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A manuscript

RYSMAGAMBETOVA AINA AKANOVNA

Assessment of the boron pollution dynamics of the groundwater and surface water of Ilek river valley

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Scientific supervisors: Pavlichenko L.M., Doctor of Geographic Sciences, Professor

Javier Rodrigo Ilarri, Ph.D., Professor Polytechnic University of Valencia, Valencia, Spain

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REGULATORY LINKS

In this dissertation, references to the following standards were used:

The Water Code of the Republic of Kazakhstan (as amended and supplemented on October 28, 2019),

The concept of development of the water sector of the Republic of Kazakhstan until 2020, 2010,

GOST 17.1.1.04-80 (State Standard System) "Protection of nature. Hydrosphere. Groundwater classification by water use goals",

GOST 27065-86 (State Standard System) "Water quality. Terms and Definitions"

The National Plan for Integrated Water Resources Management and Improving the Efficiency of Water Use of the Republic of Kazakhstan for 2009–2025. - Astana, 2008, State program for water resources management in Kazakhstan. - Astana, 2014,

GOST 2874-82 (State Standard System) "Drinking Water. Hygiene requirements and control for quality",

ST RK 2.18 (State Standard System) - State system for ensuring the uniformity of measurements of the Republic of Kazakhstan. Measurement Techniques. The procedure for the development, certification and application,

STRK GOSTR 51592 (State Standard System) - Water. General sampling requirements.

DEFINITIONS

In this dissertation, the following terms are used with the corresponding definitions:

A water intake is an engineering structure for capturing groundwater or water from a river and reservoir into water supply, irrigation, hydropower, and other systems.

Alluvium – sediments formed by constant water flows in river valleys.

Biomass is the aggregate mass of plant and animal organisms present in a biogeocenosis, of a certain size or level.

Boron is a chemical element of group III of the periodic system of elements D.I. Mendeleev. Clark boron in the earth's crust is 0.0012%. The source of boron in groundwater is rocks - saline deposits and skarns, as well as clays, which may contain boron sorbed from sea water; volcanic smoke; living matter.

Deluvium – deposits resulting from the accumulation of loose weathering products washed away from the slope by rain and melt snow water.

Dose, toxic - the minimum amount of harmful agent, which lead to a significant poisoning of the body.

Groundwater – groundwater of the first permanently existing aquifer from the surface, located on the first water-resistant layer. Groundwater has a free water surface.

Household and drinking groundwater are groundwater, on the quality in natural state or after processing meeting the standard requirements and intended for drinking and domestic needs of the people or for drinking production.

Hydraulic or pressure gradient – the ratio of the difference in pressure at two points of the hydrostatic surface to the distance between them, counting horizontally.

Hydrogeological conditions – a set of features characterizing the conditions of occurrence of groundwater; lithological composition and water properties of aquifers, movement, quality and quantity of groundwater and the features of their regime in the natural environment and under the influence of artificial factors.

Hydroisohypses – the lines connecting the points of the groundwater mirror with the same marks (absolute or relative).

Infiltration zone – the zone through which water seeps (infiltration). Corresponds to part of the aeration zone.

Maximum permissible concentration (MPC) – the legislatively approved sanitary-hygienic or fisheries management standard. MPC is understood as such a maximum concentration of chemical elements and their compounds in the environment that, with daily influence on the human body for a long time, does not cause pathological changes or diseases established by modern research methods, at any time during the life of the present and subsequent generations.

Mutagenesis (latin *Mutatio* - change, *Genes* - giving birth) - the process of emergence in the body of hereditary changes - mutations.

Proluvium – deposits of temporary water flows.

Sludge storages (sludge collectors) are large earthworks occupying very large areas, with a fillig depth of up to 50 m and a service life of more than 10-15 years.

The aeration zone is the uppermost zone of the earth's shell between the day surface and the groundwater mirror.

The aquifer is a bed of rocks homogeneous or close in facies-lithological composition and hydrogeological properties within the hydrogeological pools. Corresponding to the facies-lithological types of sediments of separate sedimentary rhythms sustained along strike.

Wastewater liquid waste after use for industrial or domestic purposes, which has changed its original composition or physical properties as a result of additional impurities (pollution).

Wastewater treatment – a set of measures to remove contaminants contained in domestic and industrial wastewater before releasing them to ponds. Wastewater treatment is carried out at special treatment facilities.

Water availability – the degree of satisfaction of the actual water needs of the economy, enterprise, irrigated area, and the national economy.

Water balance – the ratio between the income and consumption of water within a specific area.

THE LIST OF ABBREVIATIONS AND NOTATION

CFC Chlorofluorocarbons Food and Agriculture Organization FAO Geoinformation systems GIS Main Component MC MPC Maximum Permissible Concentration Maximum permissible discharge MPD Principle Component Analysis PCA Production Geological Association PGA Sustainable Development SD TPS Thermal power station United Nations Environment Program UNEP World Health Organization WHO

INTRODUCTION

Relevance of research: Population growth, development of economic activity, increase in living standards increase water consumption and wastewater volumes with the amount of pollution in them, which leads to increased competition and conflicts, due to water, between different water users. Reserves of high-quality fresh water are declining throughout the world, while the population and, consequently, water consumption are growing steadily. World water reserves are mainly salt water - 97.5%, and only 2.5% are fresh water reserves, of which only 0.3% are easily accessible to human, since the remaining reserves are concentrated in ice and deep underground [1, 2].

According to the United Nations [3], globally, more than 2 billion people live in countries in the face of extreme water shortages, defined as the ratio of total freshwater consumed to the total volume of renewable freshwater reserves above the threshold of 25 percent [4]. Therefore, the study of the imbalance of environmental systems in the presence of contamination presupposes a detailed knowledge of the pattern of the spread of pollutants in water bodies and streams [5].

The issues of protection and rational use of water resources in the republic are more relevant than ever. The public administration system in the field of environmental protection includes various mechanisms for managing, implementing and achieving the goals of ensuring the environmental safety of the state. To solve the tasks to ensure the environmental safety of the republic, the accelerated development of scientific research on the most important problems of environmental safety is necessary.

Water supply is one of the strategic state tasks. The state of water resources largely determines the level of economic development. In Kazakhstan, water is one of the determining factors in the development and distribution of productive forces. The republic is rich in land resources, which are the main reserve for the growth of arable land in the country. The scarcity of water due to its uneven distribution across the territory affects the development of agricultural production and industry [6]. Water resource of the republic are used in various sectors of the economy, but the most significant consumer of fresh water both at the present level and in the future is agriculture – irrigation, provision of water to the rural population and livestock. It accounts for about 85% of the total water consumption; the remaining 15% goes to industry and water supply to the urban population.

Surface water pollution by industrial waste is the reason for increased siltation of rivers, which has a harmful effect on the composition of bottom sediments, which form an inextricable part of the aquatic environment, of the ecological system.

Aktobe region is rich in many types of minerals, which make up a significant part of the mineral resource complex of Kazakhstan. In the Aktobe region, all republican reserves of chromite ores are concentrated, 46.2% - nickel, 28.3% - titanium, 12% - cobalt, 5.9% - zinc, 5.6% - copper, gold - 3.6% bauxite - 1.8%. That is why; the river basin in this territory is saturated with industrial enterprises of the Aktobe industrial zone. These are Aktobe Chrome compound Factory, its ponds and sludge collectors;

the Aktobe TPS and its ash removal bowl, the Aktobe KazChrome ferroalloy Factory, its slag dump and old filtration fields [7].

However, major sources of pollution in the Aktobe region are historical. This problem arose as early as 1941, when a Chemical Factory was launched at the Alga district center. For 23 years in a row, the factory dumped polluted water into Ilek. After built sludge collectors, but without a special screen. As a result, the boron still seeps into groundwater and ends up in Ilek. So on the banks of the groundwater Ilek River there is a high level of boron pollution.

It should be noted, that Ilek River is trans boundary, it flows into the Ural River and eventually the polluted water enter the Caspian Sea, to the spawning grounds of sturgeon. Pollution of groundwater and surface water by boron in the Ilek river valley and Aktobe reservoir – the sources of water supply in Aktobe region - has an impact on the socio-economic development of the region and the formation of an ecological situation in the territory [8].

It is known that boron plays a significant role in the life of plants, moreover, it is one of the five most important trace elements. However, in humans and animals, longterm consumption of water and foods with a high content of boron leads to violations of the basic life-support systems of the body.

A distinctive feature of boron and its compounds is its high mobility in the components of the natural environment, due to increased solubility. From this point of view, a serious problem is the purification of groundwater from boron contamination in the Ilek basin (Alga, Aktobe region) in connection with its migration from sludge collectors of the Alga Chemical Factory, which closed in 1997, to groundwater that wedge out into the Ilek river.

Although the boron pollution problem of the Ilek river was included in the "Register of Environmental Problems of the Republic of Kazakhstan" in 2012; but no practical work was done to improve the situation in the Alga region. Monitoring observations of water quality in the Ilek river in the region constantly record an excess of boron concentration. So, in 2018, in the vicinity of the Bestamak village, they exceeded the MPC for boron by 50 times, and in the reservoir in the area closest to sludge collectors, an excess of 143 times was observed in 2017 [9]. All this determines the relevance of research on the role of sludge collectors of the former Alga Chemical Factory in the current environmental situation. Thus, the relevance of the topic of the dissertation is beyond doubt.

In this regard, the presented work is devoted to the study of the wedging front identification of groundwater contaminated with boron.

The purpose of the PhD thesis is to identify the processes and the way specifics of movement of groundwater, which contaminated with boron in the Ilek river valley.

To achieve purpose it was necessary to solve the following tasks:

1. Analysis of the results of many years of previous studies of boron pollution of groundwater and surface water of the Ilek river valley;

2. Give a general geographical characteristic of the studying region and its affiliation to the biogeochemical provinces;

3. Studying the dynamics of changes in the hydrogeochemical situation based on a system analysis of regime observations and developing a multidimensional statistical model (component analysis);

4. The formation of a model of the flat task of the turbulent diffusion for numerical experiments of various options for providing flow and boron content in wedged groundwater;

5. Development of proposals and a system of measures to reduce the level of pollution of the llek river valley based on the proposed models.

Object of research: Ilek river valley in the territory of the Alga area of Aktobe region.

Subject of research: dynamic of boron pollution processes of ground and surface water of the Ilek river valley.

When solving the above tasks necessary to achieve the goals, the following **research methods** were used:

- collection and systematization of available information on studies performed in this territory;

- field and analytical studies;

- mathematical and multidimensional statistical modeling (component analysis and a flat task of model of turbulent diffusion);

- comparative analysis of environmental objects;
- substantiation of a set of environmental measures.

Factual material. The source materials for solving the tasks were the reports of "Center for Health and Environmental Engineering" LLP on the topic "Implementation of applied research and experimental work on the purification (protection) of groundwater from pollution by boron" for 2008. Another one was "Feasibility study to the investment project for the purification of groundwater from the Ilek River from pollution by boron" for 2009, which held by "Akpan" LLP on the topic "Study of the regime and balance, condition and rational use of groundwater in the territory of the Aktobe region" for 2004- 2007 and 2009-2012. The next one was the report of the Kazakhstan Agency for Applied Ecology (KAPE) "Designing water protection zones and bands of the Ilek River within the boundaries of large settlements (Aktobe, Alga, Kandyagash, Martuk)" for 2012.

The data for the period of the early stage of pollution was used from the Kazakh Research Institute of Mineral Raw Materials on the research report of Geophysical Production Association "KazRudGeologiya". The research title: "To study the conditions of groundwater pollution by enterprises of the USSR Ministry of Fertilizer for monitoring (using the example of the Aktobe chemical and Novojambul phosphorus factories)" 1990.

Moreover, the results of fieldwork and analytical studies, systematized as a result of cameral processing, received personally by the author in the period from 2016 to 2019.

The main provisions to be defended:

- In the filtration conditions of groundwater contaminated with boron changed from the initial acidic medium to filtration in a modern alkaline medium was

established based on a series of tasks of a multidimensional statistical model of component analysis;

- The conditions for the dilution of pollution by groundwater are determined under different wedging conditions and different background concentrations of boron in the surface water of the Ilek river based on the turbulent diffusion model;

- The main measure for prevent pollution of the Ilek river below the dam of the Aktobe reservoir is to extract sludge and then use it as fertilizer and change the bottom outlet to the overflow method.

The scientific novelty of the work:

- the changing was established in the hydrogeochemical environment from acidic to alkaline on the basis of a series of tasks of a multidimensional statistical model of component analysis;

- the insufficiency of the ecological capacity of the Ilek river for diluting contaminated groundwater that squeezed into the Ilek river was established for the first time (with water coming frequency 95% flow rate);

- The expediency of removing sludge with their subsequent use as fertilizers and replacing the bottom outlet with the overflow method has been proved.

Theoretical significance of research lies in the substantiation of a set of methods and approaches in solving the complex theoretical problem of combining motion models of groundwater and surface water in a changing environment of the pollution source for the development of environmental measures.

Practical significance of work results:

To provide sustainable economic development of the region, a set of measures for the rational use and protection of water resources is necessary.

The application of existing recommendations to improve the water quality of the Ilek river by intercepting contaminated groundwater before it wedges out into the river, cleaning it from boron element at sewage treatment plants, and also reclaiming sludge collectors are expensive. At the present, these activities are practically not feasible.

Of particular relevance is the removal of bottom sediments, silt from the Aktobe reservoir, thereby eliminating the migration of boron with surface and ground runoff.

In the work, the change in the role of the main sources of groundwater and surface water pollution in the Ilek river valley was revealed. It allows construction objectively of a system of environmental protection measures to prevent pollution of the Ilek river valley, Aktobe reservoir and the underlying territories.

The work approbation held in the form of reports at various scientific conferences. Among them are the 17th International Multidisciplinary Scientific GeoConference on Ecology, Economics, Education and Legislation, the International Student Forum "Green Bridge through Generations", the III International Congress of Young Scientists on Sustainable Development, Moscow, Russian Federation.

The results of the study were used in teaching students in the discipline "Ecology and water resources management" at Al-Farabi Kazakh National University.

Publications. According to the results of the study, The main results of the dissertation were published in 9 publications: 1 article was published in the Journal, which included in the Scopus database (39 percentile), 5 articles were published in

publications recommended by the Committee for Monitoring in the field of education and science of the Republic of Kazakhstan, 3 papers in collections of international symposia and foreign conferences.

The structure and workload. The dissertation consists of introduction, five chapters, conclusion, 180 list of used literature, 26 figures, 25 tables in 140 pages.

1 GENERAL CHARACTERISTIC OF THE RESEARCH REGION

1.1 Brief description of the geographical, geological and hydrogeological conditions of the area

The Ilek river is confined to the Aktobe region of Kazakhstan and the Orenburg region of Russian Federation, it is the largest left-bank tributary of the Ural. The cities of Kandyagash, Alga, Aktobe, and Sol-Iletsk are located on Ilek.

The research area is administratively part of the Alga district of Aktobe region. The area is 7.1 thousand km².

Relief and geological structure. According to the relief conditions, the territory under consideration belongs to the Ural-Emba (Under Ural) plateau of the naturalhistorical province. The plateau is a bumpy-hilly plain, dissected by the valley of the Ural River and its left tributaries Ilek and Utva. On the waterheds of river, heights reach 400 - 450 m above sea level (in the northeast); to the west and southwest, the plateau drops to 100 m, but very unevenly.

Among the accumulative plains, the most widely developed is the inclined deluvial-proluvial plain of the "Pre Syrt ledge". In the northern half of the region, it starts from the base of high (30-80 m) denudation ledges of a plateau and a hollow, at an angle of first degrees, descends to the surface of the sea plain of the Caspian lowland or the valley of the Zhaiyk and Ilek river.

The plateau topography is characterized by remnant erosion ridges having a relative height of up to 100-150 m, as well as ridges, hills and hills of various heights, indicating the intensity of denudation-erosion processes.

Sandy loam and loam that make up the plain with an admixture of unsorted sand, pebbles and gravel are washed out on various rocks of the Cretaceous, Paleogene, as well as Akchagyl and Syrt clays of the Upper Pliocene. Therefore, the beginning of their accumulation is considered Quaternary [10].

Climatic conditions. Alga administrative district of Aktobe region in the agroclimatic zone belongs to III-b, a slightly arid warm zone. Zone III-b - "Weakly arid warm" is located in the northern part of the region, characterized by a moisture coefficient of K = 0.6-0.8 and a sum of temperatures above 10 °C in the range of 2600-2900 °C [11].

Considering the territory has a pronounced continental climate: cold winter and hot summer, constantly blowing wind and low rainfall.

The temperature conditions in the considered valley of the Ilek river are different. In the multi-year regime, the average annual air temperature of the territory in question varies from 3.1 to 4.2 °C.

The average long-term temperature of the coldest month of January and February is minus 14.4-14.7 °C. The warmest month is July. The average long-term monthly temperature in July ranges from 20.5 °C to 22.5 °C.

The average long-term annual values of relative humidity in the considered region vary from 68% to 73%. The maximum values of relative humidity are observed in winter up to 84%, the lowest - in the warm season - 55%.

The average long-term annual saturation deficit ranges from 4.6-5.8 hPa. In winter, in the territory under consideration, it is 0.4-0.6 hPa. In the warm season, the moisture deficit changes more significantly from 7.4 hPa to 13.7 hPa.

The variety of climatic and orographic conditions of the river basin determines the uneven distribution of precipitation over its territory. Therefore, the average multiannual amount of annual precipitation amounts varies from 291 mm to 384 mm.

The wind regime is determined by baric circulation factors, orography and is somewhat different in nature. The west of the river basin under consideration is exposed to cyclone exits from the Caspian, the effect of the anticyclone is weakened, and the east (19%) and southeast (17%) wind are somewhat more repeatable here. In the warm season, the baric field is being restructured, and therefore the wind regime throughout the territory is changing. During this period, wind with a northern component prevail (7-13%). In summer, due to a more diffuse baric field, wind speeds decrease and amounts to 2.2-3.8 m / s. Long-term average annual wind speeds vary between 2.7-3.0 m /s.

In general, for a year, the frequency of wind directions is as follows (in %): North - 5, Northeast - 11, Eastern - 13, South East - 15, Southern- 13, Southwest - 14, Western- 14, Northwest - 15, calm - 19. [12]

Hydrological conditions. The inland location of the study area and the sharply continental climate led to poverty in surface water.

The Ilek River is one of the largest watercourses in the Aktobe region, formed at the confluence of the Karaganda River and the Zharyk River north of the city of Kandyagash and flows into the Ural River on the left 1085 km from its mouth. The total length of the river is 623 km with a catchment area of 41,300 km². Within the Aktobe region, the river is 257 km long with a catchment area of 29,500 km². The fall in this section is 118 m and the average slope is 0.46‰ [13-15].

The relief of the catchment is hilly, with a relative hill height of 20–50 m. The estuary part of the catchment is represented by a wavy plain. The ravine-girder system of the Ilek River is quite dense, and only in the upper part of the river is it developed moderately. On the catchment of the estuarine 30–50 kilometer section of the river there are numerous old lake, in general, drainage depressions on the catchment are not more than 1% [16].

The river valley is well developed, its width is 2-4 km in the upper part, and up to 5-7 km near the border of the region. The slopes of the valley from 15-25 m to 30-40 m high in some areas, in the upper part they are moderately shallow, below - moderately steep and steep. The slopes are terraced in places. The floodplain terrace is located at an altitude of 5-6 m above the floodplain, has a width of 0.2-0.6 km.

The floodplain from the source of the river is wide, and for the most part developed at the expense of one of the banks. Its width is at the sources of 0.5-0.8 km, expanding to 2 km (the city of Alga). To the border of the region, the prevailing floodplain width is 1-1.5 km, sometimes up to 3-4 km. The surface of the floodplain is uneven, has a slight bias towards the river and in some places is crossed by ravines and elders.

On the floodplain terraces of the Ilek River and its tributaries and on low floodplain terraces, floodplain meadow soils in combination with meadow soils are formed, and on low floodplain terraces, the combinations usually include hemihydromorphic soils (meadow chernozem and meadow chestnut) and meadow soils. The dominant soils in the river basin are dark chestnut and southern chernozems. In the upper part of the catchment, outcrops of rock and chalk deposits are noted.

The floodplain is covered with meadows, in places thickets of bushes and deciduous forest. Steppe vegetation (fescue, feather grass). In the lower part of the catchment there is woody vegetation (white larch, alder, willow, oak, birch, etc.), under which about 1% of the catchment area is occupied. Arable land accounts for about 30% of the catchment.

The conditions of runoff formation and the water regime of the river and temporary watercourses of the territory under consideration are formed under the influence of climatic factors, topography, soil and hydrogeological features.

The Ilek River is fed by both surface water and groundwater. During the flood, the Ilek River spills strongly, its water are filtered into sand and gravel soils, which increases the level of groundwater. The Ilek river is characterized by a rapid flood with a sharp increase in the water horizon and the transfer of a large number of bottom sediments, as a result of which the channel of the river changes from year to year. Islets and shoals appear others are washed off at this time. In the summer months, the water horizon drops sharply; the river becomes shallow.

Freeze-up on the Ilek River is observed in mid-November. Its duration is 120 days. The opening of the river occurs in the second half of March or in the first decade of April. Snow cover is established in the second half of November. The height of the cover varies during the winter from 5 to 10 cm in the waterheds, up to 100-150 cm in the valleys. This uneven distribution of snow cover is associated with constant winds blowing off the snow cover, which affects the depth of soil freezing, which ranges from 2.0 to 2.9 m.

Winter runoff compared to annual runoff is very negligible. Freezing of rivers is observed throughout the territory.

The flow of the rivers of the basin fluctuates sharply over the years. In high-water years, the runoff value exceeds the long-term average value by several times; in dry years, it is characterized by an extremely low value of runoff. A distinctive feature of the long run of the runoff is the high frequency of years with low water availability, often following one after another and forming shallow periods.

The runoff of suspended river sediments and temporary streams is formed due to flushing from the surface of soil (slope erosion) and erosion processes occurring in the hydrographic network. The bulk of the annual sediment runoff occurs during the spring flood, when, due to the development of erosion processes on the slopes of river basins and riverbeds, there is a strong increase in turbidity [17].

In the summer, the rivers feed mainly on groundwater, so the turbidity and sediment runoff are negligible. Sediment runoff during periods of long summerautumn and winter low-water periods is about 10% of annual runoff on large rivers and 1% - on small rivers. The long-term average turbidity of the Ilek river under natural conditions increases from the headwater downstream [18].

Hydrochemical characteristics of surface water. The hydrological regime of the Ilek river and its tributaries is strongly reflected in the hydrochemical composition of the runoff. Concentrations of chemicals vary greatly during the year, their maximum values are confined to the low-water period and exceed the minimum (during the flood period), as a rule, several times.

The water in the upper reaches of the Ilek River in the flood belongs to the class of hydrocarbonate (HCO_3^-) water, and in the low-water period to sulfate (SO_4^{2-}) . Downstream the class of water changes. In the area of the Aktobe reservoir, the water belongs to the hydrocarbon class throughout the year. As the water flow advances to the wellhead, the water class transforms into chloride (Cl^-) , and into flood, into hydrocarbonate (HCO_3^-) . Of the cations, calcium (Ca^{2+}) or sodium (Na^+) predominate throughout the river.

As a rule, during all phases of the hydrological regime, the normal oxygen regime is maintained throughout the river. However, periodically in the summer-autumn low water low water levels in the area of Aktobe, a reduced concentration of dissolved oxygen is noted.

In the territory under consideration, state hydrochemical monitoring is carried out in 3 sections. The water of the Ilek River in this section of the river undergo alternating processes of pollution and self-purification. In the city of Alga, intense water pollution occurs with boron, but up to Aktobe there is a partial self-cleaning of the runoff.

Water pollution in the area varies from a "normatively clean state" to a "high pollution level". The most relevant pollutants in this area are: sulfates, organic substances (biological oxygen consumption and chemical oxygen consumption), nutrients, boron and chromium. Their highest concentrations are observed in the low-water period.

In the basin of the Ilek river, there is an active economic activity. The water of rivers and temporary streams are intensively used for irrigation, industrial and drinking water supply. In addition, the flow of the Ilek River is distorted by the influence of the Aktobe reservoir [17, p.10].

Hydrogeological conditions. The groundwater of the Ilek valley is characterized by relatively good hydrogeological knowledge using hydrogeological surveys, groundwater exploration for various purposes, and other hydrogeological activities carried out in previous years [19-22].

The hydrogeological region is a system of pressure and non-pressure groundwater basins, which is united by a commonality of tectonic, hydrogeodynamic and capacitive characteristics of structures. The considered territory belongs to the East European (III) hydrogeological region, the Ural (III-7) province [23-25].

The Ilek River has three floodplain terraces, the first of which is very weakly expressed, rising 0.2-0.5 m above the floodplain. In some places the terrace merges with the floodplain. The terrace is composed of sand and clay deposits. Its width reaches 0.5 km. The terrace surface is characterized by elders and numerous ravines

covered with shrubs and meadow grasses. Absolute elevations of the terrace surface range from 202 to 206 m.

The second floodplain terrace 1.5-2 km wide is composed of sandy clay soils covered with a soil and plant layer. Its surface is flat, with a small number of small lakes that dry up in the summer. The transition from the first floodplain terrace to the second is expressed by a gentle sodding slope. Absolute elevations of the surface of the second floodplain terrace range from 210-220 m.

The third floodplain terrace is composed of ancient alluvial deposits. Above the second floodplain terrace, it rises by 2-3 m with steep and sometimes steep slopes. Spreading up to 3 km wide, it then passes into a flat interfluve plateau. Absolute elevations of the surface here range from 220-240 m.

From the west, the tributary of the Suyksu stream flows into the Ilek River, the flow of which is available only in the spring. At low water, the stream is divided into separate reaches. The absolute elevations of the bottom surface of the valley are 220-250 m. The root slopes of the valley are relatively flat and turn into plateau-like or bumpy elevations with absolute elevations of 280-320 m.

Groundwater is fresh and slightly mineralized. In natural vegetation, fescuefeather grass steppe associations with poor forbs predominate. Dark chestnut sandy loamy and loamy soils are formed under them, among which solonetzic and underdeveloped soils are often found. In many places, the soils are complex.

The geochemical features of landscapes consist in the fact that oxidizing, alkaline and neutral environments in soil and water dominate here; the reducing situation, if it occurs, is limited by a very local distribution. Hydrochemical features are determined by a slope runoff having a calcium bicarbonate and sodium bicarbonate composition.

Sources of boron pollution in the research territory of the Ilek river valley are "old", "new" sludge collectors, pulp stocks, and the territory of the former Alga Chemical Factory. The "old" sludge collector are located directly at the bottom of the valley in the former elders of the Ilek river. The distance from the eastern dam sludge collector to the bed of the Ilek river is 200-800 m. The surface excess of sludge collectors above the water level in the river at a low water level of up is to 10 m. The "old" sludge collectors are located in the western instrument part of the aquifers zone of the alluvial Quaternary sediments of the Ilek river valley. The horizon is composed of gravel and pebble deposits with sand aggregate with a thickness of 15-20 m., with high filtration properties, contributing to the migration of pollutants in the groundwater water contained in it.

The coefficients of filtration of aquifers 20-30 m/day; water loss 0.1-0.3. It should be noted here that in the article by N.E. Zeiberlich and G.N. Vlasko (1991) noted that part of the pollution leaked into pebbles at the bottom of the alluvium, the filtration coefficients of which, according to the data of cluster pumping, are up to 300-500 m / day [26]. Work to determine the possible value of the flow of groundwater from sludge collectors to the river has not yet been carried out.

The aquifer is underlain by sediments of the Cretaceous and Jurassic systems, composed of sand with interbeds of clay and clay with interbeds of sand, the filtration properties of which are significantly lower than that of alluvial sediments. At the same

time, groundwater can flow over them to bypass the "wall in the ground", which is built along the northwestern edge of sludge collectors. According to [25, p.16], the "wall" does not work all over; in some areas, its integrity is violated.

Figure 1 shows the view of the old sludge collector, obtained by the author using the Mavic Air DJI4 drone in 28 June, 2018 [27].



Figure 1 – Present condition of the "old" sludge collectors from the boric acid production of the Alga Chemical Factory

The "new" sludge collectors are located on the plateau-like elevation of the left bank of the Ilek river with an absolute height of 280-285 m. Their surface exceeds the Ilek river up to 50 m, up to 40 m above the bed of the Suyksu stream. Ponds filled with water are located to the west of the sludge collectors.

The "new" sludge collectors are located in the zone of distribution of low-power sandy rocks of the Albian aquifer complex, which are located on low-permeable Aptian sediments, composed mainly of clays. Below lies the locally aquiferous Hauterivian horizon, represented by clays with interlayers and lenses of sand. The filtration properties of the rocks composing the bottom of the sludge collector and the surrounding area are very low.

On this basis, previous studies have denied the possibility of filtering from a new sludge collector. In addition, even the fact of the presence of high boron concentrations in wells $N_{2}N_{2}1297$, 1298 (Appendix 1 and 2) is explained by the presence of a hydrogeochemical barrier and some other specific conditions without explaining the reasons behind this specificity. At the same time, it was noted that new sludge settling ponds and evaporation ponds built on the main shore were constructed with large defects and do not prevent leakage through the walls of the settling tanks, due to which sewage with a high concentration of toxic substances continues to pollute the soil of the adjacent territories in transeluvial and supequal landscapes, as well as the water of the Baipakty and Suyksu streams and through them Ilek.

To establish the patterns of distribution and migration of chemical elements, in particular, the polluting element - boron, the geochemical landscape level is most convenient. According to the definition of A. I. Perelman, geochemical landscapes are "a paragenetic association of conjugate elementary landscapes, interconnected by the migration of elements" [28].

The geochemical feature of the system under study is determined by the leading elements that have high clarks, actively migrate and accumulate in this system [29]. In this regard, it is necessary to consider the processes of boron migration.

1.2 Environmental and economic characteristics of the Aktobe region

The national development course of Kazakhstan was taken to be one of the 30 most developed countries in the world by 2050 [30]. Of particular importance in the implementation of the relevant socio-economic tasks is assigned to four cities of the Republic, which, due to the existing economic, social and geopolitical potential, will become centers of emerging excellent agglomerations. One of these cities is Aktobe.

However, the problem of water security in conditions of limited and vulnerable water resources is considered as a threat to the national security of the state. In this regard, in this section, it is worth paying attention to the quality of the water used for domestic and drinking purposes.

The city of Aktobe and adjoining district centers such as Alga are the main water user in the Ilek basin. According to the General Plan [31], the estimated volume of water consumption is 55895 m³ per day. The volume of water disposal amounted to $-62,227 \text{ m}^3/\text{day}$.

Water supply for drinking and household purposes and taking into account the technological needs of industrial enterprises was taken from groundwater water from deposits with approved reserves: Ilek right-bank and left-bank water intakes, Tamdy water intake, Upper Kargaly left-bank water intake and Kuandyktyr water intake.

Not all the population was covered with guaranteed water supply, because intrasettlement networks are not sufficiently developed, the technical condition of networks in most cases is unsatisfactory, which leads to frequent accidents. Water supply is carried out mainly through a network of street water taps.

On the territory of the Ilek basin, the total estimated groundwater resources according to the calculation results are, million $m^3/year$: - 665.8, including mineralization: up to 1 g / dm³ - 367.9; 1-3 g/dm³ - 184.4 and 3-10 g/dm³ - 113.5. Damage to surface runoff is estimated at 112.7 million $m^3/year$.

To meet the needs of the population, industry and agriculture, 37 groundwater water deposits have been explored and approved with a total value of operational reserves of 234.2 million m^3 /year, including mineralization, in g/dm³: up to 1 - 220.5 or more 1 - 13.7 million m^3 /year [32].

The water management complex is a combination of various sectors of the economy sharing water resources of one water basin. The water management complex of the Ilek basin includes:

- Housing and communal services of cities and towns;

- Industry and heat power;

- Agricultural production and irrigated agriculture;

- Agricultural water supply and irrigation of pastures;

- Other sectors of the economy (fish farming and recreation).

On the territory of the land reserve is 34%, agricultural land - 42.4%, land of settlements and industry, respectively, 14.8% and 1.2%, and land of the water fund - 0.1%.

It should be noted, that Aktobe region is characterized by a high level of economic development. Large deposits of oil, gas, as well as chromium, copper, titanium, phosphate ores, and potassium salt have been discovered in the region. There are coal deposits that are used for local needs.

The greatest impact on the quality of water resources is exerted by anthropogenic activity, manifested in the development of industry, agriculture, transport and public utilities. The main sources of pollution are industrial and wastewater.

In Aktobe region, there are plants of chrome compounds, ferroalloys, as well as enterprises of agricultural engineering, X-ray equipment and others. The developed metallurgical, chemical, light, food industries, as well as the production of alcoholic beverages facilitate the growth of the city's economy. More than 30% of the total volume of production produced in the city falls on the share of the metallurgical industry, about 10% - on the chemical industry. At the same time, the mining industry, the chemical industry, and ferrous metallurgy form the basis of the industrial branch of the region.

Among the largest enterprises are the Aktobe Ferroalloy Plant, which produces 22% of the country's ferroalloys; the Aktobe Factory of Chromium Compounds, the plant for the production of a variety of medical X-ray diagnostic equipment of "Aktobe Rentgen" JSC. There are a number of food industry enterprises, the largest of which are engaged in the production of flour, vegetable oil, pasta, confectionery and other products. The city also has several large and medium enterprises engaged in the production of alcoholic beverages.

The city's and adjacent territories' wastewater are discharged by a system of existing and planned gravity collectors and pressure pipelines serviced by sewage pumping stations to Public Cooperation "Akbulak" mechanical and complete artificial biological treatment, with their subsequent treatment and discharge into the Ilek river.

Agriculture adjacent to Aktobe is represented both in the field of animal husbandry and in the field of crop production. The basis of the agro-industrial complex is the livestock sector (more than 60% of gross agricultural production); in recent years, it has switched to an intensive form of development with a corresponding improvement in productivity indicators. The crop sector also has great development potential towards the introduction of innovative technologies with a subsequent increase in productivity.

According to official data [32, p.19], in the total area of the project area, agricultural land occupies about 93.9%. In the composition of agricultural land, the largest share is pastures 86.4%, the share of hayfields - 1.6%, arable land - 8.7%. It houses the economy of grain, vegetable and potato, dairy, sheep and meat.

The main objective of crop production is to meet the needs of the population for food, industry for raw materials, ensuring the production of feed for the development of livestock, as well as the creation of the necessary state reserves.

Crop yields and natural forage land productivity are dictated by unstable climatic conditions. Gross harvest of crop products is directly dependent on the yield of agricultural crops and the size of the cultivated area under a particular crop.

The growth of agricultural production depends on solving a number of complex problems. The implementation of which is aimed, in particular, at more economical expenditure of water resources, a more complete use of existing irrigated lands, improvement of their reclamation conditions, the introduction of effective irrigated farming systems that allow to obtain the maximum amount of products from each hectare of land.

Livestock breeding is an important branch of agricultural production within the territory. Widely developed dairy and meat and dairy cattle, sheep, horses and poultry. Therefore, for example, since 2015, the Alga Meat Processing Plant has been operating in the area behind the former Alga Chemical Plant, which is the main reason for the deterioration of the environmental situation in the region.

This plant positions itself on the Internet as an enterprise for the production of environmentally friendly meat products, which has modern technologies. The company independently carries out the entire processing process: from cattle breeding, compound feed production, fattening, meat processing to the shipment of finished products. The company has:

- Reproducer for breeding cattle of the breed "Aberdeen Angus" for 6,000 heads,

- Livestock feeding complex with a capacity of 22,000 heads per year

- Meat processing plant with a capacity of 7200 tons per year. All products of the meat processing plant are made from our own raw materials, this contributes to the release of only "environmentally friendly" and fresh products.

The proximity of the Alga Chemical Factory site casts doubt on the environmental cleanliness of the products. Although this enterprise is located hypsometrically above this site, which denies the inflow of groundwater contaminated with boron into its territory, the question remains of assessing the inflow of pollutants into this territory from Alga Chemical Factory emissions during its functioning. The complete absence of monitoring observations does not allow this assessment [33].

Livestock products are represented by meat of various farm animals, milk, wool and other types of main and by-products of this industry.

Due to the weak and unstable food supply, outbreeding of livestock and especially sheep and poultry, the productivity of animals is quite low and also subject to fluctuations.

Strengthening the fodder base due to feed obtained from irrigated lands, increasing the level of full-fledged feeding, introducing advanced methods of keeping livestock, as well as improving the breed quality of animals, organizing farms, and leasing will increase the productivity of animals.

The source of feed in the farms of the region is natural fodder land and field feed production. In addition, vast pasture areas are mowed for hay every year, despite the

very low productivity of these lands caused by the constant shortage of stall feeds in the region's farms.

The main feeds of field feed production are fodder, hay of perennial and annual grasses, corn for silage, fodder root crops. In addition, by-products of the plant growing industry go to feed livestock: cereal-spike straw, waste of potatoes, vegetable and melon gourds, etc.

Undoubtedly, the Ilek river is the main source of water supply for the population and all facilities of the Aktobe oblast economy. There is an increase in the number of people living in the river basin; production capacities of economic sectors objects are growing, and water consumption is growing accordingly. Since most of the population and industrial enterprises are concentrated in Aktobe, the quality of water in the Aktobe reservoir on the Ilek river, which regulates the region's water supply by water from it, plays a large role in the life of the population. In the river basin, its condition worsens every year, which is associated with both the annual decrease in water flow and the ecological state of the Ilek river and Aktobe reservoir.

1.3 The sources of groundwater and surface water pollution of the Ilek valley with boron

Technogenic pollution of river runoff with boron is associated with activities of the former Alga Chemical Factory (was built in 1937 y.), which discharged boric acid production sludge into the Ilek river without purification and pre-cleaning processes. The Figure 2 shows the present view of the former Alga Chemical Factory.



Figure 2 – Former Alga chemical factory named after S.M. Kirov

The fact of pollution of groundwater by boron was first discovered in 1972. Since 1975, the experimental ground has been monitoring changes in the natural regime of groundwater due to the filtration of industrial waste discharged into ponds. Studies of the PGA "ZapKazGeologiya" and other organizations revealed boron in industrial wastewater, in alluvium water and in the Ilek river, as well as in groundwater throughout the valley from the city of Alga to the borders of the Orenburg region, i.e. over more than 100 km.

The main areas of previous work were the study of soil and snow cover pollution in an area covering the industrial site of the Alga Chemical Factory and the city of Alga. The main research methods were a reduced chemical analysis of water and a semi-quantitative spectral analysis of soil samples and dry residue of water samples. The Main State Expertise of Aktobe region ("Akpan" LLP) carried out the studies of groundwater pollution with boron in the Ilek river valley by state order, while boron remained the only studied component of pollution. The study of surface water pollution was carried out mainly by the Aktobe center of hydrometeorology.

In 1989-1991 Ecological and geochemical studies were carried out by a comprehensive experimental-methodological batch of the PGA "ZapKazGeologiya" state educational institution, for which 340 samples were taken, including 85 samples from the factory and 255 samples from the city of Alga. The first drilling profile was passed through the site. Snow sampling was carried out at the plant in the city of Alga, and at a distance from it to the south, west and east to a distance of 10 km north to Aktobe. At the industrial site of the Aktobe chemical factory and the territory of the city of Alga, very high concentrations of a number of chemical elements were noted in soil and soil samples, many of which are toxicants (copper, lead, molybdenum, arsenic, etc.) [34]. A brief description of the distribution of the leading elements – pollutants is given in table 1.

