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Post-containment Management and Monitoring of Mercury Pollution in Site of Former PO “Khimprom” and Assessment of Environmental Risk Posed by Contamination of Groundwater and Adjacent Water Bodies of the Northern Industrial Area of Pavlodar

Final Project Technical Report

on the work performed from October 05, 2005 to December 31, 2009

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LIST OF CONTENTS

1. Brief description of the work plan: objective, expected results, technical approach

1.1. The objectives of the research

I. to identify the risk associated with the spread of groundwater plumes contaminated with mercury and oil derivates, including their movement through the network of water intake boreholes in Pavlodarskoye village, and further towards river Irtysh and/or their rise onto the pastures and, if significant, identify a management strategy to contain risk;
II. to identify a management strategy for containing the environmental risk, caused by the mercury pollution of Lake Balkyldak, including the pathway of pollutants bioaccumulation via food chains;

1.2. Expected Results

The proposed study is an applied research in the field of environmental protection. It is assumed that in the course of this works new facts might be revealed that would require the deepening and the extension of the research. The results of the research and its stages will be presented as interim and final reports.

- One of the most important results of proposed study will be the foundation of monitoring laboratory of PCP that will be capable to implement Post-containment monitoring Program in Northern industrial area of Pavlodar during 2005-2020 after completion of proposed ISTC study. This laboratory will be also capable to conduct other investigations in the field of environmental protection. The completion of Phase I of Demercurization Project does not assume termination of the investigation of mercury pollution in Pavlodar. The Phases II & III are starting that will require more detailed and more extensive studies of the residual mercury pollution and associated risk. These reasons will allow the laboratory of PCP to become self-supporting;
- PCP together with AUPET will carry out the monitoring study of the mercury contamination of groundwater in the Northern industrial area of Pavlodar;
- AUPET together with PCP will study the extent mercury contamination of pastures in the areas where the upward movement of polluted groundwater is possible;
- BMP together with PCP will conduct the monitoring study regarding to the groundwater contamination with petroleum and oil derivates in Northern industrial area of Pavlodar;
- AUPET together with PSU will determine the levels of total mercury content in bottom sediments and biota from wastewater storage pond – Lake Balkyldak;
- AUPET together with IHH will assess the risks associated with the residual mercury contamination of groundwater and wastewater storage pond – Lake Balkyldak;
- IHH together with AUPET will assess the risks posed by contamination of groundwater with oil and petroleum derivates;
- IHH will upgrade the groundwater model for the Northern industrial area of Pavlodar and make it more accurate. IHH will make forecasts for the future spread of groundwater contaminated with Hg and oil products;
- AUPET together with IHH will draw up and discuss with local stakeholders and state authorities the proposal for risk management in Northern outskirts of Pavlodar including possible implementation of 2nd stage of PO “Khimprom” demercurizing and/or brining wastewater storage pond – Lake Balkyldak to safe conditions.

1.3. Technical Approach

During sampling and chemical analyses the methods recommended by US EPA will be used as well as standard procedures on Quality Control/Quality Assurance accepted in the West. Determination of mercury in solid samples will be carried out using AAS analyzer (Lumex RA 915+); AFS analyzer (PS Analytical Millennium Merlin System) will be used for Hg determination in water samples and biological tissues. Chemical analysis of oil products' concentration in water will be conducted using CG Perkin Elmer Clarus 500.
Assessment and management of risk associated with groundwater contamination will be carried out using hydro-geological models received by means of the ModFlow GMS 5.0 software. The preliminary assessment of risk (Tier 1 of risk assessment) posed by mercury contamination of pastures and fish will be conducted using the monitoring of the level of mercury pollution and subsequent comparison of pollution indices with existing state standards and guidelines values.

2. Method, Experiments, Theory etc.

2.1. Field works

2.1.1. Groundwater survey

Groundwater table measurements were being carried out across all area of the Northern industrial site of Pavlodar in order to obtain data about its seasonal variation and then to use this material for simulation of hydro-geological conditions. Groundwater sampling was conducted in places of mercury contamination with purpose to receive the data on total and methyl mercury concentration changes.

2.1.1.1. Groundwater level measurements

Twice in July and September of 2006 groundwater table measurements were taken in 239 observation hydro-geological boreholes, in September, 2007 – in 154 boreholes and in August-September, 2008 – in 150 boreholes. The measurements were taken from boreholes' caps using a special tape-line having a plummet and clapper at the end. Separately measurements of height of borehole caps and their coordinating were performed with help of a portable GPS. The results of these seasonal measurements ("Summery table 02 and 03.2006, 01.2007, 01.2008") were used to create the local model of groundwater mercury contamination.

2.1.1.2. Groundwater sampling for their analysis for total and methyl mercury

Groundwater samples were taken from observation boreholes of the system of mercury monitoring at Northern industrial area of Pavlodar. In June and July, 2006 groundwater samples were taken from 87 boreholes, in September-October, 2007 – from 81 boreholes and in August-September, 2008 – from 74 ones. The samples were taken using a submerged electrical pump according to the special technique developed by AUPET in 2001-2002 and based on very careful rinsing of equipment for a borehole pumping and on the rinsing quality control. Simultaneously with groundwater sampling measurements of its table, temperature and pH were taken.

Water samples were taken in duplicate into single-use plastic bottles without filtration and preservation (the taken samples were delivered to the laboratory twice a day). Coca-cola plastic bottles of 0.5 liter after dispensing the cola were used. Marks were put by an indelible marker on bottles full of coca-cola to indicate volume (0.5 L) of the liquid in a bottle. Then coca-cola was poured out, empty bottles were screw-toped, put into clean plastic bags and delivered to sampling place. At the sampling place the plastic bags were opened carefully, bottles were tagged, opened, rinsed three times with groundwater and filled with groundwater up to the mark. After that the bottles filled with groundwater samples were screw-toped and enclosed within plastic bags (the same procedures were done for bottles with rinsing water). Before sampling triple volume of groundwater confined within a borehole cavity was pumped out of each observation borehole. After sampling the electric pump, electricity cables and pump hoses were taken out of the borehole and put into a special tank with capacity of 50 liters made of stainless steel. Sampling equipment was being washed from caught-on mercury in the tank. For that the tank containing the equipment was filled up by fresh tap water which had been controlled for mercury absence (tap water was transported to groundwater sampling points in alumina tank of 2 m^3 using auto trailer), then rinsing water was pumped out of the tank with help of the rinsed pump and pump hoses. Such operation was repeated three times and then the clean equipment was delivered to next borehole inside of the same airtight stainless steel tank. Sampling quality control lay in chemical analysis of final portion of rinsing water for caught-on mercury after each equipment-washing operation (samples of rinsing water were taken without duplicating). All water samples and blanks were delivered to the chemical analytical laboratory not later than in 4 hours after sampling in an icebox holding the temperature of not higher than 10^oC.

On the 21st of July, 2006 groundwater samples for methyl mercury determination were taken in duplicate from three boreholes C69-02, C32-03 and P8 generally according to the same method as that for total mercury. The difference was that water samples for analyses for methyl mercury were taken into 1 liter one-use vodka glass bottles closed with metal screw-tops having plastic cover gaskets. The bottles were washed first with bromide-bromate mixture (see below in Section 2.2.1) and then a few times with reagent water. The bottles were put in icebox just immediately after their filling up with water and delivered to the analytical laboratory of Department of Environmental Sciences, Jožef Stefan Institute, Ljubljana, Slovenia. During stops on the way the samples were kept at the temperature of 4^oC in stationary refrigerators. The samples were delivered to the laboratory on the 4th of August, 2006 and kept at 4^oC in a fridge until being processed. Also two empty bottles washed with the same way were sent to the same laboratory as blanks.

2.1.1.3. Investigation of an underground oil sump of treatment facilities of Pavlodar Oil Refinery

Field investigations proved spread of underground waste oil sump more than 2 m thick at the depth of 2.6 m over the groundwater table 25 m long beyond north-west corner of the industrial area of Pavlodar Oil Refinery. The oil sump is a source of groundwater feeding with soluble oil products.

2.1.2. Investigation of soil mercury contamination

In 2006 investigation of soil mercury contamination was conducted selectively (19 samples were taken) in sites of 2002-2004 demercurization works in order to assess the cleanup efficiency, in 2008 – in the same sites on the regular grid (additionally soil samples were taken in 240 sampling points) for producing a new map of the soil mercury contamination within the area of demercurization and in 2006 – on the regular grid in places of mercury contaminated groundwater possible rise (soil samples were taken in 111 sampling points on 5 sites) for finding new hearths of the contamination.

2.1.2.1. Preliminary investigation of mercury contamination of soil at the industrial area of the former chlor-alkali production

On the 2 July 2006 soil samples were taken at random in 19 sampling points at the industrial site of the former chlor-alkali production and in the area of the former 6th wastewater pumping station in places of the most intensive mercury contamination (for that the map of mercury pollution with results of monitoring of 2001-2002 was used) from topsoil (0-10 cm) into duple one-use plastic bags. Sampling technique lay in following: first vegetative layer was removed in sampling points using a spade then topsoil was sliced off three times at angle of 45^o, at that firs two soil portions were thrown away and third one was taken as a sample. There was no quality control of the topsoil sampling. Sampling points were coordinated with help of portable GPS. Bags with samples were tagged and delivered to AUPET laboratory in Almaty.

