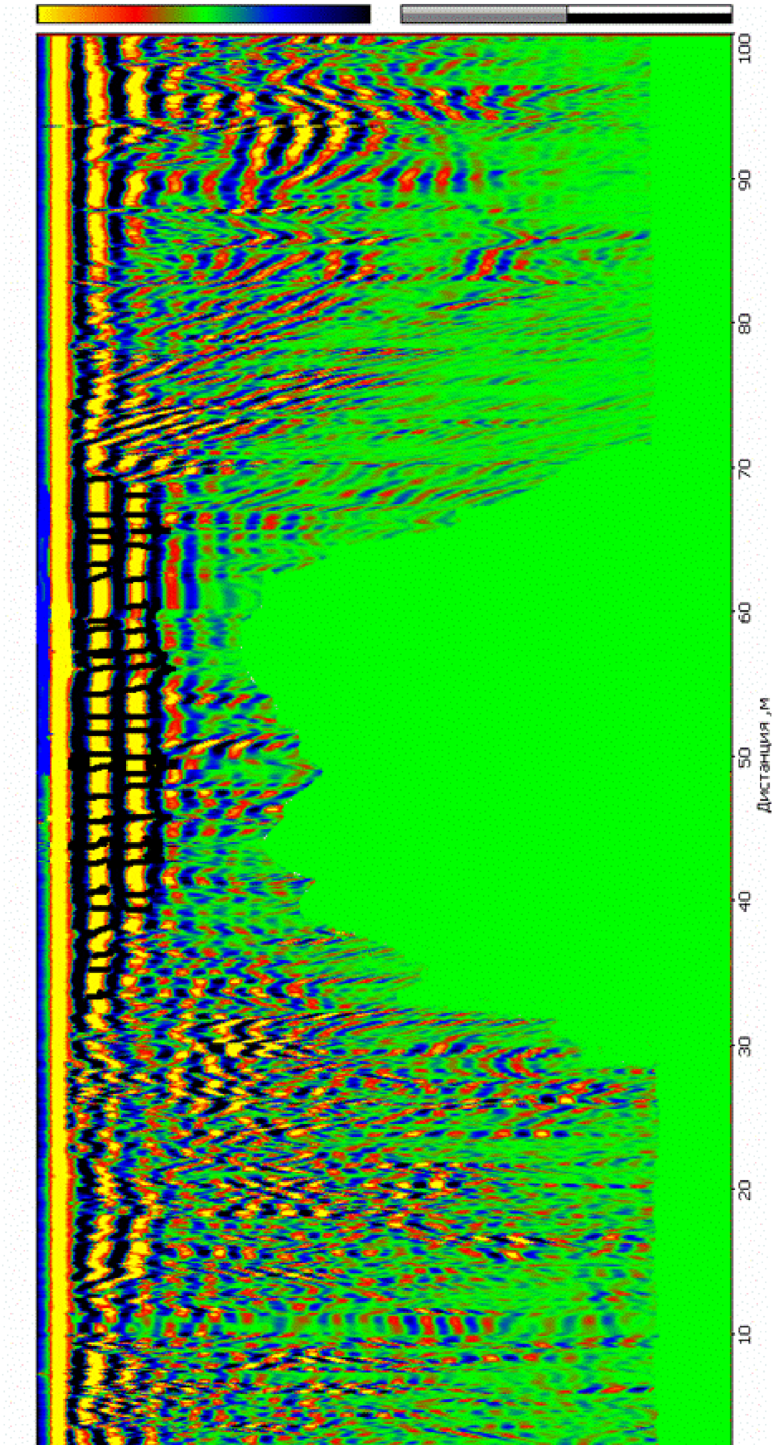


Fig. 4.30 Zones of polluted water overflow (cross section 4, longitudinal, downstream the tar ponds 900 mHz)

Fig. 4.31 Observation well used for tracer testing in the area of acid tars

Fig. 4.32 Observation wells used for fluorescein injection

Based on the analysis and mathematical processing of numerous actual data of the field and experimental researches, complex software for modeling changes of the natural-technogenic environment has been developed to perform qualitative and quantitative assessment of the dynamics of the underground water pollution distribution in the karst regions. The method is based on the balance approach, according to which the model is subdivided into elementary cells.

The software divided the studied area into numerous elementary cells, i.e. digitized it. Horizontal dimensions of all the cells were the same, but vertical ones varied forming layers of a variable thickness. Each cell was characterized by a set of parameters: water level, pressure, porosity, vertical and horizontal coefficient of filtration, concentrations of solutes and coefficient of diffusion. The software interpolates the data of monitoring of the studied territory identifying changes at any stage of simulation.

In each cell of the model the following parameters were determined for a specific period of time: the underground water balance, cation-anion balance of chemical elements, underground water pressure head, convection solute mass transfer, convection solid mass transfer, diffusion mass transfer, underground water mineralization and pollution at a given moment of time, aggressiveness of the underground, surface and technogenic waters with respect to the karstifying rocks.

In general, during the interaction of the i-cell (current) with one of the six neighbouring cells, the $i+1$-cell (neighbouring), the volume of water flowing per a unit of time was calculated according to the formula:

$$\Delta q_i / \Delta t = k_{i-(i+1)} \cdot (p_{i+1} - p_i)\,, \quad (4.4)$$

where $k_{i-(i+1)}$ is the mean coefficient of filtration for two cells; p_{i+1} is the pressure in the neighbouring cell; p_i is the pressure in the current cell.

The negative value of q corresponds to the fluid outflow from the cell, positive – to the fluid inflow. The pressure in partially filled cells was defined by the fluid head in them, while the pressure in the entirely filled-up cells was calculated in every cycle of simulation according to the arithmetic equations based on the total inflow-outflow balance of the current cell:

$$\sum q_i = 0\,. \quad (4.5)$$

Convective solute mass transfer from one cell to another was calculated as follows:

$$\Delta n_i / \Delta t = q \cdot n_{i+1} (q > 0); \quad (4.6)$$

$$\Delta n_i / \Delta t = q \cdot n_i (q < 0)\,, \quad (4.7)$$

where n is the solute quantity in the cell.

Diffusion was determined with the formula:

$$\Delta n_i / \Delta t = f_{i-(i+1)} \cdot (c_{i+1} - c_i), \qquad (4.8)$$

where $f_{i-(i+1)}$ is the mean coefficient of diffusion for two cells; c is the concentration in the corresponding cells determined as a relation of the solute quantity in the cell to the volume of solution therein.

In addition to the drawing of maps and cross sections depicting the static condition of the nature-technogenic environment, the software permitted to evaluate the dynamics of distribution of the underground water pollution with chlorides and sulphates on the waste disposal sites of the east industrial zone of the city of Dzerzhinsk (Fig. 4.33 to 4.35).

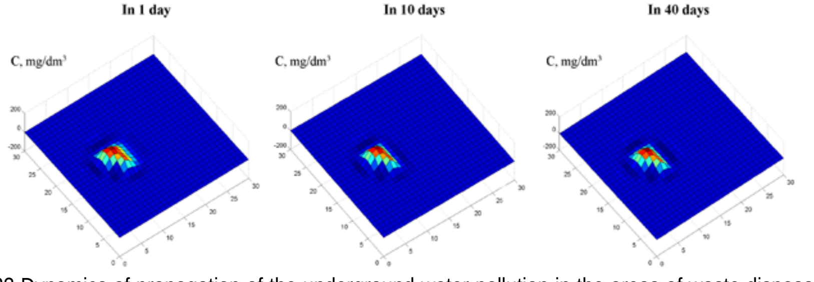


Fig. 4.33 Dynamics of propagation of the underground water pollution in the areas of waste disposal with an intact clay aquifuge overlying the karstifying rocks

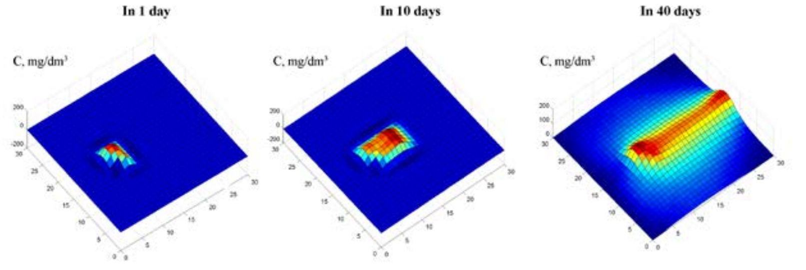


Fig. 4.34 Dynamics of propagation of the underground water pollution in the areas of waste disposal, when the karstifying rocks are not overlain by a clay aquifuge

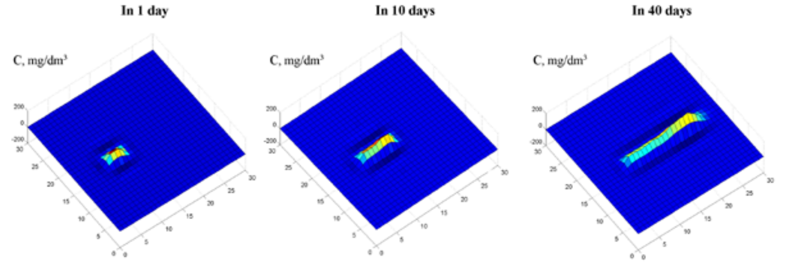


Fig. 4.35 Dynamics of propagation of the underground water pollution in the areas of waste disposal, when the continuity of the clay aquifuge overlying the karstifying rocks is disrupted by a void roof collapse

Conclusions

1. A scheme of information support for a geoecological assessment of the underground water man-caused pollution in the karst regions has been developed.
2. Regional patterns of the karst development and distribution of recent karst forms have been defined to understand the direction and dynamics of the underground water pollution in the karst regions.
3. Four types of the mechanism of distribution of the underground water technogenic pollution in the areas of covered karst have been defined and described, depending on the existence of an aquifuge above the karstifying rocks.
4. Methods of evaluation of the underground water pollution extent have been developed and substantiated. Assessment of the extent of the underground water man-caused pollution was performed for discrete karstified areas of the Nizhny Novgorod region.

Chapter 5

PRINCIPLES OF SUSTAINABLE USE OF THE UNDERGROUND WATERS IN THE KARST REGIONS

5.1 General requirements to the water resources development on the karstified territories

Karstified territories are characterized by the increased sensitivity to the man-caused impact. Because of that the existing correlations between ecosystems, types and kinds of technogenesis and conditions of karst development present a weakly balanced system *(Geoecol. issled., 1994; Vartanyan et al., 1994, 2000; Kaznov, Koposov, 1997; Gaev, 1999; Belousova 2003)*.

Therefore, while planning water resources development in the karst regions, one should observe a number of general requirements:

1. To have cartographic information about the exposure of the territory of the studied region to dangerous geoecological processes, such as karst, suffosion, underflooding and gully erosion on scale 1:500000 – 1:200000 (for a subject of the Russian Federation) and more detailed for discrete objects.
2. To understand the consequences of a possible activation of the karst-suffosion processes due to water fields development, estimate a possible damage inflicted by karst events during exploitation of natural water fields, and determine the necessity and character of karst preventive measures.
3. On the karstified territories, where the natural-technogenic environment (NTE) is already characterized by the unsatisfactory geoecological conditions, it is not allowed to add extra technogenic load without having improved the NTE's state to keep it on a self-recovery level.
4. Areas of intensive development of surface and subterranean karst should be excluded from an active hydroeconomic use. They are recommended to be used as buffer zones, parks, natural reserves, nature memorials, etc.
5. To observe NTE changes in the karst regions and dynamics of the underground water pollution development, organization and fulfillment of the monitoring programme "Underground waters in karst regions and technogenesis" are to be planned.

For a long-term planning of water resources development on the karstified territories, the authors have developed a scheme of actions consisting of five stages (Table 5.1).