Name of pollution	The concentration The number of Ch.		Characterization of	The concentration
Name of pollution	of contaminants,	samples in% with		coefficient of pollution,
component	mg / kg / MPC	pollution	the place of selection	units MPC
1	2	3	4	5
Boron, B		Plant	t territory:	•
	3000	unit	Industrial site of the	-
			boron production	
			workshop	
	$160 = \overline{C}$	average boron conte	nt at the Alga chemica	al factory industrial site
	≥100	61		
	≥200	35		-
	1000-3000	8		
		Outside the factory		
	≥100	8		
	150-400	two samples		-
	<<100	city area		
Cuprum, Cu	-	100	-	63.8
Zinc, Zn	-	100	-	96.4
Plumbum, Рв	-	100	-	37.5
Molybdenum, Mo	≤MPC	the principal amount	-	9.0
		of samples		separate territories
Argentum, Ag	0.06-25 mg / kg	100	-	-
Arsenic, As	≥ 0.005 mg / kg	100	-	470
				separate territories
Phosphorus, P	-	98.4		
-	Alga chem			
	Alga cher			
	\overline{C} = 600 (close to			

Table 1 – The results of the analysis of micro contaminants in samples of soil cover in the territory of the plant and the city of Alga

Continuation of the table 1

1	2	3	4	5
	Al			
	C – 96			
	$C_{min} = 100$			
	$C_{max} = 10000$			
		City area		
	-	70	-	-
	C _{max} =3000			
1	2	3	4	5
Hydrargyrum (total),	0.005-10	100	-	121
Hg				
Barium, Ba	300-3000	100	-	≤4.6
Bismuth, Bi	-	100		220 in selected parts of
				the territories
Antimony, SB	≥10	28.8 (total), of which	-	-
		1.8- Alga chemical		
		factory		
Lanthanum, La	-	84	-	reaches 172

The zone of high soil pollution along the boron is local and is confined directly to the workshop for its production. Overall, the area of maximum technogenic pollution corresponds to the industrial zone of the Alga Chemical Factory.

In 1988-1992, the Geoecological Party of the PGA "ZapKazGeologiya" and the Kazakh Institute of Mineral Raw Materials had research the migration of pollution components in water in the study of bottom sludge of the Aktobe reservoir.

It was found that the boron content in the water extracts from the sludge is 0.1-0.5 mg / 100 g, fluorine: 0.3-1.6 mg / 100 g. These studies established the ability of sludge to adsorb boron, as well as its high mobility, when any mechanical effect led to the return of boron sorbed by silts to the dissolved state. As a recommendation, this report proposed the liquidation of the Aktobe reservoir at the initial stage of its filling, until it turned into a new powerful source of pollution [35].

By 1997, the halo of groundwater pollution by boron in the Alga city reached 32.5 km², having increased almost 2.5 times over 10 years.

The cessation of production activities of the Alga Chemical Factory led to a significant reduction in surface and groundwater pollution with boron. The construction of the "wall in the ground" also introduced a temporary effect in reducing the concentration of boron in the groundwater water of the Ilek river valley. The decrease in the content of boron in groundwater also occurred due to a decrease in its concentration in soil as a result of the cessation of Alga Chemical Factory emissions when washing them with melt water during the spring snowmelt, and thirdly due to the natural outflow of groundwater downstream. In 2005, the maximum concentration of boron in groundwater was from 20 to 885 mg/dm³ (from 40 to 1770 MPC), with a halo of pollution of 21.1 km² [14, p.14; 36].

By the end of 2005, as can be seen from Table 2, in 80% of the wells, the boron content in groundwater is significantly higher than the MPC. Of the 43 wells in 9 wells

(20.9%), the boron content is $\leq 0.5 \text{ mg/dm}^3$, i.e. corresponds to the MPC level, up to 30% of wells is characterized by a boron concentration in the range of 19-30 mg/dm³ (38 - 60 MPC) and up to 28% from 40 to 100 mg/dm³ (80 - 200 MAC). Boron content> 300 mg/dm³ (600 MPC) is observed in 7 wells (16.4%) [37, 38].

Limits of boron	Number of wells co	ontaining boron in water
concentrations in underground well water, mg / dm ³	in unit	% of the total number of observation wells
0,2-0,5	9	20,9
0,5-1,0	2	4,7
19-30	13	30,2
40-50	7	16,3
50-100	5	11,6
300-350	1	2,4
430-530	5	11,6
885	1	2,4
Total:	43	

Table 2 – The level of groundwater pollution by boron from observation wells in the Ilek valley from the city of Alga to the city of Aktobe

Construction of the Aktobe reservoir on the Ilek river south of Aktobe, contributed to a decrease in boron content in the surface water of the Ilek river at the outlet from the Aktobe reservoir, which entailed a decrease in its concentration in most observation wells at the Ilek infiltration water intake and, accordingly, in production wells of this water intake.

At the same time, accumulation of boron-containing sludge has been and continues to be in the Aktobe reservoir, creating an ever-increasing threat of the repeated failure of Aktobe's infiltration water intakes located below the dam. This fact is confirmed by the rare cases of exceeding the MPC for boron below the dam after releases that create conditions for turbulent mixing of water in the Aktobe reservoir.

At the present stage, according to studies conducted in 2008 by the "Center for Health and Environmental Engineering" LLP, only 3,780 tons of boron have been accumulated in the focus of maximum groundwater pollution. Estimates of this center showed that until 1956 in the soil and Ilek river valley got more than 70,000 tons of boron. It becomes obvious why boron is still fixed in the Ilek river on the border with Russia.

The map of boron isoconcentrate (figure 3) was constructed by "Center for Health and Environmental Engineering" LLP based on GIS technology, according to "Akpan" LLP data at the end of 2005.



Figure 3 – Distribution areas of maximum groundwater pollution by boron, 2005 [37, p.25]

It is showing more clearly showed that local foci of contamination form a single focal point, in which in the zone with boron concentrations of more than 500 mg/dm³ there are mainly sites located along the slurry pipelines to the new sludge collector, the southwestern part of the new sludge collector. Moreover, there is the zone of the old sludge collector without its northern part, which is affected by the influence of the wall in the ground.

Particularly acute cleaning problems were emphasized by the results of layer-bylayer testing of sludge in July-August 2008 for the first time in the history of the existence of sludge collectors. Determinations of boron content in aqueous extracts from sludge samples taken from different depths of the old and new sludge collectors demonstrate high boron contents in sludge samples starting from a depth of 1 m (table 3). While the samples of sludge from a depth of 0-0.5 m gave practically zero concentrations of boron in both old and new sludge collectors, in 2007 and 2008 (table 4).

Table 3 – Boron content in aqueous extracts of sludge during layer-by-layer sampling during drilling in 2008, [37, p.25]

Old sludge collector			New sludge collector		
Number	Depth of	Boron,	Number	Depth of	Boron,
of well	sampling, m	mg/kg	of well	sampling, m	mg/kg
1-c	1,0	960	1-н	1	980
1-c	3,0	1800	1-н	2	820
1-c	4,0	240	1-н	3	1560
1-c	6,0	360	1-н	5	840
1-c	9,0	530	2-н	2	1080
1-c	23,0	840	2-н	5	1920
2-c	1,0	860	2-н	10	720
2-c	3,0	1080	3-н	1	1080
2-c	4,0	170	3-н	3	360
2-c	5,0	1060	3-н	4	720
3-с	1,0	480	3-н	7,5	600
3-с	2,0	1320	4-н	1	1320
3-с	4,0	1460	4-н	2	600
3-c	5,0	600	4-н	3	840
4-c	1,0	840	4-н	5	480
4-c	3,0	380	5-н	2	1200
4-c	4,0	1250	5-н	4	360
4-c	5,0	600	5-н	5	1200
5-c	1,0	1440	6-н	1	960
5-c	2,0	720	6-н	2	1200
5-с	9,0	600	6-н	3	670
6-c	1,0	840	6-н	4	1060
6-c	2,0	600	6-н	7,5	1130
6-с	3,0	960	7-н	1	720
6-с	13,5	890	7-н	2	1320
7-с	1,0	700	7-н	4	1080
7-с	4,0	940	7-н	5	840
7-с	5,0	860	8-н	1	1440

The maximum boron concentrations exceeding 1500 mg/dm³ in the samples for "old" and "new" sludge collectors are found in a single case and differ little (1800 and 1920, respectively). The number of samples with concentrations in the range of 1000-1500 mg/kg differs twice (6 and 12), in the intervals of 500-1000 and 200-500 mg per kg - by 1.33 times, however, in the interval with the lowest concentrations of boron for sludge collectors in aqueous extracts of sludge, there are more samples in the old accumulator.

Number of well	В	Cr^{+6}	F	Phosphates in terms of <i>P</i>	Al	Se
1-н	580,0	< 0.02	9,97	1,09	< 0.04	0,0030
2-н	1272,0	< 0.02	7,92	0,49	< 0.04	0,0040
3-н	1050,0	< 0.02	6,59	0,43	< 0.04	0,0030
4-н	380,0	< 0.02	2,5	0,39	< 0.04	0,0008
5-н	600,0	< 0.02	0,95	0,45	< 0.04	0,0008
7-н	840,0	< 0.02	2,68	0,23	0,54	0,0030
9-н	500,0	< 0.02	1,81	0,27	0,76	0,0090
1*-н	1632,0	< 0.02	9,97	1,49	< 0.04	0,0040
1-c	84,0	< 0.02	8,29	0,23	< 0.04	0,0008
2-c	400,0	< 0.02	7,06	0,20	< 0.04	0,0020
3-с	500,0	< 0.02	15,80	0,33	< 0.04	0,0004
4-c	550,0	< 0.02	15,44	6,35	< 0.04	0,0020
5-c	350,0	< 0.02	11,72	0,42	< 0.04	0,0010
6-c	450,0	< 0.02	7,39	0,52	< 0.04	0,0030
7-c	620,0	< 0.02	1,12	0,52	0,13	0,0008
*The color legend for Tables 3 and 4 is as follows:						
>1500 m	$0 \text{ mg/dm}^3 \frac{1000-1500}{\text{mg/dm}^3} \frac{500-1000}{\text{mg/dm}^3}$		500-1000 mg/dm ³	200-500 mg/dm ³ <200 r		mg/dm ³

Table 4 – The results of chemical analysis of groundwater taken during the drilling of experimental wells, mg/dm^3 [37, p.25]

The presence of delayed water exchange in the new sludge collector is clearly demonstrated by the data on the comparison of average boron concentrations in sludge and pore water (table 3 and 4) (968 mg/kg and 857 mg/dm³, respectively - a difference of 1.12 times) compared with old (835 mg/kg and 422 mg/dm³ - 1.98 times). Nevertheless, the minimum concentrations of boron in individual samples of the new sludge collector decreased to 360 mg/kg, and in the old - to 170 mg/kg.

Overall, the results of these studies made it possible to rank the main sources of groundwater and surface water pollution with boron in the Ilek basin, which include the zones of the "new" and "old" sludge collectors and the industrial site of the Alga Chemical Factory (figure 4).

As a result of summarizing the data of long-term monitoring of groundwater and surface water pollution with boron in the Alga – Aktobe section; analyzing stock hydrogeological materials and our own experimental studies; performing hydrodynamic calculations and constructing theoretical models of natural flushing in a feasibility study. It is proved the main sources of pollution form the source of pollution groundwater with high concentrations of boron with an area of 21.1 km² are: old sludge collector; new sludge collector; Alga Chemical Factory industrial site;

soil contaminated with this former factory emissions and dust from the drained surface of slime collectors and places of emergency leaks of slurry pipeline.

The main routes of boron entry into groundwater are filtration through the bottom of the old sludge collector, infiltration into the aquifer of contaminants washed away by snowmelt and storm water from the Alga Chemical Factory industrial site, new sludge collectors and dust deposition of Alga Chemical Factory emissions, old and new sludge collectors (figure 4).



Figure 4 – The main sources of boron pollution of environmental objects [37, p.25]

Thus, the Aktobe reservoir retains boron-containing silts and deposits them in its bottom sediments. When releases from the reservoir through the bottom outlet, turbulent mixing of the layers occurs, or they become agitated and, as a result, the boron passes into the solution. This situation will increase with the accumulation of sludge; the result of such releases will be pollution of the Ilek river below the dam, i.e. in the zone of Aktobe.

However, during the formation of backwater by the wall in the soil (before it flowed around), the concentration of boron in groundwater near the old sludge collector and into the Ilek river markedly decreased. The halo of pollution decreased significantly, which gave rise to the statement of "Akpan" LLP – "Nature will cope". Under the influence of these ideas, against the background of a decrease in boron concentrations, it was decided to resume the work of the Ilek water intake.

Even in the reference [38, 39], it is noted that a wall in the ground is a temporary measure for the localization of contaminated groundwater until the development of technological solutions for the elimination of pollution. Therefore, already in 2007, the

filtration of contaminated groundwater from the old sludge collector through gaps and around the wall in the ground began. This fact was the reason for the development in 2007-2009. Feasibility study on groundwater treatment of the Ilek valley. However, work on the project began.

The Aktobe reservoir still retains boron-containing sludge and deposits it in its bottom sediments, increasing the concentration of water in the Aktobe reservoir. As before, only bottom water outlets operate, spreading the dammed or lower dams towards the city of Aktobe. Over time, the volume of two sludge will gradually grow and in the future, the Aktobe reservoir will turn into a powerful source of boron. It is very difficult to clean the reservoir of boron-containing sludge, so back in 1992 [35, p.24] a recommendation was made that it should be eliminated until this source of boron became threatening.

Conclusions on the section:

1. The main sources of boron pollution in the Ilek river valley are the territory of the former Alga Chemical Plant, sludge collectors, slurry pipelines.

2. The plant is located in the slope relief zone on the floodplain terrace of Ilek. Conserved old settling pond was located in the floodplain of the river and continues to be a source of pollution of the water of the Ilek river, soils and rocks of adjacent areas from the north, east and south. The new sludge settling ponds and evaporation ponds built on the main shore are constructed with large defects. They do not prevent leakage through the walls of the settling tanks, due to which sewage with a high concentration of toxic substances continue to contaminate the soil of the adjacent territories in trans-eluvial and aqua landscapes, as well as the water of the Baipakty river and the Suyksu river and through them the Ilek river.

3. The main masses of pollution products accumulated in the soil-grounds of the industrial site, urban and adjacent territories due to atmospheric precipitation during the activity of the plant are gradually washed out during the spring flood during a short period.

2 MIGRATION CHARACTERISTIC OF BORON IN THE GROUNDWATER AND SURFACE WATER

2.1 General Description for Boron element

In nature, boron is never found in the elemental form. It exists as a mixture of the 10B (19.78%) and 11B (80.22%) isotopes [40]. Boron's chemistry is complex and resembles that of silicon [41].

Physicochemical properties. Boron is a polymorphic element that exists in many different crystalline forms: α -rhombohedral (transparent red crystals); β - α -rhombohedral (black); α -tetragonal (black, opaque crystals with a metallic luster); amorphous (black or dark brown powder); and yellow monoclinic crystals or brown amorphous powder [42]. Boron refers to electronically deficient elements, which means a strong tendency to form highly stable covalent bonds with electronegative atoms such as oxygen. Therefore, in substances, boron is usually combined with oxygen.

The concentration of boron in the earth's crust is estimated to be less than 10 ppm, but in areas rich in boron, its concentration can exceed 100 ppm [43, 44]. Minerals of borates are ubiquitous in nature in small concentrations in the form of borates of alkaline (e.g. sodium) and alkaline earth (e.g. calcium) metals and in the form of borosilicate minerals.

Borates are found in oceans, sedimentary rocks, coal, shales and soils. Elemental boron is extracted from boron-containing minerals by reduction of the latter. Boron oxide is obtained by thermal melting of boric acid [45]. A widely used borax is obtained by dissolving borate minerals in water and isolating a crystallized product. Anhydrous borax, which is obtained by high-temperature melting of borax and boric acid, is a crystalline product that is extracted from borax in reaction with hot sulfuric acid.

The most important minerals, which include boron, include borax $(Na_2B_4O_7 \cdot 10H_2O)$, kernite $(Na_2B_4O_7 \cdot 4H_2O)$, sassolin (H_3BO_3) , asharit $(2MgO \cdot B_2O_3 \cdot 3H_2O)$, datolith $(2CaO \cdot B_2O_3 \cdot 2SiO_2 \cdot H_2O)$, dolomite, danburite $(Ca[B_2Si_2O_8])$, $(CaMg(CO_3)_2)$, hydroboracide (aqueous calcium and magnesium borate), carbonate $(NaCa[B_5O_6(OH)_6] \cdot 5 H_2O)$, colemanite $(Ca_2B_6O_{11} \cdot 5H_2O)$ and other [46].

The 6 096 500 million tons of boron with an average concentration of 4450 μ g per liter are dissolved in the oceans. The concentration in river water averages 10 μ g per liter; the global annual discharge of boron with river runoff into the ocean reaches 370 thousand tons [47].

Anhydrous borates and complex borosilicates form at high temperatures, while hydrated borates form at low temperatures [48]. One of the main boron minerals is tourmaline, which is highly resistant to erosion and is therefore the most common high-temperature boron-containing mineral.

Boron-containing minerals easily pass into aqueous solutions [49]. Weathering (erosion) of boron-containing rocks is a source of borates in aqueous solutions, mainly in the form of boric acid (H_3BO_3).

Large accumulations of boron were found in evaporites (precipitates precipitated from supersaturated solutions) due to their high solubility.

Boric acid and ion $H_2BO_3^-$ the most common natural boron compounds [50]. Boric acid is the main form of boron found in soils at pH up to 9, and the ion - $H_2BO_3^-$ at higher pH 9,2.

Boron compounds are also widely present in seawater and salt lakes, oil water, hot springs, volcanic and mud muds, and in many soils [51, 52].

Chemical properties of boron. Crystalline boron is chemically inert.

- 1. Interaction with fluorine: $2B + 3F_2 = 2BF_3$.
- 2. Interaction with oxygen. Boron reacts with oxygen at 750 °C: $4B + 3O_2 = 2B_2O_3$.
- Interaction with other non-metals. At temperatures above 1200 °C, boron reacts with chlorine and nitrogen: 2B + 3Cl₂ = 2BCl₃,

 $2\mathbf{B} + \mathbf{N}_2 = 2\mathbf{B}\mathbf{N}.$

- 4. Restorative properties. With strong heating, it reacts with stable oxides: $3SiO_2 + 4B = 3Si + 2B_2O_3$.
- Interaction with acids. Crystalline boron does not interact even with boiling concentrated acid solutions. Amorphous boron is oxidized by hot concentrated solutions of nitric, sulfuric acids and aqua regia (A.R.):
 R + 3HNO₂ = H₂RO₂ + 3NO₂

 $\mathbf{B} + 3\mathbf{HNO}_3 = \mathbf{H}_3\mathbf{BO}_3 + 3\mathbf{NO}_2.$

6. Interaction with alkalis. Boron interacts with alkalis only in the presence of oxidizing agents:

 $4B + 4NaOH + 3O_2 = 4NaBO_2 + 2H_2O.$

The main compounds of boron. Boric acid H₃BO₃ is a crystalline substance in the form of flavourless flakes, has a layered triclinic lattice in which acid molecules are connected by hydrogen bonds into flat layers. Stains the flame green. Boric acid exhibits very weak acidic properties. It is relatively slightly soluble in water. When heated, boric acid dissolves metal oxides, forming salts. With alcohols in the presence of concentrated sulfuric acid forms esters. It is easily displaced from solutions of its salts by most other acids [53].

The boron sulfide B_2S_3 formed in the form of a colorless glassy mass during incandescent boron in sulfur vapor. Boron sulfide is completely *decomposed by water* into boric acid and H_2S .

Boron nitride BN is a white powder, melting only about 3000 °C (under pressure). By its crystal structure, BN is similar to graphite.

Boron carbide B_4C is formed in the form of black shiny crystals during incandescence of a mixture of boron (or B_2O_3) with coal in an electric furnace. It is distinguished by refractoriness ($t_{melting} = 2550$ °C) and extreme hardness, and boron nitride and carbide are characterized by great resistance to various chemical influences.

Boron halides of the general formula $BHal_3$ can be obtained by the interaction of elements when heated. They are colorless substances. Under normal conditions BF_3 gaseous, BCl_3 boils at $+18^{\circ}C$, BBr_3 – fluid and BJ_3 – solid. In an aqueous solution, they all undergo hydrolysis according to the scheme:

 $BHal_3 + 3H_2O = B(OH)_3 + 3HHal.$

Boron halides are characterized by reactions of the attachment of molecules of various other substances to them. In particular, boron fluoride forms an addition product with HF:

$HF + BF_3 = H[BF_4].$

Major uses. Boric acid and borates are used in glass manufacture (fiberglass, borosilicate glass, enamel, frit, and glaze), soaps and detergents, flame-retardants, and neutron absorbers for nuclear installations. Boric acid, borates, and perborates have been used in mild antiseptics, cosmetics, pharmaceuticals (as pH buffers), boron neutron capture therapy (for cancer treatment), pesticides, and agricultural fertilizers.

Boron (in the form of fibers) serves as a hardening agent for many composite materials. It is used as a hardener of composite materials (in the form of fibers), as a semiconductor for the manufacture of thermistors, thermal neutron counters, and converters of thermal energy into electrical energy. Boron and its alloys are also used as neutron-absorbing materials for the manufacture of control rods of nuclear reactors. Boron is also used in medicine for boron neutron capture therapy (a method for the selective destruction of malignant tumor cells). For many living organisms, boron is a vital element. Together with manganese, copper, molybdenum and zinc, it is one of the five most important trace elements. With a lack of boron in the soil, the yields of many crops are noticeably reduced, and especially the lack of boron affects the yield of seeds. It has been established that boron affects carbohydrate and protein metabolism in plants.

Environmental fate. Waterborne boron may be adsorbed by soils and sediments. Adsorption–desorption reactions are expected to be the only significant mechanism influencing the fate of boron in water [54]. The extent of boron adsorption depends on the pH of the water and the concentration of boron in solution. The greatest adsorption is generally observed at pH 7.5–9.0 [55-57].

In natural water, boron exists primarily as undissociated boric acid with some borate ions. As a group, the boron–oxygen compounds are sufficiently soluble in water to achieve the levels that have been observed [58]. The author [59] described boron as a significant constituent of seawater, with an average boron concentration of 4.5 mg/kg.

2.2 Migration of boron in natural water

An essential factor in the migration of matter in the landscape sphere is the possibility of the free manifestation of gravity. According to the cycles and conditions of migration of chemical elements of the Ilek river valley, it refers to para- and neoeluvial elementary landscape [60].

The regional distribution of boron solutions is noted as pollution of technogenic origin, coming from the storage pond of a chemical plant. The water intakes of the regional center of Aktobe, as well as the reservoir on the Ilek River, built between Alga and Aktobe, are contaminated with technogenic water.

As noted in scientific paper [26, p.17], technogenic pollution was developed only near the town of Alga, all other indications for boron in the Ilek valley are an aura of exogenous dispersion of highly mineralized groundwater from Permian deposits. In this regard, it is necessary to consider the geological and hydrogeological conditions of the Aktobe Ural. The geological structure of this part of the Aktobe Urals is characterized by the wide development of Perm terrigenous and hydrochemical rocks with a thickness of 5000-8000 m, crushed into linear folds of submeridional strike. These salt anticlines are complicated by salt tectonics.

Perm deposits contain fresh and brackish groundwater in the east of the Ilek basin (Berlin rill with a water salinity of 3.5 mg/dm³ and boron content with 1.2 mg/dm³). In the west, water salinity at the Bestamak fold 296-318 g/dm³, on Aktobe - up to 320 g/dm³; boron content in different structures from 0.5 to 45 mg/dm³ [61].

Triassic and Jurassic formations lie in the arches of salt uplifts on Kungur rock salt. Groundwater confined to them dissolve Kungur salts, wash them and carry them to the centers of drainage - in river valleys. In addition to boron-containing water, there borates the halogen rocks Kungur are in of the tier. Kungur deposits in this place underlie alluvium. At the rift, the alluvium water is brackish, near the Ilek valley, slightly brackish, and upstream very fresh. This definitely indicates the influx of mineralized water from Perm rocks and the migration of boron with them.

In the village of Bestamak, under the alluvium, there is the Bestamak salt anticline and its disjunctive trough. The groundwater of Permian sediments self-drain, i.e. their pressure is higher than the surface of the earth and groundwater levels, which allows them to migrate upward and enrich the ground and river water with boron.

Thus, the Ilek valley is technologically polluted with boron near the town of Alga, and downstream its entire space further to the north represents the exogenous halo of dispersion of Perm brines and boron along with them, as well as secondary technogenic pollution from sludge collectors and sludge pipelines.

Deficit and excess of elements, biogeochemical endemia, depend on the geochemical characteristics of water. In the types of biogeochemical provinces, the criterion proposed by A.P. Vinogradov and adopted by V.V. Kovalsky is used - the deficit or excess of chemical elements determined by the clarke of the concentration of the chemical element.

Clark concentration of boron in the upper part of the continental crust according to A.P. Vinogradov is 12 mg / kg [62]. As a predicted indicator of the intensity of participation of chemical elements in technogenesis, A.I. Perelman proposed using the concept of "technophilicity of chemical elements" (the ratio of the annual production of an element in tons to its average content in the earth's crust). The value of the technophilicity index of boron according to A.I. Perelman is 107 -108 [63].

The phenomena of variability of plants and animals under the influence of chemical environmental factors are quite widespread on the earth's surface. These phenomena are expressed in a wide variety of forms: morphological and physiological changes, diseases of organisms, disruption of vital functions and vitality. Many of these phenomena are associated with an excess or deficiency of individual chemical elements in the environment: in the soils from which terrestrial plants draw nutrients, in the water that enter the animal organism during its development. Areas where similar anomalous phenomena are observed in living organisms are called biogeochemical provinces [64]. The region under study is zonal in nature, and is confined to soil and climatic zones (landscape zones).

For detection the role of boron contamination of the environment components in the incidence of the population of the Alga region, a primary risk assessment for the incidence of contaminated meat and fish products was conducted. The calculations were based on the results of field studies of LLP «The Center for Health Protection and Environmental Engineering» in terms of boron concentrations of selected animal and fish samples.

Table 5 presents the results of laboratory determinations of the boron content in the samples. According to these data, "the dose-response" relationship was evaluated. The calculation procedure is described in detail in [65, 66].

The following values were taken for the consumption of products: meat and meat products - 0.126 kg/day, for fish and fish products - 0.026 kg/day.

Type of sample	Place of sampling	Content in mg/kg	Average daily intake for adults, mg/ d	The average daily intake for children, mg/d	Risk factor of non- carcinogenic risk, adults/children
Beef	Alga city	4,638	0,008	0,04	0,09/0,4
Beef	Tamdy	1,131	0,002	0,009	0,02/0,1
Mutton	Kurayly	4,389	0,008	0,04	0,09/0,4
Perch river	Aktobe Reservoir	0,362	0,0001	0,0006	0,001/0,007
Roach	Aktobe Reservoir	4,729	0,002	0,008	0,02/0,09
Yaz ordinary	River Ilek (Alga city)	4,457	0,002	0,008	0,02/0,09
Carp of silver	River Ilek (Bestamak)	1,991	0,0007	0,004	0,008/0,04
Perch river	River Ilek (Bestamak)	2,489	0,0009	0,004	0,01/0,05
Perch river	River Ilek (Alga city)	2,670	0,001	0,005	0,01/0,05

Table 5 – Results of determination of boron content in products and calculations of its entry into the body

The results of the average daily doses of boron intake into the human body, given in Table 5, are within the lower limit of the norm, which corresponds to the admissible intake of the element into the body. In this regard, the risk factor of non-carcinogenic risk when eating local meat products and fish is within normal limits.

According to the results of the study [67], the combined action of chromium and boron upon entry into the stomach, revealed general toxic and specific effects of boron. Specific actions are actions on embryos, male and female gonads, mutagenic actions,

if we talk about malignant formations, have a carcinogenic effect. It is proved that boron has a gonadotropic effect, affects reproductive function. The most negative effect is exerted by the combined effect of chromium and boron. During the study, outbred white rats were intragastrically administered combined potassium dichromate and borate. In pregnant rats, changes in reproductive function also occurred, and a general toxic effect was revealed. It turned out that the effect of the combined action is reinforced by the pollution factors of each other.



Figure 5 – Aktobe reservoir, July, 2017

For study current situation of chromium and boron province field analytical studies were conducted in July 2017 (figures 5, 6). Surface water sampling was carried out at the request of the interstate standard GOST 31861-2012. Water. General sampling requirements [68]. Chemical analysis of water was carried out in a portable laboratory based on a DR 1900 spectrophotometer (Hach-Lange, 2013) [69].

The results of the analytical work are shown in table 6 [70].


a) DR 1900 spectrophotometer



b) Aktobe reservoir, July, 2017

Figure 6 – Field research, July, 2017

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Table 6 –	The c	hemical	analysis	results	of surface	and g	roundwater	' in the	llek riv	ver vallev
						C				

		Sam	nple		Maximum	Indicator of	Hazard
	Old	Aktobe	Aktobe	Podkhoz	allowable	harmfulness	Class
Name	sludge	water	1	rural	concentration		
	storage	reservoir		(Alga)	and water		
					quality standard		
Water	5	7	8	4			
temperature						*	*
at sampling,							
° C							
The	4	7,5	6	8	6-8	sanitary	
hydrogen						toxicological	2
index, pH						toxicological	
B ³⁺ , mg/l	3,5	1,2	0,6	0,9	0,5	sanitary	3
						toxicological	5
Cr ⁶⁺ , mg/l	0,139	0,045	0,023	0,002	0,05	sanitary	2
						toxicological	2
Pb ²⁺ , mg/l	49	16	8	0,01	32,0	sanitary	2
						toxicological	2
Mo ⁶⁺ , mg/l	7,8	3,1	1,8	0,2	0,5	sanitary	2
						toxicological	Δ
Br ²⁺ , mg/l	1,2	0,39	0,2	0,13	0,2	Indicator of	Hazard
						harmfulness	Class

As the results of field studies show, the maximum permissible concentration of boron is exceeded at three sampling points, which suggests a further study of the effect of this element on the human body.

2.3 The biological role and effect of boron on the human body

The composition of the sources from which water is supplied directly affects people's health. Ideally, water should not contain any impurities that have a negative impact on human health. At the same time, natural water should contain a sufficient

number of trace elements involved in the metabolic processes of living organisms. For example, a low fluorine content in drinking water leads to the destruction of tooth enamel, and iodine deficiency causes thyroid disease.

Bacterial contamination of drinking water poses a particular danger due to the occurrence and spread of mass infections. Among parasitic diseases, giardiasis occupies a special place - a disease caused by a pathogen such as protozoa that affects the intestines and liver of a person. According to the latest epidemiological data, drinking water is considered the main route of transmission of this pathogen [71, 72].

The danger of infection of water sources is also related to the fact that the life cycles of pathogens occur with the participation of various organisms that play the intermediate role of parasite carriers (fish, mollusks, crustaceans, mosquitoes, etc.).

It is important to note that the same water quality indicators in the regulatory documents of different countries can significantly differ from each other. For example, in Kazakhstan, for some indicators, maximum permissible concentrations (MPC) are established, which are either outside the sensitivity of modern methods of analysis, or outside the technologies used for water purification [73].

The standards of the World Health Organization (WHO) are divided into groups of contaminants: organoleptic, inorganic, organic, radioactive, pesticides, substances used in the disinfection of water and impurities that do not affect human health at their normal concentrations in water (table 7) [74, 75].

Table 7 – Quality standards for drinking water in Kazakhstan (GOST), the European Union and the USA, as well as recommendations of the World Health Organization (WHO)

Denomination	Sanitary and epidemiological rules and	European Union Directive 03.11.1998 v.	USA normative (NPDWP)		WHO
	regulations 2.1.4.107401	J.	MCLG1	MCL2	
1	2	3	4	5	6
Smell, point	2	Customer Acceptable	-	-	-
Taste, point	2	Customer Acceptable	-	-	-
Color, degree platinum-cobalt scale, ^o	20	Customer Acceptable	-	-	15
Turbidity, mg / 1	2,6	Customer Acceptable	-	-	5
Водородный показатель (рН)	6,0-9,0	\geq 4,5 (6,5 – 9,5 for bottles)	-	-	6,5 - 9,5
Total salinity (dry residue), mg / l	1000	-	-	-	-
Total hardness, mmol / l	7,0	-	-	-	-

Continuation of the table 7

1	2	3	4	5	6
Permanganate	5,0	5,0	-	-	-
oxidation, mg					
O ₂ /l					
Oil products,	0,10	-	-	_	-
mg /l					
Surfactants, mg /l	0,50	-	-	-	-
Phenol, mg /l	0,01	-	-	-	-
Common	Absence	Absence (for	Absence	-	-
coliform bacteria		capacities up to	of 5 %		
(per 100 ml)		250 ml)			
B, totally, mg /l	0,50	1,0	-	-	0,50
Sulphates (SO ₄ ²⁻), mg /l	500,0	250,0	-	-	250,0
Chromium			0.10	0.10	
(Cr ⁶⁺),mg/l	0,05	0,05	0,10	0,10	0,05 (total)
$(Cr^{3+}), mg/l$	0,50	-	(lotal)	(lotal)	
Nitrite (by NO ²⁻), mg /l	3,0	0,5	1,0	1,0	3,0
Sodium (Na ⁺), mg /l	200,0	200,0	-	-	200,0

It should be marked, that MCLG1 - - determines the maximum level of contamination of drinking water at which there is no adverse effect on human health (is not mandatory). MCL2 – regulates the maximum permissible level of contamination of drinking water, which is supplied to any user of the water supply network (is mandatory).

The component composition of water is complex and diverse, and each component can have a different effect on the state of human health in case of excessive and insufficient intake of it in the body. Table 8 presents the main components of drinking water and their impact on humans.

Table 8 – Impact on human health with excessive and insufficient intake of drinking water components

Drinking water component	Standard (MPC),	Effect on the body
	no more than mg	
	/ 1	
1	2	3
Aluminum	0,5	Violation of the structure and functions of the
		nervous system
Barium	0,1	Effects on the cardiovascular system
Benzapiren	0,000005	Oncological diseases

Continuation of the table 8

1	2	3
Benzene	0,5	Damage to the liver, kidneys, heart disorders
Boron	0,5	Violations of the functions of the food,
		cardiovascular and nervous systems of the body, teratogenic effect
Iron	0,3	Allergic reactions, blood diseases
Calcium	3,5	The disadvantage is an increased risk of
		osteoporosis and rickets, impaired blood
		coagulation. Excess - hypercalcemia,
		urolithiasis, growth retardation in children
Magnesium	20	The disadvantage is a violation of enzymatic
		reactions, the functions of the nervous system
		and muscle of the heart. Excess - development
		of diseases of the gastrointestinal tract and
Malada da sera ser	0.25	respiratory tract
Molybdenum	0,25	Respiratory tract gout
Sodium	200	Deficiency - weight loss, impaired absorption
		of amino acids, neuralgia Excess - kidney
NT ¹	4.5	disease, edema
Nitrates	45	Methemoglobinemia
nitrites	33	
Fluorine	1,5	Caries, Fluorosis, Osteosarcoma
Chromium	0,5	The disadvantage is a decrease in the growth
		rate in children, an increase in blood
		cholesterol. Excess - allergic reactions, cancer

Identification and elimination of possible adverse effects of the chemical composition of drinking water on the body are important factors in maintaining health.

The boron element belongs to the class of biologically active substances. In Sanitary and Epidemiological Rules, Norms, Rules and Norms 2.1.4. 1074-01, boron on the sanitary-toxicological sign of harmfulness is referred to the second class of danger.

Boron is a biologically active trace element, so a lack of boron in the diet can lead to a disruption of macromineral metabolism (for example, osteoporosis and improper bone formation). Assessment of boron content in humans and animals is based on the results of determining its concentration in urine, plasma or blood serum. It is difficult to pinpoint the symptoms of boron deficiency. It is known that boron affects the exchange of calcium and copper. Its deficiency can lead to hyperchromic anemia and thrombocytopenia. The absence of boron in the body against a background of vitamin D deficiency causes growth retardation. Low concentrations of boron lead to a decrease in mental ability. However, with an increased content of boron in the body, it turns from a vital element to toxic.

Studies have shown that boric acid and borax are absorbed from the gastrointestinal tract and respiratory tract [76]. In acute intoxication with boron compounds (brown, boric acid), vomiting and even shock are observed. When inhaled

gaseous boron compounds may develop cramps, muscle pain, mental disorders. An endemic disease such as boric enteritis, which is found in the west and north of Kazakhstan, is described.

Oversaturation with boron leads to hair loss and anemia. In addition, boron inhibits the body's absorption of ascorbic acid, flavonoids, and sulfur-containing amino acids and enhances the effect of alcohol, as well as some antibiotics.

Long-term consumption of water and foods with a high content of boron leads to impaired functions of the cardiovascular, nervous, food and reproductive systems of people and animals. The composition of the blood undergoes changes, physical and mental development in children slows down, and the risk of pathological births increases.

Due to the fact that boron compounds belong to the second class of toxicological hazard, their content in drinking water is subject to strict control.

In Kazakhstan, the highest limit of a safe dose of boron for humans is 12-14 mg/day [77], and the MPC for the content of boron compounds in drinking water is 0.5 mg/l. The US Environmental Protection Agency has adopted 0.6 mg/l as a standard value. In the CIS countries, the maximum permissible concentration of boron in drinking water is 0.5 mg per liter. The World Health Organization and several European countries have recommended a boron limit of 0.3 mg/l in drinking water. In Japan, the permissible level of boron is even lower and equal to 0.2 mg/l.

The boron's essence for the animal organism was established in the early 1980s. According to the references [78-80], excessive *boron intake* in the body leads to the development of a number of pathological conditions, in particular, diseases of the gastrointestinal tract - boron enteritis. Boron compounds have recently been recommended as a means of weight loss, but due to harmful effects on the body, their use was prohibited. Absorption of boron compounds occurs rapidly, but their isolation is slow, i.e. there is an accumulation. Manifestations of cumulative-chronic boron intoxication - watery stools, vomiting, loss of appetite, skin rash with persistent peeling - "boron psoriasis", a state of mental confusion, anemia, and cachexia. Poisoning in infants is observed in cases when nursing mothers use a solution of boric acid to clean the nipples. Acute poisoning with boric acid is accompanied by convulsions, meningism, later collapse, followed by death. Frequent symptoms of poisoning are gastrointestinal disturbances. The toxic effect of borax is similar to that of acid. It is also known that boron acts depressingly on reproductive functions and causes infertility.

Boron is vital for representatives of marine and freshwater phytoplankton, diatom algae, and certain plants. It is an irreplaceable microelement for legumes.

Boron from food, boric acid, its sodium salt is rapidly absorbed and excreted, mainly with urine (more than 90% of the incoming amount of the element). The half-life of boron is about 11 days. This estimate is based on a daily intake of boron equal to 0.12 mmol.

Conclusions on the section:

1. In natural water, boron exists mainly in the form of non-dissociated boric acid with some borate ions. Soils and sediments can adsorb an aqueous solution of boron. The

degree of adsorption of boron depends on the pH of the water and the concentration of boron in the solution. The highest adsorption is usually observed at pH 7.5–9.

2. The Ilek river valley is technogenic pollution with boron near the town of Alga, and downstream its entire space further to the north represents the exogenous halo of dispersion of Perm brines and boron along with them, as well as secondary technogenic pollution from sludge collectors and sludge pipelines. The results of a field study showed that in the Ilek river on the Alga area was formed a technogenic boron biogeochemical province, requiring urgent action.