Efficiency of demercurization works at the industrial site of the former chlor-alkali production, at the area of the former 6th wastewater pumping station and special storage ponds for solid and liquid mercury wastes was estimated by measuring concentration of mercury vapors at near-earth air (10 cm up from the ground surface) in 20 sampling points chosen at random in places of the most intensive soil mercury contamination. The measurements were implemented on the 21st July, 2006 since 3 pm till 6 pm at the air temperature of 27^{o}C ("Summary table 05.2006") in cooperation with specialists from AO GEOtestBRNO (Brno, Czech Republic) using portable mercury atomic absorptive spectrophotometer (AAS) Lyumex RA 915+ (Russia) according to the method of the instrument manufacturer.

2.1.2.2. Investigation of soil mercury contamination for producing/developing maps of mercury contamination

Previously the soil sampling plan was prepared on the regular grid based on GIS of the Northern industrial area of Pavlodat in places of intended mapping. The technique of soil sampling is described above in the section 2.1.2.1.

2.1.3. Investigation of gramma grass mercury contamination

Gramma grass sampling for its analysis for mercury contamination was done across the pastures for private livestock belonging to inhabitants of Pavlodarskoe village. The pastures were located between the industrial site #1 of PCP and the wastewater storage pond Balkyldak. In September, 2007 4 integral samples with wet mass of about 1 kg each were taken from two spots 10 m^2 each. The grass was dried in a dry not heated room and delivered to analytical laboratory in Almaty.

2.1.4. Investigation of mercury contamination of the wastewater storage pond – Lake Balkyldak

Investigation of mercury contamination of the wastewater storage pond Balkyldak lay in investigation of its bottom sediments, surface water and biota.

2.1.4.1. Sampling and bathymetric measurements for estimation of mercury contamination of bottom sediments of the wastewater storage pond Balkyldak

Before four variants of the plan of bottom sediment sampling was based on GIS of the Northern industrial area of Pavlodar prepared on the regular grid for 200, 150, 100 and 50 sampling points so that to choose the most optimal one at the site depending on complexity and time of field work carrying out.

Winter field works was conducted in March of 2006 and 2007 when the air temperatures had gone up to – 10^{o}C. Duration of these works was limited to beginning of intensive ice cracking when the temperature elevated higher than 0^{o}C. In winter of 2006 and 2007 the ice thickness on the storage pond Balkyldak reached 0.6 – 0.9 m. It allowed using cars with cross-country capacity to move across the ice surface (the area of the pond water surface is about 23 km^2) of the lake. However snowdrifts made the field works very difficult in places of reed thickets growth. In 2006 107 bottom sediment samples were taken from 52 sampling points, in 2007 – 159 samples from 94 sampling points. The bottom sediment samples were taken through the holes drilled through the ice with help of samplers of two different constructions: soft sediments were taken layerwise at 50 cm intervals, clay samples were taken only from surface bottom layer to the depth of 25 cm. Using the samplers it was possible to take ground at pond's depths down to 12 m (bathymetric and soft sediment capacity measurements were being done simultaneously with sampling). Coordinates of sampling points were determined with help of hand-held GPS with maximum error of 7 m. The samples were taken into throwaway linen bags which in turn were packed together with an identification tags into new double plastic bags and frozen. After each sampling the equipment was cleaned thoroughly from caught-on sediments with snow and water from the storage pond (Quality control of the clean-up was not conducted). The samples were delivered to Almaty and dried to air-dry state at room temperature in aerated, warm and clean room (plastic bags were opened, but linen bags remained closed). Further dry bottom sediments were kept in the same packing where they were put in at sampling and were being dried.

Summer bottom sediment sampling was conducted in July 2006 and September 2007,in total additionally 68 samples were taken from not deep 52 sampling points located near the shoreline of wastewater storage pond Balkyldak. The samples were taken from a boat board into tagged double plastic bags similar to the winter sampling (bottom sediment sampling far from the shore was impeded due to strong waving and the equipment bulkiness). After each sampling the equipment was being cleaned very carefully with the lake water from caught-on sediments (there was no the cleaning quality control). The samples were frozen and delivered to AUPET Laboratory in Almaty where they were stored frozen.

Bathymetric measurements and measurements of soft sediments thickness were carried out ("Summary table 01.2006-2007") simultaneously with bottom sediment sampling and used to develop GIS of the Northern industrial area of Pavlodar.

2.1.4.2. Surface water sampling for total mercury analysis

In August 2008 10 samples of water the wastewater storage pond Balkyldak were taken and analyzed (water samples were taken from the depth of 0.5 m, 5 m far from the shoreline in the most contaminated place near the special ponds for liquid and solid mercury wastes) including 5 water samples which were taken using a membrane filter with pores diameter of 0.45 µm for separate determination of total and dissolved mercury. The samples were filter under the pressure of compressed nitrogen in situ using a special filter unit. After every sampling the filter unit was rinsed out similar to equipment for groundwater sampling. The sampling quality control was conducted similarly. Samples of filtered and non filtered water were analyzed on the same method as groundwater samples. The precipitates on the filters were not analyzed.

2.1.4.3. Sampling of biota of both wastewater storage pond Balkyldak and control pond

Summer sampling of aquatic life (hydro-bionts) of the wastewater storage pond Balkyldak as well as a control pond - Lake Krivoe was conducted in June-August, 2006 and May-September, 2007. In total there were taken: silver crucian – 116; carp – 1 sample; benthos organisms and plankton – 11 and 4 integral samples respectively.

Fish were caught by either fixed nets with mesh of 30-65 mm or fishing rods. Samples of plankton were taken by Apshtein plankton net and tuck net of gas-sieve at sampling stations. Samples of benthos were taken from bottom sediments which were taken on the shore and rinsed out many times at the sampling stations. Species belonging was not determined. Shellfish were taken by hands from the ground and water plants. Samples for chemical analysis for mercury were frozen and delivered to AUPET Laboratory in Almaty.

Ichthyologic research was carried out according to standard instruction on fish study. Morphological characteristics of fish were studied by beam compass measuring with accuracy up to 0.5 mm

2.2 Chemical analytical works

2.2.1. Analysis of samples for mercury content

Most part of analyses of surface water and groundwater samples for total mercury content were carried out by AUPET personnel in the laboratory building provided by AO “Kaustik” at the territory of the former “Khimprom”, Pavlodar using equipment delivered from Almaty.

Analyses of groundwater samples for methyl mercury content were conducted in an analytical laboratory of Department of Environmental Sciences, Jožef Stefan Institute, Ljubljana, Slovenia.

Analysis of 240 soil samples was carried out in Stepnogorsk Laboratory of Biomonitoring by Participant Institution BMP in 2009.

The rest chemical analytical works were done in AUPET Laboratory in Almaty. All operations on samples preparation and their analysis for mercury content were conducted using minimum of laboratory glassware (one-use where possible) and reagents in order to decrease probability of samples pollution. All solutions were prepared using special ultra-clean reagent water.

Technique of determination of total mercury content in water samples based on: PS Analytical. Customer Technical Information File, Issue No. 4.2, Issue Date: November 2 2000: “Mmhgwat, Millennium Merlin method for total mercury in drinking, surface, ground, industrial and domestic waste waters and saline waters”. QA/QC was carried out in accordance with US EPA method 1631 rev E: “Mercury in Water by Oxidation, Purge and Trap, and Cold Vapor Atomic Fluorescence Spectrometry”, August 2002. The difference lay in using one-use polyethylene tetraphthalate (PET) coca-cola bottles for samples storage instead of recommended reusable PS Analytical containers made of fluoropolymer, borosilicate glasses or polypropylene of high density. Special study undertaken by AUPET earlier showed that mercury losses were statistically negligible when storing freshwater samples in PET bottles without preservatives during a day.

Coca-Cola bottles of 0.5 L containing water samples were taken out of plastic bags immediately after their delivery to the laboratory, rinsed out with distilled water after that samples were decomposed at once. Before the decomposition 100 mL of sample were poured out of the bottle. Then 60 mL of 33% solution of hydrochloric acid and 4 mL of bromide-bromate mixture (0.4 N solution of potassium bromide and 0.4 N solution of potassium bromate at a ratio of one to one) were added into the bottle to the rest 400 mL of the water sample. Solution in bottles had to become of yellow color. If solution in some bottles did not colored or lost the yellow color after 30 minutes than 50 mL aliquot was taken from such bottles, put into new Coca-Cola bottle and diluted 10 times with blank solution.

Next day 0.24 mL of 12 % solution of hydroxylamine hydrochloride were added into the bottles with samples; the bottles were shacked and total mercury content was determined using the atomic fluorescence spectrophotometer (AFS) “Millennium Merlin” 10.025 (UK).