Table 5.1

Scheme of long-term planning of water resources development on karstified territories

Phase of development of territorial resources	Stage of work	Results
Long-term planning	First stage	Zoning the territory by the basic kinds of water-related activities under design
	Second stage	Analysis of the location of the designed water facilities with respect to the degree of karst risk existing on the selected territories
	Third stage	Evaluation of the impact of the planned technogenic loads

		on the existing balance or imbalance of the NTE state and on the dynamics of the underground water pollution process
	Fourth stage	Technical and economic assessment of the variants of neutralization or minimization of the impact of the designed technogenic loads on the existing NTE state
	Fifth stage	Decision-making for or against construction of water facilities on the given territories

5.2 Information-and-management model of the system of ecologically clean water supply from the underground sources on the karstified territories

Large resources of high quality fresh drinking waters concentrate on the karstified territories *(Borevsky et al., 1989, 1998; Koposov, 1996; Bocharov, 2000; Naidenko, 2003)*.

To guarantee the ecologically clean drinking water supply to the population from the underground sources in the karst regions, the authors have developed the following system (Fig. 5.1).

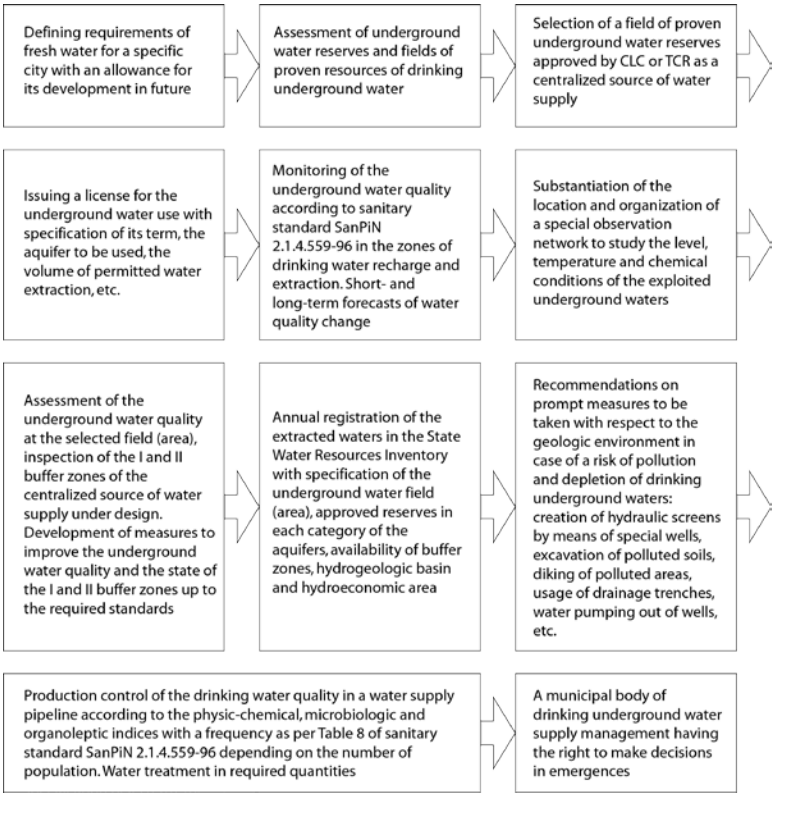


Fig. 5.1 Information-and-management model of a system of ecologically clean drinking water supply to population from the underground sources in the karst regions

5.3 Typification of water intakes by the conditions of possible pollution based on the natural protectability of the exploited aquifers and water-bearing complexes

Many recognized researchers dedicated their works to the study of conditions of possible pollution and protection of the underground water intakes *(Minkin, 1967; Tyutyunova et al., 1978, 1989; Bochever, Lapshin, Oradovskaya, 1979, 1983; Gavich, 1985; Krainov, Shvets, 1987; Shestakov, 1979, 1995; Plotnikov, 1998; and many others)*.

The authors have defined the types of the underground water intakes on the karstified territories according to the degree of their protection from the pollution and depletion, their impact on the state of the natural-technogenic environment and dynamics of the development of pollution processes depending on the method of water extraction.

Two types of water intakes have been defined (Fig. 5.2).

The first type: water intakes of the centralized water supply systems of large cities and settlements extracting water from the sand formations overlying the karstifying rocks in the valleys of the Oka and Volga rivers, as well as their tributaries. This type is characterized by the vulnerability of the exploited aquifer, presence of a thin interlayer of poorly permeable argillaceous-marl rocks between the exploited aquifer and the karstifying rock masses, direct hydraulic connections between the fracture-karst and ground waters in some areas due to the aquifuge disruption caused by collapse sinkholes that create through hydrogeologic “windows” between the aquifers, the lowering of the levels of the exploited aquifer by tens of meters, formation of large depression cones, periodic streams of small rivers, activation of karst-suffosion processes, propagation of two types of pollution – man-caused and natural (due to the upflow of unconditioned low-mineralized waters from the underlying aquifers and water-bearing complexes).

The first type is divided into two subtypes: a) *with a disrupted clay aquifuge*; b) *with the absence of clay aquifuge* above the karstifying rocks in large buried valleys.

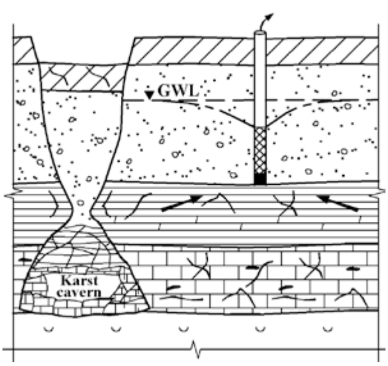
The second type: water intakes of the centralized water supply systems of cities and settlements extracting water from the soluble karstifying rocks, i.e. fracture-karst water. According to the degree of protection of the exploited aquifer from the surface man-caused pollution, the second type is divided into two subtypes:

a) *unprotected* or *conditionally protected* from the surface pollution, when the overlying rocks are represented by sand or thin clay formations and the depth of the exploited aquifer is small;

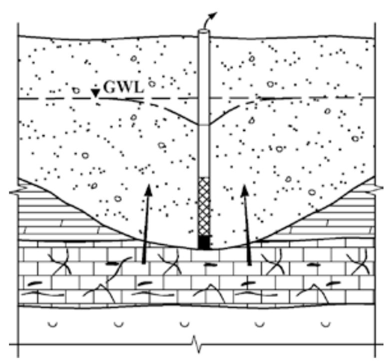
b) *protected* from the surface pollution by a layer of clayey deposits over 40-50 m thick with the aquifer's depth of occurrence is more than 100 meters.

All features attributed to the ground water intakes with direct hydraulic connections between aquifers, absence or disruption of a clayey stratum separating the karstifying massif and ground waters are typical for the first subtype. Based on the software developed by the authors, as well as methods of modeling parameters of the operating underground water intake, it is possible to forecast formation of a zone of aggressive, with respect to the karstifying rocks, waters in the areas of water intakes under different conditions and with given regimes of water extraction, as well as to develop guidelines for exploitation of water intakes on the karstified territories with a favourable, scarcely favourable and unfavourable ecological state of the natural-technogenic environment (NTE). Water intake construction is prohibited in the areas of considerably unfavourable NTE's ecological condition, which are considered as extremely dangerous according to the degree of karst risk.

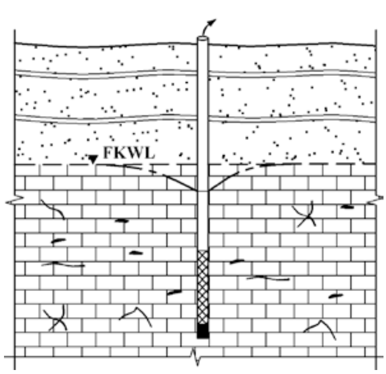
a)



b)



c)



d)

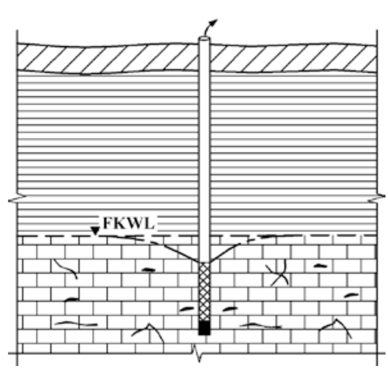


Fig. 5.2 Typification of water intakes by the conditions of possible pollution: type I – water intakes from the sand formations overlying the karstifying rocks: *a*) with a clay aquifuge disrupted by a collapse sinkhole and conjugated fractures underlying the karstifying rocks; *b*) no clay aquifuge above the karstifying rocks in the area of buried valleys. Type II – water intakes from the soluble karstifying rocks: *c*) unprotected or conditionally protected with sand formations or thin clay rocks overlying the karstifying rocks; *d*) protected from pollution by a clay layer 40-50 m thick overlying the fracture-karst waters

For the second subtype of water intakes with the depth of the fracture-karst water of more than 100 m, having head and overlain by a thick confining layer, the conditions for the contemporary karst development leading to surface deformations are unfavourable. The location, construction and exploitation of water intake facilities of this subtype are regulated by the parameters accepted during the approval of the underground water reserves of a given deposit and selection of a water user under the supervision of the corresponding state bodies.

It should be noted that during designing buffer zones for the first type and the first subtype of the second type of water intakes, patterns of distribution of surface and subterranean forms of karst in the areas of water intake influence as well as in the areas of water intake recharge should be taken into account.

5.4 System of protective measures for isolation and elimination of the existing sources of pollution of the underground hydrosphere and preventive measures for the designed facilities

Elaboration of protective measures to localize and eliminate areas of the underground water pollution requires an individual approach to every specific source of pollution depending on its kind, character, scale and intensity of pollution, engineering-geological and hydrogeological conditions, orientation of tectonic fissures, degree of karstification of the area, degree of the risk of pollution and possible malfunction of neighbouring water intakes, location of recreation zones. Discrete aspects of this problem were studied by home and foreign researchers *(Lapshin et al., 1983; Buchkin, 1988; Bochever, Lapshin, Oradovskaya, 1979; Goldberg, 1980, 1984, 1995; Gavich, 1985; Babak, 1991; Mironenko, 1995-2002; Krainov, 1999, 2000; Kuranov, 2001; Solsky, 2001; Koposov, 2002; Kultin et al., 2003; Klaperikh, 2003; Averkina, 1994; Villervald, 1995; Aldous, 1988; Mercer, 1990; Antiguedad, 2000; Fisher, 1999).* A system of engineering protective measures was recommended for isolation and elimination of the existing sources of pollution of the underground hydrosphere in the karst regions of the Nizhny Novgorod region. For petroleum chemical plants and depots of oil products, these are hydraulic screens created by a system of special wells forming a depression normal to the flow of polluted underground waters. For small local objects like landfills, ash disposal sites and ash ponds, this is construction of closed and semi-closed water tight underground walls and foundations. In case of intensive pollution by hazardous contaminants, this is a combination of the hydraulic screens and water tight underground walls. For random single leakages of pollutants, this is an excavation of contaminated soils, diking of contaminated areas (provided the zone of aeration is formed of clayey soils) and water pumping out of wells or drainage trenches.

The main measures to prevent the negative impact of designed potential sources of technogenic pollution of the underground waters in the karst regions are as follows:

- to prohibit construction of potential sources of pollution in the areas of the surface karst occurrence;
- for construction of landfills to conduct special detailed engineering-ecological surveys in two stages: a) approval of site selection; b) approval of the design and establishment of a system of control over a safe exploitation of a landfill;
- in the areas with the relatively favourable conditions for karst development, the design of facilities, which are considered potential sources of pollution, should provide for an appropriate hydraulic insulation; the monitoring "Underground waters in karst regions and technogenesis" should be necessarily organized and carried out according to the scheme developed by the authors (Fig. 5.3).

By the monitoring of the underground waters in the karst regions a special system of observations is understood, which permits to track processes taking place in the underground waters under the technogenic impact and due to the peculiarities of karst development, to assess the underground water state and forecast its change for the purpose of a rational water management.

Other definitions of the underground water monitoring are possible, but any thematic objective information about changes taking place in the underground hydrosphere should contain analysis of the reasons thereof and tendencies of their development, forecasts and substantiation of measures of prevention or elimination of the underground water pollution *(Altovsky, 1954; Frid, 1981; Konoplyantsev et al., 1984; Grozdova, 1987; Pitjeva, 1989; Klimas, 1990; Goldberg, 1990, 1991; Vartanyan, 1994; Koposov et al., 1998; Kuzmin et al., 1999; Kurennoy, 1999, 2000; Lukyanchikova, 2000; Pavlichenko, 2000).*

The basic tasks of the system of the underground water monitoring in the karst regions are:

1. To study the region-related features of the long-term natural and man-affected regime, balance, chemical composition and quality of the underground waters in the principle hydrogeologic regions for the purpose of timely detection of the negative technogenic impact on the underground waters and assessment thereof.
2. Monitoring and control of the degree of pollution and depletion of the underground waters in the karst regions subject to man-caused impact, including:
   - in the areas of the underground water extraction;
   - in the areas of industrial enterprises, complexes (potential and existing polluters);
   - in the zones of influence of the mining industry;
   - in urban areas and adjacent buffer zones;
   - in large hydroeconomic areas (areas of agricultural melioration, zones of influence of reservoirs, channels, etc.).