3. Boron is an essential element for plants and is involved in many processes of human life. However, exceeding the required standards leads to inhibition of vegetation and to severe consequences for humans. In the sanitary-epidemiological rules and regulations 2.1.4. 1074-01, boron on the sanitary-toxicological basis of harmfulness belongs to the second hazard class.

3 DYNAMICS OF POLLUTION PROCESSES OF GROUNDWATER AND SURFACE WATER OF THE ILEK RIVER VALLEY

3.1 A brief theory of component analysis

A component analysis is one of the methods of multidimensional statistics; it is based on a hypothesis: the observed or measured parameters are only indirect characteristics of the studied object or phenomenon. In fact, there are internal (hidden, not directly measured) parameters or properties, the number of which is small and which determine the values of the observed parameters [81, 82]. These internal parameters, called the main components, are supposed to store all the information contained in the set of observable variables.

Although without knowing such components in advance, component analysis sets the task of presenting the observed parameters in the form of linear combinations of the main components and determining them, i.e. for each object, specify the value of each main component. In this case, the component analysis model can be written in the form [83]:

$$\mathbf{Y}[n \times m] = \mathbf{F}[n \times m] \cdot \mathbf{A}[m \times m], \tag{1}$$

where, $\mathbf{Y}[n \times m]$ represents the totality of all n observed values of all m parameters; $\mathbf{F}[n \times m]$ – a matrix including the set of all n obtained values of all m principal components, this is the desired matrix of values of new variables at each sampling point; and $\mathbf{A}[m \times m]$ – the so-called component load matrix, or weight matrix, it is the link between old and new variables.

As you can see, in the matrix equation there are two unknown matrices $-\mathbf{A}[m \times m]$ and $\mathbf{F}[n \times m]$, and since only one unknown can be found from one equation, an additional condition is required to determine the second. Such an additional condition, the initial premise of the analysis, is the presence of a relationship between several simultaneously observed variables.

A correlation coefficient is used as a quantitative measure of the relationship between two variables. It can take values from -1 to +1. Moreover, if it approaches 0, this indicates the absence of a linear relationship, and the closer it is to +1 or -1, the closer the linear relationship exists between the variables.

All calculated correlation coefficients between each pair of variables are located accordingly in the correlation matrix. It contains important information about the relationship of variables, taking into account the influence of interference, which may be caused, for example, by the heterogeneity of the material. When analyzing such a correlation matrix, the structure of the desired hypothetical quantities is obtained (the matrix $A[m \times m]$), which are in certain relationships with variables.

This structure is found as a result of mathematical transformations of the correlation matrix calculated from the initial results of observations. The transformations are based on a theorem using the symmetry of the matrix of correlation coefficients and some simple operations on the matrices, which result in:

$$\mathbf{R}[m \times m] = \mathbf{U}'[m \times m] \cdot \mathbf{\Lambda}[m \times m] \cdot \mathbf{U}[m \times m];$$
(2)

$$\mathbf{A}[m \times m] = \mathbf{U}'[m \times m] \cdot \mathbf{\Lambda}^{\frac{1}{2}}[m \times m];$$
(3)

In the last equations $\mathbf{U}[m \times m]$ – an orthogonal matrix whose columns are the eigenvectors of the matrix $\mathbf{R}[m \times m]$, a $\Lambda[m \times m]$ – diagonal matrix composed of matrix eigenvalues $\mathbf{R}[m \times m]$, corresponding to eigenvectors, and the elements in the matrix $\Lambda[m \times m]$ arranged in descending order: $\lambda_1 > \lambda_2 > ... > \lambda_n > 0$.

So the matrix $\mathbf{A}[m \times m]$ can be considered certain if the eigenvectors and eigenvalues of the matrix are known $\mathbf{R}[m \times m]$. This process is easily carried out on a computer, since there are many standard algorithms for calculating the eigenvalues and eigenvectors of symmetric matrices. This solves the main problem of component analysis - determining the matrix of weighting coefficients, taking into account the tightness of the relationship between the features and the main components.

The component analysis model involves the accurate determination of both component loads and the values of the main components for each sampling point (for each object). In practice, usually a small number of components are left if they account for a sufficiently large percentage of the total variance of the parameters, which is equal to the trace of the matrix Λ $[m \times m]$, or matrix dimensions $\mathbf{R}[m \times m]$, that is, the number of parameters. Therefore, it is possible to select a small number of principal components (m < n) and achieve significant simplification of the description of features. Because the $\sum_{i=1}^{m} \lambda_i = m$, usually $\frac{q}{m} = 0.8 \div 0.9$, that is, 80-90% of the total variance is most often limited, although this value

 $\frac{q}{m} = 0.8 \div 0.9$, that is, 80-90% of the total variance is most often limited, although this value can be set depending on the objectives of the study and less than this value, and more.

After finding the matrix of component loads in the presence of a computer, it will not be difficult to determine the second unknown - the matrix of values of the main components at each sampling point (for each object) - according to the equation of the model record. Quite often, the analysis is limited to the calculation of the matrix $\mathbf{A}[m \times m]$, which allows you to establish the structure of new (hypothetical) variables - the main components, and sometimes interpret them from a professional point of view.

As the main component, the association of the initial features included in the component (or factor) with statistically significant values of the loads on the corresponding features is selected. And although at the first stage of analysis (matrix definition $\mathbf{A}[m \times m]$) from the identified main components, some conclusions can be drawn about the conditions that determine the course of the processes under study. The matrix of values of the main components $\mathbf{F}[n \times m]$ is an important and useful result [84], especially for mapped quantities. The first stage of component analysis can be considered final in the case when it is used to confirm the hypotheses put forward, that is, when we pre-assume a certain hierarchy of signs or their combinations, and the distinguished associations of signs (components) confirm this assumption.

If studies by component analysis are carried out in order to reduce the number of parameters (provided that the source variables are mapped values), then mapping the values of one factor by observation points will be equivalent to the image of information presented earlier on as many maps as the number of initial parameters included in the main component. The last remark is valid only in the case when each of the signs is included in only one component, which is almost never observed in the interpretation of the main components.

The main components reflect not a simple sum of the parameters describing the system they are the result of the systemic interaction of these parameters, the new property that appears when the system is built. And the process of interpreting the main components is to identify common causes that cause a "parallel" or "antiparallel" change in the measured parameters. The folding of information consists in the fact that the number of factors acting on the system is always less than the number of parameters that are their manifestation, for example, the manifestation of the climatic factor through the temperature regime, zonation of the level and chemical regime of groundwater, zoning of landscapes, etc.

Plotting the distribution of component values by objects in the space of the components themselves (for example, in the flat of the first and second main components) provides a way to group objects according to common properties, that is, it becomes possible to solve problems of classification and allocation of "special" zones. On the other hand, the obtained component values for each object can be considered as new variables that do not correlate with each other during orthogonal solution, and this is an important circumstance when using other statistical procedures, for example, when constructing regression equations on the main components.

Thus, the second stage of component analysis, or the result of solving the inverse component problem, is of significant interest. This solution is found from the previously computed matrix of component loads and the normalized matrix of source data according to the following equation:

$$\mathbf{F}[m \times n] = \mathbf{A}^{-1}[m \times m] \cdot \mathbf{Y}[m \times n]$$
(4)

This equation is valid only for the case when the full matrix of component loads is calculated $\mathbf{A}[m \times m]$, and the inverse matrix can be found. If only the first *q* components that satisfy the given accuracy are searched for, then the solution algorithms are somewhat more complicated, since the matrix $\mathbf{A}[m \times q]$ must first be supplemented with a square one:

$$\mathbf{F}[qm] = (\mathbf{A}'[q \times m] \cdot \mathbf{A}[m \times q]) \cdot \mathbf{A}'[q \times m] \cdot \mathbf{Y}[m \times n].$$
(5)

The solution obtained is the final result of component analysis in the sense of mathematical constructions, then we will have a meaningful, objective interpretation of the selected components, which, as noted in all theoretical works on component analysis, presents the main difficulty in applying this method.

Therefore, component and factor analyzes pose and solve the inverse problem, which consists in calculating the matrix of values of factors at the points of testing. However, the solution of such problems requires a large operational memory, which in the eighties could not be controlled by high-level programming languages due to its block structure. As a result,

an uncomplicated algorithm for calculating this matrix was surrounded by rather complicated programs to circumvent the difficulties of storing large amounts of data in RAM, and therefore, in the sets of statistical programs of the DOS system, the inverse factor problem is usually absent (the most commonly used STATGRAF is an example of this). We used our program, adapted to solve zoning problems and, in addition, containing additional features that facilitate the construction of components for further interpretation (programmer T.F. Savina using the algorithms L.M. Pavlichenko).

From the point of view of the geometric presentation of the results of component analysis, its task is to search for such an orthogonal system that, with the smallest number of Cartesian coordinate axes, describes the largest number of source feature vectors. The position of the new system of coordinate axes in component analysis is determined in such a way that for each subsequent axis (main component) there would be a maximum of the remaining total dispersion after taking into account the previous axes.

Although mathematically this solution is unique, it is in fact one of an infinite number of other systems that describe the configuration of the source data in the space of objects just as well as the axis system selected by the variance, that is, the problem of choosing the optimal position of the axes arises - the problem of rotation. The geometric rotation of the component axes is considered as the problem of orthogonal rotation of the matrix of component loads. However, one should always remember that the rotation procedure is carried out solely to facilitate the interpretation of the selected components, which, even without rotation, can be fully interpreted.

Let us try to analyze the mathematical results of component analysis in terms of practical applications. Its main result can be considered the matrix of eigenvectors of the matrix of paired correlation coefficients of the initial features, which actually represents its internal structure. In fact, if the number of eigenvectors is less than the number of initial parameters, this will be a signal of the presence of a linear relationship between parts of the initial features. This is expressed, for example, in the fact that one of the columns of the matrix is an algebraic sum with some constant coefficients of two, three, etc. other columns of the same matrix. Thus, the information contained in this column can be obtained by calculation, and the exclusion of this column from the matrix will not damage the total information. This is exactly what the procedure of space convolution is, known in matrix algebra.

Since the component load matrix is a matrix of eigenvectors multiplied by the diagonal matrix of the square roots of the eigenvalues, it is natural to transfer all the arguments about folding the space of attributes to the matrix of component loads. This is precisely the realization of the component analysis hypothesis about the existence of internal (hidden, not directly measured) parameters or properties that determine the values of the observed parameters. For a geoecosystem, such properties are the factors of its formation, therefore, it can be justifiably said that component analysis examines, reveals hidden relationships between the initial features of ecosystems, and, with the correct interpretation of the results, and allows us to characterize the processes that determine their formation. The component axes obtained as a result of mathematical transformations can be considered as a formal record of processes through one or another association of parameters distinguish these associations, moreover, two associations can enter one component if they have opposite signs, however, and in this case, the component describes one process.

The opposite of the signs of the loads on the initial variables, selected by the model into one component, testifies to the multidirectional influence of the studied process of the ecosystem on the association of signs with the same sign. In other words, the combination of parameters in the component in this case gives an encoded record of the process, causing a simultaneous increase in the values of the parameters of ecosystems. It is identified with an association with a positive sign of loads while reducing the values of the parameters of ecosystems identified in the same component as an association with a negative sign.

The second important result of component analysis is the eigenvalues of the matrix of pair correlation coefficients. This result allows us to judge the degree of hierarchy of the processes allocated by the matrix of component loads. The intensity of the manifestation of the interpreted factor in the territory is studied according to the third result of the model - the matrix of component values. The obtained values of the main components also have positive and negative values, however, here the difference in signs does not mean a different direction of the process, but a different intensity of its manifestation - positive values characterize areas with more intense manifestation than negative ones (at zero average). It should be noted that a positive value is not an indicator of the favorableness of the studied factor and vice versa, but only shows a different intensity of its manifestation in relation to the average value. Negativity or auspiciousness is characterized solely by an objective interpretation of the selected components.

Thus, component analysis combines the capabilities of many statistical models and recommendations of system analysis for the requirements for the choice of research methods for complex systems. From the point of view of system analysis, the component analysis model for a given composition of elements allows you to comprehensively explore the ecological system precisely from system positions. Therefore, it makes it possible to isolate the functions of the system and rank them by their contribution to the total dispersion of the system (emergence). It takes into account the nature of the relationship (the relationship of the signs of the relationships within the component shows the synergetic and antagonistic effects of the relationships) and the self-organization of the system (the possibility of the existence of closed loops in the communication system is expressed by that the same sign is included in different components). A new result of the model is not only the identification of the function of the system (system-forming factors) based on the interpretation of the system of interconnections of the initial features, but also the regionalization of the territory by the intensity of the manifestation of this function. However, the quantitative characteristics of system-forming factors that are the weak point of simulation.

Therefore, component analysis allows you to:

- Calculate relationships in the system;
- Explore the structure of relationships;

- Receive an emergent result - new information from the previous data set - identification of the processes of formation of geo-ecological systems based on information about its state at a certain point in time;

- Rank the processes according to the degree of influence on the formation of the state of the ecosystem (build a hierarchy of processes) [81, p.43; 85].

As additional arguments in favor of component analysis, the ability to process diverse data characterizing different subsystems with both quantitative and qualitative features should

be added. Another advantage is that the cartographic features presented by the coding system for their distribution areas can be converted into a quantitative category. It will make it possible accurately determine the degree of coincidence of features than the application and coating operations in a GIS, and the search procedure is not required here - spatially matching features are automatically allocated to components.

The classical component analysis model provides for the possibility of high quality forecasting of environmental processes. An example of such a qualitative forecast is the identification of trends in the boron pollution of water intakes of the Aktobe city on the Ilek river. Component analysis made it possible to forecast the zone of formation of the secondary center of groundwater pollution by boron in the area of the drinking water intake that is not mapped by traditional methods: the accumulation site of the transit boron deposited on the mechanical geochemical barrier was mapped.

3.2 Subject information for interpreting the results of component analysis

In order to correctly interpret the processes, it is necessary to attract information on the properties of all these parameters from subject areas. The main such information in the modeling of ecosystems is the laws of their formation for arid (in our case) territories. An example of informative subject information from the field of hydrogeology, which allows interpreting the associations identified by the model as the processes of formation of the hydrogeochemical environment of geoecosystems, is the work of domestic scientists, such as Perelman A.I., Posokhov E.V., Shvartsev S.L., Germanov A.I., Panteleev V.M., Shvets V.M. and others [86-90].

The process of groundwater formation manifests itself in their regime - the spatiotemporal nature of the behavior of levels and pressures, groundwater supply and discharge, and their physicochemical properties. Violation of the natural regime due to anthropogenic interference with the natural course of natural processes leads to the formation of a mixed type of regime up to the complete replacement of the natural technogenic one. Natural complexes of arid territories are most sensitive to technogenesis. This is due to the specifics of their climatic conditions, which includes groundwater.

The chemical composition of groundwater reflects the laws of formation of their dynamics and interaction with water-bearing rocks, pollution processes, relationships with surface and groundwater of different horizons, evaporation and transpiration, etc., therefore, the chemical composition of groundwater has a high informative role, i.e.. interpretation of the components can provide information on the influence of factors prevailing in the study area. Mapping of the components will make it possible to solve the main task of ecological assessment of geosystems - zoning of the territory according to the intensity of the factors. While the informativeness of the chemical groundwater can be supplemented by composition of information from hydrogeochemistry, which has accumulated a large amount of empirical information on the migration properties of chemical elements and their associations in various hydrogeological conditions.

In accordance with modern ideas, four stages are distinguished in the process of forming the chemical composition of groundwater in the infiltration cycle: atmogenic, biogenic, lithogenic and evaporative. Under arid conditions, when evaporation from

the surface of groundwater is high, the evaporation stage predominates, during which the salinity of groundwater increases and its salt composition changes - from calcium carbonate and sodium through sodium sulfate to sodium chloride with all transitional subtypes. Recording the type of component for arid conditions during the processing of hydrogeochemical data by component analysis is characterized by significant stability, reflecting the prevailing processes of formation of the chemical composition of groundwater [91-96], etc.

The decisive factors for the free migration of the chlorine ion are the lack of barriers, both solubility and biochemical, and the ability to migrate in solutions of various concentrations in the form of a free ion. These properties make it one of the main signs of the evaporation stage of the infiltration cycle of the formation of the chemical composition of groundwater [97, 98], etc.

Sulfate ions migrate well in solutions, which are formed mainly under surface and near-surface conditions, while their presence in solution at great depths is hindered by the combined action of the biochemical barrier and the phenomenon of positive hydration. Thus, for groundwater, sulfate ion can also be considered a sign of the evaporation stage, although it is also inherent in the lithogenic one.

Free migration is just as typical for sodium cations as it is for chlorine; therefore, Na⁺ is a typical sign of the evaporation stage. Magnesium is rarely the first predominant cation due to the desire for the formation of secondary minerals (magnesium silicates, dolomites, etc.) and sorption barriers. In addition, magnesium is a positively hydrating ion with a high hydration energy. In the result, it greatly increases the structural pressure of the solution, and it is difficult to maintain it in significant quantities at a depth in the dissolved state. Therefore, like a sulfate ion, magnesium can be a sign of a transitional subtype of the evaporation stage, although lithogenic and others are more characteristic of it.

The migration of bicarbonate (and carbonate) and calcium ions has much in common - they are predominant in natural water with a mineralization of about 0.5 g/l, and their value decreases with increasing mineralization, which makes it possible to consider them as signs of an atmogenic stage of the formation infiltration cycle groundwater.

Nitrogen compounds (NH_4^+ , NO_3^- , NO_2^-) are known enter the solution mainly due to microbiological processes and human activities. Ammonium ion is formed during the decomposition of the protein of animals and plant organisms under the influence of ammonification bacteria, as a result of which ammonium ion enters the solution, but this ion is unstable. In the presence of free oxygen, under the influence of bacteria, nitrification ammonium passes first to nitrites, and then to nitrates. A large number of nitrate ions is found in the areas of development of nitrate deposits, as well as in the groundwater water of those areas where soils are intensively fertilized with nitrogenous substances.

Since nitrogen compounds are formed in some cases due to the decomposition of protein of various wastes (humans and animals), and the latter are a favorable environment for the development of pathogens, nitrogen compounds serve as indirect indicators of pollution of natural water. In this case, the NH_4^+ and NO_2^- ions indicate fresh pollution, and the NO_3^- ion – the final product of nitrogen oxidation – speaks of

the "old" water pollution. Thus, nitrogenous compounds are the most prominent representatives of the biogenic stage.

Very often, in the definitions of the chemical composition of groundwater, iron, aluminum, silicic acid, and oxidizability are found. Iron enters the solution with oxidation (chemical, biochemical and electrochemical) of sulfide ores containing iron, and weathering of various ferromagnets and ferrosilicates under the influence of CO_2 and water. Iron migrates in natural water in ionic form, molecular and colloidal. Therefore, iron can be a sign of lithogenic and biogenic stages.

Silicic acid is very widespread in the earth's crust; however, due to the low solubility of SiO_2 , the silicon content in natural water is usually very small. The source of SiO_2 in natural water is quartz and silicates. In slightly alkaline and neutral water, undissociated silicic acid is present. Only in highly alkaline water does silicic acid migrate in ionic form. Therefore, in soda lakes, soda water of oil fields, etc., its amount can reach hundreds of mg/l. The solubility of silicic acid increases with increasing temperature. With water mineralization of less than 0.1 g/l, silicic acid has the largest relative role.

Thus, when interpreting the components, silicic acid can indicate either soda salinization or an elevated temperature of groundwater (if abnormal values of a component containing silicic acid appear, this may be the result of feeding groundwater with "hot" groundwater), or the biogenic stage of the formation of a chemical groundwater composition [99] and others.

The value of oxidizability characterizes the total content of ammonium, nitrous and nitric acids, hydrogen sulfide, and other indicators of the presence of decomposed industrial and household waste in water. This value is measured by the amount of oxygen required to oxidize all the organic matter contained in the water. The oxidation of natural water is measured from the first units of mg/l O_2 to the first hundreds. The highest amounts (hundreds of mg/l O_2) are characteristic of groundwater in oil fields. Increased oxidation values in ground and surface water (tens of mg/l O_2) indicate their pollution by sewage or nutrition due to swamps. Thus, the amount of oxidizability in the components always indicates a biogenic stage.

Aluminum enters natural water during the weathering (under the influence of CO_2 and water) of various silicates. The low pH of precipitation of aluminum hydroxide (4.1 - 4.2) determines its weak water migration in ionic and molecular forms. Its contents usually do not exceed fractions of mg/l. Migrates somewhat better in colloidal form. Elevated amounts of aluminum (up to 1 g/l or more) are known in the acidic water of areas of young volcanism and oxidation zones of sulfide ores. Therefore, in interpreting the components, aluminum most often will show the weathering process, which is possible only if the atmogenic stage of the formation of the chemical composition of groundwater, etc.

The study of microcomponents in water is of interest both theoretically and for solving many practical problems. During the dominance of juvenile theory, the presence of microcomponents was considered a sign confirming the connection of water with magma chambers; however, modern studies show that salts of marine origin and processes occurring in the weathering crust play a major role in the enrichment of groundwater with microcomponents. The greatest variety of microcomponents is found in water associated with the weathering crust of granites.

Among the factors that prevent the accumulation and migration of microcomponents in the aquatic environment are OH^2 , $CO_3^{2^2}$ anions present in the water (metal cations with these anions form poorly soluble compounds), as well as clay adsorption and their extraction from aqueous solutions by living organisms. Clay materials, iron hydroxide (especially for manganese, nickel, cobalt) and organic substances of varying degrees of dispersion possess the highest adsorption capacity. Thus, the presence of microcomponents in the component record indicates, first, the lithogenic and partially biogenic stage of the formation of the chemical composition of groundwater.

Of course, this information is not enough for a complete interpretation of the components identified in the result of the processing of hydrogeochemical data by component analysis. It is necessary, among other things, to analyze a set of features, look for common properties common to all the features of this set, analyze the distribution of component values by sampling points (inverse component problem), and only ultimately we can put forward a hypothesis explaining a particular set of features and consider complete statistical model of this hydrogeochemical environment.

If there are heterogeneous characters (for example, types of vegetation, soil composition, etc.), then a similar review of the properties of each feature under study will be needed for each set of them.

3.3 Assessment of the hydrogeochemical situation in Alga region based on component analysis

For 1988 and 2005 yy. To test the previously formed hypotheses about the ways of groundwater pollution and changing the hydro-geochemical situation, six samples of data on the chemical composition of groundwater were processed by component analysis. In order to identify the genetic relationships between the original characteristics, i.e. in this case, the ability of component analysis to act as a tool for testing hypotheses was used.

The data for the second quarter of 1988 (Task 1) turned out to be, on the one hand, the most representative, and on the other, this quarter is intermediate between the flood and low water. Therefore, in this quarter, the maximum number of processes forming the hydro chemical situation manifests itself, therefore the solution this task is considered in detail.

In *task 1*, the data for July 1988 are presented for 76 wells located in the Ilek river valley. These data are taken from the Report of Kazakh Research Institute of Mineral Raw Materials [35, p.24]. They were characterized by a set of 13 signs: the depth of the groundwater level (DGL), *pH*, $Na^+ + K^+$, Ca^{2+} , Mg^{2+} , *Fe*, Cl^- , SO_4^{2-} , HCO_3^- , CO_3^{2-} , NO_3^- , NH_4^+ and *B*. The distinguished seven Main Components (MC) describe 95.13% of the total dispersion of the system:

MC1: +[Mg^{2+} , B, SO_4^{2-} , $Na^+ + K^+$, Cl^- , Ca^{2+} , NH_4^+ , Fe], -[pH];

$$\begin{split} &\text{MC2:} + [NH_4^+, CO_3^{2^-}, HCO_3^-, Fe], - [Cl^-, B]; \\ &\text{MC3:} + [pH, CO_3^{2^-}, Ca^{2^+}], - [Fe, DGL]; \\ &\text{MC4:} + [Fe], - [NO_3^-, HCO_3^-, Ca^{2^+}]; \\ &\text{MC5:} + [DGL, HCO_3^-, Na^+ + K^+, Cl^-], - [Fe, SO_4^{2^-}, NO_3^-, Ca^{2^+}]; \\ &\text{MC6:} + [NO_3^-, Fe, DGL, pH], - [HCO_3^-]; \\ &\text{MC7:} + [ca^{2^+}, DGL, SO_4^{2^-}], - [Na^+ + K^+, Cl^-]. \end{split}$$

As is known, in arid conditions with significant evaporation intensity from the surface of groundwater, the evaporative stage of formation of the chemical composition of groundwater prevails, during which groundwater salinity increases and their chemical composition changes - from calcium carbonate and sodium bicarbonate to sodium chloride with all transitional subtypes [89, p.48].

Type MC1 characterizes the transition subtype $(Mg^{2+} \text{ and } SO_4^{2-} \text{ had loads}$ greater than Ca^{2+} , Cl^- , $Na^+ + K^+$) metamorphization of the chemical composition of groundwater with the participation of the biogenic stage (presence of NH_4^+ ions and *Fe*). The presence of NH_4^+ indicates a similar source of pollution, a negative load on the *pH* indicates "acidic" water, which is typical for industrial water, so a large positive load on *B* should be considered more man-made than lithogenic. Therefore, we can assume that in our case MC1 characterizes the transit of acidic industrial water from the initial stage of the biogenic stage.

The distribution of the values of this component over the sampling points (the second main result, it is often called the solution of the inverse problem of component analysis) confirms this interpretation - large positive loads are confined to the old sludge storage (MC1 values greater than 1 in the wells NoNo 1124, 1126, 1191, 1349, 1350). The largest positive value (+6.757) is in well No1297. It is characterizing the new sludge storage, i.e. in 1988 (the stage of its filling) the intensity of anthropogenic transfer (removal) of acidic industrial water from it is more than 5 times higher than the intensity of this process in the old sludge storage (in Figures 7 and 8).

If additional materials are involved in the MC1 interpretation process, we obtain a more detailed and evidence-based interpretation of both the process reflected by the MC1 and the distribution over the area of intensity of manifestation of this process. Thus, the drawing of the surface contour lines on a topographic map clearly fixes the direction of flow from the well №1297 in the southeast direction, that is, towards the Suaksu stream and the Ilek river. Consequently, both the creek and Ilek are drains, and therefore, the wedging out of groundwater into the creek can only lead to an accelerated flow of pollution by surface runoff to the Ilek river. However, in no way to wells №1353 and 1598, whose location zone in 2005 belongs to a separate source of pollution with not established causes of occurrence.

Thus, it can be noted that the results of task 1 only based on partial interpretation of MC1 with the involvement of additional materials confirmed the hypothesis of the presence of a stream directed towards the stream.



1 - areas - a) bedrock outcrops; b) sludge storages; 2 - well and its number; areas of accumulation of boron - 3 - transit and biogenic; 4 - exchange and biogenic

Figure 7 – The boron pollution schema	tic
map of groundwater of the Alga and	L
Bestamak areas	

Figure 8 – The boron pollution schematic map of groundwater in Aktobe area

Along the regional groundwater flow, the values of the components also decrease. It is remaining positive to about well N_{2} 1573 between wells $N_{2}N_{2}$ 1382 and 1381. This suggests that the influence of technogenic water in the Alga area practically ends before the right and left tributaries flow into the Ilek river, confirming both the boundary of the halo of pollution in 1988 and the main reason for the decrease in the concentration of polluting elements is soil absorption, it is gradually washed away by snow-melted water.

All other sites are characterized by negative values of the components, emphasizing a significant reduction in the process of transit of acidic industrial water by changing its direction in areas of increasing *pH*. Now, against the background of negative values, the components in the wells NoNo 27 and 1420 are abnormal components (water intakes of Aktobe).

Consequently, the substantive interpretation of MC1 also showed that the component analysis confirmed not only the hypotheses about the ways of boron entry into groundwater and the assessment of reservoirs as long-term permanent sources of boron pollution in the hydrosphere of the region. Also allowed to identify the boundary

of aloe of boron contamination of groundwater formed by filtering acidic industrial wastewater, and violation of migration processes in the area of water wells.

MC2 is also boron containing, and it is combined with a negative load with Cl^- -a purely transit element, and the biogenic traits combined with positive loads in this component.

The largest negative value of MC2 falls on well $N_{2}1297$ (-2.322) near the new sludge storage. At the same time, in the wells located near the old sludge storage, the values of this component are positive, i.e. there is active microbiological precipitation of boron. Consequently, a significant negative value of MC2 in well $N_{2}1297$ showed that near the new sludge storage in 1988 there was practically no corresponding microbiological environment. The largest positive value of MC 2 falls on well $N_{2}1378$, where some additional source of pollution is noted.

So, MC2 is actually an addition to MC1, noting the role of the biogenic stage of boron deposition, which is weakly manifested in MC1.

The remaining components do not contain a sign of boron; they characterize different shades of the processes that form the conditions for the migration of elements of the chemical composition of groundwater; therefore, we will not consider them.

We only note that MC3 with positive loads combined signs of pH, CO_3^{2-} and $_{Ca^{2+}}$, with negative loads, *Fe*, *DGL*, i.e. component characterizes the usual for migration processes change in their chemical composition, expressed in the binding of calcium through the formation of insoluble carbonates in areas of shallow groundwater level (negative load on *DGL*) with the presence of biogenic processes (*Fe*).

As noted [20, p.16], iron refers to the trace elements involved in the process of photosynthesis. Its deficiency or excess in soil and groundwater adversely affects the conditions of growth and development of plants. It is established that in the groundwater, located close to the surface of the earth, ferrous iron is greater than in the water of the lower horizons, due to the large amount of organic matter in the upper soil layers, increasing the solubility of iron compounds and low acidity.

Positive values of the components existed throughout the study area, with the exception of the wells of the Aktobe area, where among the small negative values are wells $N \otimes N \otimes 5$, 1057 and 1420, where metamorphization processes — precipitation of insoluble calcium compounds — are more active. The presence of microbiological processes (negative MC3 values) for water wells is possible only if these wells pull up river water passing through the layer of activated silt.

From the standpoint of hypothesis testing, MC3 gave indirect confirmation of the hypothesis about the cause of boron occurrence in the working water wells.

Task 2. For study, the effect of flood on the pollution of groundwater with boron was solved task 2. It presents data on 71 wells, characterized, as before, by the 13th signs (Appendix 2).

As a result of data processing, eight main components were obtained describing 96.2% of the total variance of the system:

MC1: +[
$$Mg^{2+}$$
, B , SO_4^{2-} , Cl^- , $Na^+ + K^+$, Fe , Ca^{2+}], -[pH];
MC2: +[pH , CO_3^{2-}], -[HCO_3^- , NH_4^+];

MC3: +[DGL, NH_4^+ , CO_3^{2-} , Fe, cl^-], -[ca^{2+} , pH, NO_3^-]; MC4: +[NO_3^- , VB]; MC5: +[CO_3^{2-} , HCO_3^- , pH, NH_4^+ , $Na^+ + K^+$], -[DGL, Fe]; MC6: +[DGL, pH, cl^- , $Na^+ + K^+$, HCO_3^-], -[Fe, CO_3^{2-} , NO_3^-]; MC7: +[$Na^+ + K^+$, cl^- , Fe], -[DGL, ca^{2+} , SO_4^{2-} , CO_3^{2-} , Mg^{2+}]; MC8: +[B, pH, Fe], -[ca^{2+} , Cl^- , $Na^+ + K^+$].

The first main component differs from the similar one in the July task only by reducing the load on Ca^{2+} and the absence NH_4^+ , i.e. the flood reduces the influence of the activity of "fresh" nutrient pollution; otherwise, the order and interpretation of the components are the same.

As in July, positive values mainly fall on the Alga area, and the maximum value falls on the well N_{0} 1297 (+6.636), which characterizes the new sludge storage, followed by the wells $N_{0}N_{0}$ 1350 (1.067), 1126 (2.138) and 1124 (1.624) showing the spread of contamination from an old sludge storage. Positive values in wells $N_{0}N_{0}$ 17, 1301, located above the old sludge storage, reflect the influence of spills from it. The contamination was traced to well $N_{0}1382$, then the component values downstream change sign. Again, positive values were noted only for operating wells of the Aktobe water intake.

Another boron-containing component is the eighth, characterizing boron, which entered the groundwater mainly through microbiological processes (Fe). There is such a boron on the Alga, Bestamak (wells №№1187, 1189, 1220, and 1221) and Aktobe areas, and on water intake wells. This component characterizes the biogenic deposition of boron in shallow groundwater, like MC2 in the task for July, but the role of this process is noticeably weaker than in task 1.

Thus, the impact of the flood has affected the further weakening of the biogenic stage of the metamorphization of the transit of acidic industrial water, as well as a significant decrease in the role of biogenic boron deposition with increasing pH.

Task 3 presents data for the low-flow period (September 1988) for 75 wells with the same set of features. The distinguished 7 main components describe 95.64% of the total dispersion of the system:

MC1: +[B,
$$Mg^{2^+}$$
, $SO_4^{2^-}$, Ca^{2^+} , $Na^+ + K^+$, Cl^- , HCO_3^-];
MC2: +[Fe, NH_4^+ , $CO_3^{2^-}$], -[pH];
MC3: +[DGL, Cl^- , HCO₃⁻], -[$CO_3^{2^-}$, Ca^{2^+} , pH];
MC4: +[$CO_3^{2^-}$, $Na^+ + K^+$, DGL, pH], -[NO_3^- , $SO_4^{2^-}$];
MC5: +[NO_3^- , DGL, $CO_3^{2^-}$, pH];
MC6: +[Cl^- , $Na^+ + K^+$], -[DGL, Mg^{2^+} , pH, $SO_4^{2^-}$, ca^{2^+}];
MC7: +[HCO_3^- , pH, NH_4^+ , B, Fe], -[DGL, Mg^{2^+} , $Na^+ + K^+$, Cl^- , Ca^{2^+}].
In the task 3, MC1 characterizes the transition subtype (Mg^{2^+} and $SO_4^{2^-}$ have

loads more than Ca^{2+} , $Na^+ + K^+$, Cl^- , HCO_3^-) of metamorphization in the process

of migration of polluted groundwater metamorphization (the boron *B* has the greatest load). The biogenic stage is separated into a separate second component. In addition, although the acidity (pH) is not included in the first main component, it is present in II and III with a minus sign, and in all other main components - with a plus sign. Boron-containing components are MC1 and MC7 (*B* in all components with a positive load). As in the previous tasks, the highest MC1 values fall on the Alga area with the maximum value (+7,000) of the new sludge storage, and the increased values mark the area of influence of the old sludge storage. Industrial boron is absorbed within the Alga area, then the MC1 values become negative, and positive anomalies appear in wells characterized by increased salinity of groundwater. The MC7 characterizes "biogenic" boron *B*, which is in "antiphase" with $Na^+ + K^+$ and Cl^- , i.e. this component describes the processes in shallow groundwater.

So, low water increases the pollution of groundwater with industrial effluents and weakens the effect of biogenic sedimentation compared with the July task.

In task 4, data were processed from 38 wells of background monitoring with the same set of features, and the feature CO_3^{2-} was automatically excluded from the initial analysis of the data as a feature having zero dispersion.

As a result of processing, eight main components were distinguished describing 95.38% of the total dispersion of a system of 38 wells, characterized by 12 signs:

MC1: +[Mg^{2+} , Cl^- , Ca^{2+} , $Na^+ + K^+$, Fe, NO_3^- , SO_4^{2-} , B]; MC2: +[SO_4^{2-} , NO_3^- , Ca^{2+} , pH, B], -[Fe, $Na^+ + K^+$, VB]; MC3: +[HCO_3^- , Ca^{2+}], -[pH, NH_4^+ , B, DGL]; MC4: +[NH_4^+ , B], -[DGL, NO_3^- , SO_4^{2-}]; MC5: +[B], -[NH_4^+ , NO_3^-]; MC6: +[B, NH_4^+ , SO_4^{2-} , NO_3^-] -[pH, Ca^{2+}]; MC7: +[NO_3^-], -[SO_4^{2-} , VB]; MC8: +[Ca^{2+} , DGL, B], -[SO_4^{2-} , pH, Mg^{2+} , HCO_3^- , Fe].

As can be seen from the records of the type of MC, B is found with small loads in almost all components. The maximum load (0.779) is accounted for by MC5, which gives a contribution of only 5.5% to the total dispersion. Then, the contribution to the dispersion of boron is followed by MC3 with a negative load (-0.271), MC6 has a positive load of 0.363, and the load in the first component (0.254) is significantly less than the loads for other signs.

Consequently, when characterizing the territory in which boron has concentrations below the MAC, the component view clearly records the change in its role in the formation of the hydro-geochemical environment of the background area — it moved from the first places in the "transit" component to the latter, and the main process in which boron participates - its biogenic sedimentation. In general, the interpretation of all components has undergone small changes, reflecting the absence of man-made water inflows, the increasing role of microbiological processes - their various shades characterize literally all MCs, and the role of NO_3^- has increased

significantly, i.e. organic oxidation processes are actively going on at this site.

As for *B*, here it is divided into *B* migration (transit) - MC1 - and *B*, associated with biological (MC3, MC4, MC5, MC6) and exchange processes (MC8). Analysis of the results of the inverse component task again showed that *B* comes into the water wells associated with microbiological processes, which is possible only by pulling in river water through a layer of activated sludge, which is undergoing active organic processing).

Summarizing the results of the tasks 1-4 interpretation, we can see that almost the entire industrial boron is absorbed by the soil grounds within the Alga area, the remaining quantities migrate with the underground stream, and this migration is accompanied by microbiological precipitation.

For wells in the Aktobe area (figure 8), within which all water intakes are located, small values of nutrient and exchange boron are noted, and the values of the boroncontaining components indicate a tendency to increase negative processes. On the part of the wells of the Bestamak and Ilek areas, there is boron associated with the filtration of groundwater backed by the reservoir.

Task 5 was solved to study the dynamics of changes in the hydro-geochemical state of the Ilek river valley on the basis of component analysis processing of data for the winter period of 1982. By this time, the regime network was still very rare, so task 5 processed data from 21 wells, each of which had groundwater characterized by a set of 11 features (there are no signs of depth groundwater level (DGL) and CO_3^{2-} . As a result of the treatment, seven MC were emerged, which describing 97.47% of the total dispersion of the system:

MC1: +[
$$SO_4^{2-}$$
, Mg^{2+} , Ca^{2+} , B , Cl^- , $Na^+ + K^+$, HCO_3^- , NH_4^+], -[pH];
MC2: +[NH_4^+ , Fe , Ca^{2+}], -[pH , HCO_3^- , B , Mg^{2+}];
MC3: +[NO_3^- , NH_4^+ , $Na^+ + K^+$], -[Fe , B];
MC4: +[Fe , Cl^- , $Na^+ + K^+$, pH , NO_3^-], -[HCO_3^- , NH_4^+];
MC5: +[NO_3^- , Fe , B , SO_4^{2-} , Ca^{2+} , Mg^{2+}], -[$Na^+ + K^+$, Cl^- , pH];
MC6: +[HCO_3^- , Fe , NO_3^- , Cl^-], -[pH , Mg^{2+} , B , SO_4^{2-}];
MC7: +[NH_4^+ , pH , HCO_3^- , Fe].

Comparison with components in tasks 1-4 through 1988 is made difficult by the different representativeness of wells, however, the general picture is similar. Although the boron element (B) sign has got into a large number of components, the same processes of migration, exchange with soil grounds (MC1, MC2, and MC6) and microbiological sedimentation (MC3 and MC5) describe it.