Technique of determination of methyl mercury content in water samples lay in the following: Approximately 70 mL of sample was weighed directly in a 125 mL Teflon bottle. After addition of 5 mL of concentrated HCl and 30 mL of CH_2Cl_2, the bottles were closed and shaken overnight. Water phase was then removed with water pump and approximately 40 mL of Milli-Q ultra-clean water was added to the CH_2Cl_2. Organic phase was evaporated by heating on a water bath at about 90°C. Samples were then purged with N_2 for 5 minutes to remove remaining CH_2Cl_2. This extraction was repeated twice. An aliquot of the aqueous sample was added to Teflon reaction vial and pH was adjusted to be 4.6 with addition of 100 mL of acetate buffer. At the end 50 mL of 1% $NaBEt_4$ was added in the reaction vial and the mixture was left to react at the room temperature for 15 minutes. Ethylated MeHg as ethylmethylmercury was purged onto Tenax trap for 15 minutes with Hg-free nitrogen. Tenax traps were then connected to the flow of argon and MeHg was thermally desorbed (180°C) onto isothermal GC column. Different Hg forms were reduced to Hg^0 by pyrolysis at 600°C and measured by cold vapour atomic fluorescence detector (CVAFS). The limit of detection, calculated on basis of three standard deviation of blanks, was about 10 pg MeHg/L).

The reproducibility of the method is from 5 to 10%. Estimated uncertainty was 9.1% with a coverage factor k=2.

Recovery of MeHg was estimated by spiking the samples with known amount of MeHg prior extraction and analysis and showed to be between 85 to 90 % therefore recovery factor was used in the calculation of the results. During each batch of sample analysis 2 blanks (reagent blank plus the sample processing blank) were also analysed in order to avoid uncontrolled contamination.

Technique of mercury determination in soils and bottom sediments was based on: (i) PS Analytical. Customer Technical Information File, Issue No. 4.2, Issue Date: November 2 2000: “Mmhgslud, Millennium Merlin method for mercury sludge, soils and sediments”, and (ii) US EPA Appendix to Method 1631: “Total Mercury in Tissue, Sludge, Sediment, and Soil by Acid Digestion and BrCl Oxidation”, January 2001. Quality control was done in compliance with instruction (ii).

Dried and ground soil sample was weighted (about 1 g) and put into 100 mL beaker having also 50 mL set-point hairline. 15 mL of concentrated hydrochloric acid and then 5 mL of concentrated nitric acid were carefully added to the beaker, which then was covered with a watch crystal with one-use gasket of polyethylene film and heated carefully at the temperature of 95°C on a water bath until getting even boiling. After the solution cooling the volume in the beaker was increased up to 50 mL with reagent water. In order to remove nitrogen oxides 5 mL of 12% solution of hydroxylamine hydrochlorid were added into the beaker, stirred carefully and given time for the solution getting transparent. Before measurement 10 mL of sample were taken out of the beaker and placed into volumetric flask and diluted up to 100 mL with reagent water. An aliquot was taken out of the solution, diluted with blank solution to necessary concentration level and mercury content was measured using AFS “Millennium Merlin” 10.025 (UK).

In total 3 water samples were analyzed for methyl mercury, and about 800 samples of surface and ground water samples (including blanks and replicas), 334 bottom sediment samples, 610 soil samples, 4 gramma grass samples, 132 biota samples from the wastewater storage pond Balkyldak were analyzed for total mercury content.

The results of analysis of water for total and methyl mercury, air, soil, bottom sediments and biomaterials - for total mercury were used to produce a database of chemical analytical laboratory of AUPET (“Summary tables 04-09.2006, 02-06.2007, 02-04.2008”).

It must be mentioned that the results of the analyses for total mercury of water samples taken from the same three boreholes but at 10 days interval obtained in the analytical laboratories of AUPET and Jožef Stefan Institute, Ljubljana, Slovenia (“Summary tables 04 and 05.2006”) differ from each other not more than by 15 %, that is good coincidence.

2.2.2. Analysis of groundwater samples for soluble oil products

Stepnogorsk Laboratory of Biomonitoring, Participant Institution BMP analyzed 80 groundwater samples for recoverable petroleum carbohydrates using the gas chromatographer "Hewlett Packard", USA with flame-inductive detector using an instruction of the instrument manufacturer. In none of the groundwater samples taken at the Northern industrial area of Pavlodar the oil products dissolved in water were found.

2.2.3. Determination of coefficients of mercury adsorption by Pavlodar clays

Laboratory experiment on determination of coefficients of mercury adsorption for hydro-geological simulation lay in determining mercury (II) chloride concentration in aquatic solutions which were in equilibrium with clay typical for water bearing strata of the Northern industrial area of Pavlodar. Amount of clay necessary for the experiment was taken out of integral sample of loamy sand selected during drilling an observation hydro-geological borehole in the Northern industrial area of Pavlodar in 2002. Mercury concentration in groundwater taken from the same borehole at the same time was lower than 50 ng/L Clay was drew out of the loamy sand by decanting, dried to air-dry condition, ground in a mortar and stirred thoroughly.

20 samples of clay 2 g each sifted through a plastic 2 mm mesh sieve were placed in 20 one-use tightly closed test-tubes with volume of 25 mL (newly-made preforms of polyethylene tetraphthalate (PET) for production of coca-cola bottles with screw-tops of the same material were used as test-tubes). All of these test-tubes were filled with 20 mL of 0.33% NaCl containing different concentrations of $HgCl_2$: 0; 5; 10; 20; 50; 100; 150; 200; 500; 1000 µg/L so that to have duplicates of each concentration.. Besides third set of 10 test-tubes was used for blank experiments with the same solutions of NaCl и $HgCl_2$ but not containing loamy sand. So three series of blends was made. The first and the second ones were needed for determination of mercury remaining in a solution in equilibrium, the third series - for correction of mercury content on work solutions.

All solutions were prepared on ultra-clean reagent water which was used when analyzing mercury in natural waters (see the section 2.2.1. of this report). Test-tubes were closed with screw-tops, placed into a shaker and shaken for 6 hours at a speed of 200 min^{-1} and the temperature of 15 ^{0}C.

After shaking the blends of solution and loamy sand in every test-tube (for blanks it was only solutions) were centrifuged (w = 3000 rpm, t = 10 min) for phase separation. Then 15 mL from every test-tube were filtered through membrane filter with pore size of 0.45 µm into other performs where also 0.75 mL of concentrated hydrochloric acid and 0.15mL of bromide-bromate mixture were added to. Next day they were analyzed as water samples using spectrometer “Millennium Merlin” similar to analysis of natural water samples for mercury (see the section 2.2.1. of this report).

The results of mercury determination of $HgCl_2$ in 10 blanks were used as amendments for taking into account mercury absorption by walls of vials and equipment used.

Based on the obtained results the diagram for Freundlich adsorption isotherms was constructed. The diagram consisted of two linear parts with its break at mercury concentration of 200 µg/L in initial solution. The left part of the diagram had a slope ratio close to the unity. It meant that obtained dependence was close to Henry isotherm at mercury content less than 200 µg/L in the initial solution. Since groundwater in the Northern industrial area contain mercury less than 200 µg/L it turned out to be possible to use Henry adsorption isotherm for producing computer hydro-geological model of the groundwater mercury contamination using a distribution coefficient of **0.04 L/mg** calculated on the basis of the laboratory experiment.

2.3. Office study

2.3.1. Database creation

The results of field measurements and chemical analytical works were compiled in computer Summary tables 01.2006-2007, 02–09.2006, 01-06.2007, 01-04.2008 which formed the database of post-demercurization monitoring. Due to its huge size the database is not provided in the present report.

2.3.2. Development of GIS of Northern industrial area of Pavlodar (see Q(II))

GIS of the Northern industrial area of Pavlodar produced earlier in 2000-2001 *at the area of wastewater storage pond – Lake Balkyldak* was made more detailed and completed with new data from satellite images and archival documents and also from direct measurement with help of portable GPS: vegetation boundaries, the bottom contour were input, the pond nowadays shore line was made more correct; outline of impervious barrier so called cut-off wall *at the industrial site of the former chlor-alkali production* was made more precise.

2.3.3. Analysis of the results of investigation of groundwater mercury contamination

The results of determination of mercury concentration in groundwater at the area of mercury pollution ("Summary tables 05.2006, 02.2007 and 02.2008") were inserted onto the vector map together with the results of similar research of 2004 and 2005 (Fig.1, Attachment 3). Together with Table 1 (Attachment 3) this map-scheme shows dynamic of total mercury concentration change in groundwater in post-demercurization period and allows finding spots with increasing/conserved mercury concentration at the area of groundwater mercury contamination plume (due to natural drift of the plume of mercury contamination along groundwater flow) and also spots with decrease in mercury (for example due to dilution with clean water as a result of leaks fro the waster supply system or due to cessation of groundwater recharge with mercury from the main source of contamination contained by the cut-off wall).