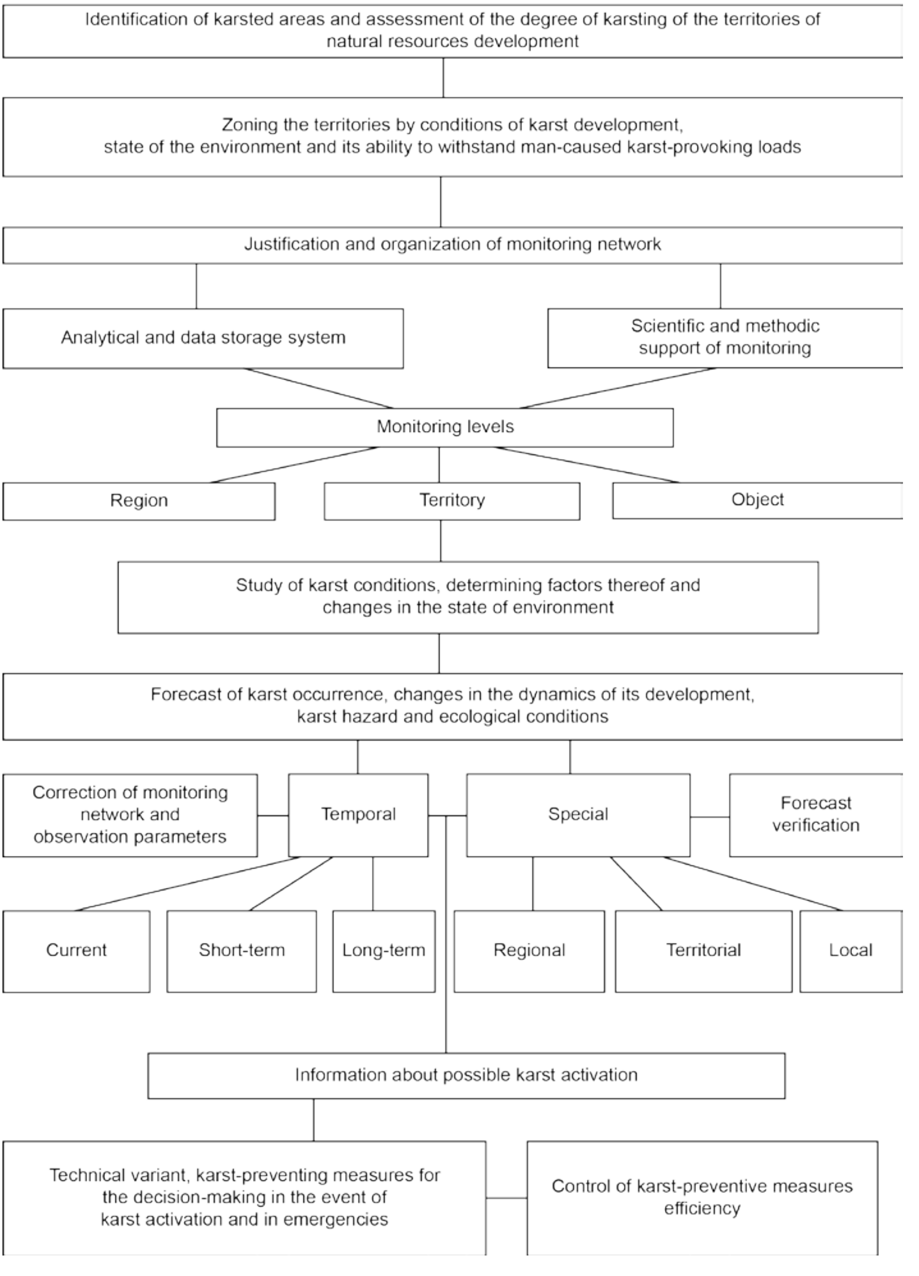


Fig. 5.3 Scheme of organization and implementation of the monitoring “Underground waters in karst regions and technogenesis”

3. To analyze and generalize the hydroregime information in order to assess the condition and quality of the underground waters, degree of technogenic impact, as well as to identify and evaluate factors affecting the regime and quality of the underground waters.
4. Forecasting (including forecasts of the underground water level conditions and constituents of the underground water balance, as well as forecasts of hydrochemical regime and dynamics of contaminants propagation in the underground waters).
5. To provide state bodies and enterprises with systematic and on-line information about changes of the regime and quality of the underground waters to take prompt measures preventing possible negative consequences.
6. To control the efficiency of measures for the underground hydrosphere protection from pollution.

The above mentioned preventive measures have been developed on the basis of the results of the karst-ecological zoning of the territory, which takes into account the natural protectability of the fracture-karst waters from the surface pollution through the zone of aeration, conditions of interconnection of the surface and underground waters, patterns of distribution of surface, subterranean and buried karst, presence of buried ancient river valleys; underground water exploitation and geochemical characteristic of the main aquifers; changes of the natural-technogenic environment caused by the man-induced impacts and loads; variants of the mechanism of propagation of the underground water technogenic pollution and dynamics of its development.

Summary

1. Analysis and generalization of the domestic and foreign experience in studying the processes of pollution and methods of protection of the underground waters in the karst regions are made. It is revealed that during the site selection and designing landfills for disposal of industrial, agricultural and communal wastes, as well as wastes of city treatment plants and other potential ground polluters the proper attention has not been paid to the assessment of the territory karstification and elaboration of corresponding measures to protect the underground hydrosphere from pollution.

2. Analysis and typification of geoecological conditions of the karstified territories with an allowance for the underground water natural protectability from the surface pollution are fulfilled. Nine types of cross sections of rock masses are defined, representing most typical geopercolating conditions of the karst regions of the Middle Volga, which permit to identified areas and zones most “sensitive” to the surface pollution. The field investigations confirmed existence of vast zones of the underground water pollution on the territories characterized by II, IV, VI, VII and VIII types of cross section. Concentrations of oil products, special components, chlorides, sulphates, nitrites and heavy metals in the underground waters in these areas are 10 to 15 times higher than their content in other cross sections.

3. By the example of the Nizhny Novgorod region the direct dependence of the intensity and directedness of the underground water pollution on the proximity of the surface polluters to the areas affected by collapse sinkholes is shown. The territories of the cities of Dzerzhinsk, Arzamas, Pervomaisk, Pavlovo, the “zarechnaya” territory of Nizhny Novgorod are described as examples.

4. Methodology of a complex assessment of the extent and degree of the underground water man-caused pollution in the karst regions is developed based on the analysis of the areal distribution of karst forms and their confinement to the lineaments of the relief, study of the mechanism of collapse formation in different types of cross sections of rock masses, field geochemical, geophysical and experimental researches, and modeling processes of contaminants migration. The methodology allows defining the contours of the most dangerous areas and zones in terms of degree and kind of contamination, forecasting ways and variants of a possible development of the underground water pollution process, and taking timely measures to protect life-supporting facilities and natural complexes.

5. Hydrogeologic calculations of the ground-water balance for the summer low-water period (levels of 50% probability) reveal that the ground-water recharge and

discharge on the “zarechnaya” territory of Nizhny Novgorod are almost equal: the total value of inflow (recharge) constitutes 50,102 m^3/day, outflow – 49,648 m^3/day, imbalance is +454 m^3/day (0.9% of the outflow). The value of recharge is slightly higher than that of discharge.

The groundwater inflow-outflow equality is an evidence of the aquifer dynamic stability. Under the existing conditions of the groundwater recharge and discharge, the aquifer levels in the low-water period remain stable and abnormally high, that leads to the underflooding of the entire territory of Zarechie. The groundwater level stability, in its turn, provides for the stability of the underflooding process.

The dynamic equilibrium of the groundwater recharge and discharge is ensured by the stability of the balance items: values of the natural and technogenous recharge and discharge and, to a greater extent, by a constantly existing regional factor – the groundwater outflow to the adjacent aquifer of the fracture-karst Kazanian deposits through the permeable interlaying strata.

6. Areas of the prevailing groundwater vertical outflow coincide with the hydrogeologic “windows” in the roof of the pre-Quaternary marl clay deposits. The intensive outflow of the ground waters (against the background of the technogenic recharge) is observed in the Oka and Volga riverside areas. The width of the discharge strip reaches 2.5 km; the zone of discharge runs parallel to the modern beds of the Oka and Volga.
7. The active groundwater outflow against the background of the natural and technogenous recharge prevails in the west part of Zarechie. The strip of the groundwater outflow into the fractured and karstified rocks of a width ranging from 1.5 to 4.5 km stretches from the Volga to the Oka (from north to south), coinciding with the area of the most corroded rocks of the interlaying aquifuge. Areas of the dominant outflow of the ground waters into the pre-Quaternary deposits almost coincide with the areas of the active surface karst development.
8. Based on the results of the implemented researches, protective measures to prevent and localize the technogenic pollution of the underground waters on the karstified territories are recommended, as well as a scheme of organizing and carrying out monitoring “Underground waters in karst regions and technogenesis” is developed.

References

1. Аверкина, Т. И. Пример оценка устойчивости массивов песчано-глинистых пород к техногенному загрязнению / Т. И. Аверкина // Геоэкология. – 1994. – № 1.

2. Акпарисова, Г. В. Влияние свалок твердых бытовых и производственных отходов на поверхностные и подземные воды / Г. В. Акпарисова, И. Н. Акулова // Инженерно-геологическое обеспечение недропользования и охраны окружающей среды : материалы междунар. науч.-практ. конф. – Пермь, 1995. – С. 217-218.

3. Алексеев, В. С. Массоперенос в водонасыщенных горных породах / В. С. Алексеев, Г. М. Коммунар, Б. С. Шержуков. – М., 1989. – 144 с. – (Итоги науки и техники. Сер. «Гидрогеология и инженерная геология» / ВИНИТИ ; т. 11).

4. Альтовский, М. Е. Методическое руководство по изучению режима подземных вод / М. Е. Альтовский, А. А. Коноплянцев. – М. : Госгеолтехиздат, 1954. – 196 с.

5. Аникеев, А. В. Некоторые особенности деформирования и разрушения массивов горных пород при техногенном изменении режима подземных вод / А. В. Аникеев, Н. Б. Артамонова, Э. В. Калинин // Геоэкология. Инженерная геология. Гидрогеология. Геокриология. – 2000. – № 3. – С. 249-256.

6. Артемов, А. В. Сравнительный анализ антропогенного загрязнения снежного покрова и гидросферы урбанизированных ландшафтов / А. В. Артемов, Е. Ю. Выговская, О. Е. Жукова // Экология и промышленность России. – 1999. – № 4. – С. 32–35, 49.

7. Бабак, В. В. Геоэкология полигонов твердых бытовых отходов Московского региона : автореф. дис. канд. геол.-минерал. наук / В. В. Бабак. – М., 1991. – 24 с.

8. Баренблатт, Г. И. Математическая теория равновесия трещин, образующихся при хрупком разрушении / Г. И. Баренблатт // Прикладная математика и техническая физика. – М., 1961. – С. 3–57.

9. Баренблатт, Г. И. О некоторых краевых задачах для уравнений фильтрации жидкости в трещиноватых породах / Г. И. Баренблатт // Прикладная математика и механика. – М., 1963. – Т. 27, вып. 2. – С. 348–350.

10. Белицкий, А. С. Охрана природных ресурсов при удалении промышленных жидких отходов в недра Земли / А. С. Белицкий. – М. : Недра, 1976. – 144 с.

11. Белоусова, А. П. Методология оценки рисков загрязнения подземных вод в контексте устойчивого развития / А. П. Белоусова // Проблемы окружающей среды и природных ресурсов. – 2003. – № 9. – С. 83–91.