MC values showed that large positive loads of MC1 and negative values of MC2 emit the old sludge storage and MC6, that is, here in 1982, absorption processes of B into soil-grounds prevailed. The uneven testing network does not allow one to trace the boundary of the influence of these processes, so the change of signs for the values of boron-containing components had to be assessed by linear interpolation between wells with different signs in the components: wells №N21351 and 1187, 1350 and 1189.

This interpolation gave a distance corresponding approximately to well № 1574,

i.e. a halo of pollution was formed by 1982 within the same boundaries as in 1988. The intensity of microbiological processes increased in the near-well wells and again in 1982 in the wells The Aktobe region showed weak anomalies in wells $N_{\mathbb{P}}N_{\mathbb{P}}1306$ and 1307, and these anomalies were noted in both exchange and microbiological processes. The remaining wells ($N_{\mathbb{P}}N_{\mathbb{P}}$ 5, 27, and 1420) were simply not observed in 1982; therefore, they were not noted in the task, although, as we see, the influence of depression craters formed during pumping by water intakes was also noted for a small number of wells.

Thus, the component analysis showed high sensitivity in the study of the hydrogeochemical situation of the territory, confirmed the hypotheses put forward earlier by boron contamination of water wells, helped to clarify the nature of boron migration from sludge storages.

In tasks 6, a similar data processing was performed in order to assess the dynamics of the identified boron migration processes after the termination of activity Alga Chemical Factory in 1997. Unfortunately, due to problems with the availability of factual material, this assessment was carried out only according to 2003 data.

These data are taken from the report of the state monitoring of groundwater of the Aktobe region, carried out with different goals for different sites, so the set of the studied biogenic parameters for the Alga territory turned out to be (without signs of a nitrate series). In addition, the sampling frequency varies over a wide range; therefore, from the available data set, a matrix of initial data has been formed that are very conditionally allocated for a warm period.

For a set of wells, approximately corresponding to the task for 1988, 77 wells were selected, characterized by 11 features: Na^++K^+ ; Ca^{2+} ; Mg^{2+} : Fe^{3+} ; Fe^{2+} ; Cl^- ; SO^{2-}_4 ; HCO^-_3 ; pH; Mineralization; B.

In the result of data processing, the following matrix of loads on the main components was obtained (table 9), in which the color indicates statistically insignificant loads in accordance with the percentage points of the sample correlation coefficient.

Features	MC1	MC2	MC3	MC4	MC5	MC6	MC7
$Na^+ + K^+$	0,8222	-0,0466	-0,4947	-0,2637	-0,0153	-0,0262	0,02315
Ca^{2+}	0,728	0,3219	0,3993	0,04729	-0,3225	-0,1244	0,2872
Mg^{2+}	0,864	0,4017	0,159	-0,0057	-0,0342	0,09213	-0,1844
Fe^{3+}	0,3028	-0,7246	-0,0704	0,5365	0,2042	0,03757	0,1907
Fe^{2+}	0,1943	-0,6033	0,438	-0,433	0,4413	0,1451	0,04201
Cl^-	0,8619	-0,2238	-0,3771	-0,2213	0,02802	-0,054	0,0654
SO^{2-4}	0,9103	0,2175	0,306	-0,0039	-0,0506	0,122	-0,0486
$(HCO_3)^-$	0,2052	0,7244	0,02976	0,1144	0,5651	-0,3158	0,00425
рН	-0,2359	0,8228	-0,219	0,04727	0,1814	0,3916	0,1746
Mineralization	0,9824	-0,0418	-0,0881	-0,1069	0,02959	0,00203	0,0374
В	0,8264	-0,1516	-0,012	0,4792	0,05941	0,1013	-0,1734

Table 9 – Component load matrix for task 6 for the warm period of 2003

From table 13, the next record kind of principal components was received:

MC1 (49%): +[*Min*, SO^{2-4} , Mg^{2+} , Cl^- , B, $(Na^+ + K^+)$, Ca^{2+} , Fe^{3+}] MC2 (23%): +[pH, $(HCO_3)^-$, Mg^{2+} , Ca^{2+}], - [Fe^{3+} , Fe^{2+}] MC3 (8%): +[Fe^{2+} , Ca^{2+} , SO_4], - [$(Na^+ + K^+)$, Cl^-] MC4 (8%): + [Fe^{3+} , B], - [Fe^{2+} , $(Na^+ + K^+)$] MC5 (6%): + [HCO^{-3} , Fe^{2+}], - [Ca^{2+}] MC6 (3%) + [pH], - [$(HCO_3)^-$] MC7 (2%) + [Ca^{2+}].

As in the 1988 data problem, MC1 characterizes the transition subtype (Mg^{2+} and SO_4^{2-} have loads greater than Ca^{2+} , Cl^- , $Na^+ + K^+$) with the participation of the biogenic stage (presence of Fe^{3+} ions). The presence in the first place of the sign *Min* (mineralization) indicates the predominance of boron in more saline water. In addition, since in the Ilek river valley in areas without noticeable anthropogenic impact is dominated by fresh water with a salinity of 0.4-0.7 g/dm³, such an arrangement of parameters in MC1 indicates the presence of industrial water, and therefore a large positive load on *B* should still be considered more man-made than lithogenic.

Therefore, we can assume that in 2003, MC1 characterizes the transit of industrial water. In contrast to the tasks of 1988, the absence of the pH attribute in this component reflects a general change in the hydro-geochemical environment — a decrease in the role of acidity.

The increased values of this component are confined mainly to the old sludge storage, although again its maximum value (5.578), as in the tasks for 1988, falls on the area near the new sludge storage (well N 1298), that is, more high boron concentrations.

MC2, in addition to the first, also reflects some increase in alkalinity of groundwater (parallel change in *pH*, $(HCO_3)^-$, Mg^{2+} and Ca^{2+}). This and MC3 do not contain boron, they characterize the territorial distribution of water of varying degrees of salinity. Acidic water characterizes MC6, which reflects only 3% of the total dispersion of traits, which also emphasizes the decreasing role of traditionally acidic industrial water.

The biogenic boron (MC4 - boron in parallel with Fe^{3+}) is distributed in more fresh water - here ($Na^+ + K^+$) with a minus sign. The maximum amount accumulated in well No1353 (5.866) is the zone of the source of pollution near the old sludge storage, in which groundwater flows from the territory of the new sludge storage and emergency leakage of the pipeline to the new sludge storage are encountered (table 10).

Table 10 - A sample of observation wells with elevated values of MC1 and MC4, characterizing the transit and biogenic migration routes of boron element

Territorial hinding	Observation well	Elevated principal components (green color)				
Territorial bilding	Observation wen					
		MCI	MC2	MC3	MC4	
1	2	3	4	5	6	
Ilek left-bank water intake	1062a	-0,442	-1,009	-0,225	2,488	
New sludge storage	1298	5,578	1,414	-2,757	-1,888	

Continuation of the table 10

1	2	3	4	5	6
Old sludge storage	1353	2,510	-4,639	-2,210	5,866
Ilek right-bank water intake	1420	1,374	-1,460	-4,110	-3,026
	1585	1,803	1,372	1,199	1,164
	1586	2,094	2,08	1,097	1,240
	1587	2,084	2,084	1,170	1,288
	1588	1,165	-0,322	1,526	0,410
	1589	1,223	-0,525	1,557	0,381
	1593	1,163	0,932	1,744	0,057
	1594	1,128	0,903	1,618	0,051
	1598	1,567	-5,244	3,654	-3,792
	1601	1,526	0,313	1,979	-0,315

In contrast to 1988, the conditions for the biogenic migration of boron formed next to the sludge storage (well No1298). Large (by module) negative MC4 value in well No1420 (Ilek right-bank water intake) demonstrates the effect of reducing the concentration of boron on the right bank, where there are no visible sources of groundwater pollution. The distribution of boron to the right bank can be explained by the influence of the "wall in the ground", when the increase in the backwater formed the conditions for pushing polluted groundwater to the right bank and continued until the beginning of the bypass filtration.

An increase in biogenic boron in the Ilek left-bank water intake demonstrates the effect of forced washing of the boron as a result of the formation of a depression funnel during the operation of the water intake. This effect has already been noted in the 1988 problem.

Thus, a comparison of the results of the processing of monitoring data for 1988 and 2003. a multidimensional statistical model of component composition showed that although the processes of boron migration in groundwater, identified according to 1988 data, continue to operate, the hydro-geochemical situation in the Alga region has noticeably changed towards a decrease in boron migration from acidic industrial water. The redistribution of high concentrations of boron transported in different ways reflects the fact that the soil washing ground and sludge accumulators with snowmelt water are far from being completed on the territory of the pollution front.

To achieve the goal of in this task, assess the dynamics of the hydro-geochemical situation in the Alga region (Aktobe, Kazakhstan) and test the existing hypotheses about groundwater pollution processes in the Ilek river valley, by processing the data of hydrochemical monitoring by the multidimensional statistics method - component analysis - solved 6 problems. The main results of their solution are reduced to the following conclusions.

Results of task 1: only on the basis of partial interpretation of MC1 with the use of additional materials, were confirmed the hypothesis of the presence of a stream directed towards the Suaksu stream, refuted the hypothesis on the formation of a geochemical barrier. Due to the low filtration properties of rocks and gave a real explanation of the reasons for the formation of the second source of pollution.

In addition, the component analysis confirmed not only the hypotheses about the ways of boron entry into groundwater and the assessment of reservoirs as long-term permanent sources of boron pollution in the hydrosphere of the region. Also made it possible to identify the boundary of a halo of boron pollution caused by filtration of acidic industrial effluents and a violation of migration processes water well zone.

The MC2 is actually an addition to MC1, noting the role of the biogenic stage of boron deposition, which is weakly manifested in MC1. From the standpoint of hypothesis testing, MC2 gave a direct, and MC3 indirect (boron in this component does not have a statistically significant load) confirming the hypothesis of the occurrence of boron in the working water wells as a result of pulling the river water into the depression funnel of the river water leaching boron deposited by silts.

The task 2 was solved to assess the impact of the flood on the nature of the hydrogeochemical environment. This effect affected the weakening of the biogenic stage of the metamorphization of the transit of acidic industrial water and a significant reduction in the role of biogenic boron precipitation with increasing pH.

Task 3 showed that low-flow water increases pollution of groundwater with industrial effluents and weakens the effect of nutrient deposition compared with the July task.

Task 4 was solved to analyze hydro-geochemical processes in the background area. The component view clearly records the change in the role of boron in the formation of the hydro-geochemical environment of the background area. It moved from the first places in the "transit" component to the last, and the main process in which boron participates - its biogenic sedimentation. In general, the interpretation of all components has undergone small changes, reflecting the absence of man-made water inflows, the increasing role of microbiological processes - their various shades characterize literally all MCs, and the role of NO_3^- has increased significantly, i.e. organic oxidation processes are actively going on at this site.

As for boron element *B*, here it is divided into *B* migration (transit) - MC1 - and *B*, associated with biological (MC3, MC4, MC5, MC6) and exchange processes (MC8). Analysis of the results of the inverse component task again showed that *B* comes into the water wells associated with microbiological processes, which is possible only by pulling in river water through a layer of activated sludge, which is undergoing active organic processing).

Summarizing the results of the interpretation of tasks 1-4, we see that almost the entire industrial boron is absorbed by the soil grounds within the Alga area, the remaining quantities migrate with the underground flow, and this migration is accompanied by microbiological precipitation. The most active filtering of pollution is observed in the area of influence of the new sludge storage, however, the boundary of its influence has spread to a much smaller distance than from the old one, although at the last new sludge inflows were stopped.

The results of the interpretation of the MC from task 5 (winter, 1982) showed that the overall picture of the processes forming the hydro-geochemical situation is similar to the picture in tasks 1-4 through 1988. Although feature B in the MC of task 5 fell into a large number of components, it is described by those the same processes of

migration, exchange with soil (MC1, MC2, MC6) and microbiological precipitation (MC3 and MC5). The area distribution of MC values showed that the old sludge storage is emitted with large positive loads of MC1 and negative values of MC2 and MC6, i.e. here in 1982, absorption processes of *B* dominated by soil grounds. A boundaries estimate of the pollution halo gave a distance corresponding to approximately well No1574, i.e. a halo of pollution was formed by 1982 within the same boundaries as in 1988. The intensity of microbiological processes increased in the near-well wells and again, as early as 1982, weak anomalies were observed in the Aktobe territory in wells NoNo1306 and 1307, and these anomalies were noted in both exchange and microbiological processes. The remaining wells (NoNo 5, 27, 1420) were simply not observed in 1982, therefore they were not noted in the task, although, as we see, the influence of depression craters formed during pumping by water intakes was also noted for a small number of wells.

Thus, the component analysis showed high sensitivity in the study of the hydrogeochemical situation of the territory, confirmed the hypotheses put forward earlier by boron contamination of water wells, helped to clarify the nature of boron migration from sludge storage.

Task 6. The interpretation of MC1 according to 2003 data still characterizes the transit of industrial water. Difference from tasks of 1988, the absence of the pH attribute in this component reflects the general change in the hydrogeochemical environment – reducing the role of acidity. While the elevated values of this component are confined mainly to the old sludge storage, although again its maximum value (5.578), as in the tasks in 1988, falls on the area near the new sludge storage (well N 1298), i.e. higher boron concentrations are still being filtered from the new sludge storage.

Biogenic boron (MC4) is still confined to shallow groundwater. The maximum amount is noted in well $N_{2}1353$ (5.866) is the zone of the source of pollution near the old sludge storage, in which groundwater flows from the territory of the new sludge storage and emergency leakage of the pipeline to the new sludge storage. In contrast to 1988, the conditions for the biogenic migration of boron formed near the sludge storage (well $N_{2}1298$).

Large (by module) negative MC4 value in the well №1420 (Ilek right-bank water intake) demonstrates the effect of reducing the concentration of boron on the right bank, where there are no visible sources of groundwater pollution. Boron propagation to the right bank is explained by the influence of the "wall in the ground", when the increase in the backwater formed the conditions for pushing polluted groundwater to the right bank and continued until the beginning of the bypass filtration. The effect of forced washing of boron as a result of the formation of a depression funnel during the operation of the Ilek left-bank water intake remains.

Thus, the goal of the work is fully realized – all the previously formed hypotheses on the ways of boron entry into groundwater were confirmed about the formation of a geochemical barrier. Component analysis demonstrated high sensitivity to changes in the hydro-geochemical environment both in the intra-annual and long-term context: in 2003, boron migration processes in groundwater, detected according to 1988 data, continue to operate, but the hydro-geochemical situation in the Alga area has significantly changed manifestations of boron migration with acidic industrial water. The redistribution of high concentrations of boron transported in different ways reflects the fact that the soil washing ground and sludge storage with snowmelt water are far from being completed on the territory of the pollution front [97, p.49; 100].

For 2011 y. To assess the synchronism in changes in various characteristics of groundwater composition, the principal component method was used. This method makes it possible to identify leading factors in their variability. That is, given the high consistency in the dynamics of the considered indicators for the territory, it can be argued that these changes are a response to global processes. The task of component analysis is to transform the initial characteristics into the main components, the dispersion of which is equal to the variance of the original series. For an adequate description of the initial series, it is considered sufficient that the number of main components whose total contribution to the total dispersion is more than 80%.

The component analysis algorithm consists in sequential extraction of components. For uniqueness of the solution in the method of principal components, the components should be ordered by decreasing proportion of the explained total variance of the source variables. The first component characterizes the largest share of variation of the source variables; the second component explains the largest proportion of variance, not explained by the first component, etc. Because of component analysis, the number of uncorrelated components obtained coincides with the number of source variables. Classical component analysis preserves the dimension of the space of variables.

Each extracted component has a characteristic called an eigenvalue. The eigenvalue shows the part of the variation of the source variables explained by the component. In component analysis, if a correlation matrix is used, each variable is standardized and its variance is 1. Therefore, if the number of source variables is k, then the total variance is k. Component analysis preserves the entire total variance; therefore, the sum of all eigenvalues is equal to the number of source variables.

Based on the obtained eigenvalues, a load matrix is calculated and an interpretation of the components is given.

Based on the final load matrix, individual values of the main components for each object of observation are calculated. The individual values of the main components on the objects are a linear combination of the source variables for each factor. In practice, components that satisfy the following conditions are used for interpretation and further analysis [101]:

- Their eigenvalues must be greater than 1 - this means that the component is more informative than the standardized variable;

- The component must have at least one load greater than the critical value - this means that the component is closely related to at least one source variable.

The components selected for further analysis are called the main components.

Of fundamental importance is the assessment of the relationship of the initial indicators with the highlighted main components. Such an assessment allows us to give an ecologically meaningful explanation of the main components.

For each chemical element in natural systems, stages of biogenic,

physicochemical, and mechanical migration are characteristic. The role of individual migration processes for different elements is not the same. For carbon, hydrogen and phosphorus, these are mainly biogenic processes, for sodium and chlorine, largely, hydrogeochemical processes, for calcium, iron, magnesium, silicon, aluminum, petrochemical or combined.

As is known, under arid conditions, at a significant rate of evaporation from the surface of groundwater, the evaporation stage of the formation of groundwater chemical composition predominates, during which groundwater mineralization increases and its chemical composition changes - from calcium and sodium bicarbonate through sodium sulfate to sodium chloride with all transition subtypes.

Experimental hypotheses were tested according to 2011 data for 28 wells located in the Ilek river valley (Appendix 2). Consider the preliminary results of statistical modeling of an expanded set of parameters of the macrocomponent composition of groundwater. The maximum set of parameters includes: pH, Na⁺ + K⁺, Ca²⁺, Mg²⁺, Cl⁻, SO_4^{2-} , HCO_3^{-} , NO_3^{-} and B. To reflect the nature of groundwater movement, signs included indicators indirectly reflecting these characteristics - absolute elevation of the earth's surface (AEES), groundwater level (h), highest level (HL), and lower groundwater level (LGL).

The 27 samples were included in the sample for the full set of parameters; this number is sufficient in accordance with the recommendations for organizing the sample for a multidimensional model. In accordance with these recommendations, the "length" of the sample should be at least twice its "width", i.e. for 13 signs we have 27 samples. Therefore, we have every reason to trust the results of a multidimensional statistical model (component analysis). The eight main components give more than 98% of the total dispersion of characters, the remaining five components in total give about 2%, so they can not be considered. According to the tables of percentage points of the sample correlation coefficient for 25 points at a 5% significance level, correlation coefficients that are large 0.323 will be significant, and for 30 points - 0.296 [102]. Linear interpolation for 27 points gives a value of 0.309. When only statistically significant loads are taken into account, the type of components can be represented as follows (table 11):

N⁰	Main components	Indicator
1.	MC1 (42%)	+ $[Mg^{2+}; SO_4^{2-}; Ca^{2+}; Na^+ + K^+; Cl^-; h; HL; LGL; AEES; B;$
		HCO ₃ ⁻]
2.	MC2 (25%)	+ [pH; Cl ⁻ ; B; AEES; Na ⁺ + K ⁺ ; NO ₃ ⁻], -[LGL; HL; h]
3.	MC3 (9%)	+ [NO ₃ ⁻ ; HCO ₃ ⁻], - [B]
4.	MC4 (7%)	$+ [NO_3^-] - [HCO_3^-; B]$
5.	MC5 (6%)	+ [AEES; pH], - [NO ₃ ⁻ ; B]
6.	MC6 (5%)	+ [B], - [Ca ²⁺ ; Mg ²⁺]
7.	MC7 (3%)	+ [pH], –[AEES]
8.	MC8 (1%)	- [Cl ⁻]

Table 11 – View of the main components for the cold period, 2011

The appearance of the components for the autumn-winter period of 2011 indicates that the water belong to the groundwater water of the infiltration-atmospheric genesis. The first main component clearly identified the evaporation stage of the formation of the chemical composition of groundwater. MC1 reflects an increase in boron content due to evaporation processes.

The second major component, in combination with positively charged B, released *pH*; *Cl⁻*; *B*; *AEES*; $Na^+ + K^+$; NO_3^- , the concentration of hydrogen ions and the genetic trait of well-processed organics. With a negative sign dynamic characteristics stood out: LGL; HL; h. The resulting distribution of loads indicates a process accompanied by an increase in the values of the first group of elements with a simultaneous decrease in the second in the region of positive values of the main components, or, conversely, in the region of negative values. With a decrease in groundwater levels, an atmogenic process of migration of boron and nutrient ion - NO_3^- occurs.

The third and fourth main components describe the exchange reaction of the absorbing complex with the participation of organics. MC4 also reflects surface contamination with boron. Recall briefly the specific features of the absorbing complex.

Colloids - a highly dispersed part of rocks - make up their "absorbing complex." In igneous and metamorphic rocks, colloids are found mainly in weathering crusts, in sedimentary deposits they are known throughout the section. Colloids are divides into two large groups: mineral and organic formations.

Usually, mineral colloids predominate in the rocks. They are represented mainly by secondary minerals having a crystalline structure, and amorphous substances. The main role belongs to clay minerals, which are aqueous silicates and aluminosilicates with layered and chain lattices. They form two- or three-layer aluminum-silicon-hydroxyl-oxygen packets, obeying the law of "closest packing". As a result, predominantly small cations ($A1^{3+}$, Fe^{3+} , Mg^{2+} , partially Li^+ , Ni^+ , etc.) are involved in the packets, which can fit in tetra- and octahedral voids without breaking the densest packing. The two-layer ones include simpler clay minerals - kaolinite, halloysite, etc. groups, the three-layer ones - complex, montmorillonite groups, hydromica, etc.

Clay minerals compose the main part of sedimentary clay rocks, weathering crusts, soils, form the finely dispersed basis of a number of clastic, and carbonate formations. Clay particles are slightly larger than typical colloids, but they are classified as colloids, because they fully possess their properties: they are characterized by a huge specific surface and carry a charge.

Organic colloids include a large number of different, mainly humic, compounds. The composition of humus includes humic acids, crepe and apocrenic acids (fulvic acids), humine and ulmin (humic coals), hematomelanic acid. Molecules of humic acids are not compact, but differ in the "spongy" structure with many micropores. This largely determines their sorption properties. The presence of humic acids as side radicals of carboxyl and phenolic groups determines their acidic nature, and in this regard, the ability to absorb cations [103].

Humus is widely distributed in soils and rocks. In soils, its content can reach 10-20% by weight. The main role in soil humus belongs to humic and fulvic acids. In sedimentary rocks, the total content of organic matter is different and depends on their

lithology. According to the sum of C_{org} (the amount of organic carbon as a percentage of the weight of the rock), sedimentary rocks form the following series: clay (0.9) - silty (0.45) - sandy (0.2) - carbonate (0.2) [104].

Calculations taking into account the prevalence of clays and the content of C_{org} in them have shown that approximately 75% of all C_{org} is contained in clays. Among organic compounds, humus often plays a major role: it makes up to 60% of the total mass of organic matter. Humus (like other organic compounds) is found in the form of inclusions in pores and fissures of rocks. In clays, it appears to be a "molecularly dispersed mixture sorbed by clay particles". Organic matter was also found in igneous rocks, but it has been studied very poorly here.

The fifth component marks with a positive load a sign of dynamics, and a hydrogen indicator. With negative load, B and NO_3^- stood out.

According to MC3, MC4 and MC5, the biogenic migration of boron clearly emerges. The indices involved in the formation of the sixth main component reflect the transitional subtype of the lithogenic stage. In the MC2 chain with a positive value, B was detected, which reflects a unique characteristic of technogenic migration.

The remaining components do not contain boron, and due to the low weight attributable to each of them, characterize the distribution of the individual components of the chemical composition of groundwater.

The eight main components for the spring-summer period account for 97% of the total variance of characters. Table 12 presents the type of PCA.

According to the data of table 12, the combination of indicators involved in the formation of the first main component measures 35% determine the total variance of the initial indicators. Since the formation of this component is dominated by indicators $Mg2^+$; SO_4^{2-} ; Cl^- ; Ca^{2+} ; HCO_3^- ; NO_3^- . This factor is determined as the evaporation stage of migration with the participation of lithogenic.

N⁰	Main	Indicator
	components	
1.	MC1 (35%)	+ $[Mg^{2+}; SO_4^{2-}; Cl^-; Ca^{2+}; HCO_3^-; NO_3^-], - [LGL; HL; h; Na^+ + K^+]$
2.	MC2 (23%)	+ [HL; h; LGL; Na ⁺ + K ⁺ ; SO ₄ ^{2–} ; HCO ₃ ⁻ ; Ca ²⁺ ; Mg ²⁺]
3.	MC3 (14%)	+ [AEES; pH; Cl ⁻], - [NO ₃ ⁻ ; HCO ₃ ⁻]
4.	MC4 (9%)	+ [B], - [AEES]
5.	MC5 (6%)	+ [B; AEES], - [pH]
6.	MC6 (5%)	+ $[Na^+ + K^+; HCO_3^-], - [Ca^{2+}]$
7.	MC7 (3%)	$-[Na^{+}+K^{+}]$
8.	MC8 (2%)	- [HCO ₃ ⁻]

Table 12 – View of the main components for the warm period, 2011

The indices involved in the formation of the second main component reflect the transitional subtype of the lithogenic stage by 23%. It should be noted that in MC1 and

MC2, the participation of boron in these processes was not revealed.

The chain of the third main component (MC3) with high loads AEES; pH; Cl⁻ characterizes the evaporation stage of migration processes.

The MC4 notes an increase in boron concentrations with a decrease in absolute groundwater level marks, i.e. with an increase in the depth of their occurrence, and MC5 shows that in areas of shallow occurrence of groundwater and in the presence of an alkaline environment, the amount of boron increases.

Indicators MC6, MC7 determined the maximum degree of evaporation processes, and the MC8 characterized of a purely atmogenic stage.

Contamination with natural salts is caused by natural hydrological factors: very low water discharge and high drainage properties of the channel during the low-water period.

Table 13 – The matrix of values of the main components for the autumn-winter period
of 2011

Observation well	MC1	MC2	MC3	MC4	MC5	MC6	MC7	MC8
5м	0,3906	0,0928	1,253	-2,238	-1,603	-0,2606	0,2365	-1,477
1306	-0,5481	-0,3693	0,03829	-0,7861	-0,8894	-0,5847	-0,5705	0,1755
19	-0,6274	-0,7275	-0,7461	0,1693	-1,368	-0,5693	-0,0418	-0,3418
153a	0,5055	-1,629	0,3336	0,1024	1,517	2,512	1,034	-0,0955
358	-0,3613	-0,1108	-0,259	1,227	-0,0184	-0,3323	1,626	-0,5707
501	-0,6162	-0,3685	-0,6455	0,6089	-0,3363	-0,6004	0,08553	-0,4271
501a	-0,4733	-0,4782	-0,5486	0,2274	-0,7401	-0,2039	-0,8933	-1,63
1062a	-0,234	-0,1871	1,669	-2,692	0,6371	0,4157	1,812	0,8448
1097	-0,6414	-0,2487	0,03808	0,7082	-0,8849	-0,0615	0,02709	-0,1859
1099	0,474	-1,751	-0,3835	1,025	0,4098	2,278	-0,1482	-2,038
1642	-0,7462	0,02778	-0,6898	0,642	0,4457	-0,9222	1,878	0,6356
4	0,07656	1,571	-1,288	1,047	1,065	0,1587	-0,1957	0,6693
6	-0,1979	0,982	0,06833	-0,0475	1,234	-0,1384	-0,4667	-0,2802
9	-0,1142	1,157	0,2836	0,00542	1,772	-0,3407	0,5205	0,2686
11	0,5696	1,832	3,293	2,45	-1,737	0,8269	0,2227	0,4205
16	0,7114	1,423	0,1935	-0,2159	1,377	-1,646	-0,1058	-2,986
17AB	-0,2712	0,5618	0,6257	-0,7513	0,9561	0,3682	-1,471	-0,3662
1126	1,757	2,388	-2,606	-1,23	-1,601	1,949	0,4136	0,4174
1127	-0,5457	0,01489	0,3825	-0,4475	0,8655	0,309	-2,831	0,9718
1178	-0,4604	-0,4322	-0,3782	0,2541	-0,403	-0,3453	0,445	0,5929
1179	-0,3699	-0,3627	-0,1701	-0,1555	-0,1183	-0,2578	0,948	0,6778
1180	-0,6381	-0,479	0,06522	-0,6491	-0,4594	-0,3177	-0,0831	0,4486
1181	-0,8057	-0,4683	-0,4932	0,1728	-0,9132	-0,6047	-0,8717	0,612
1286	0,2186	-0,4777	0,3001	0,03778	-0,1115	0,9558	-1,525	1,075
1420	-0,5361	-0,5907	-0,2397	-0,1195	-0,2826	-0,2647	0,2024	0,311
156a	4,167	-1,602	0,09512	0,3677	0,2089	-1,971	-0,3074	1,048

The analysis of statistical uniformity of the population was carried out on the basis of the matrix in table 13.



Figure 9 – Graph of the distribution of component values in space for the autumnwinter period

As can be seen from the figure, the set of values formed in one cloud with several deviation points. This cloud indicates a linear relationship between the processes of migration of chemical elements and signs of groundwater dynamics. The points of deviation are in the Alga water intake, which indicates the presence of increased boron contents as a result of its technogenic migration, it is by this criterion that the water intake works for technical water supply.

Observation well	MC1	MC2	MC3	MC4	MC5	MC6	MC7	MC8
1	2	3	4	5	6	7	8	9
5м	1,533	1,489	-3,07	-0,3109	-0,1592	1,806	1,02	-0,058
1306	0,148	-0,3386	-0,5708	0,01686	0,0951	-1,574	-1,895	0,1563
19	-0,4118	-0,4975	-0,4283	0,6907	-1,211	-0,7004	-0,9336	0,1194
153a	-1,44	0,9705	0,4286	0,08497	-0,3981	-0,8123	2,52	-1,04
358	-0,311	-0,2488	-0,5539	0,08177	-0,3884	-0,5053	0,06207	0,857
501	-0,4089	-0,5747	-0,1379	0,0623	-0,3374	-0,7049	-0,5197	0,03542
501a	-0,2455	-0,2753	-0,4706	-0,092	0,2635	-0,9793	-0,599	-0,4988
1062a	-0,3495	-0,773	0,01125	0,2376	-0,6733	-0,1519	-0,2886	0,2838
1097	0,3815	0,2335	-0,6149	0,02169	-0,4469	0,06931	-1,22	-2,706
1099	-1,3	1,188	0,1546	0,02518	0,242	-1,921	1,926	-0,9158
1642	-0,4697	-1,099	0,3341	0,4564	-1,496	0,4696	-0,1755	0,6984
4	0,8349	-0,346	1,561	-0,2703	-0,447	1,069	0,2772	0,09718
6	0,4935	-0,6521	1,096	-0,3669	-0,4844	1,524	0,1768	-0,6636
9	0,1705	-0,7189	0,226	-1,216	1,445	-0,2139	-0,3479	0,00983
11	0,4673	-0,4004	0,00594	-1,428	1,305	0,6628	0,9045	1,179
16	1,334	0,4209	0,5479	-1,05	1,677	-1,724	-0,3807	1,811
17AB	0,5882	-0,3639	0,6808	-1,458	1,371	0,3684	-0,3205	-2,879
1126	2,92	2,263	2,064	1,509	-1,155	-0,7449	-0,0665	0,1671
1127	-0,0095	-0,6524	0,2533	-0,9329	0,6325	0,4108	0,4375	0,6258

Table 14 – The matrix of values of the main components, 2011

Continuation of the table 14

1	2	3	4	5	6	7	8	9
1178	-0,2024	-0,1684	-0,9157	0,1414	-0,4107	-0,0959	0,2032	0,4434
1179	-0,2574	-0,2131	-0,6133	0,2618	-0,5728	-0,2531	-0,2984	-0,3799
1180	-0,2409	-0,5885	-0,479	0,2007	-0,4181	-0,4817	-0,7301	0,1253
1181	-0,1104	-0,9077	-0,0519	3,969	2,879	0,8998	0,3864	-0,1087
1286	-0,8895	-0,4343	0,7953	-0,2567	-0,4275	0,0797	1,456	0,8614
1420	0,5001	0,7411	-1,899	-0,0343	-0,2698	0,1889	0,3277	0,7433
156a	-2,61	3,069	0,8723	-0,2749	0,6917	1,777	-2,15	0,7789
1185	-0,1146	-1,123	0,7748	-0,0698	-1,307	1,537	0,2284	0,2561

Analysis of the statistical uniformity of the set of values of the main components for the spring-summer period (figure 10) was carried out on the basis of the data in table 14.



Figure 10 – Graph of the distribution of component values in space for the springsummer period of 2011

The graph of the distribution of component values in space for the spring-summer period of deviation points that occur in wells №1126, 5m, 156a, 1099. These wells cover the entire geographic location. It is worth noting that the anomaly is highlighted in the zone of the Aktobe reservoir.

Thus, the statistical processing of the results of chemical analyzes of groundwater in the territory of regime observations for 1988 and comparisons since 1982 showed that the technogenic factor makes an additional contribution to the natural lithogenic stage. The nature of which is described by the transit of acidic industrial water, accompanied by the absorption of polluting elements by soil and exchange reactions between groundwater and soil. The influence of fabricated water extends a little further than well №1381 on the Alga block.

Filtration conditions of contaminated industrial water differ for the old and new sludge collectors: although the aureole of pollution from the old sludge collector is greater than from the new, self-cleaning processes appeared in the latter – active microbiological deposition of boron took place. Near the new sludge collector, the corresponding microbiological medium was not formed.

Component analysis identifies three main processes in the spread of pollution of boron, filtered from sludge collectors: transit, deposition, and exchange with the active participation of nutrients. For all water wells, biogenic boron was detected, which indicates the pulling up of river water by these wells, which, passing through activated sludge, wash boron biologically deposited in the silts.

The hydrochemical situation in the region actually developed at the beginning of regime observations, since in 1982, the halo of pollution in the Alga site already corresponded to that in 1988, and in the Aktobe site, the anomalies of boron related to microbiological and metabolic processes were already recorded.

In tasks according to the data for 2003, as well as in the task according to the data for 1988, the first main component characterizes the transition subtype ($_{Mg^{2+}}$ and $_{SO_4^{2-}}$

have loads greater than Ca^{2+} , Cl^- , $Na^+ + K^+$) involving the biogenic stage (presence of Fe³⁺ ions). The presence of the Min sign (mineralization) in the first place indicates the predominance of boron in salt water. In addition, since in the valley of the river. Fresh water with a mineralization of 0.4-0.7 g/dm³ prevails in areas without noticeable anthropogenic impact, such an arrangement of parameters in MC1 indicates the presence of industrial water, and therefore a large positive load on *B* should be considered more technogenic than lithogenic.

Therefore, we can assume that in our case, the first main component characterizes the transit of industrial water. However, unlike the 1988 task, the absence of the pH attribute in this component reflects the general change in the hydrogeochemical situation – now these are not acidic industrial water, but simply water of any acidity with increased mineralization.

The increased values of this component are mainly confined to the old sludge collector, although its maximum value (5.578), as in the 1988 problem, again falls on the area near the new sludge collector (well №1298), i.e. The new sludge collector still filters higher concentrations of boron.

The second main component, in addition to the first, also reflects a slight increase in the alkalinity of groundwater (parallel changes in pH, HCO_3^- , Mg^{2+} and Ca^{2+}). This and the third main components do not contain boron; they characterize the territorial distribution of water of varying degrees of salinity. Acidic water are characterized by MC6, which reflects only 3% of the total dispersion of traits, which also emphasizes the diminishing role of traditionally acidic industrial water.

The presence of several causes of groundwater pollution with boron demonstrates the heterogeneity of the sample on the graph of the distribution of sampling points on the axes MC1 and MC2, where the presence of both anomalous points lying far from the main cloud and individual groups of wells is noted. An increase in nutrient boron in the Ilek left-bank water intake demonstrates the effect of forced washing of boron as a result of the formation of a depressing funnel during water intake operation. This effect has already been noted in the task according to 1988 data.

Thus, a comparison of the processing results of monitoring observations for 1988 and 2003. a multidimensional statistical model of the component composition showed that although the processes of boron migration in groundwater, identified according to 1988 data, continue to operate, the hydrogeochemical situation in the territory of the Alga site has noticeably changed towards a decrease in the manifestations of boron migration in acidic industrial water. The redistribution of high concentrations of boron, carried in different ways, reflects the fact that the pollution front moved along the territory of the front and the stage of washing the soil and sludge collectors with snowmelt water, far from completion.

Unfortunately, in the report on groundwater monitoring for 2010-2012 [137], the network of regime observations on the Alga site for wells in which the analysis of the macro component composition, which is the basis for identifying regional groundwater filtration processes, was greatly reduced. Currently, such monitoring is carried out only for wells characterizing water use and water intake facilities, therefore, conclusions about regional processes are made only based on a comparison with the data of a full survey in 2003.

A visible difference is the absence of boron in the first three main components in the tasks for the cold period. Nevertheless, this difference is hardly worth interpreting as a significant leaching of the territory, since there are no wells in the source data matrix near the old and new sludge collectors, industrial site and slurry pipelines.

However, the similarity of the graphs of the distribution of MC values on the MC1 and MC2 axes indicates the commonality of the main processes of formation of groundwater migration conditions - as before, the heterogeneity of the point cloud indicates several factors that affect hydrodynamic and hydrochemical processes.

Common is the practical absence of signs of migration of acidic industrial water. In the task for the cold period, boron in combination with an increase in the absolute elevations of the earth's surface (AEES) grows in acidic zones, but the addition of AEES limits the distribution region of this process to elevated areas.

The type of components for the warm period almost coincides with the components for 2003; here boron is also found in the first MC. The strange "behavior" of boron in the task for the cold period is easily explained again by the set of wells in the source data matrix. A significant part of the cold period of the river. It was ice-bound; therefore, the conditions for washing sludges enriched with boron from reaches to the river practically do not occur.

3.4 Assessment of wedging out of groundwater contaminated with boron based on hydrodynamic calculations

For 2005 y. The shape of the groundwater surface depends on the water permeability of the rocks, the nutritional conditions of the aquifer, the configuration of the banks of the rivers to which the groundwater flows, lowering the water resistance,

the thickness of the aquifer, etc. On the groundwater surface shape can be measured by hydroisohypses map.

The wedging calculations were carried out based on hydroisogypsum map taking into account the filtration characteristics of the Quaternary deposits of the Ilek river (Appendix 1). The average thickness of the alluvial aquifer m here is about 15 m, the calculated value of the filtration coefficient K is assumed to be 35 m per day, and the hydraulic gradient - I = 0.0015. It is worth noting that when calculating the flow rate, the drainage imperfection coefficient with a value of 0.3 was taken into account. Then the flow rate of the natural groundwater flow per 1 m of the width of the flow is calculated by the following formula [105, 106]:

$$Q = KLmI \cdot 0,3,\tag{6}$$

After substituting the numerical values, we obtain: $Q = 15m \times 1m \times 35 m / day \times 0.0015 \times 0.3 = 0.236 m^3/day = 236 dm^3/day.$

When converted to m^3 / h , the flow rate will be $Q \cong 0.0098 \text{ m}^3 / h$. This value will allow you to calculate the flow rate of wedged groundwater along the length of the Ilek river in the wedging area. Appendix 2 contains a map of hydroisogypsum and a hydrogeological map of the Alga site until Aktobe reservoir section with contours of the groundwater pollution zone for 2005. As can be seen from these maps, along the Ilek river, there are several zones into which contaminated groundwater wedges out.

The old sludge collector is very close to the river, the flow of contaminated groundwater wedging out in this zone is directed perpendicular to isogypsum 238 and its length from the left bank in 2005 was 1250 m. From the right bank in this zone also wedged out with a width of about 400 m. This is the area of wedging out of groundwater with the highest concentrations of boron in groundwater totaling 1650 m.