2.3.4. Analysis of the results of investigation of soil mercury contamination

2.3.4.1. The results of determination of mercury concentration in 19 soil samples taken within the industrial area of the former chlor-alkali production and in site of 6th wastewater pumping station ("Summary table 06.2006") showed that in general high levels (from 2.1 to 95.1 mg/kg) of soil mercury contamination (at maximum permissible concentration of mercury in soil - MPC_s being 2.1 mg/kg) kept up here after implementation of demercurization works both on the surface of clay screens covering concrete foundations of demolished buildings and within the territory where digging were conducted including excavation of highly contaminated topsoil. In their extreme values these concentrations could be of the order of g/kg.

Respectively mercury vapors concentrations in the near-earth air ("Summary table 07.2006") ranged from 100 to 1600 ng/m^3 (the average daily maximum permissible concentration of mercury in atmosphere MPC_{ad} equal to 300 ng/m^3 was exceeded in 7 of 16 sampling points). Also extremely high mercury vapors concentrations (above the maximum permissible mercury concentration for a working area which is 10000 ng/m^3) were found (in one measuring point) at the place where the clay covering over the concrete foundation of the building 31 was destroyed by atmospheric precipitation.

Preliminary results showed persistent high risk for working personnel posed by both soil mercury contamination within the former chlor-alkali production and insufficiency of measures on its clean up carried out on the Program of Demercurization in 2002-2004. Persistent soil mercury contamination entails in turn additional entrance of dissolved mercury into groundwater due to infiltration of atmospheric precipitation and thaw waters through the contaminated soil layer because this contamination extends beyond the area confined by the cut-off wall. All this necessitates carrying out more detailed investigation of mercury contaminated topsoil within the industrial site #1 of PCP in the framework of ISTC K-1240 project resulting in production of new map of the contamination.

Measured concentrations of mercury vapors which were about 200 ng/m^3 (on two measuring points) in the center of the landfill for building structures (50 m to the south from the former building 31) and from 100 to 200 ng/m^3 (on four measuring points) on site of special ponds for solid and liquid mercury waste located at south shore of wastewater storage pond Balkyldak proved quite good containment of the mercury waste by these engineering structures.

2.3.4.2. Analysis of the results of investigation of soil mercury contamination

The results of determination of mercury concentration in soil samples taken in 2002 on the regular grid between the industrial site #1 and the wastewater storage pond Balkyldak at 5 sites of possible mercury contaminated groundwater rise to the ground surface ("Summary table 06.2006") were used for correction of the map of the soil mercury contamination produced in 2002 (Fig.2, Attachment 3). At the result of the correction the vast area of topsoil mercury contamination was designated on the map (with maximal mercury concentration of more than 100 MPC_s) to the north from the former 6th wastewater pumping station formed by either mercury contaminated groundwater rise up to the ground surface (see the section 2.4. of this report). Average total mercury concentration in samples of grass growing in this area exceeds 0.1 mg/kg achieving the maximal value of 0.2 mg/kg. The boundaries of this area require to be more precise.

2.3.4.3. Because of discovered in 2006 remaining high level of soils mercury contamination at the territory of demercurization of chlor-alkali production (the section 2.3.4.2) and new spots of soil mercury pollution Soil Sampling Plan were produced based on GIS of the Northern industrial area of Pavlodar for creation of a new map of soil mercury contamination for 2007-2008: the Table with sampling points coordinates and 3 maps with sampling points location – (i) Plan of soil sampling at the territory of demercurization, (ii) Plan of soil sampling at the industrial site #1 of PCP (without the area of demercurization) and (iii) Plan of soil sampling at the area around the industrial site #1 of PCP (Fig. 3-5, Attachment 3). Unfortunately only the first plan of soil sampling of three developed ones was managed to realize within the framework of ISTC K-1240p project because of problems with due-timed receipt of project funds for conducting field works.

2.3.4.4. Computer map of topsoil (0-10 cm) mercury contamination at the industrial site of the former chlor-alkali production was produced on the basis of the data of "Summary table 04.2008" on 240 sampling points within the GIS of the Northern industrial area of Pavlodar city using software ArcGIS, module Spatial Analyst (Fig. 6, Attachment 3). The map showed practically the same level of soil contamination which had existed before the remediation works were done as well the high risks for people working at PCP especially in summer time. Soils with remaining high mercury content also certainly are a source of groundwater feeding with mercury.

2.3.5. Analysis of the results of the bottom sediment investigation of wastewater storage pond – Lake Balkyldak

Within GIS of the Northern industrial area of Pavlodar based on the data from "Summary table 01.2006-2007" using software ArcGIS, module Spatial Analyst a computer map of depths of the wastewater storage pond - Lake Balkyldak and thicknesses of its bottom sediments was produced on 198 sampling points (Fig.7, Attachment 3).

By the similar way the results of determination of mercury concentration in 334 bottom sediment samples ("Summary tables 08.2006 and 08.2007") taken from 198 sampling points were used to create a vector map "Mercury contamination of bottom sediments of wastewater storage pond Balkyldak" Fig.7, Attachment 3).

The data of "Summary tables 01.2006-2007, 08.2006 and 08.2007" were also used for calculation of amount of mercury deposited in the bottom sediments of the storage pond, which was done using a Spatial Analysis module of ArcGIS software and partly MapInfo Professional. Inverse distance weighted (IDW), Spline and Kriging were also tried among mathematical methods of analysis. Amount of mercury deposited in the bottom sediments of the wastewater storage pond Balkyldak were estimated as **135.336 tones.**

2.4. Computer modeling

2.4.1. Modeling of groundwater contamination spread with soluble forms of mercury

At the fist stage of modeling a local hydro-geological model of the area of groundwater mercury contamination within the former PO “Khimprom” was created and calibrated. The purpose of the works was to make the prognoses of mercury contaminated groundwater spread more exact due to taking into account the processes of mercury sorption/desorption by water bearing strata and also to study possible interconnection between waters of Lower-middle-Pliocene deposits of Pavlodar series and Oligocene deposits of Nekrasov series. Proportion of boundaries of the regional and local models in horizontal projection is shown on the Fig. 9, Attachment 3.

In order to achieve the purpose some additional archival data were collected, reconnaissance investigations were conducted, hydro-geological conditions within the local model were made more exact, schematization of hydro-geological conditions was carried out, input data were prepared in proper formats, local hydro-geological model was produced by means of software GMS 6.0 and its calibration was done.

On bases of the collected data 20 detailed hydro-geological cross sections were constructed in the sub latitudinal and sub meridional directions. The cross sections are shown on the Fig.9. Three-dimensional diagram depicting lithologic structure of the simulated area is shown on the Fig.10, Attachment 3. Based on hydro-geological cross sections the model of stratigraphy was produced by means of software GMS 6.0.

The simulated area in section is schematized as 19 layers (regional model consists of 5 layers). In horizontal projection it is approximated by orthogonal grid with step of 40 m (on the regional model the grid step ranged from 50 to 200 m in the area of the plume of contamination spread) and the block size of 113 x 92. Groundwater heads changing with time were established on outer boundaries of the local model which corresponded to groundwater heads obtained on the regional model of the Northern industrial area of Pavlodar.

The inverse stationary task was solved with the purpose of calibrating the model. Position of groundwater table as of 1970 i.e. conditionally undisturbed period was reproduced in the model. Filtration coefficients of water bearing strata and value of groundwater infiltration recharge were made more precise. Average error of the solution was not more than 1 cm. The result of the inverse stationary task solution is represented on the Fig.11, Attachment 3.

Analyses of the character of the hydro-geological conditions of the investigated area as well as the results of the modeling were implemented to estimate possible soil mercury contamination as a result of contaminated groundwater rise up to the ground surface followed by their evaporation. Spatial relation of the regional model of hydro-geological conditions in the Northern industrial area of Pavlodar and the local model of the site of groundwater mercury contamination is shown on the Fig.12, Attachment 3. Water-bearing rocks with different filtration properties are designated by colors on the cross section.

While producing the local model reproduction of detailed lithological structure of the investigated area was required (see the Fig.13, Attachment 3).

Quality of the local model calibration was evaluated according to degree of its conformity to existing natural conditions taking into account the results from the regional model. The calibration involved solution of a series of inverse tasks: stationary and non-stationary hydro-dynamic ones as well as the task on mercury transport by groundwater flow.

When solving inverse stationary hydro-dynamic task position of groundwater tables as of 1970 i.e. conditionally undisturbed period was reproduced in the model. Solution of the inverse non-stationary hydro-dynamic task on the model simulated the change in groundwater table surface from 1970 to 2006. Specific yield was established as 0.22. Specific storage of water-bearing rocks was equal to 0.001 1/m. Maximal value of groundwater recharge due to losses from engineering services achieved 0.002 m/day. Boundary conditions were established by interpolation of the local model solution obtained on the regional model into boundary blocks (See the Fig.14, Attachment 3).

Inverse transport task (for the period from 1975 to 2006) was solved for simulation of the process of mercury transport by groundwater flow. Advective component of the substance flow was calculated based on solving the hydro-dynamic task. Mercury adsorption by water-bearing rocks was reproduced on the local model. Equilibrium between liquid and solid phases was assumed to attain immediately. The linear isotherm Henry (the model of irreversible equilibrium sorption) was used to describe the process of dissolved mercury adsorption:

$$\overline{C} = K_d C ,$$

where $\overline{C}$ [MM^{-1}] – sorbed substance concentration, C [M/L^3] – dissolved substance concentration, K_d [L^3M^{-1}] – distribution coefficient.