12. Беляева, Ю. Л. Влияние накопителей жидких отходов на окружающую среду и здоровье человека в западном Прикаспии : автореф. дис. … канд. геол.-минерал. наук / Ю. Л. Беляева. – Волгоград, 2001. – 23 с.

13. Бирюкова, Л. А. Результаты режимных наблюдений за загрязнением подземных вод на опытном полигоне в Горьковской области / Л. А. Бирюкова, Р. А. Ченцова // Сборник научных трудов / ВСЕГИНГЕО. – М., 1990. – С. 73–77.

14. Боравская, Т. В. и др. Европейский опыт обращения с отходами

производства и потребления. Торгово-промышленная палата РФ. – М., 2010. – 212 с.

15. Боревский, Б. В. Оценка запасов подземных вод / Б. В. Боревский, Н. И. Дробноход, Л. С. Язвин. – Киев : Выщ. шк., 1989. – 407 с.

16. Боревский, Б. В. Специальные опытно-миграционные работы для моделирования техногенного загрязнения подземных вод в водоносных горизонтах большой мощности / Б. В. Боревский, Г. Е. Ершов, С. Л. Шубин // Доклады международного рабочего семинара по гидрогеологическому моделированию и экологической геологии (21–27 авг. 1994 г., Ждярские Врхи) : сборник. – М., 1994. – С. 97–108.

17. Боровский, Б. В. Экологически чистые подземные питьевые воды (минеральные природные столовые) : рекомендации по обоснованию перспективных участков для добычи с целью промышленного розлива / Б. В. Боровский [и др.]. – М. : ГИДЭК, 1998. – 31 с.

18. Бочаров, Л. В. Использование программных средств для изучения гидроэкологических дисциплин студентами геологических специальностей / Л. С. Бочаров, В. С. Стародубцев // День Земли : экология и образование : материалы 3-й Между- нар. межвуз. конф. / Бийск. гос. пед. ин-т. – Бийск, 1998. – С. 73–74.

19. Бочаров, Н. А. Оценка запасов пресных вод в Поволжье / Н. А. Бочаров, В. П. Агафонов // Разведка и охрана недр. – 2000. – № 10. – С. 53.

20. Бочевер, Ф. М. Защита подземных вод от загрязнения / Ф. М. Бочевер, Н. Н. Лапшин, А. Е. Орадовская. – М. : Недра, 1979. – 254 с.

21. Бузаев, В. В. Методы прогноза миграции солей в слоистых водоносных пластах : автореф. дис. канд. хим. наук / В. В. Бузаев. – М., 1982.

22. Бучкин, М. Н. Оценка перспективности территории Московской области для размещения полигонов твердых бытовых и промышленных отходов / М. Н. Бучкин, Л. П. Гибанова, В. В. Бабак // Инженерная геология. – 1988. – № 1. – С. 97–100.

23. Быков, В. Н. О проблеме размещения в недрах токсичных отходов / В. Н. Быков // Материалы конференции. – Пермь, 1997. – С. 222–224.

24. Вакар, Н. Г. Методика районирования территории по опасности загрязнения диоксидами подземных вод (на примере Московской обл.) / Н. Г. Вакар, Ю. С. Зеегофер // Водные ресурсы. – 2000. – № 1. – С. 21–31.

25. Вартанян, Г. С. Современные геоэкологические проблемы Центральной Евразии / Г. С. Вартанян, И. Тагиев // Отечественная геология : докл. XXXI Междунар. геол. конф. – Рио-де-Жанейро, 2000. – № 8, Спец. вып. – С. 13.

26. Вартанян, Г. С. Экологическое состояние геологической среды России / Г. С. Вартанян, В. В. Куренной // Геоэкологические исследования и охрана недр : науч.-техн. информ. сб. – М., 1994. – Вып. 2. – С. 3-15.

27. Вернадский, В. И. История природных вод / В. И. Вернадский. – М. : Наука, 2003. – 750 с. – (Библиотека трудов академика В. И. Вернадского).

28. Виллевальд, Р. С. Управление и нормативно-правовое регулирование обращения с твердыми промышленными и бытовыми отходами / Р. С. Виллевальд // Геоэкология. Инженерная геология. Гидрогеология. Геокриология. – 1995. – № 3. –

С. 56-59.
29. Владимиров, В. В. Экологический императив города / В. В. Владимиров // Промышленное и гражданское строительство. – 2000. – № 9. – С. 18–20.
30. Водопользование и национальная безопасность / А. А. Беляков, Е. В. Веницианов, И. К. Комаров [и др.]. – М. : Вымпел, 1997. – 296 с.
31. Вопросы информационной политики в области использования, охраны и восстановления водных объектов / А. Н. Подуст, А. М. Черняев, Л. В. Оганесян, В. С. Кукош // Использование и охрана природных ресурсов России. – 2000. – № 4. – С. 57-70.
32. Врба, Я. Экологические последствия влияния технологенных факторов на качество подземных вод / Я. Врба, В. Йиржеле, Я. Балек // Доклады XXVII Международного геологического конгресса. Секция 16 : Гидрогеология. – М., 1984. – С. 93-104.
33. Гавич, И. К. Методы охраны подземных вод от загрязнений и истощения / И.К. Гавич. – М. : Недра, 1985. – 320 с.
34. Гаев, А. Я. Техногенез, карстогенез и геологическая деятельность подземных вод / А. Я. Гаев // Проблемы геологии Пермского Урала и Приуралья : материалы регион. науч. конф. – Пермь, 1999. – С. 118-119.
35. Галицин, М. С. Особенности геохимической эволюции подземных вод на техногенном этапе / М. С. Галицин // Подземные воды и эволюция литосферы : тез. докл. Всесоюз. конф. – М., 1985. – Т. 11. – С. 364-367.
36. Гелашвили, Д. Б. Экология Нижнего Новгорода / Д. Б. Гелашвили, Е. В. Копосов, Л. А. Лаптев. – ННГАСУ. – Н. Новгород, 2008. – 530 с.
37. Геоэкологические исследования и охрана недр : информ. сб. Вып. 2 / Ком. Рос. Федерации по геологии и использованию недр. – М. : Геоинформмарк, 1994. – 56 с.
38. Геоэкологическое картографирование : тез. докл. Всерос. науч.-практ. конф., 24-27 февр. 1998 г. Ч. 1. – М. : ВСЕГИНГЕО, 1998. – 164 с.
39. Геоэкология : проблемы и решения : тез. докл. и сообщ. Всесоюз. науч.-техн. конф. / Всерос. науч.-исслед. ин-т гидрогеологии и инженер. геологии (ВСЕГИНГЕО). – М. : [б. и.], 1991. – 182 с.
40. Геоэкология. В 2 ч. Ч. 2 : Глобальная и ландшафтная геоэкология / Ю. Н. Гладкий, А. И. Жиров, В. И. Игнатенко [и др.] ; Рос. гос. пед. ун-т им. А. И. Герцена. – СПб. : Образование, 1997. – 261 с.
41. Гидродинамические и физико-химические свойства горных пород / Н. Н. Веригин, С. В. Васильев, В. С. Саркисян, Б. С. Шержуков. – М. : Недра, 1977. – 271 с.
42. Голодковская, Г. А. Геологическая среда промышленных регионов / Г. А. Голодковская, Ю. Б. Елисеев. – М. : Недра, 1989. – 219 с.
43. Голубев, Г. Н. Геоэкология и глобальные изменения / Г. Н. Голубев // Вестник МГУ. Сер. 5, География. – 1998. – № 4. – С. 61-70.
44. Гольдберг, В. М. Взаимосвязь загрязнений подземных вод и природной среды / В. М. Гольдберг. – Л. : Гидрометеоиздат, 1987. – 248 с.
45. Гольдберг, В. М. Гидрогеологическое обоснование размещения полигонов промышленных отходов / В. М. Гольдберг // Геоэкология. – 1995. – № 3. – С. 43-49.

46. Гольдберг, В. М. Загрязнение подземных вод и его геоэкологические последствия / В. М. Гольдберг // Геэкология : тез. докл. Всесоюз. науч.-техн. конф. / ВСЕГИНГЕО. – М., 1991. – Ч. 2. – С. 6-8.

47. Гольдберг, В. М. Изучение загрязнения подземных вод в натурных условиях на полигонах / В. М. Гольдберг // Сборник научных трудов / ВСЕГИНГЕО. –М., 1990. – С. 5-12.

48. Гольдберг, В. М. Методические рекомендации по гидрогеологическим исследованиям и прогнозам для контроля за охраной подземных вод / В. М. Гольдберг. М. : ВСЕГИНГЕО, 1980. – 86 с.

49. Гольдберг, В. М. Методы оценки защищенности подземных вод от загрязнения / В. М. Гольдберг // Изучение защищенности подземных вод : сб. науч. тр. / ВСЕГИНГЕО. – М., 1986. – С. 6-14.

50. Гольдберг, В. М. Проницаемость и фильтрация в глинах / В. М. Гольдберг, Н. П. Скворцов. – М. : Недра, 1986. – 160 с. : ил.

51. Гольдберг, В. Н. Гидрогеологические основы охраны подземных вод от загрязнения / В. Н. Гольдберг, С. М. Газда. – М. : Недра, 1984. – 262 с.

52. Гольдберг, В. Н. Изучение загрязнения подземных вод и окружающей среды на примере одного из промышленных районов / В. Н. Гольдберг, В. М. Мошкин // Бюллетень Московского общества испытателей природы. – 1980. – Т. 55, вып.

53. ГОСТ 2874-82. Вода питьевая. Технические требования и контроль за качеством. – Взамен ГОСТ 2874-73 ; введ. с 01.01.85. – М. : Изд-во стандартов, 1983. – 7 с.

54. Гочаров, В. С. Методические рекомендации по применению флуоресцентных индикаторов при гидрогеологических исследованиях / В. С. Гончаров, С. И. Латышев. – М. : ВСЕГИНГЕО, 1982. – 89 с.

55. Грибанова, Л. П. Оценка влияния полигонов складирования твердых бытовых и промышленных отходов на геологическую среду / Л. П. Грибанова [и др.] // Инженерная геология. – 1987. – № 4. – С. 68-73.

56. Грибанова, Л. П. Оценка геохимических изменений геологической среды на полигонах промышленно-бытовых отходов / Л. П. Грибанова, А. С. Зайцев // Инженерная геология. – 1990. – № 3. – С. 78-84.

57. Грибанова, Л. П. Проблема захоронения и утилизации твердых бытовых отходов в Московском регионе / Л. П. Грибанова // Геоэкология. Инженерная геология. Гидрогеология. Геокриология. – 1995. – № 3. – С. 50-55.

58. Гриневский, С. О. Анализ фильтрационной неоднородности карбонатного водоносного горизонта по данным опытно-фильтрационных работ / С. О. Гриневский, Е. Е. Бобылова // Ломоносовские чтения – 2000 : тез. докл. науч. конф. – М., 2000. – С. 60-61.

59. Гроздова, О. И. Картографирование и региональные прогнозы техногенных изменений подземной гидросферы / О. И. Гроздова // Гидрогеология и инженерная геология / ВИЭМС. – М., 1987. – С. 64-68.

60. Дашко, Р. Э. Геоэкологические проблемы трансформации окислительно-восстановительной обстановки в грунтовых водах и дисперсных породах / Р. Э. Дашко, Е. С. Рудченко, Л. П. Норова // Записки Санкт-Петербургского горного института. – СПб.,

1995. – С. 194-207.

61. Делятицкий, С. В. Некоторые результаты изучения территорий свалок промышленных и бытовых отходов / С. В. Делятицкий, А. Д. Кочев, Л. Г. Чертков // Инженерная геология. – 1990. – № 3. – С. 71-77.

62. Демин, А. П. Использование и охрана водных ресурсов в России в последней трети XX века / А. П. Демин // Вода : экология и технология : тез. докл. 4 Междунар. конгр. (Москва, 30 мая-2 июня 2000 г.). – М., 2000. – С. 65.

63. Динамика основных показателей водопользования, режима и качества подземных вод Российской Федерации / В. В. Куренной [и др.] // Геоэкологические исследования и охрана недр. – 2000. – № 1. – С. 12-20, 58.