According to the contour of the contamination source, groundwater water with concentrations of more than 100 mg / dm³ can wedge out in this zone from both banks. Thus, taking into account the drainage imperfection coefficient of 0.3, 390 m³ / day wedges out into this zone. Since 1 mg / dm³ = 1 g / m³, a salinity of 100 mg / dm³ corresponds to 100 g / m³. Thus, from this wedging zone per day in the Ilek river carried 39 kg of boron, and during the low-water period (~ 300 days) - about 12,000 tons per year.

In the Ilek river dilutes contaminated groundwater contaminated with boron. The extent of dilution could be estimated by the concentration of boron in surface water at section IV-IV, which is located in the zone of direct influence of the old sludge collector. In the river In this section, the boron concentration in 2005 was 13.44 mg/dm³, which is 7.44 less than the concentration of wedged groundwater. However, this concentration is 27 times higher than the maximum permissible concentration for boron, even taking into account their changes in 2015 from 0.017 to 0.5 mg/dm³. Of course, this amount does not reach the Aktobe reservoir; the silts of the Ilek river precipitate boron, but in the flood, part of this silt contaminated with boron is carried ashore. A decrease in concentration can be traced slightly further than the fifth target,
when moving towards it, the boron concentration in groundwater decreased to 49.5 mg/dm^3 , and in the Ilek river - up to 1.98 mg/dm^3 .

The second high-boron groundwater wedging out zone begins below the VI-VI site after 750 m, then has a gap and continues in the confluence of the Suyksu stream (temporary watercourse) for another 1130 m. Groundwater from the right bank with a small concentration of boron wedges out into the gap, they were not taken into account. Therefore, the second zone of wedging out of contaminated groundwater on the left bank has a length of 1880 m. Then 444 m³/day wedges out in this zone. Focusing on the concentration of boron in wells №1600 (82.7 mg/dm³), we get 36.7 kg of boron per day, or 11 tons per year. The total amount of boron carried by groundwater to the Ilek river according to observations, a hydroisogypsum map and a hydrogeological map with a halo of pollution for 2005, amounted to 23 t/year.

For 2011-2012 yy. To determine the amount of the boron carried in the river Ilek should determine the size of the wedging zone. This procedure is carried out according to hydrogeological maps for 2011-2012 (Appendix 2). LLP «Akpan» compiled these maps on a scale of 1: 25000, i.e. 1 cm on the maps corresponds to 250 m on the surface of the study area. A small ubiquitous change in groundwater levels as a whole will not change the direction of their movement, so you can focus on the existing map of hydroisogypsum.

As can be seen from the hydrogeological maps for 2011 and 2012 (Appendix 2), along the Ilek river, several zones could be identified where contaminated groundwater with different concentrations of boron wedges out. In addition, if for the maps of 2011 and 2012, the outline drawing differs slightly, then compared to the map of 2005 (Appendix 1), noticeable changes are noted. So, if in 2005 two separate zones were distinguished, then the 2011 and 2012 maps demonstrate a significant increase in the halo of the spread of contaminated groundwater, and almost all along the contour there is pollution on the right bank of the Ilek river.

This view is a clear confirmation of the specificity of the rivers of Kazakhstan type. The essence of this specificity lies in the fact that the lowland rivers of Kazakhstan are not regional drains due to the small depth of the cut of their channel. The regional drain is the entire floodplain of the river (to the first floodplain terrace).

In table 14, the results of determining the actual values of the groundwater flow width by the ranges of boron concentrations mapping the aureole of pinching out of polluted groundwater are presented.

N⁰	Boron content,	The actual width of the zone, taking into account the								
	mg/dm ³	scale of	the map, m							
		2011	2012							
1	0,5-10	5525	3050							
2	10-50	8500	11750							
3	50-100	3575	1550							
4	>100	300	225							
Total:		17900	16575							

	Table 15 –	Groundwater	wedging	out zones
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The values of the width take into account zones from both the left and right banks.

As before, the flow of contaminated groundwater with the highest concentration of boron is observed near the old sludge collector, however, there have been noticeable changes in the size of wedging zones with different ranges of boron concentrations. This is expressed in the fact that the zone with the maximum concentrations has decreased very much.

In 2005, this zone was 1650 m, in 2011 - 300 m, and in 2012 - 225. Thus, over 6 years this zone decreased by more than 5 times, averaging 18% per year. However, in 2012, compared with 2011, this zone decreased by 75 m, i.e. zone reduction occurred by 25% (of course, subject to the full reliability of the constructions).

The question immediately arises why the washing rate of the old sludge collector so quickly increased, although the washing conditions did not change - this, as noted in Section 1.1., is spring snowmelt water and precipitation. The latter, judging by the analysis of climatic factors carried out in the report on groundwater monitoring for 2010-2012, not only did not increase, but, on the contrary, decreased, causing a regional decrease in groundwater level by 0.3 m.

This situation could be explained only by a decrease or termination of additional sources of groundwater pollution, which were considered in Section 1.2. The most likely source, from the point of view of proximity to the sludge collector, is the territory of the former Alga chemical plant, which ceased operations in 1996, but before still not subjected to any means of reclamation.

For 15-16 years of natural washing of contaminated soil in the territory of the plant, the situation could well have changed. In addition, already in 2007, samples of sludge taken at the old sludge collector in the interval from the surface to 0.5 m showed the absence of boron in them. Drilling of wells around and on the area of the sludge collector confirmed this fact, but showed that the bulk of the boron was now concentrated under the bottom of the old sludge collector at depths of up to 25 m.

It is clear that the channel of the Ilek river cannot drain groundwater from such depths. On the other hand, the assessment of the speed of advancement of the groundwater pollution front, made possible by analyzing the influence of the "wall in the ground" near the old sludge collector, showed the possibility of getting into the site of the old sludge collector a contaminated groundwater flow from the territory of the Alga Chemical Factory. With a speed of advancement of the pollution front of 300-500 m per year, this path of pollution can be quite real, because the former factory territory is located 1-2 km from the sludge collector.

The same reason is the explanation of a significant increase in the aureole of pollution in the north, north-west and east directions of the zone compared to 2005 with a range of boron concentrations of 50-100 mg/dm³.

The practical adjoining of the pollution halo with boron concentrations of 0.5-10 mg/dm³ to the western terrace of the Ilek river valley confirms the correctness of the assumption that traces of emergency spills of sludge pipelines and filtration from a new sludge collector are identified as sources of pollution. The Figure 11 shows the current view of Sludge Pipes and «New» Sludge Collector. These photos were taken during field surveys of territories in 2017.

The hydrogeologists of the LLP «Akpan» did not deny the photo of the traces of accidental spills of the pulp supplying the sludge to the new sludge collector, then with respect to the new sludge collector they built different hypotheses for the detection of boron in neighboring wells to refute the possibility of filtering boron from it. However, here, the 2008 drilling operations on the territory of the new sludge collector showed almost the same picture as the old sludge collector. There, boron was found at depths of up to 25 m below its bottom and practical washing of the upper layer of sludge.



a) Sludge Pipes

b) «New» Sludge Collector



It should be noted that the hypsometric position of the old sludge collector allows drainage of polluted groundwater to and from the layers below the bottom of the new sludge collector by the Ilek river. To prevent an increase in pollution of the Ilek river and Aktobe Reservoir, LLP «The Center for Health Protection and Environmental Engineering» has developed a feasibility study for the groundwater treatment project for the Ilek river valley (the layout of water intake and injection wells and treatment facilities is given on the hydrogeological map in Appendix 1).

In 2008, the pollution front from the new sludge collector, sludge spills, and the contaminated areas of the plant has not yet approached the site for water wells provided for in the feasibility study. Technical solutions in the feasibility study proposed in 2009-2010 works could have a positive effect on the purification of groundwater in the Ilek valley below the alignment, where purified groundwater was supposed to be pumped. However, a comparison of pollution halos for 2005 and 2011-2012 witnesses that the pollution front has advanced beyond the line of projected water intake and injection well sections.

Thus, the technical solutions provided for in the feasibility study lost their relevance, and boron from all sources of pollution began to flow into the Ilek river and Aktobe reservoir. We calculate the amount of boron in the Ilek river when wedging out contaminated groundwater.

When calculating the wedging out, the results of monitoring observations of groundwater levels were taken into account. LLP «Akpan» carried out the work concluded that there was an almost universal decrease in the groundwater level by 0.3 m due to with a decrease in rainfall in the observed period.

Thus, for the average thickness of the alluvial aquifer m when calculating according to 2011-2012. A value of 14.70 m was taken. The remaining design parameters remained the same. The application of the above formula (6), made it possible to calculate the specified value of the discharge of pinch-out groundwater water per 1 m flow width.

 $Q = 14,70 \text{ m} \times 5,25 \text{ m} \times 35 \text{ m/day} \times 0,0015 \times 0,3 = 0,231 \text{ m}^3/\text{day} = 231 \text{ dm}^3/\text{day}.$

The difference between the obtained value and the flow rate in 2005 was 0.005 m^3 /day per 1 meter of the width of the wedged out contaminated groundwater flow. However, a comparative analysis of the wedging zones in 2005 and 2011-2012 showed a significant increase in the size of the wedging zones.

Knowing the size of the wedging zone, which just characterizes the width of the flow of contaminated groundwater coming from the left or right bank of the Ilek river, as well as the specified value of the groundwater flow per one meter of the wedging zone, it is possible to determine the flow rate of groundwater contaminated with boron. The last stage of wedging calculations is performed by the elementary operation of multiplying the average boron concentration range of the contour on the hydrogeological map by the flow rate that is determined for this zone. As a result, we obtain the mass of boron carried out in the Ilek river groundwater, in accordance with the recording of this procedure in the form of calculation formula (7):

$$m = Q \times C(B) \times L,\tag{7}$$

where m – the mass of boron carried out over 1 day by polluted groundwater into the Ilek river, kg/day;

C(B) – the actual concentration of boron in groundwater, mg/dm³, or kg/m³;

L – the actual wedging length, m.

Q – groundwater flow rate from 1 m of their pinch-out zone in the Ilek river, equal to 0.231 m³/(day·m).

Now we will consider each zone where contaminated groundwater with different concentrations wedges out, according to hydrogeological maps for 2011-2012 in accordance with the data in Table 21.

First, we consider a zone with maximum pinch out concentrations. This is the smallest zone with a width of 300m in 2011 and 225m in 2012, wedging with a concentration of more than 100 mg/dm³ occurs only from the left bank. Observation target II - II passes through it (in the 2005 report, this target was number IV-IV). The closest to the Ilek river is located well №1587 with a concentration on 07/01/2011, equal to 185 mg/dm³, 104.5 mg/dm³ on 10/01/2011; 110.5 mg/dm³ as of 01.01.2012 and 120.8 mg/dm³ as of 01.04.2012.

Thus, the average boron concentration when wedged out in this zone for 2011 can be taken equal to 145 mg/dm^3 . Then in the 300 meter zone will wedge out:

 $m = 0,231 \times 145 \times 300 = 10048,5 \text{ g} = 10 \text{ kg per day, for one year} - 3 \text{ ton.}$

The boron concentration for 2012 is assumed 115 mg/dm³. Then in the 300-meter zone will wedge out:

 $m = 0,231 \times 115 \times 300 = 7969,5$ g = 8 kg per day, for one year -2,4 ton.

The zone with a range of boron concentrations of 50-100 mg/dm³ is drawn in a purely interpolation manner - there are no wells in it that could clarify the average concentration, so we take the middle of the range of 75 mg/dm³ as its quality. Then for 2011 and 2012, we get:

 $m_{2011} = 0,231 \times 75 \times 3575 = 61936,9 \text{ g} = 6,2 \text{ kg per day, for one year} - 18,6 \text{ ton.}$ $m_{2012} = 0,231 \times 75 \times 1550 = 26853,75 \text{ g} = 26,8 \text{ kg per day, for one year} - 8,06 \text{ ton.}$

The zone with boron concentrations in groundwater from 10 to 50 mg/dm³ is the largest in area and has a clear tendency to decrease concentrations in the wells of the observation network as you move away from the old sludge collector and the Suyksu stream. The shape of the contour in 2011 has two extensions - opposite the new sludge collector and the valley of the Suyksu stream. This zone ends at well area No1382.

In 2012, this zone narrows, preserving the "tongue" opposite the new sludge collector and significantly lengthening along the Ilek riverbed, almost equal to the boundary of the distribution of the circuit with boron concentrations in the range of $0.5-10 \text{ mg/dm}^3$. Such changes could be explained by a decrease in the flow of pollution from one or more sources of pollution.

Judging by the significant reduction in 2012 of the zone with a range of 50-100 mg/dm³, which now actually outlines the old sludge collector, this source should be south of this sludge collector. We are witnessing a sharp decrease in the impact of pollution at the plant. An extension of the contour of $10-50 \text{ mg/dm}^3$ is an additional evidence of the manifestation of signs of cleansing of the soil of the territory of the former Alga Chemical Factory – now this is a picture of the progress of the pollution front along the groundwater flow.

Now we calculate the pinch-out of groundwater from this zone to the Ilek river. Due to the significant scatter of boron concentrations in this zone, we will also accept for this zone as the average concentration the middle of the range of contour concentrations - 30 mg/dm^3 .

 $m_{2011} = 0,231 \times 30 \times 8500 = 58905$ g = 58,905 kg per day, and 17,67 ton per year, $m_{2012} = 0,231 \times 30 \times 11750 = 81427,5$ g = 81,43 kg per day, and 24,43 ton per year.

It remains to calculate the wedging out of the zone with concentrations in the range of $0.5-10 \text{ mg/dm}^3$. This zone marks the manifestations of the initial stage of

pollution of new territories and this manifests itself in the advancement of the polluted groundwater flow both towards the Aktobe reservoir and in the expansion of the flow boundaries from the new sludge collector, which is still denied by local hydrogeologists. For this zone, taking into account the data in Table 20, we obtain at an average concentration of 5 mg/dm³.

 $m_{2011} = 0,231 \times 5 \times 5525 = 6381,4$ g = 6,38 kg per day, and 1,91 ton per year, $m_{2012} = 0,231 \times 5 \times 3050 = 3522,75$ g = 3,52 kg per day, and 1,06 ton per year.

Now you can estimate the amount of boron carried in the river. Ilek pinch out

groundwater water. The results are presented in table 16.

Table 16 – The results of calculations of boron removal in the Ilek river polluted groundwater

	Boror	n content	,	The actua	l width of	The mass	of boron ca	rried into th	e Ilek river					
	m	g/dm ³		the zone, the account the	taking into ne scale of	by polluted groundwater								
N⁰		Rataver	nge rage	the m	ap, m	20	011	2012						
		2011	2012	2011	2012	kg/day	ton/year	kg/day	ton/year					
1	0,5-10	5	5	5525	3050	6,38	19,11	3,52	1,07					
2	10-50	30	30) 8500 11750		5,89	17,67	8,14	24428,25					
3	50-100	75	75	3575	1550	61,94	18,58	26,85	8,06					
4	>100 145 115		115	300	225	10,05	3,01	5,98	1,79					
то	TAL					84,26	58,36	44,49	35,35					

3.5 Evaluation of the self-purification processes of the Ilek river

The evaluation of self-cleaning processes Ilek river based on regime observations of RSE "KazHydroMet" [107]. It is based on regression models (trends of observation series). According to the description of the observational network in the Information Bulletins on the State of the Environment in the Republic of Kazakhstan, the Center for Environmental Monitoring of the Environment of the Republic of Kazakhstan RSE "KazHydroMet" within the Aktobe region has five observation points (Table 17).

Table 17 – Location of water posts on the Ilek river

N⁰	Name of the water post	Location
1	Alga 1	1 km above sludge collector
2	Alga 2	0.5 km below the groundwater outlet
3	Aktobe 1	0,5 km above the city
4	Aktobe 3	0,5 km below the mouth of the river Zhenishke
5	Georgievka village	0,5 km below the groundwater outlet

The first three posts are located in the Alga-Aktobe reservoir area, and the last of them can be taken as a post at the Aktobe reservoir, since it is 0.5 km above the city of Aktobe, i.e. below the dam. The first post is a background in relation to the old sludge collector, which is considered the main source of pollution of the river due to its close proximity. The second post is located 0.5 km below the village of Bestamak and 21 km below the old sludge collector. The distance from the village of Bestamak to the southern (opposite dam) boundary of the reservoir is 3.5 km from this village (5.15 km along the channel).

According to the information bulletins, table 18 was compiled based on the registered cases of high pollution averaged over the year. According to these data (table 17), graphs of changes in the concentration of boron were constructed over the years and the equations of trends (regression) were selected for each post. Gradients of natural self-purification were calculated in the time aspect for each observation point as the difference in concentration of a particular year and the previous one, and in a territorial aspect by the difference in concentrations for each year between different observation points.

The same data was used to plot graphs of boron concentrations in each observational system, and then the regression equations were selected for these graphs in Excel.

Ecological capacity of the Ilek river we understood in the traditional sense of [108, 109]: it is the ability of the natural environment to contain anthropogenic pressures, harmful chemical and other impacts to the extent that they do not lead to land degradation and the entire environment [110]. Since even according to regime observations, it can be seen that even when comparing with MPC for boron 2015 (the MPC value for fishery purposes was previously taken, which was 0.017 mg/dm³), the average annual concentrations almost reached the MPC, i.e. even in the background, the ecological capacity of the river was almost exhausted.

In the Alga 2 section, 21 km below the main source of pollution, the boron concentration for almost the entire observation period, presented in the sample (Table 22), exceeded the maximum allowable concentration of 2015 for boron, i.e. this section shows the excess of the ecological capacity of the river [111].

Thus, we should consider the task of determining the ecological capacity as the inverse — determining the period when natural self-purification processes restore at least the maximum limits of the ecological capacity to 0.5 mg/dm³ at the Alga 2. This problem is solved using the regression equation for this alignment on the forecast part of it (after 2018).

Based on the regime observations of RSE "KazHydroMet" (table 18), the authors evaluated the self-purification processes of the Ilek river [112]. According to these data, charts were constructed and empirical curves of the dynamics of changes in boron concentrations were calculated for each post for the period 1997-2018 yy. (table 17, figure 12).

The predominantly positive values of the temporal self-cleaning gradients for each post demonstrate the manifestation of natural self-purification factors — washing the soil contaminated with Alga Chemical Factory emissions and the old sludge collector with snow melt water and precipitation. The presence of scattered negative values of temporal gradients confirms this pattern: here the change of water content of the year affects.

		Gradients of self-purification of the Ilek river from boron												
NºNº	Years	Time	aspect, mg	/dm ³ ·year	Spatial aspect, mg/dm ³ · (distance between posts)									
		Alga 1 (background)	Alga 2	Aktobe reservoir 1	Alga 1 - Alga 2									
1	1997				-0,66									
2	1998	0,13	0,11	0,04	-0,68									
3	2000	0,13	0,29	0,04	-0,52									
4	2001	0,01	0,24	0,05	-0,29									
5	2002	-0,22	-0,6	-0,15	-0,67									
6	2003	0,19	0,13	-0,32	-0,73									
7	2004	0,03	0,23	0,48	-0,53									
8	2005	0	0,09	0,03	-0,44									
9	2006	-0,16	-0,4	-0,1	-0,68									
10	2007	0,01	0,32	0,03	-0,37									
11	2008	-0,01	0,09	0,02	-0,27									
12	2009	-0,01	-0,01	-0,11	-0,27									
13	2010	0,01	-0,05	0,03	-0,33									
14	2011	0,15	0,16	0,07	-0,32									
15	2012	-0,08	-0,11	-0,03	-0,35									
16	2013	0,03	0,2	0,11	-0,18									
17	2014	-0,01	0,03	0,04	-0,14									
18	2015	-0,06	-0,07	0,06	-0,15									
19	2016	0,108	0,185	-0,124	-0,073									
20	2017	-0,015	-0,404	0,114	-0,462									
21	2018	0,035	-0,501	-0,002	-0,998									

Table 18 – The results of observations of pollution of surface water with boron on the Alga-Aktobe region, in mg/dm³ for the period 1997-2018 yy.

The negative values of temporary self-cleaning gradients for each post demonstrate the natural self-cleaning factors. With a small change in the discharge of the Ilek river this year compared to the previous year, this means a decrease in the flow of pollution into the riverbed. In the background post, this is the result of washing soil, which contaminated with emissions from the former Alga Chemical Factory territory and their area. In the Alga 2 section, it is the result of washing the soil, which contaminated with emissions from the former Alga Chemical Factory territory from the area below the city, including the old sludge collector, with snowmelt water and atmospheric precipitation, and pinching out of polluted groundwater. With an increase in the discharge of the Ilek River, the potential for self-cleaning increases, which should work for all three posts simultaneously.

The presence of positive values of temporary gradients means an increase in pollution compared to the previous year. Here, the dependencies established above have the opposite meaning - with a constant flow rate in the Ilek river, this is an increase in the flow of pollutants into the channel, or this is a decrease in the flow of water in the river.

The negative values of the spatial aspects of the gradients are due to the excess of the ecological capacity of the Ilek river at a distance of 21.5 km downstream from the old sludge collector to the Alga 2 gauge. The change in the spatial gradient modulus by year, as well as the temporal aspects of the gradient, reflects the water characteristics of the year.

Negative values in the third column of table 17 (Aktobe reservoir 1) show that the main part of boron, which is sorbed by silts (oozes), is deposited in the reservoir, once again emphasizing its role as a boron accumulator.

As can be seen from the record of the trend equations (figure 13), a low value of the approximation of the curves for the posts Alga 1 and Alga 2 has been obtained. The large amplitudes of fluctuations in the boron content in surface water at these posts are evidence that the Aktobe reservoir enters the Ilek river's runoff groundwater, thinning-out different places in accordance with the map of hydroisogypsum. Since the eastern groundwater flow from the old sludge collector passes the shortest way to the river (about 400 m), its influence at groundwater speeds of 300 m/year affects the concentration of boron in the reservoir next year, and therefore in the period up to 2003 it affects the influence of the formed groundwater flow around the "wall".

From the remaining pinch-out zones, the impact of this breakthrough of groundwater, backed by the "wall" affects a few years later, depending on the distance of this zone from the old sludge tank. Another reason for the increase in concentration on the Alga 2 post in 2016-2018. There may be a manifestation of the influence of additional sources of pollution, the front of polluted groundwater from which approached the thinning-out zones.

Thus, the curve for the Alga 2 post reflects the change in the self-cleaning process - the emergence of new sources, which can be the flow from washing the spill pipe of the sludge pipe to the new sludge collector and leaks from it. That is, there is an additional reason for exceeding the ecological capacity of the Ilek river. The observation period for the new process is short. However, the rapid increase in boron concentration (over 2 years it increased from 0.295 to 1.2 mg/dm³) indicates a significant intensification of the process of thinning-out polluted groundwater water in the Ilek river.



Figure 12 – Dynamics of changes in boron concentrations for each post over the period 1997 -2018

The next step is assess the timing of the restoration of the ecological capacity to its maximum possible value (the achievement of the MPC according to the criteria for fisheries use). To do this, we consider the curve for the Alga 2 post until 2016, when the old sludge collector acted as the main source (figure 13).



Figure 13 – Dynamics of the boron concentrations changes in the Alga 2 post over the period 1997 -2016 yy.

For the process of natural self-purification, the most justified type of trend equation is an exponential relationship, ensuring a gradual decrease in concentrations without falling into negative values. To simplify the appearance of the trend line, instead of the year of monitoring, its position in the sample was taken. This technique and the limitation of consideration by one process significantly simplified the appearance of the trend equation and increased the approximation coefficient. Now, using this equation, we could calculate the self-cleaning or purifying time of the Ilek river before the ecological capacity is restored on the forecast part of the trend equation. Calculate the values of the function for the period after 2016 (table 19).

Table 19 – The results of calculations of the predicted values of the boron concentration in the Alga 2, in the impact condition of the old sludge collector only

Characteristic	Years											
Characteristic	2015	2016	2017		2076	2077	2078	2079	2080			
The ordinal number of the year in the sample	18	19	20		79	80	81	82	83			
Average annual boron concentration according to regime observations, mg/dm ³	0,48	0,295										
Boron concentration value by approximating function	0,442	0,420	0,400		0,021	0,020	0,019	0,018	0,017			

Thus, natural cleaning or purification processes from the effects of the old sludge collector can ensure the restoration of the full ecological capacity only by 2080. When exposed to additional sources of pollution, this period may be postponed for many more years, increasing pollution of the Aktobe reservoir.

Conclusions on the section:

1. Statistical processing of the results of chemical analyzes of groundwater in the territory of regime observations showed that the technogenic factor makes an additional contribution to the natural lithogenic stage, the nature of which is described by the transit of acidic industrial water, accompanied by the absorption of polluting elements by ground and exchange reactions between groundwater and ground.

2. Component analysis identifies three main processes in the spread of pollution of boron, filtered from sludge collectors: transit, deposition, and exchange with the active participation of nutrients. For all water wells, nutrient boron was detected, which indicates the pulling up of river water by these wells, which, passing through activated sludge, wash boron biologically deposited in the sludge.

3. The hydrochemical situation in the region actually developed at the beginning of regime observations, since in 1982, the halo of pollution in the Alga site already corresponded to that in 1988, and in the Aktobe site, the anomalies of boron related to microbiological and metabolic processes were already recorded.

4. A comparison of the processing results of monitoring observations for 1988 and 2003 with a multidimensional statistical model of the component composition showed that although the processes of boron migration in groundwater, which identified according to 1988 data, continue to operate. The hydrogeochemical situation in the territory of the Alga site has noticeably changed towards a decrease in the manifestations of boron migration in acidic industrial water. The redistribution of high concentrations of boron, carried in different ways, reflects the fact that the pollution front moved along the territory of the front and the stage of washing the soil and sludge collectors with snowmelt water, far from completion.

5. In the report on groundwater monitoring for 2010-2012, the network of regime observations on the Alga site for wells in which the analysis of the macro component composition, which is the basis for identifying regional groundwater filtration processes, was greatly reduced. Currently, such monitoring is carried out only for wells characterizing water use and water intake facilities, therefore, conclusions about regional processes are made only based on a comparison with the data of a full survey in 2003.

6. A visible difference is the absence of boron in the first three main components in the tasks for the cold period. Nevertheless, this difference is hardly worth interpreting as a significant leaching of the territory, since there are no wells in the source data matrix near the old and new sludge collectors, industrial site and slurry pipelines.

7. Common is the practical absence of signs of migration of acidic industrial water. In the task for the cold period, boron in combination with an increase in the absolute elevations of the earth's surface (AEES) grows in acidic zones, but the addition of AEES limits the distribution region of this process to elevated areas.

8. The type of components for the warm period almost coincides with the components for 2003; here boron is also found in the first MC. A significant part of the cold period of the river is ice-bound; therefore, the conditions for washing sludge enriched with boron from reaches to the river practically do not occur.

9. The zone with boron concentrations in groundwater from 10 to 50 mg/dm³ is the largest in area and has a clear tendency to decrease concentrations in the wells of the observation network as you move away from the old sludge collector and the Suyksu stream. The shape of the contour in 2011 has two extensions - opposite the new sludge collector and the valley of the Suyksu stream. This zone ends at well area N_{01382} .

10. In 2012, this zone narrows, preserving the "tongue" opposite the new sludge collector and significantly lengthening along the Ilek riverbed, almost equal to the boundary of the distribution of the circuit with boron concentrations in the range of $0.5-10 \text{ mg/dm}^3$. Such changes could be explained by a decrease in the flow of pollution from one or more sources of pollution.

11. Judging by the significant reduction in 2012 of the zone with a range of 50-100 mg/dm³, which now actually outlines the old sludge collector, this source should be south of this sludge collector. We are witnessing a sharp decrease in the impact of pollution at the plant. An extension of the contour of $10-50 \text{ mg/dm}^3$ is an additional evidence of the manifestation of signs of cleansing of the soil of the territory of the former Alga Chemical Factory – now this is a picture of the progress of the pollution front along the groundwater flow.

12. A general conclusion on a series of tasks of processing data from monitoring observations is to identify the dynamics of hydrogeochemical processes of pollution of groundwater by boron. This dynamics is manifested not only by a change in the intensity of processes across the territory (values of the main components within the same task), but also by a change in the types of processes in time (a gradual change in the hydrogeochemical environment from acidic to alkaline).

13. The dynamics of surface water pollution can be traced at 3 points of KazHydroMet on the Alga region. Graphs of changes in boron content in the Ilek river in sections above the city of Alga (Alga1), near the village of Bestamak (Alga2) and above the city of Aktobe (Hydropost 1) for the period 1997-2018 show a consistent decrease in boron content until 2016. At Alga1 and Aktobe Hydropost 1 posts, the downward trend continues, and at Alga 2, a sharp jump in boron content is observed.

14. Such a trend in the graphs can be explained by the manifestation of the influence of a new pollution source, which can only be a new sludge collector, the pollution front of which in 2016 approached the Ilek river. Compared to the 2011 contour, an increase in the boundary contour in the range of 0.5–10 mg/dm³ by 600 m appeared on the contour of the contour site on the Hydrogeological map of 2012, directly opposite the contour center of the new sludge collector, i.e. the pollution front from the new sludge collector in 2011 was recorded.

15. With the width of the Ilek river valley is 4 km away, while the Ilek river is 2 km away. This front can advance 1800-2000 m by 2016 with a forward speed of 600 m per year, which is recorded in the Ilek river Alga 2 post in 2016.

4 MODEL OF TURBULENT DILUTION OF POLLUTION OF ILEK RIVER WITH GROUNDWATER WATER

4.1 A summary of the theory and methodology of calculations for the flat task model

In the works on the theory of turbulent diffusion as applied to the spread of pollutants when they are discharged into water bodies or streams, it is noted that two tasks should be distinguished: predicting the quality of water during stationary and unsteady release of a polluting substance. In the first case, the concentration of the pollutant in the reservoir changes only in space, in the second case – in space and time. In addition, depending on the configuration and depth of the reservoir, one-, two- or three-dimensional problems of the distribution of matter can be observed.

Typical hydraulic values when calculating the spread of a pollution substance are as follows: for rivers, the average flow rate, hydraulic radius and slope, which together make it possible to determine indicators characterizing the mixing process; for nonflowing water bodies - wind currents, and therefore the calculation of the speed of these currents should precede the mixing calculations.

The calculation of the concentration of pollutants in water bodies can be based on: 1) a semi-empirical theory of turbulent diffusion; 2) the theory of turbulent diffusion with finite speed; 3) empirical formulas for calculating the distribution of matter in a turbulent flow.

The most developed semi-empirical theory of turbulent diffusion and empirical methods. The theory of turbulent diffusion with a finite velocity is not applied, although comparatively much attention is currently being paid to it. Numerous studies have been carried out in the application of the theory of turbulent diffusion for engineering calculations. However, the results obtained are approximate, since the accuracy of the calculations primarily depends on the accuracy in determining the calculated coefficients.

The turbulent diffusion equation, as is known, expresses the law of conservation of matter, and it is based on the following assumptions:

1) The fluid is incompressible;

2) The Reynolds number is so large that one can refuse to take into account the molecular effect of diffusion;

3) The amount of substance released per unit time per unit volume is extremely small, and its effect on turbulence can be neglected [113-116].

The law of conservation of a unit mass of pollutants S in the process of forced convection through an elementary volume of liquid in rectangular coordinates after performing the usual averaging operation could be expressed by the equation:

$$\frac{\partial \overline{S}}{\partial t} + \overline{u}_{x} \cdot \frac{\partial \overline{S}}{\partial x} + \overline{u}_{y} \cdot \frac{\partial \overline{S}}{\partial y} + \overline{u}_{z} \cdot \frac{\partial \overline{S}}{\partial z} + \frac{\partial}{\partial x} \left(\overline{S'u'_{x}} \right) + \frac{\partial}{\partial y} \left(\overline{S'u'_{y}} \right) + \frac{\partial}{\partial z} \left(\overline{S'u'_{z}} \right) + F(s) = 0$$
(8)

where F(S) - term characterizing the non-conservative nature of the pollutant. \overline{S} – time-averaged concentration of a substance.

Thus, the distribution of matter *S* in averaged turbulent motion is affected by the members of convective turbulent motion, which is determined by the correlation $\overline{s'u'_i}$ – between the turbulent components of the pulsations of speed and matter.

In the calculation of the transfer of matter in a turbulent flow, it is usually assumed that the diffusion of the gradient type occurs during transport, i.e. it is believed that the gradient field of the distribution of matter and transport occur in the direction of decreasing the gradient of concentration of the substance. Moreover, it is accepted that the double correlation of the pulsation components of the substance and the velocities is directly proportional to the concentration gradient of the substance, i.e.

$$-\overline{S'u'_{x}} = k_{x}\frac{\partial\overline{S}}{\partial x}; \qquad -\overline{S'u'_{y}} = \frac{\partial S}{\partial y}; \qquad -\overline{S'u'_{z}} = \frac{\partial\overline{S}}{\partial z}$$
(9)

where k_x , k_y and k_z – coefficients of turbulent diffusion of matter in the direction of the coordinate axes *x*,*y*, *z*.

Taylor proposed this simplest and earliest theory of turbulent diffusion [117]. Schmidt [118] first introduced the turbulent diffusion coefficient.

From the dependence (9), it follows that since the quantities $\overline{S'u'_i}$ and $\frac{\partial \overline{S}}{\partial x}$ – are vectors, i.e. tensors of the first order, then the turbulent diffusion coefficients must be scalar or second-order tensors. A first-order tensor can be formed from another first-order tensor only if the latter is scalarly multiplied by a scalar or second-order tensor. Combining the basic equation of the law of conservation of matter (4.1.2) and equation (9), We obtain (10). The equation (10.) is a semi-empirical equation of turbulent diffusion, since (4.1.2.) is hypothetical in character:

$$\frac{\partial \overline{S}}{\partial t} + \overline{u}_{x} \cdot \frac{\partial \overline{S}}{\partial x} + \overline{u}_{y} \cdot \frac{\partial \overline{S}}{\partial y} + \overline{u}_{z} \cdot \frac{\partial \overline{S}}{\partial z} + \frac{\partial}{\partial x} \left(-k_{x} \frac{\partial \overline{S}}{\partial x} \right) + \frac{\partial}{\partial y} \left(-k_{y} \frac{\partial \overline{S}}{\partial y} \right) + \frac{\partial}{\partial z} \left(-k_{z} \frac{\partial \overline{S}}{\partial x} \right) + F(s) = 0$$

$$(10)$$

In diffusion calculations, the turbulent flow could be divided into two main types:

1) Isotropic turbulence, when the statistical characteristics of turbulence are independent of the direction and, therefore, the average direction of shear and the gradient of the averaged velocity cannot exist;

2) Anisotropic turbulence or shear flow turbulence when the average velocity has a gradient.

In isotropic turbulence, the averaged flow rate is constant over the entire flow region. The diffusion coefficients are spherically symmetric, i.e.:

$$k_x = k_y = k_z \tag{11}$$

Such conditions are commonly observed in the oceans and upper atmosphere. In conditions of rivers and other shallow water bodies, such conditions are not fulfilled and equality (11.), strictly, is not valid.

The equation of turbulent diffusion (10) has no practical application, and the solution of this equation with diffusion coefficients presents certain difficulties, since there is very little information about the laws of variation of the coefficients k_x , k_y and k_z .

In solving problems of determining the mixing of pollutants with the water of a reservoir, Taylor suggested using integral (throughout the entire live section of the flow) diffusion coefficients, i.e. dispersion coefficients. Taylor, studying the transport process in a straight pipe, found that a large transfer intensity is generated by the difference between the velocity at a given point of the cross section and the average velocity.

The total effect of convective transport is caused by a transverse velocity gradient and turbulent diffusion. Thus, taking into account the velocity distributions in the living cross section of the flow, the dispersion coefficient is a characteristic transport quantity for the entire flow.

Given the above, equation (10) for a conservative substance will take the form:

$$\frac{\partial S}{\partial t} + V_x \cdot \frac{\partial S}{\partial x} + V_y \cdot \frac{\partial S}{\partial y} + V_z \cdot \frac{\partial S}{\partial z} - D_x \frac{\partial^2 S}{\partial x^2} - D_y \frac{\partial^2 S}{\partial y^2} - D_z \frac{\partial^2 S}{\partial z^2} = 0$$
(12)

There are V_x , V_y , V_z – average speed in directions; x, y, z; D_x , D_y , D_z - dispersion coefficients.

In the conditions of flowing water bodies (rivers, canals, etc.) $V_z = V_y = 0$. Then equation (8) has the form:

$$\frac{\partial S}{\partial t} + V_x \cdot \frac{\partial S}{\partial x} - D_x \frac{\partial^2 S}{\partial x^2} - D_y \frac{\partial^2 S}{\partial y^2} - D_z \frac{\partial^2 S}{\partial z^2} = 0$$
(13)

There is V_x – flow rate average over the live section.

In this equation, as in the following, only time-averaged concentrations of a substance are considered, and therefore, the averaged values are determined as S, not as \overline{S} .

The dispersion coefficients are determined averaged for a living flow section, therefore they are independent of the coordinates and their magnitude and can be determined through the hydraulic parameters of the channel.

In equation (13), the first two terms take into account changes in the concentration of a substance over time, and the remaining terms take into account convective transport, i.e. the addition of uncontaminated water.

Sometimes in reservoirs in the absence or very weak currents it is convenient to apply the dispersion equation in cylindrical coordinates to solve the problem of substance propagation. A.V. Karaushev [119], assuming that the vertical concentration of the substance is leveled at a short distance from the place of its release, recommends an equation in the form:

$$\frac{\partial S}{\partial t} - \frac{\beta}{r} \cdot \frac{\partial S}{\partial r} - D \cdot \frac{\partial^2 S}{\partial r^2} = 0, \qquad (14)$$

where β – he parameter determined by the formula:

$$\beta = D - \frac{q_{ww}}{\varphi H} \tag{15}$$

 q_{ww} – wastewater consumption; φ – central angle; H – the average depth of the reservoir at the wastewater distribution site.

In order to take into account the conditions for the release of pollutants into the reservoir and initial dilution, some authors propose introducing an additional term into equation (12) alternatively (15) As a function of the initial distribution. This member is sometimes expressed as S(x, y, z, and t).

The process of self-cleaning in reservoirs proceeds differently, depending on the characteristics of the pollutant. Moreover, all pollutants can be divided into conservative and non-conservative. The concentration of conservative substances varies only due to dilution. The concentration of non-conservative substances in the water of the reservoir changes not only due to dilution, but also due to chemical interactions, physicochemical processes (sorption, desorption, deposition, precipitation, etc.) and biochemical reactions. In this case, the starting material undergoes complex transformations in parallel and sequential reactions in which various intermediate and final products are formed.

In predicting the water quality of water bodies, in addition to the hydrological regime, the morphometry of the channel or bed plays a very significant role. To assess the dependence of the intensity of mixing of water masses on the morphometric indicators of water bodies, a technique for typing water bodies was developed [120]. According to this technique, rivers are classified into three types: mountain, foothill and lowland, and each type of river, in turn, is further subdivided into two groups - medium, small and streams.

The main factors determining the rate of wastewater mixing are the transverse flow and the Chezy coefficient. The transverse flow depends on the tortuosity of the river and reaches its greatest value at the curvature of the stream. A characteristic of the tortuosity of a river is the quantity φ determined by the formula [121]:

$$\varphi = \frac{L_{fairway.}}{L_n},\tag{16}$$

where $L_{fairway}$ – length of a river section, measured along the fairway, L_n – the length of the same section, measured in a straight line.