Based on the results of laboratory experiments on mercury adsorption by clay fraction contained in loamy sand taken from the area of contamination (see the section 2.2.2. of the present report) the Henry constant was assumed to range from 0.01 to 0.04 l/mg for clay material and from 0.00001 l/mg for different-size grained sand to 0.0015 l/mg for clay and dust sands (depending on admixture of clay there). Porosity of clay material was assumed to be 0.3, sand one – 0.22. Dissolved mercury concentration in groundwater closed to hotspots of soil mercury contamination ranged from 0.5 to 0.04 mg/l.

High degree of precision coincidence of calculated values of both groundwater tables and mercury concentrations with values obtained as a results of field trials suggests adequacy of the detailed local model to existing natural conditions (see the Fig.15, Attachment 3).

Within the area being simulated water-bearing rocks are presented by sands interlaced irregularly with clay and loam. Mercury can not go even through thin clay interlayers but it can be adsorbed by their surface.

2.4.2. Modeling of groundwater contamination spread with soluble oil products

Based on collected achieve data large-scale local hydro-dynamic model of the area of groundwater contamination with oil products was created and calibrated using GMS 6.0 software, which simulated groundwater movement under pressure of natural and technogenic factors.

The purpose was to predict change in hydro-geological conditions at the model as well as to determine a trajectory of movement of oil products dissolved in the groundwater.

Relation of boundaries of regional and local model in the horizontal projection is shown on the Fig.16, Attachment 3. Structure of the modeled area in section is given on the Fig. 17 and 18 Attachment 3.

The modeled area in section is schematized as 13 layers. In horizontal projection it is approximated by orthogonal grid a step which is ranged from 10m in the source of the groundwater contamination with oil products to 40 m in the periphery part of the modeled area. The grid size is of 113 x 92 blocks. Groundwater heads changing with time were established on outer boundaries of the local model which corresponded to groundwater heads obtained on the regional model of the Northern industrial area of Pavlodar.

The inverse stationary task was solved with the purpose of calibrating the model. Position of groundwater table as of 1970 i.e. conditionally undisturbed period was reproduced in the model. Filtration coefficients of water bearing strata and value of groundwater infiltration recharge were made more precise. The result of the inverse stationary task solution is represented on the Fig.19, Attachment 3. Average error of the solution was about 0.3 m.

Solution of the inverse non-stationary hydro-dynamic task on the model simulated the change in groundwater table surface from 1970 to 2006. The result of the solution of the inverse non-stationary task is shown on Fig.20, Attachment 3. Average error of the solution was about 0.3 m.

Change of hydro-geological conditions for thirty-year period was predicted with the help of MODFLOW module. When establishing prognosis task the main source of contamination was expected to be the oil sump at treatment facilities of Pavlodar Oil Refinery (see the section 2.1.1.3.). Using ModPath module the trajectories of movement of oil products dissolved in groundwater were calculated.

Within ISTC K-1240p project scheduled field studies and detailed mapping of the existing plume of groundwater contamination with oil products, determination of migration parameters of oil products, actual velocity of the contamination spread were not managed to implement. That is why the model depicting only trajectory of the most possible predicted spread of dissolved oil products without taking processes of sorption, biodegradation etc. into consideration was created for assessment of risk of the groundwater contamination with oil products for population living in the northern outskirt of Pavlodar and the Irysh River floodplain.

3. Results

Task 1: Study of the movement of mercury in the groundwater rise in depressed area in saturated and unsaturated zones and its accumulation in the shallow ponds, soil and vegetation. Development of management strategy to contain the risk to population in the vicinity and livestock.

Three-year post-demercurization monitoring in the Northern industrial area of Pavlodar city (which mainly lay in observation over groundwater and soils mercury pollution) showed expansion of the groundwater mercury contamination beyond the industrial site of PCP to north-north-west direction from the former chlor-alkali production and 6^{th} wastewater pumping station as it had been predicted by the results of the computer modeling (see Fig.1 and Table 2 in Attachment 3). The continued spread of the plume of the contamination is a reason of appearance and increase of high mercury concentrations in the boreholes 73-02 and 79-02 where mercury was not found at all before though. This also show itself in continued increase of high mercury concentrations in the boreholes C-15-03, C-14-03, 66-02, 84-02, 68-02, B-21 and B-22 as well as in remaining high mercury concentrations in the boreholes C-8-03, C-9-03, C-12-03, C-13-03. Spread of the plume of groundwater contamination in very dangerous because in spite of absence of risks of mercury contamination for both water supply system of Pavlodarskoe village and mercury ingress to the Irtysh River, there exists mercury contamination of the topsoil (more than MPC equal to 2.1 mg/kg) and vegetation in sites where mercury-bearing groundwater can rise up to the original ground.

At the map of soil mercury contamination of the Northern industrial area of Pavlodar (2002) expanded with the results of the field investigation of 2006 (see Fig.2, Attachment 3) at the site where mercury contaminated groundwater reached the ground surface there is an extensive area of similar contamination of the topsoil with mercury concentrations of hundreds of mg/kg for soils and a few hundreds of μg/kg for grass. Unfortunately the boundaries of this area were not determined whilst this territory is used as a pasture for livestock belonging to inhabitants of Pavlodarskoe village.

In boreholes located along eastern contour of the plume of contamination beyond the industrial site #1 of PCP (see Fig.1 and Table 1 in Attachment 3) a different picture is observed also predicted by computer modeling when mercury concentrations in groundwater are reduced systematically.

Decrease of mercury concentration in groundwater occurs also within the industrial area of PCP (see Fig.1 and Table 1 in Attachment 3) however it happens extremely irregularly (in the middle part of the plum mercury concentration dropped very fast down to safe level, i.e. lower than 500 ng/L, in the plum head it was going down slower than expected) that conformed to the prognosis not very well. This can resulted from two reasons: (i) dilution of the contaminated groundwater as a result of leaks of clean water from water supply system, (ii) remaining interaction of the groundwater with these or some other sources of mercury contamination despite containment of the main mercury hotspots.

The results of determination of methyl mercury concentration in water taken from three boreholes within the plume of mercury pollution ("Summary table 04.2006") range from several ng/L to tens of ng/L that averages 0.01% of total mercury concentration.

The level of mercury contamination of the topsoil directly at the territory of the industrial site of the former chloк-alkali production remains to be extremely high (extreme mercury concentrations of the order of g/kg were found, that 1000 times as high as MPC for soils) despite cleanup works conducted. Clay screens which cover concrete foundations of demolished buildings of chlor-alkali production are washed out with atmospheric precipitation and spring flood waters so that mercury drops are visible on the ground surface. All this causes high emission of mercury vapors to the atmosphere (mercury concentration in near-earth layer in its extreme values exceeded 10000 ng/m^3, that is higher not only than MPC for residential area equal to 300 ng/m^3, but even than MPC for working area) and ingress of soluble mercury forms into groundwater beyond the perimeter of the anti-filtration barrier so called "cut-off wall" which enclose the main underground hearths of mercury contamination. Besides persistent high risks to the environment and health of JSC "Kaustik" personnel such a situation does not allow estimating the efficiency of the cut-off wall as a way of mercury hotspots isolation from groundwater.

At the same time it was proved that landfills at the industrial area of PCP and at special ponds for liquid and solid mercury wastes pose no any risk as a source of groundwater mercury pollution. Measured concentrations of mercury vapors which were about 200 ng/m^3 (on two measuring points) in the center of the landfill for building structures (50 m to the south from the former building 31) and from 100 to 200 ng/m^3 (on four measuring points) on site of special ponds for solid and liquid mercury waste located at south shore of wastewater storage pond Balkyldak proved quite good containment of the mercury waste by these engineering structures.

A map of the topsoil mercury contamination given on the Fig.6, Attachment 3 in a zone of demercurization was produced (2008), which can be basis for development of Feasibility Study of the II phase of demercurization of the industrial site #1 of the former PO "Khimprom". The most cost effective and promising technology of mercury recovery from the topsoil was chosen of all technologies discussed at conferences and workshops. It is used by the company "GEOtest, Brno, Czech Republic at the former chlor-alkali production in Vlora city, Albania and lies in pulping soil contaminated with metallic mercury followed by gravitational separation of the mercury.

Hydro-geological data and the results of chemical analysis obtained as a result of groundwater monitoring allowed developing and improving the computer model of the groundwater mercury contamination. They also became the basis of successful conducting field tests of a technology of groundwater bioremediation carried out in 2010-2011 on ISTC K-1477p project. This technology has a perspective to become the most cost effective and efficient way of mercury immobilization in groundwater of the Northern industrial area of Pavlodar city.