64. Дмитриев, Е. С. Руководящие принципы экологического мониторинга / Е. С. Дмитриев // Экологические системы и приборы. – 1999. – № 3. – С. 43-49.

65. Домрачев, Г. И. Направленность перестройки подземного стока при антропогенном воздействии (на примере Горьковской агломерации) / Г. И. Домрачев, И. Н. Гришина, Д. В. Кочетова // Подземные воды и эволюция литосферы : тез. докл. Всесоюз. конф. – М., 1985. – Т. 11. – С. 380-382.

66. Дривер, Дж. Геохимия природных вод / Дж. Дривер ; пер. с англ. Л. Н. Барабанова, Г. А. Соломина. – М. : Мир, 1985. – 440 с.

67. Евстратова, А. А. Загрязнение подземных вод Северо-Западного региона в связи с разработкой месторождения полезных ископаемых /А. А. Евстратова // Региональная экология. – 1999. – № 4. – С. 61-65, 120.

68. Заговенкова, Е. Н. Природные и антропогенные загрязнения воды / Е. Н. Заговенкова // Геологические науки – 98 : тез. докл. науч. конф. / Науч.-исслед. ин-т геологии и геол. фак. Сарат. гос. ун-та. – Саратов, 1998. – С. 58.

69. Заиканов, В. Г. Методические основы геоэкологической оценки урбанизированных территорий / В. Г. Заиканов, Т. Б. Минакова // Геоэкология. Инженерная геология. Гидрогеология. Геокриология. – 1995. – № 5. – С. 96-107.

70. Закарстованность карбонатных массивов железнодорожных трасс : изучение, оценка, прогноз / Э. И. Афанасиди, В. В. Бодин, О. Н. Грязнов, С. Г. Ду- бейковский // Геоэкологические проблемы урбанизированный территорий : тр. междунар. науч. конф. / Томск. гос. архитектур.-строит. ун-т. – Томск, 1999. – С. 56-57.

71. Зауербрей, И. И. К вопросу о коэффициенте фильтрации грунтов и методике его исследования / И. И. Зауербрей // Известия Всероссийского научно-исследовательского института гидротехники им. Б. Е. Веденеева (ВНИИГ). – 1932. – Т. 3, вып. 5. – С. 173-205.

72. Зверев, В. П. Массопотоки подземной гидросферы / В. П. Зверев. – М. : Наука, 1999. – 97 с.

73. Злобина, В. Л. Влияние эксплуатации подземных вод на развитие карстово-суффозионных процессов / В. Л. Злобина. – М. : Наука, 1986. – 133 с.

74. Иванкин, В. О геоэкологических условиях захоронений промстоков в недрах Земли / В. Иванкин, Г. И. Худяков // Труды / НИИ геологии Сарат. гос. ун-та. – Саратов, 1999. – С. 201-206.

75. Иванников, В. И. Миграция углеводородов и ее движущие силы / В. И. Иванников // Геология, геофизика и разработка нефтяных месторождений. –2000. – № 3. – С. 21-23.

76. Изучение загрязнения подземных вод на опытно-производственных полигонах : сб. науч. тр. / Всерос. науч.-исслед. ин-т гидрогеологии и инженер. геологии (ВСЕГИНГЕО) ; ред. В. М. Гольдберг. – М. : ВСЕГИНГЕО, 1990. – 172 с.

77. Ипатов, П. П. Инженерно-геологические условия строительства станции метрополитена в г. Омске / П. П. Ипатов, Н. И. Теплякова // Геоэкологические проблемы урбанизированных территорий : тр. Междунар. науч. конф. / Томск. гос. архитектур.-строит. ун-т. – Томск, 1999. – С. 149-150.

78. Использование комплекса геофизических методов для получения информации о загрязнении природной среды предприятиями и свалками промышленных отходов / А. Н. Боголюбов, Н. П. Боголюбова, М. В. Леоненко, Б. А. Гантов // Материалы конференции. – Пермь, 1997.

79. Казнов, С. Д. Геоэкологическое районирование территорий с целью выбора и размещения площадок по обезвреживанию и захоронению токсичных промотходов (на примере Нижегородской области) / С. Д. Казнов, Е. В. Копосов // Известия жилищно-коммунальной академии. Сер. «Городское хозяйство и экология». – 1995. – № 2. – С. 42-46.

80. Казнов, С. Д. Типизация опасных инженерно-геологических процессов на территории Нижегородской области и основные защитные мероприятия / С. Д. Казнов, Е. В. Копосов // Известия вузов. Сер. «Строительство». – Новосибирск, 1997. – № 8. – С. 102-107.

81. Керкис, Е. Е. К вопросу о движении подземных вод в трещиноватых породах / Е. Е. Керкис // Записки Ленинградского горного института. – Л, 1948. – С. 26-27.

82. Клаперих, Х. Геотехнические требования к рекультивации нарушенных территорий (на примере разработок в Германии) / Х. Клаперих, Р. Азом // Геоэкология. Инженерная геология. Гидрогеология. Геокриология. – 2003. – № 2. – С. 160-169.

83. Клейн, И. С. Численное моделирование линзы нефтяных загрязнений на поверхности подземных вод в районе расположения нефтеперерабатывающего завода / И. С. Клейн, И. С. Пашковский // Прикладная геоэкология, чрезвычайные ситуации, земельный кадастр и мониторинг. – 1997. – № 2. – С. 114-119.

84. Климас, А. Й. Организация литомониторинга в карстовом районе Северной Литвы / А. Й. Климас, Б. П. Паукштис // Инженерная геология. – 1990. – № 4.

85. Ковалева, И. В. Экологическое состояние и использование подземных вод / И. В. Ковалева, В. В. Куренной, Ю. Б. Челидзе // Использование и охрана природных ресурсов России. – 1999. – № 5/6. – С. 64-65.

86. Ковалевский, Ю. В. Загрязнение подземных вод азотистыми соединениями / Ю. В. Ковалевский // Сборник научных трудов / Всерос. науч.-исслед. ин-т гидрогеологии и инженер. геологии. – М., 1986. – С. 53-60.

87. Коноплянцев, А. А. Мониторинг подземных вод / А. А. Коноплянцев, Л. П. Лапшова, С. М. Семенов // Сборник научных трудов / Всерос. науч.-исслед. ин-т гидрогеологии и инженер. геологии. – М., 1984. – С. 20-27.

88. Коносавский, П. К. Разработка и апробация моделей индикаторного опробования комплексов трещиноватых пород / П. К. Коносавский, В. А. Мироненко, В. Г. Румынин // Геоэкология. – 1993. – № 3. – С. 104-124.

89. Контроль и прогнозирование миграции малорастворимых токсичных веществ в водоносных горизонтах / В. Г. Балахонов, А. Н. Жиганов, А. Д. Истомин, Н. Д. Носков // Контроль и реабилитация окружающей среды : тез. докл. – Томск, 1998. – С. 138-139.

90. Копосов, Е. В. Геоэкологическая оценка состояния подземных вод Нижегородской области с учетом техногенной нагрузки и анализ использования их в качестве централизованных источников водоснабжения / Е. В. Копосов, С. Д. Казнов // Известия жилищно-коммунальной академии. Сер. «Городское хозяйство и экология». – 1996. – № 4. – С. 37-42.

91. Копосов, Е. В. Методология информационного обеспечения безопасной эксплуатации метрополитенов на закарстованных территориях / Е. В. Копосов, С. Д. Казнов, С. Е. Копосов // Известия вузов. Сер. «Строительство». – 2002. – № 8. – С. 119-123.

92. Копосов, Е. В. Моделирование влияния техногенных нагрузок на активизацию опасных геоэкологических процессов / Е. В. Копосов, С. Е. Копосов // Известия жилищно-коммунальной академии. Сер. «Городское хозяйство и экология». – 2000. – № 2. – С. 75-81.

93. Копосов, Е. В. О повышении безопасности и эффективности систем жизнеобеспечения городов, расположенных в зонах развития карста / Е. В. Копосов, С. Е. Копосов // Великие реки-2002 : тез. докл. Междунар. науч.-пром. форума. – Н. Новгород, 2002. – С. 240-241.

94. Копосов, Е. В. Организация карстологического мониторинга на муниципальном и объектном уровнях. Стадии, виды, содержание и конечные результаты работы / Е. В. Копосов, О. В. Тычина, С. Е. Копосов // Известия жилищно-коммунальной академии. Сер. «Городское хозяйство и экология». – М., 1998. – № 2. – С. 60-73.

95. Копосов, Е. В. Пути рационального и экологически сбалансированного использования подземных вод на закарстованных территориях / Е. В. Копосов, С. Е. Копосов // Известия жилищно-коммунальной академии. Сер. «Городское хозяйство и экология». – 2002. – № 1. – С. 26-31.

96. Копосов, Е. В. Типизация техногенных источников загрязнения подземных вод / Е. В. Копосов, С. Е. Копосов // Архитектура и строительство-2000 : тез. докл. науч.-техн. конф. / Нижегор. гос. архитектур.-строит. ун-т. – Н. Новгород, 2000. – Ч. 3. – С. 127-128.

97. Копосов, С. Е. Анализ зарубежного и отечественного опыта складирования и захоронения отходов на закарстованных территориях / С. Е. Копосов // Архитектура. Геоэкология. Экономика : сб. тр. аспирантов и магистрантов / Нижегор. гос. архитектур.-строит. ун-т. – Н. Новгород, 2003. – С. 72-76.

98. Копосов, С. Е. Анализ особенностей процессов миграции подземных вод в карстовых районах / С. Е. Копосов // Архитектура. Геоэкология. Экономика : сб. тр. аспирантов / Нижегор. гос. архитектур.-строит. ун-т. – Н. Новгород, 2002. – С. 55-58.

99. Копосов, С. Е. Изучение процесса загрязнения подземных вод на закарстованных территориях крупных промышленных городов / С. Е. Копосов // Великие реки-2002 : тез.

докл. Междунар. науч.-пром. форума. – Н. Новгород, 2002. – С. 241-242.

100. Копосов, С. Е. Об экологических кризисах в истории Земли / С. Е. Копосов, О. В. Тычина // Приборостроение в аэрокосмической технике : тез. докл. / Всерос. молодеж. науч.-техн. конф. – Арзамас, 1999. – С. 162-163.

101. Копосов, С. Е. Особенности обоснования проектных решений для объектов жизнеобеспечения городов со сложными инженерно-строительными условиями / С. Е. Копосов, С. С. Казнов // Приборостроение в аэрокосмической технике : тез. докл. / Всерос. молодеж. науч.-техн. конф. – Арзамас, 1999. – С. 160-161.

102. Копосов, С. Е. Оценка масштабов загрязнения подземных вод на закарстованных территориях крупных промышленных центров / С. Е. Копосов, Е. В. Копосов // Великие реки-2004 : тез. докл. Междунар. науч.-пром. форума. – Н. Новгород, 2004. – С. 287-288.

103. Копосов, С. Е. Проблемы загрязнения подземных вод на участках утилизации промотходов и складирования кислых гудронов / С. Е. Копосов // Архитектура и строительство-2003 : тез. докл. науч.-техн. конф. профессорско-преподават. состава, аспирантов и студентов / Нижегор. гос. архитектур.-строит. ун-т. – Н. Новгород, 2004. – Ч. 2. – С. 219-222.

104. Копосов, С. Е. Проблемы строительного освоения территорий и безопасной эксплуатации зданий и сооружений в карстовых районах / Е. В. Копосов, С. Е. Копосов // Теоретические основы строительства : сб. докл. XIII словац.-пол.-рос. семинара / Моск. гос. строит. ун-т. – М., 2004. – С. 227-230.

105. Копосов, С. Е. Развитие опасных геоэкологических процессов в бассейне реки Волги / С. Е. Копосов // Строительство-2002 : тез. докл. Междунар. науч.- практ. конф. – Ростов н/Дону, 2002. – С. 73-74.

106. Копосов, С. Е. Разработка и совершенствование системы противокарстовой защиты инженерных сооружений с использованием новейших методов и технических средств диагностики строительных конструкций / Е. В. Копосов, С. Д. Казнов, С. Е. Копосов // Наука, инновации, подготовка кадров в строительстве : сб. докл. науч.-практ. конф. / Моск. гос. строит. ун-т. – М., 2003. – С. 57-60.