The Chezy coefficient characterizes the intensity of mixing. Smaller values correspond to more intense turbulent mixing, and, conversely, for large values of the Chezy coefficient, mixing is weaker.

To calculate the process of turbulent diffusion, it is also necessary to have a plan of the water body in isobaths in order to determine the mirror area, depth and width of the object at the calculated flow rate. Using the river plan, you can also assess the ruggedness of the coastline, which determines the presence or absence of stagnant zones. In cases where the calculated river segment consists of separate sections with different hydraulic parameters, it should be divided into sections with more or less the same hydraulic parameters. For the entire calculation interval, these parameters are determined as weighted average values along the length of individual sections. If the calculation is carried out without dividing the river into separate calculated sections, then the average values of the morphometric and hydraulic elements for that part of the river for which the calculation is scheduled to be performed are calculated. All hydraulic parameters are determined at the calculated flow rate.

In the conditions of non-flowing reservoirs, all hydraulic characteristics are determined by calculation (effective diameter of bottom sediments, Chezy coefficient, flow velocity, etc.), and the calculation is carried out with or without separation of the reservoir into separate calculated sections. Since in non-flowing water bodies the most powerful are currents that develop under the influence of wind, the calculation of wind currents is a necessary prerequisite for calculating mixing. Of the many calculated formulas of wind currents, the most reliable formulas are A.V. Karaushev [122], which allows one to obtain velocity values for the case of a stationary wind flow.

When solving the problems of the distribution and transport of dissolved and suspended substances in natural flows, equations are proposed [123]:

$$\frac{dC}{dt} = D \cdot \left(\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2} + \frac{\partial^2 C}{\partial z^2} \right) - U \cdot \frac{\partial C}{\partial y}, \tag{17}$$

$$\frac{dC}{dt} = \frac{\partial C}{\partial t} + V_x \cdot \frac{\partial C}{\partial x} + V_y \cdot \frac{\partial C}{\partial y} + V_z \cdot \frac{\partial C}{\partial z}, \qquad (18)$$

where C – pollutant concentration in water, mg/l; t – time, c; U – hydraulic size of suspended solids, m/s (for dissolved substances U = 0 and the equation is written without the last term); V_x , V_y , V_z – flow velocity components (m/s) relative to coordinates x, y, z (m). The x-axis is directed along the flow, the y-axis is from the surface to the bottom, the z-axis is along the width of the stream; D - coefficient of turbulent diffusion (m^2/s).

A.V. Karaushev developed detailed methods for solving the turbulent diffusion equation, allowing to obtain a concentration field of a pollutant within the entire area under consideration, from the place of discharge of wastewater to the control site.

The equation (17) could be significantly simplified, for example, in the case of considering the problem of the spread of pollution in water in one flat. For example, in horizontal, when the so-called flat task, the equation is written in the form:

$$V_x \cdot \frac{\partial C}{\partial x} = D \cdot \frac{\partial^2 C}{\partial z^2}.$$
 (19)

This problem arises, in particular, in the case when along the vertical axis the mixing of pollutants with water occurs very quickly, there are no transverse flows and it is interesting to trace the spread of pollutants along the width of the stream at various distances from the place of discharge of wastewater.

The boundary conditions used in the calculation are based on the principle of conservation of the substance, taking into account that the transport of the pollutant through the surface restricting the fluid flow is zero, i.e. for the coastal line of the stream; the boundary conditions are written in the form:

$$D \cdot \frac{\partial C}{\partial x} = 0. \tag{20}$$

Since the coefficient *D* cannot be zero ($D \neq 0$), the expression (4.1.13.) takes the form:

$$D \cdot \frac{\partial C}{\partial x} = 0. \tag{21}$$

The initial conditions can be specified either in the form of a distribution of the concentration of a pollutant on the initial diameter, or in the form of a flow rate and the concentration of a pollutant entering a water body with an indication of its place of entry.

Equation (17) could be written in the form of finite differences. The differentials contained in it ∂C , ∂x , ∂z replaced by finite increments ΔC , Δx , Δy . The equation (17) takes the form:

$$\frac{\Delta C}{\Delta x} = \frac{D_{cp}}{V_{cp}} \cdot \frac{\Delta^2 C}{\Delta z^2}$$
(22)

To calculate turbulent diffusion, we divide the entire computational domain of the flow by flats parallel to the coordinate ones into computational cells - elements. On the X-axis, we denote the current elements by k, on the Z-axis, by m. Each element is assigned its own index along the corresponding coordinate axes (figure 14).



Figure 14 – Grid for the calculation of turbulent diffusion for the conditions of a flat task

Changing the index by one indicates the transition from one element to the next. Concentration values in each element are assigned the same indices. The calculation equation that allows you to determine the distribution of the concentration of a pollutant along the length and width of the stream, i.e., for the conditions of a planar problem, is written in the form:

$$C_{k+1,m} = 0.5 \cdot \left(C_{k-1,m} + C_{k,m+1}\right)$$
(23)

The values of Δx and Δz are related by:

$$\Delta x = \frac{V_{cp} \cdot \Delta z^2}{2D} \tag{24}$$

The turbulent diffusion coefficient is determined by the formula:

$$D = \frac{g \cdot V_{average}}{M \cdot C}$$
(25)

where $H_{average}$ – average depth in the considered area, m; $V_{average}$ – average watercourse flow rate in the area, m/s; g – acceleration of gravity, $^{m}/sec^2$; C – Chezy coefficient, m^{1/2}/sec; M – coefficient, which dependents from C: given that: 10 < C < 60, M= - 0,7C + 6, if $C \ge 60$ M = 48 = const. The product MC has dimension m/s^2 .

Under varying hydraulic conditions in separate sections of the wastewater distribution to the target section, the turbulent diffusion coefficient is determined for each section by the expression (23), and then for the entire calculated length by the ratio:

$$D = \frac{D_1 \cdot L_1 + D_2 \cdot L_2 + \dots + D_n \cdot L_n}{L_1 + L_2 + \dots + L_n},$$
(26)

where D_1 , D_2 , D_n – coefficients of turbulent diffusion of individual sections, L_1 , L_2 , L_n – the length of individual sections.

When the pollutant reaches the boundary surfaces of the flow, to calculate the diffusion, it is necessary to take into account the special conditions at the walls, equation (21), which is written in the final differences in the form:

$$\left(\frac{\Delta C}{\Delta z}\right)_{\substack{boundary\\surface}} = 0.$$
 (27)

The concentration field and the computational grid can be arbitrarily extended beyond the flow limits (beyond the wall). That is why extrapolate the concentration beyond the surface restricting the water flow.

In this case, the extrapolation value of the concentration $C_{k,ext}$ in the element adjacent to the outer surface of the wall, and the value of the concentration $C_{k,i}$ in the element located in the stream and adjacent to the inner surface of the wall must satisfy condition (21), which is possible only when observed:

$$C_{k,\ ext} = C_{k,\ 1} \tag{28}$$

The ratio (28) defines the rule for extrapolating the concentration of a pollutant. In determining diffusion, extrapolation concentration values are used as real. When performing the calculation on the water body plan, the place of wastewater entering the water body (the initial target) is designated. Downstream, the flow is schematized and divided into design elements. The rate of wastewater into a water body at the discharge site is V_{ww} taken equal to the velocity of the watercourse $V_{average}$.

The conditional cross-sectional area of the inflow δ at the place of its inflow is calculated by the formula:

$$\delta = \frac{q_{ww}}{V_{average}}.$$
(29)

Determination of the width of the contaminated stream stream *b* in the zero section is carried out according to the formula:

$$b = \frac{\delta}{H_{average}} = \frac{q_{ww}}{H_{average} \cdot V_{average}}.$$
(30)

In accordance with the value of b, the width of the design element is assigned. The largest allowable value Δz for coastal wastewater discharge is found from the ratio:

$$\Delta z = b. \tag{31}$$

When discharging wastewater at a certain distance from the coast or in the channel, the value Δz is found from the ratio:

$$\Delta z = \frac{b}{2}.$$
(32)

It is necessary to comply with the condition under which the following inequality Δz was fulfilled:

$$\Delta z \le \frac{B}{10},\tag{33}$$

where B – watercourse width.

Thus, when calculating turbulent diffusion, the entire section of the flow (from the zero gauge to the calculated gauge or the gauge that interests us according to the conditions of the problem being solved) is divided into cells with sides Δx and Δz , obtaining a computational grid.

Cells that enter a watercourse with wastewater in the initial diameter (zero target) are filled with numbers expressing the concentration of the pollutant in the wastewater, the remaining cells are filled with numbers reflecting the natural concentration of the pollutant in the watercourse (in a particular case, it can be zero concentration).

If the length of the section of the watercourse of interest is large and the cell size is small, then the calculation is carried out to a certain alignment, after which the cells in the section are combined (enlarged), obtaining new average values of the concentration of the polluting substance and new linear parameters of the cell. The values of the concentrations of the contaminant are obtained as the arithmetic average of the sum of the concentrations of the combined cells. The enlargement of cells can be repeated several times, starting with a specific alignment.

4.2 Initial data for constructing a flat task model for two-sided wedging of groundwater contaminated with boron in the Ilek river

The algorithm for the implementation of turbulent diffusion is not difficult from the standpoint of calculations, the entire flow section (from the zero target to the calculated one or the target that we are interested in according to the conditions of the problem being solved) is divided into cells with sides Δx and Δz , obtaining a computational grid.

Cells that enter a watercourse with wastewater in the initial diameter (zero target) are filled with numbers expressing the concentration of the pollutant in the wastewater, the remaining cells are filled with numbers reflecting the natural concentration of the pollutant in the watercourse (in a particular case, it can be zero concentration).

If the length of the section of the watercourse of interest is large and the cell size is small, then the calculation is carried out to a certain alignment, after which the cells in the section are combined (enlarged), obtaining new average values of the concentration of the polluting substance and new linear parameters of the cell. The values of the concentrations of the contaminant are obtained as the arithmetic average of the sum of the concentrations of the combined cells. The enlargement of cells can be repeated several times, starting with a specific alignment.

There are no hydrological posts above Aktobe city, the data from the Institute of Hydrogeology and Geoecology after named U.M. Ahmedsafin on the project of water protection zones and strips on the Ilek river for 2010 [17, p.15]. The hydrological part of the project contains data on three gradations of frequency (Ilek river) in the alignment of the Aktobe reservoir - 95, 75 and 50%.

The data on the parameters of wedged out groundwater were taken from wedge calculations made on the basis of tabular and graphical material according to the results of groundwater monitoring of the Aktobe region for 2010-2012. These are the last available factual materials. In the previous section, we performed the calculations that will be used to construct a flat task with using the turbulent diffusion model.

The target of the Bestamak settlement, in which there is the "KazHydroMet" observation post, as well as the shore of the Aktobe reservoir closest to the research area, was chosen.

Calculations were performed for conditions of 50%, 75% and 95% frequency. The width of the river was assumed to be constant, equal to 30 m. When calculating the size of the blocks during their enlargement, the requirement (33) For the maximum size of the block width according to Δz .

Thus, with a river width of 30 m, Δz cannot exceed 3 m. The sizes Δx of the blocks are not changed by phased doubling, but are calculated by the relationship (19) between them. The calculation results of the model parameters are presented in Table 20.

The calculated		Frequency, %										
parameters	95	75	50									
1	2	3	4									
Qcp	7,17689	8,4834	11,302									
H _{cp}	1,22407	1,3037	1,44027									
V _{cp}	0,39088	0,43381	0,52314									
q	0,02216	0,02216	0,02216									
$n_{\iota\iota}$	0,04	0,04	0,04									

Table 20 – The flat task parameters of the spread of pollution in the watercourse

Continuation of the table 20

1	2	3	4
R	1,22407	1,3037	1,44027
у	0,28702	0,28437	0,27999
Chezy coefficient	26,4937	26,9583	27,6887
М	24,5456	24,8708	25,3821
D	0,00721	0,00827	0,01051
δ	0,05669	0,05108	0,04236
b	0,0181	0,017	0,01539
Δz	0,0181	0,017	0,01539
Δx	0,00888	0,00758	0,00589

The block size Δz for the initial condition determined before the block enlargement procedure turned out to be 0.0181 m, or 1.81 cm. To reflect the river width of 30 m, 1657 blocks will be required. It is clear that building a model with so many blocks is unrealistic. Therefore, the technique of gradual enlargement of blocks is usually used. The most common use is doubling the size of the block Δz , and then calculating the length of the block Δx corresponding to this doubled width is calculated using the coupling equation (24). Table 21 presents the calculations of the phased enlargement of the blocks.

	Frequency, %													
Stages	95	5	,	75	50									
	Δz	Δx	Δz	Δx	Δz	Δx								
0	0,0181	0,0088	0,017	0,0076	0,0154	0,0059								
1	0,0362	0,0356	0,034	0,0303	0,0308	0,0236								
2	0,0724	0,1421	0,068	0,1213	0,0615	0,0943								
3	0,1448	0,5685	0,136	0,4852	0,1231	0,3772								
4	0,2897	2,2742	0,272	1,9408	0,2462	1,5088								
5	0,5793	9,0966	0,5439	7,7631	0,49238	6,035								
6	1,1586	36,3864	1,0878	31,0525	0,9847	24,1402								
7	2,3172	145,546	2,1757	124,21	1,9694	96,5608								
8	4,6345		4,3514		3,9388									

Table 21 – The results of the calculation of the phased enlargement of the blocks of the turbulent diffusion model

The table 21 shows that the number of stages of unit enlargement for all three conditions should be limited to 7 stages, because Δz in the eighth stage takes values greater than 3 m, i.e. does not satisfy the requirements of the condition (33).

The control target was the Kazhydromet Alga 2 observation target located in the of Bestamak settlement. The length of the river, taking into account the tortuosity coefficient from the border of the pollution halo near the well №1574 to the settlement of Bestamak, determined by the hydrogeological map for 2012, is 8650 m. The length of the river, taking into account the tortuosity coefficient from the Bestamak settlement

to the Aktobe reservoir, is 12150 m. Thus, the total concentration of boron formed by groundwater wedging out into the focal zone will be diluted with water of Ilek river at a distance of 20800 m.

The length of the contaminated groundwater wedging out zone was 8288 m. The shape of the contamination center on the hydrogeological map with the ubiquitous presence of boron on the right bank was the justification for the double-sided pinch pattern. The discharge of wedging out groundwater water was 1914.528 m³/day, or 0.02216 m³/s. The removal of boron into the riverbed amounted to 44.49 kg/day. The weighted average concentration of boron is 61.5 g/m³. The position of the zero alignment is determined by the boundary of the halo of pollution.

To reveal the nature of dilution, the flat task of turbulent diffusion was solved in several versions, which are considered in the next subsection.

4.3 Calculations of dilution options in the Ilek river for wedging out of groundwater contaminated with boron for 95% of the flow rate of the Ilek river without background concentration

The task of left-bank wedging of groundwater with a weighted average concentration $61,5 \text{ mg/dm}^3$. The block size Δz for the initial condition determined before the block enlargement procedure (bases on the table 20) turned out to be 0.0181 m, or 1.81 cm. To reflect the river width of 30 m, 1657 blocks will be required. Due to the actual unreality of their full reflection, we consider the option of left bank wedging and trace the nature of dilution, taking into account the procedure of enlargement of blocks. The construction of the block model is presented in figure 15.



Figure 15 – Screen shot of the first stage of the task of dilution of groundwater contaminated with boron during left bank wedging with a weighted average concentration of boron for 95% frequency flow rate of the Ilek River

It can be seen from the Figure 15 that the simulation begins with the construction of the Z-axis (blocks along the width of the river, pink scale) and X (blocks along the

bank along the river, orange scale). The extrapolation wall is indicated in yellow, which makes it possible to implement the calculation equation for determining the distribution of the concentration of a pollutant along the length and width of the stream. At the first stage, pollution spreads at a distance of 14.48 cm from the shore after 18 steps along the stream through 13.35 cm.

At the stage of the first enlargement of the blocks, pollution extends already to a width of 0.8688 m with a length of 0.70150 m. The enlargement of the blocks continues until the sixth stage. This model showed that in the absence of background pollution in the Ilek river the initial concentration of 61.5 mg/dm³ is diluted to the MPC for boron (0.5 mg/dm³). That is to say, more than 300 times at a distance of only 10 m from the wedging, but a further decrease in concentrations is already slower – a similar decrease of 300 times (to 0.0017 mg/dm³) is observed at a distance of 990 m.

The task of left bank wedging out of groundwater with maximum concentration 115 mg/dm^3 . Let us check the effect of the wedging concentration on the change in the nature of turbulent dilution, which is presented in the figure 16.

- si	A	В	C	D	E	F	G	н	1	J	К	L	M	N	0	Р	Q	R	S	Т
1		Axis X		The border																
2	Axis Z			0	0,0181	0,0362	0,0543	0,0724	0,0905	0,1086	0,1267	0,1448	0,1629	0,181	0,1991	0,2172	0,2353	0,2534	0,2715	0,2896
3	0,0089	0	115	115	0	0	0	0	0	0	0	0	0	0	0					
4		0,00890	57.5	57.5	57,5	0	0	0	0	0	0	0	0	0	0					
5		0,01780	57,5	57,5	28,75	28,75	0	0	0	0	0	0	0	0	0					
6		0,02670	43,125	43,125	43,125	14,375	14,375	0	0	0	0	0	0	0	0					
7		0,03560	43,125	43,125	28,75	28,75	7,1875	7,1875	0	0	0	0	0	0	0					
8		0,04450	35,9375	35,9375	35,9375	17,96875	17,96875	3,59375	3,59375	0	0	0	0	0	0					
9		0,05340	35,9375	35,9375	26,95313	26,95313	10,78125	10,78125	1,796875	1,796875	0	0	0	0	0					
10		0,06230	31,4453125	31,44531	31,44531	18,86719	18,86719	6,289063	6,289063	0,898438	0,898438	0	0	0	0					
11		0,07120	31,4453125	31,44531	25,15625	25,15625	12,57813	12,57813	3,59375	3,59375	0,449219	0,449219	0	0	0	0	0	0	0	0
12		0,08010	28,3007813	28,30078	28,30078	18,86719	18,86719	8,085938	8,085938	2,021484	2,021484	0,224609	0,224609	0	0	0	0	0	0	0
13		0,08900	28,3007813	28,30078	23,58398	23,58398	13,47656	13,47656	5,053711	5,053711	1,123047	1,123047	0,112305	0,11230469	0	0	0	0	0	0
14		0,09790	25,9423828	25,94238	25,94238	18,53027	18,53027	9,265137	9,265137	3,088379	3,088379	0,617676	0,617676	0,05615234	0,05615234	0	0	0	0	0
15		0,10680	25,9423828	25,94238	22,23633	22,23633	13,89771	13,89771	6,176758	6,176758	1,853027	1,853027	0,336914	0,33691406	0,02807617	0,02807617	0	0	0	0
16		0,11570	24,0893555	24,08936	24,08936	18,06702	18,06702	10,03723	10,03723	4,014893	4,014893	1,094971	1,094971	0,18249512	0,18249512	0,01403809	0,01403809	0	0	0
17		0,12460	24,0893555	24,08936	21,07819	21,07819	14,05212	14,05212	7,026062	7,026062	2,554932	2,554932	0,638733	0,63873291	0,0982666	0,0982666	0,00701904	0,00701904	0	0
18		0,13350	22,5837708	22,58377	22,58377	17,56516	17,56516	10,53909	10,53909	4,790497	4,790497	1,596832	1,596832	0,36849976	0,36849976	0,05264282	0,05264282	0,00350952	0,003509521	0
19				22,58377		17,56516		10,53909		4,790497		1,596832		0,36849976		0,05264282		0,00350952		0
20		0,03620		0	0,0362	0,0724	0,1086	0,1448	0,181	0,2172	0,2534	0,2896	0,3258	0,362	0,3982	0,4344	0,4706	0,5068	0,543	0,5792
21	0,0355	0,13350	22,58377	22,58377	17,56516	10,53909	4,790497	1,596832	0,3685	0,052643	0,00351	0	0	0	0	0	0	0	0	0
22		0,16900	20,07446	20,07446	16,56143	11,17783	6,067963	2,579498	0,824738	0,186005	0,026321	0,001755	0	0	0	0	0	0	0	0
23		0,20450	18,31795	18,31795	15,62614	11,3147	6,878662	3,44635	1,382751	0,425529	0,09388	0,013161	0,000877	0	0	0	0	0	0	0
24		0,24000	16,97205	16,97205	14,81632	11,2524	7,380524	4,130707	1,93594	0,738316	0,219345	0,047379	0,00658	0,00043869	0	0	0	0	0	0
25		0,27550	15,89418	15,89418	14,11222	11,09842	7,691555	4,658232	2,434511	1,077642	0,392847	0,112963	0,023909	0,00329018	0,00021935	0	0	0	0	0
26		0,31100	15,00320	15,0032	13,4963	10,90189	7,878327	5,063033	2,867937	1,413679	0,595303	0,208378	0,058126	0,01206398	0,00164509	0,00010967	0	0	0	0
27		0,34650	14,24975	14,24975	12,95255	10,68732	7,982461	5,373132	3,238356	1,73162	0,811028	0,326715	0,110221	0,02988577	0,00608683	0,00082254	5,4836E-05	0	0	0
28		0,38200	13,60115	13,60115	12,46853	10,4675	8,030224	5,610409	3,552376	2,024692	1,029167	0,460625	0,1783	0,05815387	0,01535416	0,00307083	0,00041127	2,7418E-05	0	0
29		0,41750	13,03484	13,03484	12,03433	10,24938	8,038957	5,7913	3,817551	2,290772	1,242658	0,603734	0,259389	0,09682715	0,03061235	0,00788271	0,00154912	0,00020564	1,37091E-05	0
30		0,45300	12,53458	12,53458	11,64211	10,03664	8,02034	5,928254	4,041036	2,530105	1,447253	0,751024	0,35028	0,14500082	0,05235493	0,01608074	0,00404418	0,00078142	0,000102818	6,85E-06
31		0,48850	12,08835	12,08835	11,28561	9,831225	7,982448	6,030688	4,229179	2,744144	1,640564	0,898767	0,448012	0,20131767	0,08054078	0,02819955	0,00843108	0,0020735	0,000394136	5,14E-05
32		0,52400	11,68698	11,68698	10,95979	9,634031	7,930956	6,105813	4,387416	2,934872	1,821455	1,044288	0,550042	0,26427656	0,11475861	0,04448593	0,01513653	0,00441261	0,001062453	0,000199
33		0,55950	11,32338	11,32338	10,66051	9,445372	7,869922	6,159186	4,520342	3,104436	1,98958	1,185749	0,654282	0,33240035	0,15438125	0,06494757	0,02444927	0,00809949	0,002305694	0,000544
34		0,59500	10,99194	10,99194	10,38438	9,265214	7,802279	6,195132	4,631811	3,254961	2,145092	1,321931	0,759075	0,40433183	0,19867396	0,08941526	0,03652353	0,01337748	0,004321784	0,001203
35		0,63050	10,68816	10,68816	10,12858	9,093328	7,730173	6,217045	4,725047	3,388452	2,288446	1,452083	0,863132	0,47887425	0,24687354	0,11759874	0,05139637	0,02042266	0,007290225	0,0023
	·	15 слева без фона	115фон	150+фон 1	50 6ea 🔶 🛛	mpasa30 0	права 30+фо	н Двухсто	р 30ф+150ф	270 без фо	на 270фо	н 🕘		(4)						

Figure 16 – Screen shot of the first two stages of the task of diluting groundwater contaminated with boron during left bank wedging with a maximum boron concentration for 95% frequency flow rate of the Ilek River

Comparing the concentrations at the same points as in the first problem, we find out that with an increase in the wedging concentration of less than 2 times at the point where MPC was reached at 61.5 mg/dm³. This is a point between 9.67 and 10.25 m in which the concentration of boron was 2.05709201 and 1.9713412 mg/dm³, i.e. 2.0142 mg/dm³. Thus, the concentration of boron at this point is now no less than the MPC, but more than 4 times. MPC is now reached already at a distance of 70 m, i.e. 7 times further.

In other words, dilution processes are not a linear function of concentration, and prediction of the nature of dilution should be based on model building.

The task of right-bank wedging out of groundwater with a maximum concentration in the source of pollution 15 mg/dm³. The specifics of modeling the

right-bank wedging is due to the need to reconstruct the boundary conditions not by increasing the values in the river section blocks, but by decreasing them. In this case, traditional communication algorithms by the name of the previous cell do not work - Excel recognizes this as a possible error - a circular link. However, since some calculations are performed in the program, a thorough check of the values of the river width ranges reflected by the blocks along the Z-axis after each stage of enlargement is necessary.

Figure 17 shows a block model of turbulent dilution of the right-bank wedging.

	W	х	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	
4														0	7,5	7,5	7,5	0,00890	
5													0	3,75	3,75	7,5	7,5	0,01780	
6												0	1,875	1,875	5,625	5,625	5,625	0,02670	
7											0	0,9375	0,9375	3,75	3,75	5,625	5,625	0,03560	
8										0	0,46875	0,46875	2,34375	2,34375	4,6875	4,6875	4,6875	0,04450	
9									0	0,234375	0,234375	1,40625	1,40625	3,515625	3,515625	4,6875	4,6875	0,05340	
10								0	0,1171875	0,1171875	0,8203125	0,8203125	2,4609375	2,4609375	4,1015625	4,1015625	4,1015625	0,06230	
11							0	0,0585938	0,0585938	0,46875	0,46875	1,640625	1,640625	3,28125	3,28125	4,1015625	4,1015625	0,07120	
12						0	0,0292969	0,0292969	0,2636719	0,2636719	1,0546875	1,0546875	2,4609375	2,4609375	3,6914063	3,6914063	3,6914063	0,08010	
13					0	0,014648438	0,0146484	0,1464844	0,1464844	0,6591797	0,6591797	1,7578125	1,7578125	3,0761719	3,0761719	3,6914063	3,6914063	0,08900	
14				0	0,007324219	0,007324219	0,0805664	0,0805664	0,402832	0,402832	1,2084961	1,2084961	2,4169922	2,4169922	3,3837891	3,3837891	3,3837891	0,09790	
15			0	0,003662109	0,003662109	0,043945313	0,0439453	0,2416992	0,2416992	0,8056641	0,8056641	1,8127441	1,8127441	2,9003906	2,9003906	3,3837891	3,3837891	0,10680	
16		0	0,001831055	0,001831055	0,023803711	0,023803711	0,1428223	0,1428223	0,5236816	0,5236816	1,3092041	1,3092041	2,3565674	2,3565674	3,1420898	3,1420898	3,1420898	0,11570	
17	0	0,000915527	0,000915527	0,012817383	0,012817383	0,083312988	0,083313	0,333252	0,333252	0,9164429	0,9164429	1,8328857	1,8328857	2,7493286	2,7493286	3,1420898	3,1420898	0,12460	1
18		0,000915527		0,012817383		0,083312988		0,333252		0,9164429		1,8328857		2,7493286		3,1420898	3,1420898		
19	29,457	29,4932	29,5294	29,5656	29,6018	29,638	29,6742	29,7104	29,7466	29,7828	29,819	29,8552	29,8914	29,9276	29,9638	30		0,03620	
20								0	0,0009155	0,0128174	0,083313	0,333252	0,9164429	1,8328857	2,7493286	3,1420898	3,1420898	0,12460	
21	0	0	0	0	0	0	0	0,0004578	0,0064087	0,0421143	0,1730347	0,4998779	1,0830688	1,8328857	2,4874878	2,9457092	2,9457092	0,16010	
22	0	0	0	0	0	0	0,0002289	0,0032043	0,021286	0,0897217	0,2709961	0,6280518	1,1663818	1,7852783	2,3892975	2,7165985	2,7165985	0,19560	
23	0	0	0	0	0	0,000114441	0,0016022	0,0107574	0,046463	0,1461411	0,3588867	0,718689	1,206665	1,7778397	2,2509384	2,552948	2,552948	0,23110	
24	0	0	0	0	5,72205E-05	0,000801086	0,0054359	0,0240326	0,0784492	0,2026749	0,432415	0,7827759	1,2482643	1,7288017	2,1653938	2,4019432	2,4019432	0,26660	
25	0	0	0	2,86102E-05	0,000400543	0,002746582	0,0124168	0,0419426	0,1133537	0,2554321	0,4927254	0,8403397	1,2557888	1,7068291	2,0653725	2,2836685	2,2836685	0,30210	
26	0	0	1,43051E-05	0,000200272	0,001387596	0,006408691	0,0223446	0,0628853	0,1486874	0,3030396	0,5478859	0,8742571	1,2735844	1,6605806	1,9952488	2,1745205	2,1745205	0,33760	
27	0	7,15256E-06	0,000100136	0,000700951	0,003304482	0,011866093	0,034647	0,085516	0,1829624	0,3482866	0,5886483	0,9107351	1,2674189	1,6344166	1,9175506	2,0848846	2,0848846	0,37310	
28	3,57628E-06	5,00679E-05	0,000354052	0,001702309	0,006283522	0,018975735	0,048691	0,1088047	0,2169013	0,3858054	0,6295109	0,9280336	1,2725759	1,5924847	1,8596506	2,0012176	2,0012176	0,40860	
29	2,5034E-05	0,000178814	0,000876188	0,003318787	0,010339022	0,027487278	0,0638902	0,1327962	0,247305	0,4232061	0,6569195	0,9510434	1,2602592	1,5661132	1,7968512	1,9304341	1,9304341	0,44410	
30	9,0301E-05	0,000450611	0,0017488	0,005607605	0,015403032	0,03711462	0,0801417	0,1555976	0,2780011	0,4521123	0,6871247	0,9585893	1,2585783	1,5285552	1,7482737	1,8636426	1,8636426	0,47960	
31	0,000231564	0,000919551	0,003029108	0,008575916	0,021361113	0,047772378	0,0963561	0,1790714	0,3038549	0,4825629	0,7053508	0,9728515	1,2435722	1,503426	1,6960989	1,8059582	1,8059582	0,51510	
32	0,000482574	0,001630336	0,004747733	0,01219511	0,028174147	0,058858618	0,1134219	0,2001055	0,3308172	0,5046029	0,7277072	0,9744615	1,2381388	1,4698356	1,6546921	1,7510285	1,7510285	0,55060	
33	0,000874624	0,002615154	0,006912723	0,01646094	0,035526864	0,070798025	0,1294821	0,2221195	0,3523542	0,5292622	0,7395322	0,982923	1,2221485	1,4464154	1,610432	1,7028603	1,7028603	0,58610	
34	0,001433976	0,003893673	0,009538047	0,021219794	0,043629482	0,08250447	0,1464588	0,2409181	0,3756909	0,5459432	0,7560926	0,9808404	1,2146692	1,4162903	1,5746379	1,6566462	1,6566462	0,62160	
35	0,002180748	0,005486012	0,012556734	0,026583765	0,051862132	0,095044132	0,1617113	0,2610748	0,3934307	0,5658917	0,7633918	0,9853809	1,1985653	1,3946535	1,5364682	1,615642	1,615642	0,65710	
36	0,003134552	0,007368741	0,016034888	0,032209433	0,060813949	0,106786718	0,1780595	0,277571	0,4134833	0,5784112	0,7756363	0,9809786	1,1900172	1,3675168	1,5051478	1,5760551	1,5760551	0,69260	
37		0,011701814		0,046511691		0,142423098		0,3455271		0,6770238		1,0854979		1,4363323		1,5760551			
38	28,914	28,9864	29,0588	29,1312	29,2036	29,276	29,3484	29,4208	29,4932	29,5656	29,638	29,7104	29,7828	29,8552	29,9276	30		0,07240	
39				0	8,45175E-07	2,21073E-05	0,0002794	0,0021749	0,0117018	0,0465117	0,1424231	0,3455271	0,6770238	1,0854979	1,4363323	1,5760551	1,5760551	0,69260	
40	0	0	0	4,22588E-07	1,10536E-05	0,000140138	0,0010985	0,0059906	0,0243433	0,0770625	0,1960194	0,4097234	0,7155125	1,056678	1,3307765	1,5061937	1,5061937	0,69262	
41	0	0	2,11294E-07	5,52682E-06	7,02805E-05	0,000554767	0,0030654	0,0127209	0,0415265	0,1101813	0,2433929	0,455766	0,7332007	1,0231445	1,2814359	1,4184851	1,4184851	0,69264	
42	0	1,05647E-07	2,76341E-06	3,52459E-05	0,000280147	0,001567831	0,0066378	0,022296	0,0614511	0,1424597	0,2829737	0,4882968	0,7394552	1,0073183	1,2208148	1,3499605	1,3499605	0,69266	
43	5,28235E-08	1,3817E-06	1,76758E-05	0,000141455	0,000801538	0,003458984	0,0119319	0,0340445	0,0823779	0,1722124	0,3153783	0,5112144	0,7478076	0,980135	1,1786394	1,2853876	1,2853876	0,69268	
44	6,90852E-07	8,8643E-06	7,14184E-05	0,000409607	0,00180022	0,006366717	0,0187517	0,0471549	0,1031284	0,1988781	0,3417134	0,5315929	0,7456747	0,9632235	1,1327613	1,2320135	1,2320135	0,69271	
45	4,44536E-06	3,60546E-05	0,000209236	0,000935819	0,003388162	0,010275972	0,0267608	0,0609401	0,1230165	0,2224209	0,3652355	0,5436941	0,7474082	0,939218	1,0976185	1,1823874	1,1823874	0,69273	-

Figure 17 – Screen shot of the beginner two stages of the task of diluting groundwater contaminated with boron with right-bank wedging with a boron concentration of 15 g/m^3 for a 95% frequency flow rate of the Ilek River

Concentration from 15 to 2 mg/dm³ decreases already after 0.5 m, to maximum concentration limit – after 3 m, after 10 m it becomes equal to 0.25 mg/dm³ (0.5MPC). Complete purification (concentration 0.0001 mg/dm³) is achieved after 2120 m if there are no background concentrations in the river.

The dependence of the character of turbulent dilution on the concentration and wedging conditions of contaminated groundwater is shown in figure 18. Because a sharp decrease in concentrations occurs at the first stage, the dilution plot is shown in the diagram after the concentration at the first stages decreases to 4 g/m^3 .



Figure 18 – Diagrams of various options for diluting boron concentrations entering the Ilek river when groundwater is wedging out

The diagram shows that the flattening of the curves for different concentrations occurs at a distance of 50-75 m from the wedging area.

The task of double-sided wedging with concentrations of 115 mg/dm³ from the left bank and 15 mg/dm³ from the right bank river without background concentration. The task of bilateral wedging out is actually a combination of tasks 2 and 3 through 5 stages of enlargement of the blocks, when the entire width of the river turned out to be represented by 13 blocks. The upper part (up to 57.75 m) of the stream was considered in tasks 2 and 3. When combined, that part of the river width where the influence of right-sided wedging did not yet fall was transferred to the model without changes. A similar procedure was repeated on the right side of the river. In the blocks where the influence of both types of wedging was manifested, the concentrations formed according to the results of tasks 2 and 3. Thus, the boundary conditions for the problem of two-sided wedging were formed.

Figure 19 shows the results of the initial stage of turbulent mixing provided there is no background pollution in the Ilek river, and figure 20 shows the nature of the turbulent dilution of polluted groundwater at the stage of the last enlargement of the blocks.