Task 2: Assessment of possibility for mercury-polluted groundwater flow to change its direction; study of interaction of contaminated groundwater with bearing strata and underlying aquifers

Additional collected data on groundwater mercury contamination ("Summary tables 02–05.2006, 01-02.2007, 01-02.2008") and mercury sorption with strata of the Northern industrial area of Pavlodar (see the section 2.2.3. of the present report) as well as the use of the modeling system GMS 6.0 software allowed dividing the computer model of mercury contamination for regional model and local one that created additional opportunities for modeling. In particular on the results of modeling mercury transport was found to occur not only horizontally through sand between clay interlayers but also in vertical bottom-up direction through so called "windows" in places of clay interlayers pinching-out. It allows making up a conclusion about existence of spots where mercury can get to zone of aeration and then to plants and surface water.

Finding the spots of mercury getting to zone of aeration in turn required additional analysis of both character of hydro-geological conditions within the area of investigation and the results of modeling. For that 13 more precise hydro-geological cross sections were constructed within the area of mercury contamination spread on the basis of source hydro-geological information being in databases. The map produced on the basis of the material available and four main cross sections are shown on the Fig.21-25, Attachment 3. These cross sections along with the results of solution on the local model of different scenarios of prognosis tasks underlay the area zoning (according to groundwater table occurrence depth, mercury concentration in groundwater and the character of lithological structure). To carry out zoning the maps of lithological structure were used, where there were taken into account following factors: spots not having clay in the top of a cross section, distribution of mercury concentration in groundwater at different points of time, depth of groundwater table occurrence marking the depths less than critical one. Value of critical depth (i.e. the depth from which groundwater evaporation starts) was established as 2.4 m based on earlier field studies. Thus zones were revealed where mercury contaminated groundwater can rise up to lower boundary of aeration (Fig.26, Attachment 3). Three-dimensional diagram of the plum of groundwater mercury pollution spread based on the results of modeling as of the end of 2006 is presented on the Fig.27, Attachment 3.

Prognosis of the plume of groundwater mercury contamination spread for 30 years (2007-2037) suggests high risk of formation of new hotspots of mercury contamination of soil at the territory between the industrial site #1 and the wastewater storage pond Balkyldak. At the same time the prognosis was proved that there is no threat of mercury pollution to both the Irtysh River and water-supply wells of Pavlodarskoye village in case of unchangeable hydro-geological conditions which determine the direction of mercury contaminated groundwater movement. At the same time unfavorable change of hydro-geological conditions can be caused only by some technogenic reasons.

Task 3: Study of the spread of groundwater plume contaminated with oil products from the territory of Pavlodar Oil Refinery; development of model and assessment of environmental risk posed by oil-products contamination of groundwater in the Northern industrial area of Pavlodar

Produced local computer hydro-dynamic model took into account character of lithological structure in the area of the spread of the plume of groundwater contamination with oil products more detailed than the regional one. A step of the grid approximation of the modeled area was reduced in a horizontal projection down to 10 m (on the regional model it ranged fro 50 to 200 m at the area of the spread of the plume of groundwater contamination with oil products). Hydro-geological conditions in section were schematized more detailed – number of layer of the local model was increased up to 13 ones (while the regional model consists of 5 layers). At the model prognosis trajectory of movement of oil products dissolved in groundwater from treatment facilities of the industrial site of Pavlodar Oil Refinery (north-west corner) towards the Irtysh River was calculated (see the Fig.27, Attachment 3).

The trajectory calculated using ModPath module goes towards the Irtysh River in fact through the centre of Pavlodarskoe village that proves high risks of oil products ingress into water supply wells of Pavlodarskoe village. More detailed prognosis requires conducting additional field and laboratory studies on mapping of the plum of groundwater contamination with oil products and determining actual velocity of it movement. It is needed to determine composition of oil products going down to the groundwater and their properties as well as functional dependences between permeability of bearing strata, their saturation and pressure of fluid. For obtaining more reliable results the model must take into account the filtration of three-component fluid (water, air, oil products), therefore dependences between penetrability, saturation and pressure shall be received for each of the components.

Task 4: Assessment of possibility to contain the risk posed by mercury pollution of Lake Balkyldak including the fish within it

Field and chemical analytical studies conducted in 2006-2008 allowed developing GIS of the wastewater storage pond Balkyldak and producing a vector map of thickness of its bottom sediments and their mercury contamination (Fig.7 and 8, Attachment 3). As a result of continued waving activity reaching the bottom of this not very deep water body (maximal depths of down to 10 m are observed only in two relatively small depressions which remained from their being as natural salty lakes) redistribution of technogenic silts resulted in accumulation of basic mass of mercury containing sediments within the area coming to 1/5 part of the pond water space. Amount of mercury which came to the pond Balkyldak with wastewater of PO “Kkimprom” was calculated to be **135 336 kg**. This figure allows estimating mercury losses at similar chlor-alkali productions of the former USSR, which disposed their wastewater to flow-through water bodies, e.g. Volga, Ob’ and Angara rivers. The map of mercury contamination of the pond Balkyldak can be a basis for development of a Feasibility Study and its demercurization. The most cost effective and promising technology of mercury contaminated bottom sediments removal was chosen of all technologies discussed at workshops and conferences. It was used in Minamata Bay, Japan and lies in pumping soft sediments using a hydraulic dredge and transporting them to some isolated earth reservoir on the shore of the storage pond followed by the sediment burial in landfill constructed on site of the same reservoir.

Chemical analysis of samples of surface water of the wastewater storage pond Balkyldak taken close to the former special ponds for liquid and solid mercury wastes (“Summary table 03.2008”) showed decrease of the level of their mercury contamination after construction of the landfill on site of the special ponds for mercury wastes: average concentration of total mercury in water was 300 ng/L (0.6 MPC_w) in 2008 against stable 3000 ng/L (6 MPC_w) in 2001-2002 at the same place of sampling. However it is worth taking into consideration that in 2001-2004 average concentration of total mercury in surface water of the rest water area of the pond was at the level of 100-300 ng/L and varied generally depending on waving of its water surface (and respectively on suspension silt particles), and average concentration of dissolved mercury in filtered water samples taken from the pond was steadily lower than 10ng/L for any random sampling points on the pond water surface (the latest data were also confirmed in 2008). Thus observed decrease of the level of contamination of the surface water of the storage pond is quite local one and results from cessation of dusting of solid mercury wastes from the special ponds at its shore, which in mainly sulfide of mercury (II).

Ichthyo-fauna of the technical water body Balkyldak is uniform and 99% consists of silver crucian. Food chains do not contain predators and are primitive. Since the main component of the crucian feeding is soft water vegetation and algae than average levels of total mercury content in plankton (0.485 mg/kg for 2007), benthos and shellfish (0.545 mg/kg for 2007) and fish (0.271 mg/kg for 2006 and 0.376 mg/kg for 2007) are the values of the same order. Local 10 times decrease of the surface water mercury contamination in the wastewater storage pond Balkyldak was enough for noticeable decrease of mercury contamination in fish inhabiting there: average total mercury concentration in silver crucian (2006-2007) decreased to 0.3 mg/kg (1 MPC_{npf}) compared to 2.1 mg/kg (7MPC_{npf}) in 2001-2002. It is also possible that such decrease in level of mercury content in fish resulted from considerable decrease of concentration of dissolved mercury coming to the storage pond Balkyldak together with groundwater pinching-out on the pond bottom: for the boreholes C21-03, C22-03, C25-03, C27-03, C30-03 (see the Fig. 1 and the Table 1, Attachment 3) located at the shore of the storage pond close to the special ponds there happened decrease in mercury concentration in groundwater at that twice – for two of them and 8 times – for one borehole.

However fish containing mercury from 1.0 to 1.5 mg/kg (3-5 MPC_{npf}) kept on occurring widely in the storage pond Balkyldak in 2006 and 2007 that means that risks for health of people dealing with fishing remain relatively high. The local authority should continue their explanatory activity through the mass media such as warning about a danger to use fish from the wastewater pond Balkyldak as a foodstuff and a practice of administrative ban against commercial fishing in the pond Balkyldak.

A question about removal of mercury contaminated bottom sediments of the wastewater storage pond Balkyldak should be examined after decision about its further use would have been made that depends first of all on perspectives of JSC "Kaustik" development.

Task 5. To draw up and discuss with local stakeholders the recommendations for the 2nd stage of demercurization and other remediation activities in the area of the former PO "Khimprom" (Northern industrial area of Pavlodar), including the recommendation for abolishment or further safe use of the wastewater storage pond – lake Balkyldak

Recommendations on the II phase of demercurization and other remediation activities in the Northern industrial area of Pavlodar on site of the former PO "Khimprom" were discussed and provided to the regional authorities, the main of which are as follows:

- it is necessary to follow up monitoring of mercury contamination of the Northern industrial area of Pavlodar (mainly that of groundwater) and mapping of soil mercury contamination, as well as to prepare Feasibility Study for the II phase of demercurization works at the industrial site #1 of PCP;

-work specification for preparing Feasibility Study for the II phase of demercurization works shall involve development of three remediation projects: (i) on soil clean up from mercury and soil restoration at the industrial site of the former chlor-alkali production, (ii) on immobilization of mercury in groundwater, and (iii) on cleaning of mercury contaminated bottom sediments of the wastewater storage pond Balkyldak.