107. Копосов, С. Е. Техногенные изменения качества подземных вод в карстовых районах бассейна Волги / В. В. Найденко, С. Е. Копосов, Е. В. Копосов // Великие реки-2004 : тез. докл. Междунар. науч.-пром. форума. – Н. Новгород, 2004. – С. 162-163.

108. Костарев, В. П. О геоэкологических изысканиях для строительства / А. П. Костарев // Гидрогеология и карстоведение. – 2000. – № 13. – С. 37-41.

109. Крайнов, С. Р. Компьютерное моделирование процессов формирования химического состава подземных вод / С. Р. Крайнев // Разведка и охрана недр. – 1999. – № 12. – С. 10-16.

110. Крайнов, С. Р. Анализ разрешающих возможностей прогнозных моделей техногенных изменений химического состава подземных вод, их оптимальное геохимическое содержание / С. Р. Крайнов, Б. Н. Рыженко // Геохимия. – 2000. – № 7. – С. 691-703.

111. Крайнов, С. Р. Геохимические модели прогноза формирования качества

подземных вод (обзор возможностей и ограничений) / С. Р. Крайнов // Водные ресурсы. – 1999. – № 3. – С. 322-334.

112. Крайнов, С. Р. Геохимия подземных вод хозяйственно-питьевого назначения / С. Р. Крайнов, В. М. Швец. – М. : Недра, 1987. – 237 с.

113. Крайнов, С. Р. Качество подземных вод России, прогнозы их изменения и пути улучшения / С. Р. Крайнов, Б. Н. Рыженко // Отечественная геология : докл. на МГК-XXXI. – Рио-де-Жанейро, 2000. – № 8, Спец. вып. – С. 34.

114. Крайнов, С. Р. Основы геохимии подземных вод / С. Р. Крайнов, В. М. Швец. – М. : Недра, 1980. – 285 с.

115. Круподеров, В. С. Учение о режиме экзогенных геологических процессов : проблемы и пути их решения / В. С. Круподеров // Отечественная геология : докл. на МГК-XXXI. – Рио-де-Жанейро, 2000. – № 8, Спец. вып. – С. 38.

116. Кузнецов, М. М. Фильтрационная неоднородность аллювиальных отложений и ее влияние на структуру течения подземных вод / М. М. Кузнецов, Н. В. Макарова // Ломоносовские чтения-2000 : тез. докл. науч. конф. – М., 2000. – С. 63-64.

117. Кузьмин, М. Н. Концепция эколого-аналитического контроля в Российской Федерации / М. Н. Кузьмин, Е. Я. Нейман, А. А. Попов // Приборы. – 1999. – № 9. – С. 43-48.

118. Кулинич, Г. С. Естественная защищенность подземных вод от загрязнения при современном уровне химизации сельского хозяйства (на примере Горьковской области) / Г. С. Кулинич, Н.Н. Калачев // Межвузовский сборник научных трудов / Горьк. гос. пед. ин-т им. М. Горького. – Горький, 1985. – С. 79-87.

119. Кульчицкий, Л. И. Изучение трещиноватости глин как фактора их проницаемости с позиций микрогеологии / Л. И. Кульчицкий, Ю. Г. Ткаченко // Сборник научных трудов / Всерос. науч.-исслед. ин-т гидрогеологии и инженер. геологии. – М., 1986. – С. 109-118.

120. Куранов, П. Н. Обоснование системы инженерной защиты водозаборов при загрязнении подземных вод углеводородами : автореф. дис. канд. техн. наук / П. Н. Куранов. – М., 2001. – 26 с.

121. Куренной, В. В. Мониторинг геологической среды - основа экологической оценки техногенных изменений состояния недр / В. В. Куренной, А. А. Шпак // Разведка и охрана недр. – 1999. – № 12. – С. 46-49.

122. Куренной, В. В. Принципы выбора участков наблюдения для ведения мониторинга подземных водных объектов / В. В. Куренной // Вода : экология и технологии : тез. докл. – М., 2000. – С. 250-251.

123. Куренной, В. В. Проблемы суперэксплуатации при использовании подземных вод для крупного водоснабжения / В. В. Куренной, Н. В. Седов // Отечественная геология : докл. на МГК-XXXI. – Рио-де-Жанейро, 2000. – № 8, Спец. вып. – С. 40.

124. Куренной, В. В. Экологическое состояние подземных вод Европейской части России / В. В. Куренной, А. А. Шпак // Разведка и охрана недр. – 2000. – № 5. – С. 21-23.

125. Кушнарев, И. П. Об изучении трещинной тектоники / И. П. Кушнарев, Л. И. Лукин // Проблемы тектонофизики : тр. I Всесоюз. тектонофиз. совещ., 1957 г. – М, 1960. –

С. 17-20.

126. Лапшин, Н. Н. Рекомендации по гидрогеологическим расчетам для определения границ второго и третьего поясов зон санитарной охраны подземных источников хозяйственно-питьевого водоснабжения / Н. Н. Лапшин, А. Е. Орадовская ; Всесоюз. науч.-исслед. ин-т водоснабжения, канализации, гидротехн. сооружений и инженер. гидрогеологии. – М. : ВОДГЕО, 1983. – 102 с.

127. Летувнининкас, А. И. Геохимические аспекты формирования техногенного загрязнения территории города / А. И. Летувнининкас // Геоэкологические проблемы урбанизированных территорий : тр. Междунар. науч. конф. / Томск. гос. архитектур.-строит. ун-т. – Томск, 1999. – С. 58-59.

128. Ливчак, И. Ф. О задачах инженера-эколога (обзор литературы) / И. Ф. Ливчак // Инженерная экология. – 1999. – № 4. – С. 40-47.

129. Лукичев, Ю. Ф. Природоохранная деятельность в Нижнем Новгороде / Ю. Ф. Лукичев, Е. Н. Петрова // Нижегородский медицинский журнал. – 1999. – № 3. – С. 22-25.

130. Лукнер, Л. Моделирование миграции подземных вод / Л. Лукнер, В. М. Шестаков. – М. : Недра, 1986. – 208 с.

131. Лукьянчиков, В. М. Движение углеводородов через зону аэрации / В. М. Лукьянчиков // Сборник научных трудов / Всерос. науч.-исслед. ин-т гидрогеологии и инженер. геологии. – М., 1986. – С. 21-27.

132. Лукьянчиков, В. М. Источники углеводородного загрязнения подземных вод и методы его изучения / В. М. Лукьянчиков // Сборник научных трудов / Всерос. науч.-исслед. ин-т гидрогеологии и инженер. геологии. – М., 1984. – С. 48-52.

133. Лукьянчиков, В. М. Опыт локализации крупного очага нефтепродуктового загрязнения подземных вод / В. М. Лукьянчиков // Отечественная геология : докл. на МГК-XXXI. – Рио-де-Жанейро, 2000. – № 8, Спец. вып. – С. 44.

134. Лукьянчикова, Л. Г. Влияние сорбции на движение загрязняющих веществ в подземных водах / Л. Г. Лукьянчикова // Сборник научных трудов / Всерос. науч.- исслед. ин-т гидрогеологии и инженер. геологии. – М., 1986. – С. 37-44.

135. Лукьянчикова, Л. Г. Мониторинг, прогноз и управление состоянием незащищенных подземных вод на одном из водозаборов Нижегородской области / Л. Г. Лукьянчикова // Отечественная геология : докл. на МГК-XXXI. – Рио-де-Жанейро, 2000. – № 8, Спец. вып. – С. 45.

136. Ляховецкий, Ф. М. Инженерная геофизика / Ф. М. Ляховецкий, В. К. Хмелевский, З. Г. Ященко. – М. : Недра, 1989. – 253 с.

137. Максимов, М. Т. Радиоактивные загрязнения и их измерение / М. Т. Максимов, Г. О. Оджагов. – М. : Энергоатомиздат, 1989. – 304 с.

138. Малюгина, Н. Н. Оценка защищенности грунтовых вод на территории Центрального и Центрально-Черноземного экономических районов / Н. Н. Малюгина, Л. Т. Осипова // Разведка и охрана недр. – 1986. – № 10. – С. 39-43.

139. Мамонова, Т. В. Анализ исследований захоронений отходов на закарстованных территориях / Т. В. Мамонова, В. В. Толмачев // Материалы конференции. Пермь, 1997.

140. Манкиш, В. Д. Внутригодовое распределение стока рек в карстовом районе на

юге Горьковской области и северной части Мордовской АССР / В. Д. Манкиш // Сборник работ Горьковской и Волжской гидрометеорологических обсерваторий. –Л., 1969. – Вып. 6.

141. Методические подходы и технические требования производства инженерно-геоэкологических изысканий и мониторинга для строительства / А. П. Камышев, С. В. Смирнов, Е. П. Абрамов, А. А. Донецков // Геологические науки – 99 : тез. докл. Межведомств. науч. конф., посвящ. 90-летию Сарат. гос. ун-та им. Н. Г. Чернышевского. – Саратов, 1999. – С. 70.

142. Методические рекомендации по геохимической оценке загрязнения территории городов химическими элементами / Б. В. Ревич [и др.] – М. : ИМГРЭ, 1982. – 112 с.

143. Методические рекомендации по применению флуоресцентных индикаторов при гидрогеологических работах / В. С. Гончаров [и др.] ; Всерос. науч.-исслед. ин-т гидрогеологии и инженер. геологии. – М. : ВСЕГИНГЕО, 1982. – 89 с.

144. Методы геофизики в гидрогеологии и инженерной геологии. – М. : Недра, 1984. – 184 с.

145. Методы охраны подземных вод от загрязнения и истощения / под ред. И. К. Гавич. – М. : Недра, 1985. – 320 с.

146. Минкин, Е. Л. Гидрогеологические расчеты для выделения зон санитарной охраны водозаборов подземных вод / Е. Л. Минкин. – М. : Недра, 1967. – 124 с.

147. Минский, Е. М. Статистическое обоснование уравнений фильтрационного движения / Е. М. Минский // Доклады АН СССР. – 1958. – Т. 118, № 2. – С. 34-36.

148. Мироненко, В. А. Изучение загрязнения подземных вод в горнодобывающих районах / В. А. Мироненко, Е. В. Мольский, В. Г. Румынин. – Л. : Недра, 1988. – 250 с.

149. Мироненко, В. А. О требованиях и подходах к реабилитации подземных вод на загрязненных территориях / В. А. Мироненко // Теория и методика полевых гидрогеологических исследований. Четвертые Толстихинские чтения : науч. материалы / С.-Петерб. гор. ин-т. – СПб, 1995. – С. 23-34.

150. Мироненко, В. А. Опытно-миграционные работы в водоносных пластах / В. А. Мироненко, В. Г. Румынин. – М. : Недра, 1986. – 240 с.

151. Моделирование влияния загрязнения подземных вод от полигона твердых бытовых отходов / В. И. Косов, В. Е. Клыков, В. Н. Иванов, Л. В. Фирсова // Экологические системы и приборы. – 2000. – № 2. – С. 2-7.

152. Москалишин, В. С. Месторождение подземных вод «Восточное» / В. С. Москалишин, Д. С. Покровский ; Томск. гос. архитектур.-строит. ун-т. – Томск : ТГАСУ, 1999. –Найденко, В. В. Федеральная целевая программа «Возрождение Волги». Основные цели. Особенности и приоритеты. Проблемы реализации / В. В. Найденко // Известия жилищно-коммунальной академии. Сер. «Городское хозяйство и экология». – 1995. – № 2. – С. 47-55.

153. Найденко, В. В. Великая Волга на рубеже тысячелетий от экологического кризиса к устойчивому развитию / В. В. Найденко. – Н. Новгород : Промграфика, 2003. – Т. 1-2.

154. Носенко, О. А. Исследование фильтрации в трещиноватых породах с учетом заполнителя трещин / О. А. Носенко // Сборник научных трудов / Всерос. науч.-исслед. ин–т гидрогеологии и инженерной геологии. – М., 1986. – С. 118-126.

155. Носенко, О. А. Оценка изменения проницаемости трещиноватой породы под влиянием перераспределения рыхлого материала при закачке промстоков / О. А. Носенко // Сборник научных трудов / Всерос. науч.-исслед. ин–т гидрогеологии и инженерной геологии. – М., 1990. – С. 39-42.