	В	С	D	E	F	G	н	1	J	к	L	М	N	0	Р	Q	R	
1																		
2	2,3173		2,3173	4,6346	6,9519	9,2692	11,5865	13,7789	16,0962	18,4135	20,7308	23,0481	25,3654	27,6827	30	30	2,3173	
3	57,75448	0,5971299	0,5971299	0,568074	0,4887906	0,3792449	0,262515	0,159417	0,073599	0,019788	0,031856	0,0457892	0,0592	0,06901	0,07263	0,07263	57,75448	
4	60,07178	0,582602	0,582602	0,5429603	0,4736595	0,3756528	0,269331	0,168057	0,089603	0,0527275	0,0327886	0,045528	0,0573996	0,065915	0,07082	0,07082	60,07178	
5	62,38908	0,5627811	0,5627811	0,5281307	0,4593065	0,3714952	0,2718549	0,179467	0,1103923	0,0611958	0,0491278	0,0450941	0,0557215	0,0641098	0,0683675	0,0683675	62,38908	
6	64,70638	0,5454559	0,5454559	0,5110438	0,449813	0,3655807	0,2754811	0,1911236	0,1203314	0,07976	0,053145	0,0524246	0,054602	0,0620445	0,0662387	0,0662387	64,70638	
7	67,02368	0,5282499	0,5282499	0,4976344	0,4383123	0,362647	0,2783521	0,1979062	0,1354418	0,0867382	0,0660923	0,0538735	0,0572346	0,0604203	0,0641416	0,0641416	67,02368	
8	69,34098	0,5129421	0,5129421	0,4832811	0,4301407	0,3583322	0,2802766	0,206897	0,1423222	0,1007671	0,0703058	0,0616634	0,0571469	0,0606881	0,0622809	0,0622809	69,34098	
9	71,65828	0,4981116	0,4981116	0,4715414	0,4208066	0,3552087	0,2826146	0,2112994	0,153832	0,106314	0,0812152	0,0637263	0,0611758	0,0597139	0,0614845	0,0614845	71,65828	
10	73,97558	0,4848265	0,4848265	0,4594591	0,4133751	0,3517106	0,283254	0,2182233	0,1588067	0,1175236	0,0850202	0,0711955	0,0617201	0,0613301	0,0605992	0,0605992	73,97558	
11	76,29288	0,4721428	0,4721428	0,4491008	0,4055849	0,3483145	0,284967	0,2210304	0,1678735	0,1219134	0,0943596	0,0733701	0,0662628	0,0611597	0,0609647	0,0609647	76,29288	
12	78,61018	0,4606218	0,4606218	0,4388638	0,3987077	0,3452759	0,2846725	0,2264202	0,1714719	0,1311165	0,0976418	0,0803112	0,0672649	0,0636137	0,0610622	0,0610622	78,61018	
13	80,92748	0,4497428	0,4497428	0,4296647	0,3920699	0,3416901	0,2858481	0,2280722	0,1787684	0,1345569	0,1057138	0,0824534	0,0719625	0,0641635	0,062338	0,062338	80,92748	
14	83,24478	0,4397038	0,4397038	0,4209063	0,3856774	0,338959	0,2848811	0,2323082	0,1813145	0,1422411	0,1085051	0,0888382	0,0733084	0,0671502	0,0632507	0,0632507	83,24478	
15	85,56208	0,4303051	0,4303051	0,4126906	0,3799327	0,3352793	0,2856336	0,2330978	0,1872747	0,1449098	0,1155396	0,0909068	0,0779942	0,0682796	0,0652005	0,0652005	85,56208	
16	87,87938	0,4214978	0,4214978	0,4051189	0,3739849	0,3327831	0,2841885	0,2364541	0,1890038	0,1514071	0,1179083	0,0967669	0,0795932	0,0715973	0,06674	0,06674	87,87938	
17	90,19668	0,4133083	0,4133083	0,3977414	0,368951	0,3290867	0,2846186	0,2365962	0,1939306	0,1534561	0,124087	0,0987507	0,0841821	0,0731666	0,0691687	0,0691687	90,19668	
18	92,51398	0,4055249	0,4055249	0,3911297	0,3634141	0,3267848	0,2828415	0,2392746	0,1950261	0,1590088	0,1261034	0,1041346	0,0859587	0,0766754	0,0711676	0,0711676	92,51398	
19	94,83128	0,3983273	0,3983273	0,3844695	0,3589572	0,3231278	0,2830297	0,2389338	0,1991417	0,1605648	0,1315717	0,106031	0,090405	0,0785632	0,0739215	0,0739215	94,83128	
20	97,14858	0,3913984	0,3913984	0,3786422	0,3537986	0,3209935	0,2810308	0,2410857	0,1997493	0,1653567	0,1332979	0,1109883	0,0922971	0,0821633	0,0762423	0,0762423	97,14858	
21	99,46588	0,3850203	0,3850203	0,3725985	0,3498179	0,3174147	0,2810396	0,24039	0,2032212	0,1665236	0,1381725	0,1127975	0,0965758	0,0842697	0,0792028	0,0792028	99,46588	
22	101,78318	0,3788094	0,3788094	0,3674191	0,3450066	0,3154287	0,2789024	0,2421304	0,2034568	0,1706969	0,1396605	0,1173742	0,0985336	0,0878893	0,0817363	0,0817363	101,78318	
23	104,10048	0,3731142	0,3731142	0,361908	0,3414239	0,3119545	0,2787796	0,2411796	0,2064136	0,1715587	0,1440355	0,1190971	0,1026317	0,0901349	0,0848128	0,0848128	104,10048	
24	106,41778	0,3675111	0,3675111	0,3572691	0,3369312	0,3101017	0,276567	0,2425966	0,2063691	0,1752246	0,1453279	0,1233336	0,104616	0,0937223	0,0874739	0,0874739	106,41778	
25	108,73508	0,3623901	0,3623901	0,3522212	0,3336854	0,3067491	0,2763492	0,2414681	0,2089106	0,1758485	0,1492791	0,1249719	0,1085279	0,0960449	0,0905981	0,0905981	108,73508	
26	111,05238	0,3573056	0,3573056	0,3480377	0,3294851	0,3050173	0,2741086	0,2426299	0,2086583	0,1790948	0,1504102	0,1289035	0,1105084	0,099563	0,0933215	0,0933215	111,05238	
27	113,36968	0,3526717	0,3526717	0,3433954	0,3265275	0,3017969	0,2738236	0,2413834	0,2108624	0,1795343	0,1539992	0,1304593	0,1142333	0,101915	0,0964422	0,0964422	113,36968	
28	115,68698	0,3480335	0,3480335	0,3395996	0,3225961	0,3001756	0,2715902	0,242343	0,2104588	0,1824308	0,1549968	0,1341162	0,1161871	0,1053378	0,0991786	0,0991786	115,68698	
29	118,00428	0,3438166	0,3438166	0,3353148	0,3198876	0,2970931	0,2712593	0,2410245	0,2123869	0,1827278	0,1582735	0,135592	0,119727	0,1076829	0,1022582	0,1022582	118,00428	
30	120,32158	0,3395657	0,3395657	0,3318521	0,316204	0,2955734	0,2690588	0,2418231	0,2118762	0,1853302	0,1591599	0,1390002	0,1216374	0,1109926	0,1049705	0,1049705	120,32158	
31	122,63888	0,3357089	0,3357089	0,3278848	0,3137127	0,2926314	0,2686982	0,2404675	0,2135766	0,185518	0,1621652	0,1403987	0,1249964	0,113304	0,1079816	0,1079816	122,63888	
32	124,95618	0,3317969	0,3317969	0,3247108	0,3102581	0,2912055	0,2665495	0,2411374	0,2129928	0,1878709	0,1629583	0,1435808	0,1268513	0,116489	0,1106428	0,1106428	124,95618	
33	127,27348	0,3282538	0,3282538	0,3210275	0,3079582	0,2884038	0,2661715	0,2397711	0,2145042	0,1879756	0,1657259	0,1449048	0,1300349	0,118747	0,1135659	0,1135659	127,27348	
34	129,59078	0,3246407	0,3246407	0,318106	0,3047156	0,2870648	0,2640874	0,2403378	0,2138733	0,190115	0,1664402	0,1478804	0,1318259	0,1218004	0,1161565	0,1161565	129,59078	
35	131,90808	0,3213733	0,3213733	0,3146782	0,3025854	0,2844015	0,2637013	0,2389804	0,2152264	0,1901568	0,1689977	0,1491331	0,1348404	0,1239912	0,1189784	0,1189784	131,90808	
36		0,3180257	0,3180257	0,3119794	0,2995399	0,2831434	0,261691	0,2394639	0,2145686	0,1921121	0,1696449	0,151919	0,1365621	0,1269094	0,1214848	0,1214848	134,22538	
37	136,54268	0,3150026	0,3150026	0,3087828	0,2975614	0,2806154	0,2613036	0,2381298	0,215788	0,1921067	0,1720156	0,1531035	0,1394142	0,1290235	0,1241971	0,1241971	136,54268	
20	120.05000	0.2110027	0.2110027	0.206202	0.0046001	0.0704226	0.2502726	0.0006460	0.0161102	0.1020010	0.1736061	0.16671.40	0.1.410626	0.1210057	0 1066102	0.1266102	120.05000	JL¥.

Figure 19 – Screen shot of the last stage of the task of joint mixing and dilution of groundwater contaminated with boron with two-sided wedging for 95% frequency flow rate of the Ilek River



Figure 20 – The character of the turbulent dilution of polluted groundwater at the stage of the last enlargement of model blocks

The last figure 20 demonstrates the effect of the interaction of the processes of dilution of groundwater wedging from opposite shores. The prevailing role of high concentration in this interaction is manifested in a unidirectional successive decrease. The right-bank concentration of boron was constantly decreasing at all stages of

enlargement of the model blocks, except the last. Here, after a short-term decline, its growth began under the influence of the spread of high concentration from the left bank. The result of this interaction is the equalization of concentrations over the entire width of the river at the level of 0.2 mg/dm^3 , i.e. at a concentration of 2.5 times lower than the concentration of MPC.

Of course, such a low leveling concentration is due to the absence of the influence of the background pollution of the river, which was taken as zero for studying the character of dilution from wedged groundwater.

Overall, the results of modeling turbulent dilution processes have shown that the equalization of concentrations over the entire width of the river occurs rather quickly - 500 m below the wedging zone.

4.4 Assessment of the frequency flow rate effect on dilution of left-side wedging concentration and background concentration

Earlier in the dissertation, it was noted that we were forced to build models and calculations according to groundwater monitoring data for 2012 due to the restriction to later data. Nevertheless, even according to these data, it was possible to identify the exit of the pollution front from the new sludge collector. Section 3.4. the reliability of this conclusion is justified by a sharp increase in boron concentration in the Ilek River at the Alga 2 post.

Above (Section 4.3), experimental calculations were performed in the range of concentrations of groundwater wedging into the Ilek River. Since the new sludge collector can make very noticeable changes in the concentration of groundwater, it is necessary to consider this fact in further experimental calculations. Increased boron concentration from 2016 to 2018 in paragraph Alga 2, it was noted from 0.3 to 1.2 mg/dm³, i.e. 4 times, and from 2016 to 2017, the concentration of boron increased from 0.3 to 0.3 to 0.7 mg/dm³, and in the period 2017-2018 - from 0.7 to 1.2 mg/dm³. Therefore, as concentrations of wedging, we consider the values of 150 and 270 mg/dm³.

There are held on the assessment of the effect of frequency flow rate on dilution of left-side wedging concentration 270 mg/dm^3 and background concentration of 0.37 mg/dm³.

- 24	A	В	C	D	E	F	G	Н	T.	J	K	L	M	N	0	P	Q	R	S	Т	U	V A
1		Axis X		The border																		
2 /	Axis Z			0	0,0181	0,0362	0,0543	0,0724	0,0905	0,1086	0,1267	0,1448	0,1629	0,181	0,1991	0,2172	0,2353	0,2534	0,2715	0,2896	0,3077	0,32
3	0,0089	0	270	270	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
4		0,00890	135	135	135	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
5		0,01780	135	135	67,5	67,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
6		0,02670	101,25	101,25	101,25	33,75	33,75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
7		0,03560	101,25	101,25	67,5	67,5	16,875	16,875	0	0	0	0	0	0	0	0	0	0	0	0	0	
8		0,04450	84,375	84,375	84,375	42,1875	42,1875	8,4375	8,4375	0	0	0	0	0	0	0	0	0	0	0	0	
9		0,05340	84,375	84,375	63,28125	63,28125	25,3125	25,3125	4,21875	4,21875	0	0	0	0	0	0	0	0	0	0	0	
10		0,06230	73,828125	73,828125	73,828125	44,296875	44,296875	14,765625	14,765625	2,109375	2,109375	0	0	0	0	0	0	0	0	0	0	
11		0,07120	73,828125	73,828125	59,0625	59,0625	29,53125	29,53125	8,4375	8,4375	1,0546875	1,0546875	0	0	0	0	0	0	0	0	0	
12		0,08010	66,4453125	66,445313	66,445313	44,296875	44,296875	18,984375	18,984375	4,7460938	4,7460938	0,5273438	0,52734375	0	0	0	0	0	0	0	0	
13		0,08900	66,4453125	66,445313	55,371094	55,371094	31,640625	31,640625	11,865234	11,865234	2,6367188	2,6367188	0,263671875	0,263671875	0	0	0	0	0	0	0	
14		0,09790	60,90820313	60,908203	60,908203	43,505859	43,505859	21,75293	21,75293	7,2509766	7,2509766	1,4501953	1,450195313	0,131835938	0,131835938	0	0	0	0	0	0	
15		0,10680	60,90820313	60,908203	52,207031	52,207031	32,629395	32,629395	14,501953	14,501953	4,3505859	4,3505859	0,791015625	0,791015625	0,065917969	0,065917969	0	0	0	0	0	
16		0,11570	56,55761719	56,557617	56,557617	42,418213	42,418213	23,565674	23,565674	9,4262695	9,4262695	2,5708008	2,570800781	0,428466797	0,428466797	0,032958984	0,032958984	0	0	0	0	
17		0,12460	56,55761719	56,557617	49,487915	49,487915	32,991943	32,991943	16,495972	16,495972	5,9985352	5,9985352	1,499633789	1,499633789	0,230712891	0,230712891	0,016479492	0,016479492	0	0	0	
18		0,13350	53,02276611	53,022766	53,022766	41,239929	41,239929	24,743958	24,743958	11,247253	11,247253	3,7490845	3,749084473	0,86517334	0,86517334	0,123596191	0,123596191	0,008239746	0,008239746	0	0	
19				53,022766		41,239929		24,743958		11,247253		3,7490845		0,86517334		0,123596191		0,008239746		0		
20		0,03620		0	0,0362	0,0724	0,1086	0,1448	0,181	0,2172	0,2534	0,2896	0,3258	0,362	0,3982	0,4344	0,4706	0,5068	0,543	0,5792	0,6154	0,65
21	0,0355	0,13350	53,02277	53,022766	41,239929	24,743958	11,247253	3,7490845	0,8651733	0,1235962	0,0082397	0	0	0	0	0	0	0	0	0	0	
22		0,16900	47,13135	47,131348	38,883362	26,243591	14,246521	6,0562134	1,9363403	0,4367065	0,0617981	0,0041199	0	0	0	0	0	0	0	0	0	
23		0,20450	43,00735	43,007355	36,687469	26,564941	16,149902	8,0914307	3,24646	0,9990692	0,2204132	0,030899	0,002059937	0	0	0	0	0	0	0	0	
24		0,24000	39,84741	39,847412	34,786148	26,418686	17,328186	9,6981812	4,5452499	1,7334366	0,5149841	0,1112366	0,015449524	0,001029968	0	0	0	0	0	0	0	
25		0,27550	37,31678	37,31678	33,133049	26,057167	18,058434	10,936718	5,7158089	2,530117	0,9223366	0,2652168	0,05613327	0,007724762	0,000514984	0	0	0	0	0	0	
26		0,31100	35,22491	35,224915	31,686974	25,595741	18,496943	11,887121	6,7334175	3,3190727	1,3976669	0,4892349	0,136470795	0,028324127	0,003862381	0,000257492	0	0	0	0	0	
27		0,34650	33,45594	33,455944	30,410328	25,091958	18,741431	12,61518	7,603097	4,0655422	1,9041538	0,7670689	0,258779526	0,070166588	0,01429081	0,00193119	0,000128746	0	0	0	0	
28		0,38200	31,93314	31,933136	29,273951	24,57588	18,853569	13,172264	8,3403611	4,7536254	2,4163055	1,0814667	0,418617725	0,136535168	0,036048889	0,007209778	0,000965595	6,4373E-05	0	0	0	
29		0,41750	30,60354	30,603544	28,254508	24,06376	18,874072	13,596965	8,9629447	5,3783333	2,917546	1,4174616	0,609000921	0,227333307	0,071872473	0,018507242	0,003637075	0,000482798	3,21865E-05	0	0	
30		0,45300	29,42903	29,429026	27,333652	23,56429	18,830363	13,918508	9,4876492	5,9402454	3,3978975	1,7632735	0,82239747	0,340436697	0,122920275	0,037754774	0,00949502	0,001834631	0,000241399	1,60933E-05	0	
31		0,48850	28,38134	28,381339	26,496658	23,082007	18,741399	14,159006	9,9293768	6,4427733	3,8517594	2,1101475	1,051855087	0,472658873	0,189095736	0,066207647	0,019794703	0,004868209	0,000925362	0,000120699	8,04663E-06	
32		0,52400	27,43900	27,438998	25,731673	22,619028	18,620507	14,335388	10,30089	6,8905681	4,2764604	2,4518073	1,291403174	0,620475411	0,26943326	0,104445219	0,035537928	0,010360032	0,002494454	0,000466704	6,03497E-05	4,02331E
33		0,55950	26,58534	26,585336	25,029013	22,17609	18,477208	14,460698	10,612978	7,288675	4,6711877	2,7839318	1,536141336	0,780418217	0,362460315	0,152485594	0,057402626	0,019016191	0,005413368	0,001277402	0,000235364	3,01749E
34		0,59500	25,80717	25,807174	24,380713	21,753111	18,318394	14,545093	10,874687	7,6420829	5,0363034	3,1036645	1,782175004	0,949300826	0,466451906	0,20993147	0,085750893	0,031407997	0,010146797	0,002824366	0,000653788	0,0001180
35		0,63050	25,09394	25,093944	23,780143	21,349553	18,149102	14,59654	11,093588	7,955495	5,3728737	3,4092392	2,026482671	1,124313455	0,579616148	0,276101399	0,120669734	0,047948845	0,017116182	0,005400293	0,001471527	0,0003344
36		0,66600	24,43704	24,437043	23,221748	20,964622	17,973047	14,621345	11,276018	8,2332308	5,6823671	3,6996782	2,266776329	1,30304941	0,700207427	0,350142941	0,162025122	0,068892958	0,026674569	0,009293854	0,002867365	0,0007656
37		0,70150	23,82940	23,829396	22,700833	20,597398	17,792984	14,624532	11,427288	8,4791923	5,9664545	3,9745717	2,501363796	1,483491878	0,826596175	0,431116275	0,209517949	0,094349845	0,039093406	0,014770967	0,005029771	0,0015191
38			23,26511	23,265114		19,195191		13,02591		7,2228234		3,2379678		1,155044027		0,320317112		0,066721626		0,009900369		0,0009585
39		0,07240		0	0,0724	0,1448	0,2172	0,2896	0,362	0,4344	0,5068	0,5792	0,6516	0,724	0,7964	0,8688	0,9412	1,0136	1,086	1,1584	1,2308	1,3(-
4		115 слева без ф	она 115фо	он 150+ф	он 150 б	ез ф 🛛 спра	ава30 Сп	рава 30+фо	н Двухст	op 30 φ +150	φ 270 6e	ез фона 2	70фон (+		•							Þ
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Figure 21 - A screenshot of the first two stages of the dilution of groundwater contaminated with boron during left-bank wedging with a boron concentration of 270 mg/m³ for a 95% frequency flow rate of the Ilek River without background concentration

1		Axis X		The border											
2	Axis Z			0	0,0181	0,0362	0,0543	0,0724	0,0905	0,1086	0,1267	0,1448	0,1629	0,181	0,1991
3	0,0089	0	270	270	0,37	0,37	0,37	0,37	0,37	0,37	0,37	0,37	0,37	0,37	0,37
4		0,00890	135,185	135,185	135,185	0,37	0,37	0,37	0,37	0,37	0,37	0,37	0,37	0,37	0,37
5		0,01780	135,185	135,185	67,7775	67,7775	0,37	0,37	0,37	0,37	0,37	0,37	0,37	0,37	0,37
6		0,02670	101,48125	101,48125	101,48125	34,07375	34,07375	0,37	0,37	0,37	0,37	0,37	0,37	0,37	0,37
7		0,03560	101,48125	101,48125	67,7775	67,7775	17,221875	17,221875	0,37	0,37	0,37	0,37	0,37	0,37	0,37
8		0,04450	84,629375	84,629375	84,629375	42,499688	42,499688	8,7959375	8,7959375	0,37	0,37	0,37	0,37	0,37	0,37
9		0,05340	84,629375	84,629375	63,564531	63,564531	25,647813	25,647813	4,5829688	4,5829688	0,37	0,37	0,37	0,37	0,37
10		0,06230	74,09695313	74,096953	74,096953	44,606172	44,606172	15,115391	15,115391	2,4764844	2,4764844	0,37	0,37	0,37	0,37
11		0,07120	74,09695313	74,096953	59,351563	59,351563	29,860781	29,860781	8,7959375	8,7959375	1,4232422	1,4232422	0,37	0,37	0,37
12		0,08010	66,72425781	66,724258	66,724258	44,606172	44,606172	19,328359	19,328359	5,1095898	5,1095898	0,8966211	0,896621094	0,37	0,37
13		0,08900	66,72425781	66,724258	55,665215	55,665215	31,967266	31,967266	12,218975	12,218975	3,0031055	3,0031055	0,633310547	0,633310547	0,37
14		0,09790	61,19473633	61,194736	61,194736	43,81624	43,81624	22,09312	22,09312	7,61104	7,61104	1,818208	1,818208008	0,501655273	0,501655273
15		0,10680	61,19473633	61,194736	52,505488	52,505488	32,95468	32,95468	14,85208	14,85208	4,714624	4,714624	1,159931641	1,159931641	0,435827637
16		0,11570	56,8501123	56,850112	56,850112	42,730084	42,730084	23,90338	23,90338	9,7833521	9,7833521	2,9372778	2,937277832	0,797879639	0,797879639
17		0,12460	56,8501123	56,850112	49,790098	49,790098	33,316732	33,316732	16,843366	16,843366	6,3603149	6,3603149	1,867578735	1,867578735	0,600396729
18		0,13350	53,32010529	53,320105	53,320105	41,553415	41,553415	25,080049	25,080049	11,601841	11,601841	4,1139468	4,113946838	1,233987732	1,233987732
19				53,320105		41,553415		25,080049		11,601841		4,1139468		1,233987732	
20		0,03620		0	0,0362	0,0724	0,1086	0,1448	0,181	0,2172	0,2534	0,2896	0,3258	0,362	0,3982
21	0,0355	0,13350	53,32011	53,320105	41,553415	25,080049	11,601841	4,1139468	1,2339877	0,4934268	0,3782285	0,37	0,37	0,37	0,37
22		0,16900	47,43676	47,43676	39,200077	26,577628	14,596998	6,4179141	2,3036868	0,8061081	0,4317134	0,3741142	0,37	0,37	0,37
23		0,20450	43,31842	43,318419	37,007194	26,898538	16,497771	8,4503424	3,6120111	1,3677001	0,5901112	0,4008567	0,372057114	0,37	0,37
24		0,24000	40,16281	40,162806	35,108478	26,752483	17,67444	10,054891	4,9090213	2,1010611	0,8842784	0,4810841	0,385428352	0,371028557	0,37
25		0,27550	37,63564	37,635642	33,457644	26,391459	18,403687	11,291731	6,0779761	2,8966498	1,2910726	0,6348534	0,426056347	0,377714176	0,370514278
26		0,31100	35,54664	35,546643	32,013551	25,930666	18,841595	12,240831	7,0941902	3,6845244	1,7657516	0,8585645	0,506283779	0,398285313	0,373857088
- 17	→ 115 сле	ева без фона 115фон	150+фон 150	без ф справа30	Справа 30+ф	он Двухстор 3	0q+150q 270	без фона 270ф	он ⊕	1 4200700	0 0715444	1 12/0177	0.(20121002	0 440070424	0.204271226

Figure 22 – Screenshot of the first two stages of the dilution of groundwater contaminated with boron during left-bank wedging with boron concentration of 270 g/m³ for 95% frequency flow rate of the Ilek River with 0,37 mg/m³ background concentration

Repeating the modeling procedures for different frequency flow rate of the Ilek River, we obtain the following table 22 for control points.

Frequency, %	Dilution conc background	centrations without in points, mg/dm ³	Dilution concentrations with background in points, mg/dm ³					
	Bestamak	Aktobe reservoir	Bestamak	Aktobe reservoir				
95	0,215	0,178	0,587	0,556				
75	0,202	0,171	0,572	0,534				
50	0,179	0,152	0,54	0,52				

Table 22 – Predicted concentrations for control points with different frequency flow rates of the Ilek River

A comparison of the data on dilution concentrations in Bestamak and at the entrance to the Aktobe reservoir shows a logical result - a decrease in concentrations for both points with a decrease in the percentage of availability, i.e. with increasing runoff of the Ilek river. This regularity is satisfied both in the absence of runoff, and in the presence of it.

At the same time, it is noteworthy that in the absence of a background with any security, the concentration at the point Alga 2 (Bestamak) is more than two times lower than the maximum permissible concentration, and when approaching the reservoir, it is already one third of the maximum permissible concentration. If such cases were possible, we would not have to talk about the problem of pollution of the river and the reservoir.

However, taking into account the background concentration immediately demonstrates the opposite effect: for any flow rate at both points, the concentration exceeds the MPC, so we dwell on the role of the background concentration.

4.5 Assessment of the effect of background pollution on the nature of the turbulent dilution of contaminated groundwater wedging out into the Ilek River for 95% frequency flow rate

The block sizes of the flat task problem of the turbulent diffusion model was taken for 95% frequency. Figure 23 shows a visual solution for diluting 150 mg/dm³ in the problem without background pollution, and in figure 24 - with the background.



Figure 23 – Screenshot of the first two stages of the task of diluting groundwater contaminated with boron during left-bank wedging out with a boron concentration of 150 g/m³ for 95% frequency flow rate of the Ilek River without background

concentration

1		Axis X		The border	-	10						-			-	1	1		-
2	Acxis Z		2	0	0.0181	0.0362	0.0543	0,0724	0.0905	0,1086	0.1267	0.1448	0,1629	0,181	0,1991	0,2172	0,2353	0.2534	0,2715
3	0.0089	0	150	150	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
4	0,0000	0.00890	75.185	75.185	75.185	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
5		0.01780	75.185	75.185	37.7775	37.7775	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
6		0.02670	56.48125	56.48125	56.48125	19.07375	19.07375	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
7		0.03560	56.48125	56.48125	37,7775	37,7775	9.721875	9.721875	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
8		0.04450	47,129375	47,12938	47.12938	23,74969	23,74969	5.045938	5.045938	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
9		0,05340	47,129375	47,12938	35,43953	35,43953	14,39781	14,39781	2,707969	2,707969	0,37	0,37	0,37	0,37	0,37	0,37	0,37	0,37	0,37
10		0,06230	41,2844531	41,28445	41,28445	24,91867	24,91867	8,552891	8,552891	1,538984	1,538984	0,37	0,37	0.37	0.37	0,37	0,37	0.37	0,37
11		0,07120	41,2844531	41,28445	33,10156	33,10156	16,73578	16,73578	5,045938	5,045938	0,954492	0,954492	0,37	0,37	0,37	0,37	0,37	0,37	0,37
12		0,08010	37,1930078	37,19301	37,19301	24,91867	24,91867	10,89086	10,89086	3,000215	3,000215	0,662246	0,662246094	0,37	0,37	0,37	0,37	0,37	0,37
13		0,08900	37,1930078	37,19301	31,05584	31,05584	17,90477	17,90477	6,945537	6,945537	1,83123	1,83123	0,516123047	0,51612305	0,37	0,37	0,37	0,37	0,37
14		0,09790	34,1244238	34,12442	34,12442	24,4803	24,4803	12,42515	12,42515	4,388384	4,388384	1,173677	1,173676758	0,44306152	0,44306152	0,37	0,37	0,37	0,37
15		0,10680	34,1244238	34,12442	29,30236	29,30236	18,45273	18,45273	8,406768	8,406768	2,78103	2,78103	0,808369141	0,80836914	0,40653076	0,406530762	0,37	0,37	0,37
16		0,11570	31,7133936	31,71339	31,71339	23,87755	23,87755	13,42975	13,42975	5,593899	5,593899	1,7947	1,794699707	0,60744995	0,60744995	0,388265381	0,388265381	0,37	0,37
17		0,12460	31,7133936	31,71339	27,79547	27,79547	18,65365	18,65365	9,511823	9,511823	3,694299	3,694299	1,201074829	1,20107483	0,49785767	0,497857666	0,37913269	0,379133	0,37
18		0,13350	29,7544315	29,75443	29,75443	23,22456	23,22456	14,08273	14,08273	6,603061	6,603061	2,447687	2,447687073	0,84946625	0,84946625	0,438495178	0,438495178	0,374566	0,37456635
19				29,75443		23,22456		14,08273		6,603061		2,447687		0,84946625		0,438495178		0,374566	
20		0,03620		0	0,0362	0,0724	0,1086	0,1448	0,181	0,2172	0,2534	0,2896	0,3258	0,362	0,3982	0,4344	0,4706	0,5068	0,543
21	0,0355	0,13350	29,75443	29,75443	23,22456	14,08273	6,603061	2,447687	0,849466	0,438495	0,374566	0,37	0,37	0,37	0,37	0,37	0,37	0,37	0,37
22		0,16900	26,48949	26,48949	21,91858	14,91381	8,265211	3,726264	1,443091	0,612016	0,404248	0,372283	0,37	0,37	0,37	0,37	0,37	0,37	0,37
23		0,20450	24,20404	24,20404	20,70165	15,0919	9,320037	4,854151	2,16914	0,923669	0,49215	0,387124	0,371141586	0,37	0,37	0,37	0,37	0,37	0,37
24		0,24000	22,45285	22,45285	19,64797	15,01084	9,973024	5,744588	2,88891	1,330645	0,655397	0,431646	0,378561897	0,37057079	0,37	0,37	0,37	0,37	0,37
25		0,27550	21,05041	21,05041	18,73184	14,8105	10,37772	6,430967	3,537617	1,772153	0,881145	0,516979	0,401108227	0,37428095	0,3702854	0,37	0,37	0,37	0,37
26		0,31100	19,89113	19,89113	17,93045	14,55478	10,62073	6,957666	4,10156	2,209381	1,144566	0,641127	0,445630093	0,38569681	0,37214047	0,370142698	0,37	0,37	0,37
27		0,34650	18,91079	18,91079	17,22295	14,27559	10,75622	7,361146	4,583524	2,623063	1,425254	0,795098	0,513411779	0,40888528	0,37791975	0,371070237	0,370071349	0,37	0,37
28		0,38200	18,06687	18,06687	16,59319	13,98959	10,81837	7,669874	4,992105	3,004389	1,709081	0,969333	0,601991742	0,44566577	0,38997776	0,373995552	0,370535119	0,370036	0,37
29		0,41750	17,33003	17,33003	16,02823	13,70578	10,82973	7,905237	5,337131	3,350593	1,986861	1,155536	0,707499288	0,49598475	0,40983066	0,380256439	0,372015613	0,370268	0,37001784
30		0,45300	16,67913	16,67913	15,5179	13,42898	10,80551	8,083431	5,627915	3,661996	2,253064	1,34718	0,825760494	0,55866497	0,4381206	0,390923136	0,375261999	0,371017	0,37013378
31		0,48850	16,09852	16,09852	15,05406	13,16171	10,75621	8,216711	5,872714	3,94049	2,504588	1,539412	0,952922506	0,63194054	0,47479406	0,406691297	0,380969931	0,372698	0,37051282
32		0,52400	15,57629	15,57629	14,63011	12,90513	10,68921	8,31446	6,0786	4,188651	2,739951	1,728755	1,085676507	0,71385828	0,51931592	0,427881993	0,389694593	0,375741	0,37138239
33		0,55950	15,10320	15,1032	14,24071	12,65966	10,6098	8,383905	6,251555	4,409276	2,958703	1,912814	1,221306771	0,80249621	0,57087014	0,454505257	0,401811685	0,380538	0,37300001
34		0,59500	14,67195	14,67195	13,88143	12,42525	10,52178	8,430675	6,39659	4,605129	3,161045	2,090005	1,357654985	0,89608845	0,62850074	0,486340911	0,417521874	0,387406	0,3756232
35		0,63050	14,27669	14,27669	13,5486	12,20161	10,42796	8,459186	6,517902	4,778817	3,347567	2,25935	1,493046675	0,99307786	0,69121468	0,523011305	0,436873379	0,396573	0,37948553
	2 .m.	15 слева без фона	115фон	150 - фон 1	50 6es ф 🔤 c	npasa30 c	Справа 30+фо	н Двужсто	р 30ф+150ф	270 Ges ф	эна 270фо	•	1 4	0					

Figure 24 – Screenshot of the first two stages of the task of diluting groundwater contaminated with boron during left-bank wedging out with a boron concentration of 150 g/m³ for 95% frequency flow rate of the Ilek River and 0.37 mg/dm³ background concentration

As can be seen from the figure, in the absence of a background, only 10 cm from the wedging out zone, the concentration decreases from 150 to 33.84 g/m³, and with a background concentration of 34.12 g/m³, i.e. almost 5 times, but the background slightly reduces the rate of dilution at this distance. In the Bestamak area (after 8600 m), the influence of the background is already very strong - 0.12 g/m³ without a background and 0.49 g/m³ with a background. When approaching the Aktobe reservoir, the concentration decreases to 0.1 and 0.47 g/m³, respectively.



Figure 25 - A chart comparing the spatial dynamics of dilution of groundwater contaminated with boron during left bank wedging with a boron concentration of 150 g/m³ with and without background concentration

The chart first reflects an increasing (figure 25), and after 200 m, almost constant distance between the dilution curves for wedging options with and without background concentration. Thus, the influence of the background affects distances greater than 100 m when diluted concentrations approach 1 g/m³. The difference in concentrations after flattening the curves is almost equal to the background concentration. Thus, this result allows us to simplify and speed up the modeling process, because implementing a model with a background takes much more time. Knowing the character of dilution without a background concentration, it is simple to calculate at the required points (after 100 m from the wedging zone) by adding the value of this background to model concentrations without a background.

In our case, we considered a background concentration equal to 0.37 g/m^3 and obtained a concentration of 0.49 g/m^3 in paragraph Alga 2. Consequently, a very small change in the background concentration (for example, to 0.39 mg/dm^3) will reduce the ecological capacity of the Ilek River to an unacceptable value - an excess of the MPC for boron and an increase in pollution of the Aktobe reservoir.

The main conclusion from the turbulent modeling results is that the background concentration has a much greater influence on the ecological capacity of the Ilek River. This position is demonstrated by a task without a background. A more than twofold increase in concentration can be compensated by the ecological capacity of the Ilek river if the background concentration does not absorb this capacity.

This conclusion can also be confirmed by comparing the distances at which the initial wedging concentration decreases to 1 mg/dm^3 (figure 26).



Figure 26 – Dependencies of distances from the wedging zone, at which different concentrations of wedged out groundwater are diluted to 1 mg/dm³.

The presented figure 26 very clearly demonstrates the role of background pollution. The lower curve, which shows dilution without a background, shows that for dilutions of up to $1 \text{ mg} / \text{dm}^3$. the concentration of wedged out groundwater more noticeably affects up to 150 mg / dm3, after which the curve practically flattens - an increase in concentration from 150 to 270 mg / dm³ (almost two times) the distance increases from 111.1 to 118.1 m (1.06 times). Thus, the ecological capacity of the Ilek river with a channel length of less than 120 m is sufficient to dilute up to 2 MAC for pinching concentrations up to 270 mg / dm³, provided that there is no background pollution even with a minimum flow volume (95% of the flow rate).

A completely different picture is observed in the presence of background concentration (we took 0.37 mg/dm³ in accordance with the data of "KazHydroMet" at the Alga 1 post). Here, up to 30 mg/dm³, the curves practically merge, but then the concentration curve with the background takes a shape close to the exponential dependence, although we took the range of groundwater concentrations for the same for both curves. From this it follows that the concept of ecological capacity of the river is ambiguous. It is impossible to speak only in relation to the dilution of pollution from groundwater. As can be seen from the difference in the course of the curves, small background concentrations absorb the ecological capacity of the river.

Conclusions on the section:

1. Comparing the concentrations at the same points as in the first problem, we find out that with an increase in the wedging concentration of less than 2 times at the point where MPC was reached at 61.5 mg/dm³. This is a point between 9.67 and 10.25 m in which the concentration of boron was 2.05709201 and 1.9713412 mg/dm³, i.e. 2.0142 mg/dm³. Thus, the concentration of boron at this point is now no less than the MPC, but more than 4 times. MPC is now reached already at a distance of 70 m, i.e. 7 times further.

2. The effect of the interaction of the processes of dilution of groundwater wedging from opposite shores manifests itself in the prevailing role of high concentration through its unidirectional successive decrease. The right-bank concentration of boron was constantly decreasing at all stages of enlargement of model blocks, except the last. Here, after a short-term decline, its growth began under the influence of the spread of high concentration from the left bank. The result of this interaction is the practical equalization of concentrations over the entire width of the river for different concentrations of both left- and right-bank wedging.

3. In the absence of background pollution of the river with the availability of 50, 75 and 95% in point Alga 2 and at the entrance to the Aktobe reservoir, the concentration of boron would not exceed half the MPC. The simulation results showed that the ecological capacity of the Ilek river with a channel length of less than 120 m is sufficient to dilute up to 2 MPC for wedging concentrations up to 270 mg / dm3, provided that there is no background pollution even with a minimum flow rate (95% frequency flow rate).

4. However, the presence of background pollution significantly reduces the ecological capacity of the river, therefore, at control points for all considered security conditions, the dilution concentration becomes higher than the MAC when wedging groundwater with concentrations above 150 mg/dm³. This conclusion is confirmed by

solving a series of versions of the model of the flat task of turbulent diffusion problem for different concentrations and different flow conditions.

5. Overall, the results of modeling turbulent dilution processes have shown that the concept of the ecological capacity of a river is ambiguous. It is impossible to talk about environmental capacity only in relation to the dilution of pollution from groundwater. The discrepancy between the curves along the dilution points up to 1 mg / dm3 for the solution options with and without background showed that background concentrations literally absorb the ecological capacity of the river.

5. THE MEASURES TO REDUCE THE BORON POLLUTION IN THE ILEK RIVER VALLEY

5.1 The methods for the removal of boron compounds from natural and industrial water

Even before the beginning of the 90s, all existing methods for removing boron from solutions were formed at this stage. These methods are: 1) extraction; 2) coprecipitation and deposition; 3) sorption; 4) ion exchange; 5) electrodialysis and reverse osmosis. Over the past decade, some of the existing methods have been refined and improved. For a reasonable choice of boron removal method as applied to specific conditions, it is of interest to analyze and the scope of each of these methods.

Organic Solvent Extraction

Organic substances are mainly used as extractants for boron-containing compounds. Organic solvent extraction of boron is one of the highly efficient and selective methods.

The research works [124] showed that the most effective extractants for boron were hydroxyl-containing organic compounds. In general, the more hydroxyl groups are contained in a given volume of organic solvent, the higher its effectiveness. The concentration of hydroxyl groups can be increased either by reducing the molecular weight of the monohydric alcohols, or by increasing the number of hydroxyl groups in the molecule upon transition to polyols. From this, two main directions in the study of boron extraction were revealed - extraction with monohydric and polyhydric alcohols.

Studies on a number of alcohols from butanol and pentanol to n-dodecanol showed that the efficiency of boron extraction with alcohols decreases with an increase in their molecular weight. To reduce the efficiency of boron extraction with alcohols, they are ranked: μ -C₄H₉OH, μ -C₄H₉OH, μ -C₅H₁₁OH, μ -C₅H₁₁OH..., μ -C₈H₁₇OH..., μ -C₁₂H₂₅OH. With an increase in the concentration of MgCl₂ salting out agent in the aqueous phase, the order of effectiveness among normal alcohols generally remains, but alcohols of isostructure become much more effective than alcohols of normal structure. In concentrated MgCl₂ solutions, the effectiveness of branched alcohols increases with increasing carbon chain length. The order of effectiveness among alcohols becomes different: μ -C₈H₁₇OH... μ -C₅H₁₁OH..., μ -C₄H₉OH... μ -C₅H₁₁OH...

Thus, in the extraction of boron (and purification from boron) from bischofite brines, the most effective organic extractants are isooctanol and isoamyl alcohol [125-127]. The use of alcohols is limited to concentrated solutions of salts [128].

The extractant for the extraction of boric acid [129] is a mixture of fatty alcohols: isoamyl -60-70 %, isobutyl-20-25%, propylbutyl-5-10 % This mixture does not mix with water; it has a specific gravity of 0.84 and a pH <7. The extractant is selective for boron in the presence of halogens and has a significant extraction ability without any other additives. The maximum recovery of boron (99%) can be achieved with a boron content of 1 g/l in the initial solution.

Studied [130] the extraction of boric acid from aqueous solutions of 2-propyl-1.3-heptanediol (I), 2-butyl-1.3-octanediol (II) 2-isopropyl-5-methyl-1.3-hexanediol
(III), 2,2, 4-trimethyl-1.3-pentanediol (IV), 2,2,5-trimethyl-1.3-hexanediol (V) in various diluents and depending on various conditions. That is to say, pH of the medium and nature of the salting-out agent, concentration of extractant and boric acid, phase contact time. The extractants I-III are viscous, colorless liquids, and IV, V are white crystalline substances. All diols studied are highly effective boric acid extractants. The best diluents for I-III-chlorine derivatives of hydrocarbons, toluene. Kerosene can also be used. In alcohols, the distribution coefficient of boric acid is much lower, but in case III it is sufficient to ensure a high degree of extraction (92.31%). For IV and V, chloroform is the best diluent.

The studied extractants extract boric acid in a wide pH range (from 6 to 8), only in a tetrachlorethylene solution does the degree of extraction decrease at pH = 1 to 50%. At pH above 8, the degree of extraction drops sharply, especially in the case of IV, V. Re-extraction of boric acid from organic extracts is carried out with NaOH solutions.

At the Moscow Institute of Fine Chemical Technology [131], an extractant for boron Yarrezin-B was tested, tested at Industrial Organization "Bor". The extractant is an aminophenol formaldehyde oligomer. The prospects of the extraction method for the extraction of boron from hydromineral raw materials are shown.

As boron extractants, alkyl pyrocatechols and methylol derivatives of alkyl phenols were synthesized. These extractants in the presence of aromatic amine additives extract boron from neutral and slightly acidic solutions. Re-extraction of boron from the organic phase in this case is carried out with mineral acids to obtain a solution of boric acid. The potential capabilities of this extraction system will be determined in the process of research on industrial solutions.

Extraction, according to experts [132], is one of the most promising methods for extracting boron from brines, which has such undoubted advantages as ease of automation, high speed of the process, the possibility of a continuous process, high purity of the resulting product. However, along with this, the method has serious drawbacks that limit its application: the complexity of the equipment and the partial solubility of organic extractants in water, which leads to the loss of expensive reagents, and creates a big environmental problem.

According to the authors [133], extraction technology for the deep extraction of boron from industrial wastewater and low saline water is not economically feasible.