4. Conclusion

Three-year post-demercurization monitoring in the Northern industrial area of Pavlodar city showed expansion of the groundwater mercury contamination beyond the industrial site of PCP to north-north-west direction from the former chlor-alkali production and the former 6th wastewater pumping station as it had been predicted by the results of the computer modeling. At that in spite of absence of risks of both mercury contamination of water supply system in Pavlodarskoe village and mercury ingress to the Irtysh River, there is mercury contamination of the topsoil (more than MPC_s equal to 2.1 mg/kg) and vegetation in sites where mercury-bearing groundwater can rise up to the original ground.

Within the industrial area of PCP decrease of mercury concentration in groundwater is extremely irregular (in the middle part of the plum mercury concentration dropped very fast down to the safe level, i.e. lower than 500 ng/L, in the plum head it was going down slower than expected) that conformed to the prognosis not very well. This can result from two reasons: (i) dilution of the contaminated groundwater as a result of leaks of clean water from a water supply system, (ii) remaining interaction of the groundwater with sources of the groundwater feeding with mercury despite containment of the main mercury hotspots.

At the territory of the former chlor-alkali production of PO “Khimprom”, Pavlodar in 2010-2011 field tests of a technology of groundwater bioremediation were carried out successfully in 2010-2011 on ISTC K-1477p project. This technology has a perspective to become the most cost effective and efficient way of mercury immobilization in groundwater of the Northern industrial area of Pavlodar city.

The level of mercury contamination of the topsoil directly at the territory of the industrial site of the former chloк-alkali production remains to be extremely high (extreme mercury concentrations of the order of g/kg were found, that 1000 times as high as MPC_s for soils) despite cleanup works conducted. Clay screens which cover concrete foundations of demolished buildings of chlor-alkali production are washed out with atmospheric precipitation and spring flood waters so that mercury drops are visible on the ground surface. All this causes high emission of mercury vapors to the atmosphere (mercury concentration in the near-earth layer in its extreme values exceeded 10000 ng/m^3, that is higher not only than MPC_{ra} for residential area equal to 300 ng/m^3, but even than MPC_{wa} for working area) and ingress of soluble mercury forms into groundwater beyond the perimeter of the anti-filtration barrier so called “cut-off wall” which enclose the main underground sources of mercury contamination. Besides persistent high risks to the environment and health of JSC “Kaustik” personnel such a situation does not allow estimating the efficiency of the cut-off wall as a way of mercury hotspots isolation from groundwater.

At the same time it was proved that landfills at the industrial area of PCP and at special ponds for liquid and solid mercury wastes pose no any risk as a source of groundwater and the atmosphere mercury pollution.

The most cost effective and promising technology of mercury recovery from the topsoil for its use at the territory of PCP was chosen of all discussed technologies. It is used by the company “GEOtest, Brno, Czech Republic at the former chlor-alkali production in Vlora city, Albania and lies in pulping contaminated soil followed by gravitational separation of mercury.

Additional data gathered on groundwater mercury pollution and sorption of mercury with bearing strata in the Northern industrial area of Pavlodar city as well as application of modeling system GMS 6.0 software allowed developing the computer model of mercury contamination having divided it into regional model and local one and prepared three-dimensional variant of the model.

Prognosis of the plume of groundwater mercury contamination spread given for 30 years (2007-2037) suggests high risk of formation of new hotspots of mercury contamination of soil at the territory between the industrial site #1 and the wastewater storage pond Balkyldak due to transport of soluble mercury to a zone of aeration. At the same time there is no threat of mercury pollution to both the Irtysh River and water-supply wells of Pavlodarskoye village if hydro-geological conditions which determine direction of mercury contaminated groundwater movement remain the same.

Field investigations proved the spread of a underground waste oil sump more than 2 m thick at the depth of 2.6 m over the groundwater table and 25 m long beyond north-west corner of the industrial area of Pavlodar Oil Refinery. The oil sump is a source of groundwater feeding with soluble oil products.

Created a computer hydro-dynamic model of spread of groundwater contamination with oil products between Pavlodar Oil Refinery and Pavlodarskoye village allowed calculating a trajectory of the plume of contamination which go to the Irtysh River through the middle of the village and proving high probability of the oil product ingress into the village water supply wells and respectively high potential risks to health of the village inhabitants.

Field and chemical analytical studies conducted in 2006-2008 allowed developing GIS of the wastewater storage pond Balkyldak and producing a vector map of mercury contamination of its bottom sediments. Amount of mercury which came to the pond Balkyldak with wastewater of PO “Kkimprom” was calculated to be **135 336 kg**. The map of mercury contamination of the pond Balkyldak can be a basis for development of a Feasibility Study and its demercurization. The most cost effective and promising technology of mercury contaminated bottom sediments removal for the wastewater storage pond Balkyldak was chosen of all discussed technologies. It was used in Minamata Bay, Japan and lies in removal of soft sediments followed by the sediments burial in a landfill.

Biota and possible food chains of the wastewater storage pond Balkyldak were studied. Taking into account considerable decrease of mercury concentration in after-demercurization period both in the pond water (lower than MPC_w for natural water) and in fish caught out of the pond (at the level of MPC_{npf} for non predator fish for average values and 4 MPC_{npf} for extreme cases) and respectively decrease of risks to human health, the local authority was given a recommendation to continue both their explanatory activity through the mass media such as warning about a danger to use fish from the wastewater storage pond Balkyldak as a foodstuff and a practice of administrative ban against commercial fishing in the pond Balkyldak.

A question about removal of mercury contaminated bottom sediments of the wastewater storage pond Balkyldak should be examined after decision about its further use would have been made that depends first of all on perspectives of JSC “Kaustik” development.

5. References

- The results of ISTC K-1240p project have been provided to local authorities for continuation of monitoring of mercury contamination at the Northern industrial area of Pavlodar city and preparation of the II phase of demercurization works at the industrial site #1 of PCP. The results of monitoring and computer modeling of groundwater contamination with oil products require continuation of field studies and first of all creation of a network of observation boreholes along the trajectory of the possible plum of groundwater contamination with oil products. Unfortunately this direction of the research on K-1240p project did not find any support of the local authority because it infringed on interests of the operating Pavlodar Oil Refinery. However, sooner or later, these data will be claimed.
- Final reports on ISTC K-1240p project will be put out in the INTERNET at the website http://Hg-Pavlodar.narod.ru and will become accessible for all comers by the same way how it was done with all quarter technical and annual reports on the project.
- Based on the material obtained on ISTC K-1240p project it has become possible to draw up work specifications for development of Feasibility Study for three projects: (i) on remediation of mercury contaminated bottom sediments of the wastewater storage pond Balkyldak; (ii) on cleaning and restoration of mercury contaminated soils at the industrial site of the former chlor-alkali production; (iii) on immobilization of mercury in groundwater. The original biotechnology of mercury immobilization in groundwater was being developed on ISTC K-756p and K-1477p projects with support of ISTC K-

1240p project. The biotechnology has been brought to a stage of successful completion of preliminary field trials of the pilot plant.

Attachment 1: List of published papers and reports with abstracts

1. M.A.Ilyushchenko, L.V.Yakovleva. Change of a concept for technologies of remediation of water bodies and territories contaminated with mercury. In book: Mercury in the biosphere: ecological-geochemical aspects. Proceedings of International Symposium (Russia, Moscow, GEOHI RAH, 7-9 September, 2010). M. GEOHI RAN, 2010, P. 414-418 (Ru).
From experience of completed projects of remediation of mercury contaminated areas (Minamata Bay, chlor-alkali production in Pavlodar) efficiency of demercuryzation technologies were considered. Complete cleanup using conventional technologies was shown to be impossible due to economic constraints. Those technologies are perspective which contain mercury hotspots or immobilize mercury as well as microbiological technologies of its recovery.

2. L.V.Yakovleva, M.A.Ilyushchenko. Experience of demercurization of chlor-alkali and acetaldehyde productions in Kazakhstan. In book: Mercury in the biosphere: ecological-geochemical aspects. Proceedings of International Symposium (Russia, Moscow, GEOHI RAH, 7-9 September, 2010). M. GEOHI RAN, 2010, P. 456-460 (Ru).
Comparison of cleanup technologies and results of remediation of cases of mercury pollutions in Pavlodar and Temirtau cities, Kazakhstan..

3. V.Yu.Panichkin, O.L.Miroshnichenko, M.Ilyushchenko, T.W.Tanton, P.Randall. Mathematical model of groundwater mercury contamination at the Northern part of Pavlodar industrial region (the Republic of Kazakhstan). In a book: Mercury in the biosphere: ecological-geochemical aspects. Proceedings of International Symposium (Russia, Moscow, GEOHI RAH, 7-9 September, 2010). M. GEOHI RAN, 2010, P. 440-445 (Ru).
Development and application of a hydro-geological model for risks assessment and prognosis of efficiency of technologies of mercury contamination demercurization in Pavlodar, Kazakhstan.