156. Ольховатенко, В. Е. Геоэкологические проблемы урбанизированных территорий / В. Е. Ольховатенко // Труды Международной научной конференции / Томск. гос. архитектур.-строит. ун-т. – Томск, 1999. – 165 с.

157. Ольховатенко, В. Е. Геоэкологические проблемы урбанизированных территорий и научные подходы их решения / В. Е. Ольховатенко // Геоэкологические проблемы урбанизированных территорий : тр. междунар. науч. конф. / Томск. гос. архитектур.-строит. ун-т. – Томск, 1999. – С. 4-11.

158. Опытно-миграционные работы на месторождениях питьевых вод : метод. рекомендации / В. А. Мироненко [и др.]. – М. : ГИДЭК, 1998. – 93 с.

159. Орадовская, А. Е. Миграция микробных загрязнения в подземных водах / А. Е. Орадовская, Е. Н. Моложавая // Труды Всесоюзного научно-исследовательского института водоснабжения, канализации, гидротехнических сооружений и инженерной гидрогеологии. – 1977. – Вып. 63. – С. 70-77.

160. Орадовская, А. Е. Санитарная охрана водозаборов подземных вод / А. Е. Орадовская, Н. Н. Лапшин. – М. : Недра, 1987. – 167 с.

161. Орлов, М. С. Загрязнение подземных вод коммунальной свалкой / М. С. Орлов, М. М. Кузнецов // Вестник МГУ. Сер. 4, Геология. – 1988. – № 5. –С. 43-48.

162. Орфаниди, Е. Л. Моделирование процессов фильтрации и изменения качества подземных вод в условиях высоких техногенных нагрузок / Е. Л. Орфаниди, Л. В. Семендяева // Отечественная геология : докл. на МГК-XXXI. – Рио-де-Жанейро, 2000. – № 8, Спец. вып. – С. 55.

163. Основные геологические и гидрогеологические аспекты карстовых процессов и особенности их изучения геофизическими методами в республике Татарстан / П. В. Вишневский, Ю. Б. Антонов, Г. Е. Кузнецов, М. Я. Боровский // Гидрогеология и карстоведение. – Пермь, 2000. – № 13. – С. 110–116.

164. Охрана подземных вод при сооружении скважин / В. В. Сутягин, В. И. Антипов, В. М. Касаткин [и др.] - М. : Недра, 1986. - 168 с.

165. Павлик, Г. Н. Математическая модель распространения нефтяного загрязнения в грунтовой среде / Г. Н. Павлик, Е. Д. Павлик. // Известия вузов. Северо-Кавказский регион, Естественные науки. – 2000. – № 3. – С. 119-120, 198.

166. Павличенко, Л. М. К проблеме ограничения и оптимизации геоэкологического мониторинга / Л. М. Павличенко // Известия вузов. Сер. «Геология и разведка». – 2000. – № 5. – С. 95-108, 144.

167. Пенчев, П. Экспериментальные исследования одновременной миграции тяжелых металлов в песках средней крупности / П. Пенчев, Б. Великов // Известия вузов. Сер. «Геология и разведка». – 1982. – № 2. – С. 110-116.

168. Петин, А. Н. Техногенное воздействие и экологическое состояние геологической среды Белгородской области / А. Н. Петин, А. И. Спиридонов // Научные ведомости

Белорусского государственного университета. – 2000. – № 3. – С. 40-47.

169. Питьева, К. Е. Гидрогеохимические аспекты охраны геологической среды / К. Е. Питьева, Н. В. Роговская. – М. : Наука, 1989. – 221 с.

170. Плотников, Н. И. Введение в экологическую гидрогеологию / Н. И. Плотников. - М. : Изд-во МГУ, 1998. – 240 с.

171. Погребняк, И. Ф. Подземные воды Нечерноземной зоны Среднего Поволжья и проблемы их использования / И. Ф. Погребняк // Новые данные по геологии и гидрогеологии Нечерноземной зоны Поволжья / Геолфонд РСФСР. – М., 1980.

172. Поздеев, В. Б. О содержании геоэкологии / В. Б. Поздеев // Проблемы региональной геоэкологии : материалы науч. семинара. – Тверь, 1999. – С. 8-10.

173. Позднякова И. А. Загрязнение подземных вод отходами животноводства / И. А. Позднякова, В. С. Путилина // Геоэкологические исследования и охрана недр. – 1998. – № 3. – С. 1-4, 57-64.

174. Полынов, Б. Б. Выветривание и почвообразные / Б. Б. Плынов. – М. : АН СССР, 1950. – 211 с.

175. Пономарев, С. Н. Загрязнение подземных вод азотными соединениями (на примере Горьковской области) / С. Н. Пономарев // Межвузовский сборник научных трудов / Горьк. гос. пед. ин-т им. М. Горького. – Горький, 1985. – С. 87-94.

176. Применение статических методов анализа химического состава подземных вод в районах интенсивного техногенного воздействия / А. В. Лехов [и др.] // Ломоносовские чтения-2000 : тез. докл. науч. конф. – М., 2000. – С. 61-63.

177. Проблемы сосредоточения эксплуатации подземных вод / В. В. Куренной [и др.] // Геологический вестник центральных районов России. – 1999. – № 3. – С. 23-27.

178. Прогноз качества подземных вод в связи с их охраной от загрязнения / Ф. И. Тютюнова, И. Я. Пантелеев [и др.]. - М. : Наука, 1978. – 208 с.

179. Прокудин, И. А. Классификация антропогенного воздействия на подземные воды / И. А. Прокудин // Геологические науки-1998 : тез. докл. науч. конф. / НИИ геологии ; Геол. фак. Сарат. гос. ун-та. – Саратов, 1998. – С. 57.

180. Райнин, В. Е. Экологические проблемы великих рек / В. Е. Райнин // Мелиорация и водное хозяйство. – 2000. – № 2. – С. 31-34.

181. Районирование территории Москвы по геологическому строению и условиям взаимосвязи водоносных горизонтов с учетом распространения древних эрозионных врезов / В. М. Кутепов [и др.] // Геоэкология. Инженерная геология. Гидрогеология. Геокриология. – 1999. – № 5. – С. 472-479.

182. Расторгуев, А. В. Определение положения зон санитарной охраны водозаборов подземных вод на основе вероятностного моделирования / А. В. Расторгуев, А. Б. Кульчитский // Вода : экология и технологии : тез. докл. 4-й Междунар. конгр. – М., 2000. – С. 267-268.

183. Рац, М. В. Трещиноватость и свойства трещиноватых горных пород / М. В. Рац, С. Н. Чернышов. – М. : Недра, 1970. – 164 с.

184. Рекомендации по изучению карста геофизическими методами / Произв. науч.-исслед. ин-т по инженер. изысканиям в стр-ве. - М. : Стройиздат, 1986. – 112 с.

185.Рекомендации по прогнозу изменения агрессивности грунтовых вод на застроенных территориях. – М. : ВНИИ ВОДГЕО ГОССТРОЯ СССР, 1986. – 24 с.

186. Решение задач охраны подземных вод методами численного моделирования / Г. Н. Гензель, Н. Ф. Карачевцев, П. К. Коносавский [и др.] ; под ред. В. А. Мироненко. - М. : Недра, 1992. - 380 с.

187.Роговская, Н. В. Проблема экологической оценки состояния геологической среды (ГС) / Н. В. Роговская // Прикладная геоэкология, чрезвычайные ситуации, земельный кадастр и мониторинг : сб. науч. тр. – М., 1997. – Вып. 2. – С. 76-79.

188. Ромм, Е. С. Фильтрационные свойства трещиноватых горных пород / Е. С. Ромм. – М. : Недра, 1966. – 283 с.

189. Рошаль, А. А. Методы определения миграционных параметров / А. А. Рошаль // Гидрогеология и инженерная геология : обзор / Всерос. ин-т экономики минер. сырья и недропользования. - М., 1980. - 62 с.

190. Рошаль, А. А. Полевые методы определения миграционных параметров / А. А. Рошаль // Гидрогеология и инженерная геология : обзор / Всерос. ин-т экономики минер. сырья и недропользования. - М., 1981. - 61 с.

191. Руководство по инженерно-геологическим изысканиям в районах развития карста / Производств. науч.-исслед. ин-т по инженер. изысканиям в стр-ве. – М. : ПНИИИС, 1995. – 165 с.

192. Саевец, Т. Н. Система мониторинга подземных вод в республике Марий Эл / Т. Н. Саевец // Разведка и охрана недр. – [20--?]. – № 10. – С. 49-50.

193. Самсонов, Б. Г. Миграция вещества и решение гидрогеологических задач / Б. Г. Самсонов, Л. М. Самсонова - М. : Недра, 1987. – 118 с.

194. СанПиН 2.1.4.544-96. Требования к качеству воды нецентрализованного водоснабжения. Санитарная охрана источников [Электронный ресурс] : утв. постановлением Госкомсанэпиднадзора Рос. Федерации от 07.08.1996 № 18. – Режим доступа : КонсультантПлюс. Законодательство. Эксперт-приложение.

195. СанПин.2.1.4.559-96. Питьевая вода. Гигиенические требования к качеству воды централизованных систем питьевого водоснабжения. Контроль качества [Электронный ресурс] : утв. постановлением Госкомсанэпиднадзора Рос. Федерации от 24.10.1996 № 26. – Режим доступа : КонсультантПлюс. Законодательство. Эксперт-приложение.

196. Сапунов, В. Б. Критерии экологического благополучия / В. Б. Сапунов // Ноология, экология ноосферы, здоровье и образ жизни : материалы Междунар. науч. конф. - СПб., 1996. – С. 80-85.

197. Сафронов, В. Н. Геоэкологический анализ зоны свободного водообмена (на примере Республики Мордовия) : автореф. дис. канд. географ. наук / В. Н. Сафронов. – М., 2002. – 25 с.

198. Сергеев, С. В. Особенности мониторинга подземной среды городов в регионе КМА / С. В. Сергеев, А. В. Зинченко, Л. П. Ганичев // Тезисы докладов Международной научно-практической конференции / Алт. гос. техн. ун-т. – Барнаул, 1999. – С. 46.

199. Силин-Бекчурин, А. И. Методическое руководство по гидрогеологическим, гидрохимическим и микробиологическим исследованиям / А. И. Силин-Бекчурин. М. :

Гостоптехиздат, 1961. – 253 с.

200. Скворцов, Н. П. Изучение вертикального профиля проницаемости глинистых толщ для оценки их экранирующих толщ / Н. П. Скворцов // Сборник научных трудов / Всерос. науч.-исслед. ин-т гидрогеологии и инженер. геологии (ВСЕГИНГЕО). – М., 1986. – С. 100-109.

201. СНиП 2.01.28-85. Полигоны по обезвреживанию и захоронению токсичных промышленных отходов. Основные положения по проектированию [Электронный ресурс] : утв. постановлением Госстроя СССР от 26.06.1985 № 98. – Режим доступа : КонсультантПлюс. Законодательство. Технические нормы и правила.

202. СНиП 22-01-95. Геофизика опасных природных воздействий : строит. нормы и правила [Электронный ресурс] : утв. постановлением М-ва стр-ва Рос. Федерации от 27.11.1995 № 18-100. – Режим доступа : КонсультантПлюс. Законодательство. Технические нормы и правила.

203. Сольский, С. В. Обеспечение защиты природных вод в районах размещения полигонов твердых бытовых отходов / С. В. Сольский, И. А. Кветная, Д. П. Самофалов // Известия ВНИИГ им. Б. Е. Веденеева : сб. науч. тр. – 2001. – С. 239 ; 225-236; 276-277; 282.

204. Сомов, М. М. Водные источники в четвертичных отложениях (закономерности их размещения, использование и охрана) / М. М. Сомов ; Всерос. науч.-исслед. геол. ин-т. - СПб, 1998. - С. 176-177.

205. СП 11-102-97. Инженерно-экологические изыскания для строительства [Электронный ресурс] : утв. постановлением Госстроя Рос. Федерации от 10.07.1997 № 9-1-1/69. – Режим доступа : КонсультантПлюс. Законодательство. Технические нормы и правила.