Thus, the extraction method is effective in the extraction of boron compounds from mineralized water, has a number of the above advantages. However, it also has drawbacks: the limited industrial production of extractants, the complexity of the equipment, and the solubility of extractants in water, which leads to the loss of expensive substances and adversely affects the environment.

Coprecipitation on metal hydroxides and precipitation in the form of sparingly soluble compounds.

From dilute solutions ($C_{BO} < 0.05$ M), the precipitation of boron compounds with hydroxides occurs as a result of the exchange of borate anions for hydroxide groups of sorbents [134-137].

In the case of concentrated solutions (CBO > 0.1 M), ion exchange is the main process only during the coprecipitation of borate ions with hydroxides of 3 and 4 valence metals: Sn (IV), Ti (IV), Mn (IV), Fe (III) and others. When coprecipitated from concentrated solutions with hydroxides Ni (II), Zn (II), Mg (II), along with ion exchange, there is an interaction of borate ions with metal cations in solution and the formation of the corresponding sparingly soluble borates.

The removal efficiency of boron compounds by hydroxides of magnesium, aluminum, lanthanum, silicon, titanium, zirconium and iron (III) was studied in seawater. The experimental results are shown in table 23.

Element Oxide	Equilibrium value pH	Degree of precipitation, %			
		1 part	2 part	3 part	
Al ₂ O ₃	6.24	15.0	14.0	17.0	
ZrO	8.26	64.0	63.0	63.3	
La_2O_3	8.27	18.2	25.1	23.3	
SiO ₂	8.24	33.3	34.8	-	
TiO ₂	8.20	15.7	13.5	21.4	
Fe ₂ O ₃	8.27	11.6	13.1	-	
MgO	11.0	71.0	60.0	75.0	
SiO ₂	9.9	63.5	60.0	63.8	

Table 23 – Results of experimental studies on the removal of boron compounds

As can be seen from the data table 10, at pH 8.2–8.3, the greatest degree of precipitation is observed when dosing zirconium hydroxide. The specified hydroxide exhibits an increased affinity for boron compounds dissolved in water. By the author [138] this phenomenon is explained by the formation of strong sparingly soluble compounds of variable composition Na[ZrO(OH)_x \cdot (B₄O₇)_y]. The ratio of zirconium to boron in these compounds varies from 1: 1.7 to 1: 2.8 as a result of the replacement of OH groups with tetraborate anions.

Magnesium and silicon hydroxides have a similar effect; however, this requires higher pH values of 10-11.

According to the efficiency of extraction of boron compounds at pH 8.2-8.3, hydroxides are arranged in a row as follows: $ZrO_2 > La_2O_3 > SiO_2 > TiO_2 > Fe_2O_3$, Al_2O_3 .

As a sorbent zirconium hydroxide is proposed, which is obtained directly in boron-containing solutions. So, from a solution containing 1 g / 1 of B_2O_3 , after four precipitations, the degree of extraction is 98.5% of B_2O_3 . Boron is extracted from the precipitate, transferring it to the borax with caustic soda, and leached with warm water.

The presence of hydroxides in the above series, although at the end of it, indicates the possibility of using them as co-precipitators, widely used in the practice of water treatment of coagulants.

In the research papers [139, 140] presents the results of a study on the extraction of boron compounds from natural water with hydroxides of iron and aluminum. The maximum efficiency of the extraction of boron compounds by iron and aluminum hydroxides is achieved at the time of the formation of hydroxides. With an increase in hydroxide mass, the coprecipitation effect increases, but up to a certain limit. The coprecipitation of boron compounds does not reach 100% recovery.

Based on the results of a study of the main factors on the deposition effect and determination of the static exchange capacitances Al(OH)₃ and Fe(OH)₃, a variant of the technological scheme of the removal of boron compounds from groundwater by the coprecipitation method is proposed. This possibility is provided by the well-known method of electrocoagulation, in which hydroxides of iron or aluminum are formed directly in the treated water when lowering the electrodes of the corresponding metal. Because the maximum efficiency of the extraction of boron compounds is achieved within the first 10-15 minutes, the removal of hydroxide is possible by immediately passing water through a filter structure operating according to the type of contact coagulation (contact filter, contact clarifier). From this point of view, filter electrolyzers [141] deserve attention.

Therefore, an analysis of the methods of coprecipitation and removal of boron compounds by metal hydroxides from groundwater showed its fundamental possibility, however, low sorption capacities for boron, the difficulty of reusing hydroxides, and the complexity of the processes, limits the spread of this technology in industrial practice without further improvement.

It is known that boron does not form sparingly soluble compounds and easily migrates in solutions [142]. It was found that pre-treatment of wastewater from the processing of boron-containing raw materials with lime milk can significantly reduce and stabilize the concentration of boron.

Wastewater containing with boric acid electrolytes is averaged and mixed with lime milk for two hours to a pH of 11-14, sedimented and filtered. Crystalline calcium borate is dried until the adsorption moisture is completely removed. The removal efficiency of boric acid 96-97%. The technology is processed in an industrial installation [143]. The interaction of boric acid with milk of lime occurs as follows:

$$2H_3BO_3 + Ca(OH)_2 + 2H_2O \rightarrow CaB_2O \cdot 6H_2O.$$

The calcareous precipitation method is adopted in the technology of boron extraction from wastewater of iodine production [144]. In the process of obtaining a bormagnesium concentrate and processing it into a marketable product, the following main stages are distinguished: precipitation, sedimentation, filtration, enrichment, extraction, and stripping. Borax yield on this technology is 95-97%.

For a deeper extraction of boron from technological solutions and wastewater compared with precipitation with milk of lime (solubility of calcium borate 1.8-2.0 g/l), a method using polycomplexes and disposal of organoboron complexes in the form of fertilizers is proposed [145]. The method is characterized in that in order to increase the degree of extraction of boron compounds from low-concentrated solutions, nitrilotrimethylphosphonic acid is used as an organic reagent, followed by the introduction of calcium hydroxide to a pH of 9-10.5.

Laboratory and industrial tests were carried out on real "Boron" Industry organization for boron extraction using polycomplexones of alkanodiphosphonic acid

derivatives: Etidronic acid, ATMP or aminotris (methylenephosphonic acid). Received borcalcium complexonates could be used as boron micronutrient fertilizers, successfully [146].

Precipitation methods can be used in the recovery of boron compounds from wash and regeneration solutions containing significant concentrations of boric acid or its salts.

Sorption based on inorganic sorbents. Methods of boron compounds coprecipitation with precipitates of metal hydroxides directly obtained in purified water are laborious and non-technological. Therefore, already in the works [147, 148] it was proposed to obtain a gel of zirconium hydroxide separately, granulate it and then use it as a sorbent.

The sorbent obtained after freezing has a high capacity for boric acid, the value of which can reach 108-121 mg B_2O_3 per l of sorbent. Later, the authors improved the method of obtaining a new sorbent, thereby increasing its sorption capacity.

Sorption properties of hydrated zirconium dioxide to a large extent depend on its preparation. The authors [149] emphasize that during drying the sorbent is obtained in the form of spherical granules with increased mechanical strength, which is especially important for repeated use of the sorbent in the sorption – desorption cycles.

The sorption properties of zirconium hydroxide granulated by freezing and solgel methods were also studied on boron-containing wastewater [150]. An attempt to increase the mechanical strength of zirconium hydroxide is work [151]. For this, the method of co-precipitation of gels of hydroxides of iron and manganese was used. Mixed hydroxides have increased mechanical strength and chemical resistance, and have a significant capacity for boron.

In accordance with research papers [152, 153], the removal of boron from natural brines is carried out using an Al_2O_3 adsorbent. The suspension containing Al_2O_3 is heated to 60-80 °C and stirred for 30-60 minutes. The completeness of boron extraction is 87-97%. Boron compounds from the adsorbent are desorbed with a mannitol solution. Desorption is carried out within 5 minutes and the adsorbent is returned to the cycle.

Japanese technology [154] also uses activated alumina or activated bauxite to extract boron. Sorption properties of the investigated materials for the extraction of boron from water are given in table 24 [155].

Materials	Boron concentration in the initial	Extract boron, mg/g	
	solution, mg/dm ³		
ZrO ₂	4.37	56	
Al ₂ O ₃	4.37	47	
SiO ₂	4.37	5	
TiO ₂	4.36	24	

Table 24 – Sorption characteristics of various materials for boron

Thus, to optimize the sorption characteristics, aluminum and zirconium oxides were selected. The authors carried out work on the grinding and mechanical activation of these oxides with subsequent testing of their filtering ability and sorption characteristics in static conditions (table 25).

Table $25 - The$	e dependence	of the	sorption	properties	of the	powders	on the	degree of	f
grinding									

Shredders	Average particle diameter	Extract boron, %		Filtering ability of materials, m/h	
		Al ₂ O ₃	ZrO ₂	Al ₂ O ₃	ZrO ₂
Source powder	0.2 mm	47	56	28	30
Ball mill, ШЛ-1	200-500 μm	49	59	12	24
Vibratory mill, M-20	50-60 μm	52	64	8	15
Disintegrator, УДА-15М	1-6 µm	76	89	0	0
Planetary mill AFO-3	1 μm	85	96	0	0

The table shows that with a decrease in particle size, the sorption capacity of materials increases, but their filtering properties quickly decrease. Therefore, they refused to use ground powders and adopted the option of using dispersed hydrated zirconia and aluminum obtained by the sol-gel method.

The electrochemical treatment of zirconium oxychloride and aluminum chloride solutions allows one to obtain a colloidal sorbent with a highly active and highly developed (up to 400 m² per gram) surface and stable filtration ability. This process hold in combination with the precipitation of the obtained semi-colloidal solutions with ammonia and filtration under a controlled regime of heat and mass transfer through a gelling sedimentary system.

Thus, zirconium sorbents can serve as an effective material for water treatment. The high total salt background and the variety of impurities make it difficult to selectively extract each of them. This is especially true for compounds of boron and bromine. In solving the problems of selective extraction of impurities, inorganic sorbents have proven themselves well, among which oxohydrate zirconium sorbents (OZS) have occupied a prominent place [156, 157].

However, the production of oxohydrate zirconium sorbents with a given set of properties and their reproducibility is hindered by the multi-stage synthesis methods used the probabilistic nature of structure-forming processes, and the increased role of the instrumental factor.

Ion exchange. Selective ion exchange resins for the extraction of borates from natural water. The exchange capacity for oxoborates of ion-exchange resins depends on such factors as the state of anion exchange resin, the concentration of oxoborates,

temperature and the salt content of boron-containing solutions. The state of anion exchange resin is determined by its nature, the nature of the functional groups, and the initial salt form.

According to the magnitude of the exchange activity, the studied anionites in the Cl⁻ form are located in the following order:

EDE-10> AH-22> AH-16> AH-25> AH-18> AH-9> AH-24> AH -2FG> >AH-23 > AB-17(8)> IR-45 > AB-17(Γ) > AH-21 > AB-27 .

In the OH form, the use of strongly basic ion-exchange resins is more effective.

The effect of pH on the sorption of boron by anion-exchange resins AB-17-10p, AB-17, EDE-10p in the Cl⁻ form has been proved. The experiments were carried out in a static mode with a concentration of boric acid equal to 0.11%. It was shown that in the pH range 2.0–8.5, two maxima are observed on the sorption curves, the pH values of which coincide for all anions exchangers and are equal to 3.0 and 8.5. The most probable is the absorption of boron from acidic solutions in the form of ions of pentaborate acid $B_5O_8^-$. At pH 8.5, boron is sorbed in the form of tetraboric acid ions. Thus, the effect of pH on the amount of boron absorbed is the same for different anion-exchange resins. In dilute solutions, polyborates are hydrolyzed to form orthoboric acid, which in a highly alkaline medium passes into the tetrahydroxoborate anion. The maximum sorption of boron from such solutions is observed at pH 10.5–11.0.

A study of the effect of NaCl, Na₂SO₄, KCl, MgSO₂, MgCl₂ on the sorption of boron by anionite AN-31 in the Cl form showed that an increase in the concentration of salts significantly reduces the sorption of boron, and the greatest change in absorption is observed with an increase in the salt concentration from 0 to 2%.

The study of boron sorption by anion exchangers AB-17, EDE-10p in Cl form at a boric acid concentration of 0.2 M showed that the introduction of Li, Na, K, Mg, Ca (1M) chlorides suppresses the process of boron absorption. For the multifunctional anion exchanger EDE-10p, greater selectivity is observed in comparison with the resin AB-17, which can be explained by the presence of hydroxyl groups in its structure. The dependence of boron sorption on pH in the presence of salts with a maximum, as for solutions containing only boric acid. The pH of the solution does not significantly affect the absorption of boron by the monofunctional resin AB-17.

There is a definite relationship between the amount of boron absorption by anion exchange resin and the nature of the anions present in the solution. It is well known that the energy of hydration of anions decreases from $CH_3COO^- < Cl^- < NO_3^- < Br^- < I^-$. Obviously, the smaller the hydrated anion and the smaller its radius, the more competitive it is with respect to boron.

In practice, the removal of borates using ion exchangers is associated with certain difficulties. Actually, ion exchange occurs most efficiently on strongly basic anion exchangers in the absence of strong acid anions [158].

Polymerization-type ion-exchange resins with anion-exchange groups can be used to extract boron in the treatment of solutions and process water. It has been established that the use of strongly basic or mixed anion-exchange resins is most effective. However, in the presence of a salt background, the sorption capacity of these resins for boron sharply decreases and is limited to pure solutions of boric acid. The nature of absorption on a monofunctional anion exchange resin, for example, AB-17, depends on the form of boron in solution and their selectivity to the resin. Of aqueous solutions of boric acid and borates, boron is significantly absorbed in the alkaline region, while sorption practically does not occur at pH <5.

In the case of a multifunctional anion exchange resin, for example, EDE-10p, the absorption also depends on the acidity of the solution.

Anion exchange resin SB-1 with amino hydroxyl groups is superior to ionite with diol groups in sorption of boron from solutions containing B_2O_3 of at least 1 g/l. However, when the solution is diluted with boron, the capacity of SB-1 anion exchange resin sharply decreases and becomes significantly lower than the capacity of the polyvinyl glycol sorbent. This is probably due to the low resistance of aminohydroxyl borate complexes to hydrolysis, since boron adsorbed by SB-1 anionite is completely eluted with water [159, 160].

"Purolite" Firm (England) developed an improved technology for producing macroporous polystyrene-based anion exchange resin - Purolite S-108 [161-163] to remove boron salts from technological solutions and natural drinking water. The selectivity of anion exchange resin to boron-containing compounds is due to complex amines. After conditioning, the resin works effectively in the OH⁻ form in a wide range of pH and concentrations of boron hydroxo compounds. Purolite S-108 boron-selective resin is included in the international list of pharmaceutical preparations FDA.

The analogue of anion exchange resin S-108 is the American resin Amberlite IRA 743, which is similar in composition to domestic developments of anion exchangers based on a copolymer of styrene and divinyl benzene with N-methylglucopolyol groups. Anionite IRA 743 has a high static and dynamic capacity for boron compounds at the corresponding filter cycle speeds and the presence of a salt background of natural water.

The practical use of selective resins in the development of technologies for the extraction of oxoborates from natural water poses the challenge of improving their selectivity by modifying polyhydroxy compounds based on a styrene-divilbenzene copolymer. Technologists [164, 165] have developed a highly selective resin based on modified sorbitol in the form of spheres, treated successively with chlorosulfonation, amidation with N-propylamine and condensation with epichlorohydrin, which makes it possible to remove boron at its level of 5-10 mg/dm³.

Along with high boron selectivity, the resins showed satisfactory mechanical and chemical resistance, regeneration efficiency, and concentration of boron in regeneration solutions.

As a result of studies of the kinetics of boron adsorption (C = 20-40 mg/l) under static conditions with intensive mixing of the phases, it was found that all the studied resins (IRA-743, S-108, MK-51 and CRB 02) are characterized by a similar velocity achieving equilibrium in the system of anion exchange resin - solution of oxoborate. The equations of adsorption kinetics are obtained, the values of current adsorption are calculated and compared with experimental ones. The average values of the relative error are in the range 4.7–13.7%. Thus, the studied boreselective anion exchangers are recommended for the development of technology for the extraction of boron compounds from groundwater by filtration in a wide range of boron concentrations, especially in the region of low values of about 4–6 MPC. In order to realize the purification of groundwater from boron by ion exchange methods using selective resins, it is advisable to work out the optimal conditions for the regeneration of anion exchangers with repeated reuse of regeneration solutions and the technology for their processing and disposal of valuable products.

Electrodialysis, reverse osmosis. The recent increase in the shortage of fresh water necessitates an ever-wider use of saline and brackish water after desalination for public water supply. When desalinating water using the most promising membrane methods, up to 40% of boron is retained simultaneously with salt ions. That is, taking into account the hygienic standard for boron 0.5 mg/dm³, the concentration of boron in the source water supplied to desalination should not exceed 0.8 mg/dm³. However, the content of borates in a whole series of boron-containing natural water sources significantly exceeds this value with simultaneously high total mineralization [166, 167].

Thus, the desalination process of these water should be combined with technology to reduce the concentration of boron. Otherwise, either the use of water sources with a high boron content or the desalination of such water by membrane methods will be significantly limited.

The study of boron electroextraction from model solutions and real ocean water using MK-40 and MA-40 membranes showed that at pH> 9 boron transfer to the concentration chamber increases sharply [168].

A systematic study of the electrodialysis of solutions containing 40 mg/dm³/boron and 11.7 g/dm³NaCl was carried out. The effect of pH, current density, and the presence of electrolytes on boron transfer through ion-exchange membranes MK-40, MK-41, MA-40, MA-41L, MK-100, MK-100M, MA-100, MF-4SK was revealed. It was shown that in the acidic and neutral regions boron transfer through cationite membranes is constant, while in an alkaline medium (pH> 8) it sharply decreases.

For anion exchange membranes, the nature of the effect of pH on boron transfer depends on the average basic anion exchanger EDE-10P, boron transfer increases in a highly alkaline medium (pH> 9), membranes MA-41L and MA-100, which have highly basic amino groups as fixed ions, are practically independent of pH.

A direct study of boron transfer through cation-exchange membranes in electric and diffusion fields, as well as studying the NMR spectra of membranes and their chemical analogues, allowed us to conclude that boron transfer is based on the complexation of boric acid with functional sulfonic and phosphate groups of membranes.

 $B(OH)_3 + 4(R - SO_3H) = B(R - SO_3H)_4 + 3H_2O + H^+.$

Due to the rigidity of the attachment of functional groups to the matrix surface, the processes of exchange of the same type of ligands in the coordination sphere of boron can proceed not only due to microequilibria with the participation of neighboring groups, but also by moving (translating along the surface) of the central atom - the B^{3+} cation. The application of an electric field increases the component of the directed motion through the membrane. When boron leaves the membrane, hydrolysis occurs:

$$B^{3+} + 3H_2O \rightarrow H_3BO_3 + 3H^+.$$

Since the amount of undissociated boric acid molecules in the solution decreases with increasing pH, the probability of interaction described by the equation decreases. This leads to a decrease in the boron content in the membrane and, accordingly, its electro migration transfer to the concentration chamber. Thus, the proposed mechanism of boron transfer through cationic membranes allows us to explain the obtained data on the effect of pH on this process.

Improving the electrodialysis method of desalination of boron-containing water by creating optimal conditions for the removal of boron in a slightly alkaline environment, which would ensure a deep purification from boron during the desalination process, while simultaneously simplifying and cheapening the process.

For this, the desalination chambers of the electrodialysis cell were filled with various ion-exchange materials, including boron-selective ones. On the one hand, this should reduce the negative effect of polarization phenomena on the process of boron extraction, on the other hand, increase the concentration of boron in the membrane (due to the selectivity of the sorbent to boron) and increase the degree of its extraction from the solution.

It is known that the boron-selective sorbent ANB-11g, representing a styrenedivinylbenzene polymer matrix modified with N-methylglucamine, has the highest boron capacity from solutions with low concentrations and maximum mechanical strength.

Moreover, the maximum sorption of boron is observed in the pH range of 7-10.

The experiments to identify the influence of this sorbent on the process of boron electroextraction were carried out in a six-chamber electrodialysis apparatus, assembled according to the scheme:

Cathode $\frac{1}{K}/2$ A/3/K/A/A/5/K/6/ Anode,

where K and A are respectively MK-40 and MA-40 cationite and anionite membranes. The working surface of one membrane is 9.7 cm^2 , the intermembrane distance is 5 mm. Platinum was used as the cathode and anode. The 5 dm³ of an initial solution containing 40 mg/dm³ of boron, 11.7 g/dm³ of sodium chloride at a pH of 2-12 were circulated through a desalination chamber 4 filled with ANB-11g boron selective sorbent.

The experiments showed that loading the desalination chambers of the electrodialysis apparatus with EDE-10p anion exchange resin during desalination of boron-containing water with MK-40 and MA-40 membranes has a positive effect. It is consisting in the possibility of the process in the less alkaline region (pH range 7.5-9.5 instead of 10.7-11.2) while reducing the required degree of purification from boron compounds, as well as reducing the energy consumption for desalination (by 30%).

With an increase in the initial concentration of boron in the solution, the optimal pH range shifts to a more alkaline region. The use of the ANB-11g boron selective sorbent is inefficient due to the low mobility of boron in its phase.

Considering that the content of boron in the ocean and some groundwater reaches 4.0–4.7 mg/dm³, and in the water of the Black and Azov Seas, 2.3 and 1.5 mg/dm³, respectively, the permeate obtained during reverse osmosis contains boron of at least 0.9–2.8 mg/dm³, which significantly exceeds its MPC in drinking water. It was shown that during the desalination of water in the Sea of Azov in a multi-element reverse osmosis unit UMP20/2000P with MGA-95 and MGA-100 membranes, the boron content decreases from 1.2 to 0.66 mg/dm³.

The project was defended by work [168, p. 116] and the construction of a desalinated drinking water station with a capacity of 20 thousand m3 per day is being carried out based on the permeate of a two-stage reverse osmosis unit with a single module $q = 4.4 \text{ m}^3/\text{h}$. Membranes BW 300-400 of the company Dow Chemisal USA.

The source water for total organic carbon (TOC) is the Caspian Sea with a content of boron compounds of 4.5 mg/dm³ (boron). The first stage of the TOC gives a 44.4% decontamination effect with a residual boron of 2.5 mg/dm³. In order to condition the permeate in boron to the maximum permissible concentration in drinking water — 0.5 mg/dm³, the permeate of the first stage is alkalized and at a pH of 10 they are decontaminated in the second stage of the TOC.

The reverse osmosis method is not always economically feasible, since it does not reduce the boron compounds to the MPC standards.

Thus, the existing real technological developments on the extraction of boron compounds from natural water, brines and technological solutions have classification as follows: extraction, coprecipitation and precipitation, sorption, ion exchange, electrodialysis, reverse osmosis and ultrafiltration.

The extraction method for the extraction of boron compounds from natural water is impractical for economic and environmental reasons. The specified technology could be used in the development of methods for the disposal of boron-containing regenerative waste.

The methods of reverse osmosis and electrodialysis do not provide deep purification of natural water from boron compounds due to the lack of selective membranes. Depending on the initial concentration of boron in water, pH and type of membranes, the cleaning effect is in the range of 40-60% with desalination in one-step. To increase the efficiency of decontamination, alkalization of water (pH 9-10) and multi-stage desalination are performed.

Of the considered methods for the extraction of boron-oxygen compounds from technological solutions and natural water, sorption has found wide application. The most effective inorganic sorbent is zirconium hydroxide and the development on its basis of selective charges with zirconium oxyhydrate.

Of the other inorganic sorbents whose action is associated with the effect of chemisorption and coprecipitation, the coagulant $Al_2(SO_4)_3$ is known. This possibility is provided by the well-known method of electrocoagulation, in which aluminum

hydroxide is formed directly in the treated water. The aluminum hydroxide's unit removal works by the type of contact coagulation (contact filter, contact clarifier).

Polymerization-type ion-exchange resins with anion-exchange groups can also be used to extract boron during the purification of natural water and technological solutions. In this method, the latest developments are used according to the already studied and well-proven method.

Borselective anion exchangers are recommended for the development of technology for the extraction of boron compounds from groundwater by filtration in a *wide range of boron concentrations, including low ranges of about 4-6 MPC*. This is one of the main advantages of this method compared to others. It is this method at the present stage that is recommended as the main one, which provides deep removal of boron to the MPC standards.

5.2 Removing of the bottom sediments and silts from Aktobe reservoir

To ensure sustainable economic development of the region, it is necessary to implement a set of measures for the rational use and protection of water resources.

The development of industrial and agricultural production in the region often occurs in violation of environmental requirements, which has had a negative impact on all types of natural resources and public health. For many decades, the environmental impact has not been taken into account, and therefore a number of serious problems have arisen in the Ilek basin regarding the protection of water bodies.

Among the main problems requiring a priority solution for a radical improvement of water quality and prevention of their further pollution are:

1. Boron contamination from the waste accumulators of the boron production of the former Alga chemical factory;

2. Chromium pollution from sludge collectors of Aktobe Chromium Compounds Factory;

3. Presence of unregulated waste storage of the factories;

4. Discharge of warm wastewater "Aktobe Heat Electric Center" into the ash pan, enhancing the wedging out of chromium-containing groundwater in the Ilek riverbed;

5. Migration of chromium to groundwater at an industrial site of Aktobe Chromium Compounds Factory;

6. Discharge of untreated sewage in Aktobe in the Ilek river;

7. Organic matter, phenol and nitrogen compounds during low-water periods due to domestic wastewater and animal husbandry facilities: manure depots, summer pens and livestock watering points;

8. High content of natural salts during the low season.

For solving these environmental issues, a number of measures have been proposed. For example, the Kazakhstan Agency for Applied Ecology (KAPE) in the report on the "Project of water protection zones and bands of the Ilek river within the boundaries of large settlements (Aktobe, Alga, Kandyagash, Martuk) for 2012" recommended the development and implementation of a project for the rehabilitation of sludge collectors, eliminating the boron migration with surface and groundwater runoff [17, p.15]. The following activities were noted in the project:

1. To reduce water pollution by natural salts and at the same time to dilute the concentrations of other pollutants, it is necessary to carry out sanitary-environmental releases during the low-water period. Since river runoff, pollution by natural salts is caused by natural hydrological factors: very low water discharge and high drainage properties of the channel during the low-water period.

2. A significant way to change the situation is to build a reservoir in the upper part of the Ilek River basin in order to fully detain spring ultra-fresh floodwater for sustainable water supply to the local population and industrial facilities, as well as to create a favorable flow during the low-water period. Since, the water reserves of the Aktobe reservoir are not enough to meet industrial, household and environmental needs.

2. To reduce pollution by organic and nutrients, it is necessary to provide measures in cities and rural settlements that ensure the rational and safe management of household waste and wastewater. For deep wastewater treatment from organics and nutrients, biological ponds should be widely used with higher aquatic vegetation in the last section of the pond. The reducing the mass of undecomposed organics entering the river with surface melt and rainwater is necessary for eliminating runoff from livestock facilities (livestock farms, manure storage). Moreover, it is need to remove catars, camps, pens, summer cattle ranks, sheep sanitation facilities outside water protection zones and strips; equip permanent livestock watering places, clean the floodplain of the river from unauthorized landfills for household and other waste.

3. To eliminate pollution of the Ilek river with boron and chromium, it is recommended to continue the ongoing measures to curb river pollution with these elements. The development and implementation of a project for the reclamation of sludge collectors, pyrite cinder and industrial waste from the former Alga chemical plant, sludge collectors of the Aktobe chromium compounds plant, slags of the Aktobe ferroalloy plant was recommended, thereby eliminating the migration of boron and chromium from surface and underground runoff.

It should be noted, that reclamation options for sludge collectors can be considered as competitive solutions. However, the reclamation method due to the large area of sludge collectors Alga Chemical Factory - 377,4 ha (177,4 ha – "old" sludge collector, 200 ha – "new" sludge collector) is expensive. It has a temporary effect, because pollution remains in soil, and as international experience shows, it is not used without treatment facilities. Especially for the "old" sludge collector due to the large coefficients of water conductivity in the zone of its location, that is why this method is not acceptable [169].

Another possible way to localize the pollution of the Ilek river is to create an impenetrable screen (wall in the ground) around the main foci of groundwater pollution, in particular above the "old" sludge collector. However, the implementation of this option meets a number of serious objections. Firstly, creating a "wall in the ground" is very difficult technically. Secondly, the low efficiency of this method has already been demonstrated by the construction of a "wall" 1925 m long built in the area of the "old" sludge collector. In addition, the creation of a "wall in the ground" will not ensure water purification outside the fenced area, where the bulk of groundwater

polluted by boron. At the same time, there will be a threat that the part of the aquifer and aeration zone will be completely filled with a fenced wall due to infiltration of precipitation, snowmelt water, etc.

As an alternative method, sludge disposal may be considered. The expert and experimental evaluations showed that it will take at least 200 years to dispose of the sludge (due to their toxicity and radiation hazard, a large amount of clean building materials is required for dilution).

Nevertheless, according to expert estimates, sludge can be used in road construction, and only outside of settlements, by building a powerful asphalt plant of regional scale. More successful disposal can be carried out on the "new" sludge collector, as the removal of sludge will increase the height of its debris and reduce the likelihood of spills on the surface. When disposing of sludge from the "old" sludge collector, surface spills will decrease, but the washing conditions will improve, since an additional column of water with an increase in the height of the shafts will create a prerequisite for increased filtration through the bottom of the sludge collector.

Thus, the utilization of sludge, as well as reclamation, do not prevent the pollution of groundwater, the Ilek river and the Aktobe reservoir, and therefore must be accompanied by the same groundwater treatment.

It is also worth noting that the "Center for Health Protection and Environmental Engineering" LLP developed a feasibility study for the groundwater treatment project for the Ilek river valley [170, 171]. In which, the proposal was considered: intercepting contaminated groundwater before it wedged out in the Ilek river, their purification from boron at sewage treatment plants and either the direct use of purified groundwater, or their injection after treatment by injection wells to flush the entire groundwater horizon.

Considering the migration peculiarity of boron, its dynamics of advancement by underground and surface runoffs of the Ilek River based on a series of tasks of the turbulent diffusion model, as well as all research and development on pollution control, we offer the following measures:

Cleaning bottom sediments. This measure leads to the restoration of the normal bio-balance of the source, improving water quality. Purification of Aktyubinsk reservoir from mud deposits is a complex of special measures aimed at the removal of silt contaminated with boron. Regular cleaning will keep the bottom clean, prevent the abundant growth of algae, which impede the enrichment of water with oxygen and, ultimately, create the most comfortable conditions for a natural increase in the number of fish [172, 173].

There are ways to clean water. These include mechanized, hydromechanical, chemical methods. Drainage by pumping, removal of deposits by crawler excavators is the process of cleaning the reservoir of the mechanized method. For pumping, industrial pumping units with electric and diesel drives are used. The most convenient are small-sized motor pumps that can be moved along the shoreline manually, thereby simplifying the solution of current problems. The distance of the water supply is determined taking into account the height of its pressure, drive power, pipeline section. After draining the bottom of the reservoir, an excavator is launched into the channel,

and active development of bottom sediments begins. They are shipped to dump trucks. The method is effective, but expensive, since it involves the use of a large number of specialized equipment[174-176].

Hydromechanized development is carried out using dredgers. In this case, the development of underwater soils is carried out simultaneously with their movement through the pipeline over considerable distances. Loosening of sludge is carried out due to the rotating organs of land shells. Loosened soils with water are sucked through the pump. Then fed to the sludge alluvium card through pipes. There should be enough water for the installation to work; otherwise, there can be no talk of effective cleaning. The use of a land projectile is justified in the case of prolonged work, as the equipment is expensive to use.

Chemical. It involves the filling in a reservoir of chemicals that initiate the decomposition of sludge into completely natural components - water, organic matter and carbon dioxide. Such cleaning of reservoirs, basins from mud deposits is carried out quickly, significantly slows down the further formation of sludge, and requires a minimum of costs. The disadvantages of the method include poor efficiency in flowing water bodies, as well as the inability to use in lakes and ponds intended for fish farming [177].

Organization of boron-containing fertilizers for green spaces. For green spaces, the use of silts of the Aktobe reservoir is proposed as a source of raw materials. As already noted in Section 2.2, the boron element is an essential element. Boric fertilizers significantly increase yield and improve the quality of flax. The introduction of boron under flax on calcareous soil dramatically increases the yield of seeds and fiber, significantly improving the quality and yield of the latter [178-180].

The boron contaminated fertilizers have a great influence not only on calcareous, but also not calcareous: sod-podzolic, sod-gley, peat and other soils, and this is especially pronounced on soils with a low boron content.

Thus, the proposed measures can reduce the environmental pressure of the Ilek River valley and improve agricultural activities.

Conclusions to the section:

1) There are methods for removing boron from solutions: extraction, coprecipitation and precipitation, sorption, ion exchange, electrodialysis, and reverse osmosis. However, the problem of removing boron from water is because in most cases boron in water is in the form of orthoboric acid (H_3BO_3), which in turn weakly dissociates.

2) Considering the migratory peculiarity of boron, its dynamics of advancement by underground and surface runoffs of the Ilek river based on a series of tasks of the turbulent diffusion model, as well as all research and development on pollution control, we offer such measures as:

- cleaning of bottom sediments, between stages of sludge suction, releases from the reservoir should be carried out by the overflow method, and not through bottom outlets,

- organization of boron-containing fertilizers for green spaces.

CONCLUSION

As a conclusion, we can offer the following main conclusions.

1. The main sources of boron pollution in the Ilek river valley are the territory of the former Alga Chemical Factory, sludge collectors, and places for accidental spill of slurry pipelines.

2. The former factory is located in the slope zone on the floodplain terrace of the Ilek river. The old settling pond was located in the floodplain of the river and continues to be a source of water pollution of the Ilek River, soils and rocks of adjacent areas. New sludge collectors was built on the main shore are constructed with large defects and do not prevent leakage through the walls of the settling tanks. That is why sewage with a high concentration of toxic substances continues to contaminate the soil of the adjacent territories in trans-eluvial and supequal landscapes, as well as the water of the Baipakty and Suyksu streams flowing into the Ilek River.

3. The main masses of pollution products, in particular boron, accumulated in the soil and soil of the industrial site, urban and adjacent territories as a result of atmospheric precipitation during the period of activity of the plant, are gradually washed out during the spring flood.

4. The Ilek river valley is subject to industrial pollution with boron from sludge collectors and sludge pipelines. In addition, Alga area and downstream, its entire space further to the north is an exogenous aureole of dispersal of Permian rocks and boron with them. However, studies by geologists (Zeyberlikh N.E., Vlasko G.N.) established that there is no flow from the regional halo to the ground horizon; this flow can be wedged out in the uplift zone in the vicinity of Bestamak settlement.

5. In natural water, boron exists mainly in the form of undissociated boric acid with some borate ions. Soils and sediments can adsorb an aqueous solution of boron. The degree of adsorption of boron depends on the pH of the water and the concentration of boron in the solution. The highest adsorption is usually observed at pH 7.5–9.0.

6. The boron is an essential element for plants and is involved in many processes of human life. However, exceeding the required standards leads to inhibition of vegetation and to severe consequences for humans. In the sanitary-epidemiological rules, norms, rules and norms 2.1.4. 1074-01, boron on the sanitary-toxicological basis of harmfulness belongs to the second hazard class.

7. Statistical processing of the results of chemical analyzes of groundwater in the territory of regime observations for the period 1982-2003 showed that the technogenic factor makes an additional contribution to the natural lithogenic stage. The character of this process is described by the transit of acidic industrial water, accompanied by the absorption of polluting elements by soil and exchange reactions between groundwater and soil. According to 2011-2012 revealed the practical absence of signs of migration of acidic industrial water.

8. Component analysis has identified three main processes in the spread of boron pollution, filtered from sludge collectors: transit, deposition, and exchange with the active participation of nutrients. For all water wells, biogenic boron was detected, which indicates the pulling of river water by these wells, which, passing through activated sludge, wash boron biologically deposited in the sludge.

9. A comparative assessment of the contours of the contamination source on hydrogeological maps for 2011 and 2012 allowed us to identify the initial stage of the advancement of the pollution front from the new sludge collector and the reduction of the effect of pollution of the territory of the Alga Chemical Factory.

10. The dynamics of surface water pollution can be traced at 3 points of Kazhydromet on the Alga area. Graphs of changes in boron content in the Ilek river in control point above the city of Alga (Alga1), near the village of Bestamak (Alga 2) and above the Aktobe city (Hydropost 1) for the period 1997-2018 show a consistent decrease in boron content until 2016. At Alga 1 and Aktobe Hydropost 1 posts, the downward trend continues, and at Alga 2, there is a sharp jump in boron content, which can be explained by the manifestation of the influence of a new pollution source. Thus, confirmation of the influence of the new sludge collector on the pollution of the Ilek river is obtained.

11. A comparative assessment of the dilution of boron concentration at the same points shows that with an increase in the wedging out concentration, the distances at which a concentration of 1 mg/dm^3 is reached also increases both in the presence of background pollution and without it. However, dilution processes are not a linear function of concentration, and prediction of the nature of dilution should be based on model building.

12. The effect of the interaction of the processes of dilution of groundwater wedging from opposite shores manifests itself in the prevailing role of high concentration through its unidirectional successive decrease. The right-bank concentration of boron was constantly decreasing at all stages of enlargement of model blocks, except the last. Here, after a short-term decline, its growth began under the influence of the spread of high concentration from the left bank. The result of this interaction is the practical equalization of concentrations over the entire width of the river for different concentrations of both left- and right-bank wedging.

13. In the absence of background pollution of the river with the availability of 50, 75 and 95% in point Alga 2 and at the entrance to the Aktobe reservoir, the concentration of boron would not exceed half the MPC. The simulation results showed that the ecological capacity of the Ilek river with a channel length of less than 120 m is sufficient to dilute up to 2 MPC for wedging concentrations up to 270 mg / dm3, provided that there is no background pollution even with a minimum flow rate (95% frequency flow rate).

14. However, the presence of background concentration of pollution significantly reduces the ecological capacity of the river, therefore, at control points for all considered security conditions, the dilution concentration becomes higher than the MPC when wedging groundwater with concentrations above 150 mg/dm³. This conclusion is confirmed by solving a series of versions of the model of the flat task of turbulent diffusion problem for different concentrations and different flow conditions.

15. In general, the results of modeling turbulent dilution processes have shown that the concept of the ecological capacity of a river is ambiguous. It is impossible to talk

about environmental capacity only in relation to the dilution of pollution from groundwater. The discrepancy between the curves along the dilution points up to 1 mg/dm³ for the solution options with and without background showed that background concentrations literally absorb the ecological capacity of the river.

16. A reserve for increasing the ecological capacity of the river is the deposition of boron by silts. However, it is not possible to quantify this process based on the available factual material due to its absence.

17. The smallest negative environmental consequences and the maximum effect can be ensured by the suction of sludge from the Aktobe reservoir with their subsequent use as fertilizers. Between the stages of sludge suction, releases from the reservoir should be carried out by the overflow method, and not through bottom outlets. These measures should be complemented by a traditional set to organize the prevention of pollution from excessive quantities of fertilizers and plant protection products.

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APPENDIX A – The hydroisohypsum map of Ilek River, 2008 y.



APPENDIX B – The Hydrogeological map of the Alga-Aktobe section

Figure B_1 , paper 1 – The Hydrogeological map of the Alga-Aktobe section with the location of an observational network for the study of groundwater pollution with boron for 2011 y.



Figure B_1 , paper 2 – The Hydrogeological map of the Alga-Aktobe section with the location of an observational network for the study of groundwater pollution with boron for 2012 y.