206. СП 11-105-97. Инженерно-геологические изыскания для строительства. Ч. II. Правила производства работ в районах развития опасных геологических и инженерно-геологических процессов [Электронный ресурс] : утв. постановлением Госстроя Рос. Федерации от 25.09.2000 N 5-11/88. – Режим доступа : Консультант- Плюс. Законодательство. Технические нормы и правила.

207. Способ ограничения миграции загрязнения в подземных водоносных горизонтах : пат. 2154008 Россия, ПМК В 65 G 5/00 / Ю. В. Культин [и др.] ; Всерос. проект.-изыск. и науч.-исслед. ин-т пром. технологий. – № 99105679/03, Бюл. № 22.

208. Тихоненков, Ю. Э. Статический анализ и оценка защищенности подземных вод / Ю. Э. Тихоненков // Вода : экология и технология : тез. докл. 4-й Междунар. конгр. – М., 2000. – С. 273-274.

209. Токарский, О. Г. Особенности карбонатных коллекторов как резервуаров для захоронения промстоков / О. Г. Токарский, Д. А. Подборонов // Геологические науки – 1998 : тез. докл. науч. конф. / НИИ геологии, геол. фак. Сарат. гос. ун-та. – Саратов, 1998. – С. 64.

210. Толкачев, П. Окружающая природная среда – будущая сфера приложения капитала / П. Толкачев // Инвестиции в России. – 1998. - № 5. – С. 14-15.

211. Толмачев, В. В. Проблемы захоронения промышленных отходов в карстовых

районах / В. В. Толмачев, Т. В. Мамонова // Известия академии промышленной экологии. – 1997. – № 1. – С. 23-26.

212. Толмачев, В. Карстологический мониторинг / В. Толмачев // Гражданская защита. - 2000. – № 8. – С. 40.

213. Трофимов, В. Т. Классификация техногенных воздействий на геологическую среду / В. Т. Трофимов, В. А. Королев, А. С. Герасимова // Геоэкология. Инженерная геология. Гидрогеология. Геокриология. – 1995. - № 5. - С. 96-107.

214. Труфманова, Е. П. Геоэкологическая оценка территорий бывших свалок (два аспекта) / Е. П. Труфманова, И. В. Галицкая // Геоэкология. Инженерная геология. Гидрогеология. Геокриология. – 1999. – № 5. – С. 480-485.

215. ТСН 22-308-98 НН. Инженерные изыскания, проектирование, строительство и эксплуатация зданий и сооружений на закарстованных территориях Нижегородской области [Электронный ресурс] : утв. постановлением Администрации Нижегор. обл. от 30.08.1999 № 267. – Режим доступа : КонсультантПлюс. Законода- тельство. Нижегор. обл.

216. Тютюнова, Ф. И. Физико-химические процессы в подземных водах. Взаимосвязь с антропогенными факторами / Ф. И. Тютюнова. - М. : Наука, 1976. - 126 с.

217. Тютюнова, Ф. М. Гидрогеохимия техногенеза / Ф. М. Тютюнова. – М. : Наука, 1989. – 380 с.

218. Уильямс, Дуглас. Трехсотлетняя война. Хроника экологического бедствия / Дуглас Уильямс. – М. : Прогресс, 1975. – 240 с.

219. Утиллин, Р. В. Геоэлектрический контроль загрязнения геологической среды / Р. В. Утиллин, С. В. Назаров, С. В. Назаров // Физические проблемы экологии. - 2002. - № 9. – С. 113-120.

220. Федорова, Т. К. Физико-химические процессы в подземных водах / Т. К. Федорова - М. : Недра, 1985. - 185 с.

221. Фрид, Ж. Загрязнение подземных вод / Ж. Фрид. - М. : Недра, 1981. - 304 с.

222. Хмелев, К. Ф. О некоторых фундаментальных проблемах обеспечения безопасности экологических систем / К. Ф. Хмелев // Безопасность. – 1999. – № 1-2. – С. 198-200.

223. Хмелевский, В. К. Электрическое зондирование геологической среды / В. К. Хмелевский, В. А. Шевнин. – М. : МГУ, 1992. – Ч. II. – 199 с.

224. Хоффманн, М. Гидрохимические исследования распределения загрязнения рек, подземной и питьевой воды / М. Хоффманн, А. А. Галаган // Химия и технология воды. – 1999. – № 2. – С. 154-167.

225. Черепанский, М. М. Комплекс программ для оценки влияния эксплуатации подземных вод на гидрогеоэкологические условия прилегающих территорий методом моделирования / М. М. Черепанский, А. Е. Злебова // Вода : экология и технология : тез. докл. 4-й Междунар. конгр. – М., 2000. – С. 281-282.

226. Черепанский, М. М. Региональные и локальные гидрогеологические про- гнозы взаимосвязи поверхностных и подземных вод при их эксплуатации / М. М. Черепанский // Вода : экология и технология : тез. докл. 4-й Междунар. конгр. – М., 2000. – С. 280-281.

227. Черняев, А. М. Россия : водно-ресурсный потенциал / А. М. Черняев ; Рос. науч.-

исслед. ин-т комплекс. использования и охраны вод. ресурсов (РосНИИВХ). -Екатеринбург : Аэрокрсмоэкология, 1998. – 342 с.

228. Чубаров, В. Н. Питание и загрязнение подземных вод через зону аэрации (закономерности, методы оценки, технологии) / В. Н. Чубаров // Вода : экология и технология : тез. докл. 4-й Междунар. конгр. – М., 2000. – С. 283-284.

229. Шатский, Н. С. Очерки тектоники Волго-Уральской нефтегазоносной области и смежной части западного склона Южного Урала / Н. С. Шатский // Материалы к познанию геологического строения СССР. – М., 1945. – Вып. 2 (6).

230. Шелкачев, В. Н. Подземная гидравлика / В. Н. Шелкачев, Б. В. Ланук. – М. : Гостоптехиздат, 1949. – 523 с.

231. Шестаков, В. М. Гидрогеодинамика / В. М. Шестаков. - 3-е изд. – М. : МГУ, 1995. – 368 с.

232. Шестаков, В. М. Динамика подземных вод / В. М. Шестаков. – М. : МГУ, 1979. – 368 с.

233. Шульц, С. С. Об изучении планетарной трещиноватости / С. С. Шульц // Деформация пород и тектоника : докл. совет. геологов к XXII сес. МГК. – М, 1964. – С. 38-41.

234. Экогеология России. Т. 1 : Европейская часть / Г. С. Вартанян, М. С. Голицын, В.С. Круподеров [и др.] ; под ред. Г. С. Вартаняна ; Всерос. науч.-исслед. ин-т гидрогеологии и инженер. геологии (ВСЕГИГЕО). – М. : Геоинформмарк, 2000. – 299 с.

235. Эрден-Груз, Т. Явления переноса в водных растворах / Т. Эрден-Груз. – М. : Мир, 1976. – 592 с.

236. Ядерно-геофизические методы в гидрогеологии и инженерной геологии / В. Т. Дубинчук, В. А. Поляков, Н. Д. Корниенко [и др.]. – М. : Недра, 1988. – 223 с. : ил.

237. Aldous, P. J. Tracing Ground-Water Movement in Abandoned Coal Mines Aquifer Using Fluorescent Dyes / P. J. Aldous, P. L. Smart // Ground Water. - 1988. - P. 172-178.

238. Antiguedad, I. Tracages au Pays Basque : vers une meilleure connaissance de la dynamique decoulement et de transport des aquifers karstiques dan la perspective le leur protection / I. Antiguedad, T. Morales // Hydrologie. - 2000. - № 3. – P. 47-58.

239. Bodhankar, N. Pollution of limestone aquifer due to urban waste disposal around Raipur, Madhya, Pradesh, India / N. Bodhankar, B. Chatterjee. - India, 1993.

240. Calvin, E. Bellechester Minnesota lagoon collapse / E. Calvin, Andrew R. Kehren.- USA, 1993.

241. Crawford, N. C. Groundwater investigations to determine contaminant movement in the karst aquifers of the Lewisburg, Tennesee area / N. C. Crawford, C. S. – Ulmer (USA), 1993.

242. Dullmann, H. Danerbesttandikeit von nocht tonmineralishen Beimengungen in Dichtuhgstonen unter Deponiebegin-gungen / H. Dullmann // 10 Nat. Tagung fur Ingenieurgeologie. – [S. I], 1999.

243. Edwards, A. J. Waste disposal on karstfields carboniferous limestone aquifers of England an Walles / A. J. Edwards, P. L. Smart. - UK, 1989.

244. Fisher, J. A. Design of geotechnical fabrics for septic sistems in karst / J. A. Fisher, J. J. Fisher. - USA, 1999.

245. Frimmel, F. Komplexierung von Metallionen durch Gewasserhuminstoffe / F. Frimmel // Z. Wasser Adwasser Forsh. – 1981. – Vol. 14, № 1, 7-10.

246. Hall, P. J. Site investigation, monitoring, and successful landfill closure within a karst terrain / P. J. Hall, A. J. Meccasker, C. T. Bingham. - USA, 1995.

247. Heitfekd, K. H. Die Bedeutuhg tektoniseher Storungen die Beurteilung von Deponiestandorten / K. H. Heitfekd, M. Heitfekd. - [S. I], 2000.

248. Investigation of sources of groundwater nitrate contamination in the Burbank- Walluba area of Washington / R. F. Spalding, M. E. Exner, C. W. Lindan, D. W. Caton // Journal of Hydrology. - 1982. - Vol. 58, № 3/4. - P. 307-324.

249. Groundwater and the environment : experience of Dutch research for Russia / A. A. Jorov, A. N. Klykvin, V. N. Lasarenko, I. S. Pashkovky (eds). – M., 1998. – 380 p.

250. Mazac, O. Surface geoelectrics for ground water pollution and protection studies / O. Mazac, W. E. Kelly, I. Landa // Journal of Hydrology. - 1987. - № 93. – P. 277-294.

251. Melke, J. Diagnostic methods in the control of noise and vibration / J. Melke, S. Kraemer // Of sound and vibration. - 1983. – Vol. 87, № 2. – P. 377-386.

252. Mercer, J. W. A review of immiscible fluids in the subsurface / J. W. Mercer, R. M. Coher // Journal of Contaminant Hydrology. - 1990. - № 6. – P. 107-163.

253. Muller, L. Deponen uberchehdeponieteshnische und ingenieurgrebogische Aspekte am Beispiel eines neuen Uberdachungskonzeptes fur Deponien / L. Muller. – [S. I], 1999.

254. RenZeng-ping, Гидравлический метод перехвата расчет (загрязнений в грунтовых водах) и его достижения / RenZeng-ping // And Eng. Geol. - 2001. – Vol. 28. – № 6. – P. 73-77.

255. Slifer, D. W. Sinkhole dums and the risk to ground water in Virginia’s karst areas / D. W. Slifer, R. A. Erchul. - USA, 1989.

256. Toxic and explosive fumes rising from carbonate aquifers: A hazard for residents of sinkhole plains // Sinkholes: their geology, engineering and environmental impact / conf., 15-17 okt. 1984. – Orlando (Florida). – 1984. – P. 297-304.

257. Valocchi Albert, J. Describing the transport of ion-exchanging contaminants using an effective Kd approach / J. Valocchi Albert // Water Resour. Res. - 1984. - Vol. 20, № 4. – P. 499-503.

258. Zhao, You-cai. Excavation and characterization of refuse in closed landfill / You-cai Zhao // Envron. Sci. – China, 2002. – Vol. 14, № 3. – P. 303-308.

259. Ziqiang, M. Stability evolution for the siting of municipal landfills in karst / M. Ziqiang, E. C. Drumm. – USA, 1999.

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Monograph

Editor
L.Yu. Vorontsov

Signed for publishing on 13.11.2012. Format 84x108/16. Offset paper. Digital printing. Ref. publ.p. 18,7. Ref.prtd p 19,4. Edition 500 copies. Order No. 287.
Nizhny Novgorod State University of Architecture and Civil Engineering
65, Iljinskaya St., Nizhny Novgorod, 603950, Russia.
Printed in the publishing house “Delovaya taktika”,
134, Argronomicheskaya St., Nizhny Novgorod, 600305, Russia

ISBN 978-5-87941-860-6

9 785879 418606