4. M.A.Ilyushchenko, L.V.Yakovleva. Change of a concept of remediation in case of mercury contamination. CD-ROM Proceedings 11-th International UFZ-Deltares/TNO Conference on Management of Soil, Groundwater & Sediments. Consoil 2010 (Salzburg, Austria 22-24 September 2010).
From experience of completed projects of remediation of mercury contaminated areas (Minamata Bay, chlor-alkali production in Pavlodar) efficiency of demercuryzation technologies were considered. Complete cleanup using conventional technologies was shown to be impossible due to economic constraints. Those technologies are perspective which contain mercury hotspots or immobilize mercury as well as microbiological technologies of its recovery.

5. L.V.Yakovleva, M.A.Ilyushchenko. Experience of demercurization of chlor-alkali and acetaldehyde productions in Kazakhstan. CD-ROM Proceedings 11-th International UFZ-Deltares/TNO Conference on Management of Soil, Groundwater & Sediments. Consoil 2010 (Salzburg, Austria 22-24 September 2010) Comparison of cleanup technologies and results of remediation of cases of mercury pollutions in Pavlodar and Temirtau cities, Kazakhstan.

6. A.V.Ubaskin, A.P.Bondarenko, B.A.Tuleubaev, G.A.Baimukhanova. Experience of students and schoolchildren participation in an international environmental project in basin of the Middle Irtysh. Materials of IV International scientific-practical conference “Actual environmental problems” (Kazakhstan, Karaganda 09-10.12.2010), Karaganda, 2010, P. 229-234 (Ru).
Involvement of young people in discussion and popularization of results of studies of risks in sites of mercury contamination in Pavlodar has turned out to be effective way to cut down fishing at the wastewater storage pond – Lake Balkyldak.

7. A.P.Bondarenko, A.V.Ubaskin. Realization of a complex approach when studding a technogenic ecosystem with participation of students and schoolchildren. International conference “Rivers of Siberia” (16-18 April, 2010), Russia, Tomsk, 2010, P. 20-22 (Ru).
Environmental research of a technogenic water body – Lake Balkyldak was carried out with participation of teachers, universities students and students of high schools and colleges for 2006-2009.
Tasks of the research involved the subjects of contemporary biodiversity of ecosystems, a level of mercury accumulation by different groups of the water body’s biota and mercury redistribution on food chains. Three-year research allowed estimating the current condition of the lake ecosystem being used as a wastewater storage pond and revealing changes in biological and environmental characteristics under influence of pollutants. The project participants could observe and estimate in real field conditions a scale of wildlife transformation caused by industrial activity. Many components of educational process and world view character were realized successfully.

8. M.Ilyushchenko, V.Yu.Panichkin, P.Randall, T.W.Tanton, S.A.Abdrashitova, O.L.Miroshnichenko, L.V.Yakovleva, W.J.Devis-Hoover, R.Devereux. Influence of efficiency of chlor-alkali production cleanup from mercury on groundwater status in Pavlodar City, Kazakhstan. CD-ROM “Proceedings of the International Symposium on Contaminated Soils and Sediments” RemTech2009 (Ferrara, Italy 23-24 September 2009). DEA “EDIZIONI”, 2009.
Typical for the former USSR case of mercury pollution in Pavlodar city was examined: history of the pollution, risks assessment and preparation of a project of demercurization, cleanup works, post-demercurization monitoring and new risks assessment, development of biotechnology of mercury cleanup from mercury.

9. M.Ilyushchenko, L.V.Yakovleva. Problems of demercurization of industrial objects within the former USSR. ISTC Science Workshop at the International Conference on Mercury as a Global Pollutant. ICMGP 2009 (7- 12 June 2009) Guizhou’s Great Hall of the People Guiyang, China. The International Science and Technology Center, 2009, P.5-10.
Typical problems arising while closing down chlor-alkali and other large-scale chemical industries using mercury technologies were examined. Projects of remediation of sites of mercury pollution in Kazakhstan are pioneer ones and their experience is valuable for next works on remediation.

10. V.Yu.Panichkin, O.L.Miroshnichenko, M.A.Ilyushchenko, P.M.Randall, T.W.Tanton. Evaluation of demercurization efficiency of chlor-alkali production in Pavlodar City, Kazakhstan. ISTC Science Workshop at the International Conference on Mercury as a Global Pollutant. ICMGP 2009 (7- 12 June 2009) Guizhou’s Great Hall of the People Guiyang, China. The International Science and Technology Center, 2009, P.26-30
Typical for the former USSR case of mercury pollution in Pavlodar city was examined: history of the pollution, risks assessment and preparation of a project of demercurization, cleanup

works, post-demercurization monitoring and new risks assessment, development of biotechnology of mercury cleanup from mercury.

11. V.Yu.Panichkin, O.L.Miroshnichenko, M.A.Ilyushchenko, T.W.Tanton, P.M.Randall. Matematical modeling of groundwater mercury pollution (case of Northern industrial area of Pavlodar City, Kazakhstan). ISTC Science Workshop at the International Conference on Mercury as a Global Pollutant. ICMGP 2009 (7- 12 June 2009) Guizhou's Great Hall of the People Guiyang, China. The International Science and Technology Center, 2009, P.31-38.
Development and application of a hydro-geological model for risks assessment and prognosis of efficiency of technologies of mercury contamination demercurization in Pavlodar, Kazakhstan.

12. M.A.Ilyushchenko, P.M.Randall, T.W.Tanton, A.V.Ubaskin, G.A.Uskov. Mercury Risk Assessment from a Wastewater Storage Pond in Pavlodar City, Northern Kazakhstan. ISTC Science Workshop at the International Conference on Mercury as a Global Pollutant. ICMGP 2009 (7- 12 June 2009) Guizhou's Great Hall of the People Guiyang, China. The International Science and Technology Center, 2009, 38-41.
Technical characteristics and history of the wastewater storage pond Balkyldak, its pollution with mercury as a result of disposal of wastewater of chlor-alkali production, risks assessment carried out, problems of demercurization and its further exploitation were described.

13. V.Yu.Panichkin, O.L.Miroshnichenko. State-of-the-art technique and technology of hydro-geological modeling (case of a system of mathematical models of groundwater mercury contamination at Pavlodar industrial area). Proceedings of International Scientific-practical Conference “Groundwater – strategic resource of sustainable development of Kazakhstan” devoted to 100th anniversary of B.A.Kenesarina (Kazakhstan, Almaty, 1-3 October, 2008), Almaty. 2009, P.201-205 (Ru).
Developed methods and technology of hydro-geological modeling using up-to-date information technologies and software which were tried out while producing a system of interrelated different-scale models of groundwater mercury contamination of Pavlodar industrial region were described.

14. M.Ilyushchenko, P.Randall, T.Tanton, R.Kamberov, L.Yakovleva. Demercurization and post-demercurization monitoring in the area of an industrial site of a derilict clor-alkali facility in Pavlodar city, Northern Kazakhstan. Proceedings of ISTC Science Workshop at the International Conference on Contamination Soil, Consoil 2008 (Milan, Italy 3-6 June 2008). ISTC, M., P. 104-106.
Typical for the former USSR case of mercury pollution in Pavlodar city was examined: history of the pollution, risks assessment and preparation of a project of demercurization, cleanup works, post-demercurization monitoring and new risks assessment, development of biotechnology of mercury cleanup from mercury.

15. K. Arani Kajenthira, Simon A. Jackman, Murray Gardner, Don Porcelli, Tom Scott, Olga Riba, Mikhail A. Ilyushchenko, Rustam I. Kamberov, Jeremy Wingate, Frans De Leij, Tony Hutchings. Bioremediation of Mercury Contamination in Kazakhstan: A Multifaceted Approach. In CD: Bruce M. Sass (Conference Chair), Remediation of Chlorinated and Recalcitrant Compounds—2008. Proceedings of the Sixth International Conference on Remediation of Chlorinated and Recalcitrant Compounds (Monterey, CA; May 2008). Published by Battelle, Columbus, OH, Abstract H-009.
Potentiality of the use of technologies of bioremediation foe cases of mercury pollution in Kazakhstan.

16. Mikhail Ilyushchenko, Rustam Kamberov, Lyudmila Yakovleva, Trevor Tanton, Susanne Ullrich, Paul Randall. Monitoring the Effectiveness of Measures to Contain the Primary Sources of Mercury Pollution on the Site of a Former Chloralkali Plant in Kazakhstan. In CD: Bruce M. Sass (Conference Chair), *Remediation of Chlorinated and Recalcitrant Compounds—2008.* Proceedings of the Sixth International Conference on Remediation of Chlorinated and Recalcitrant Compounds (Monterey, CA; May 2008). Published by Battelle, Columbus, OH, Paper H-015.
Typical for the former USSR case of mercury pollution in Pavlodar city was examined: history of the pollution, risks assessment and preparation of a project of demercurization, cleanup works, post-demercurization monitoring and new risks assessment, development of biotechnology of mercury cleanup from mercury.

17. Vladimir Yu. Panichkin, Oxana L. Miroshnichenko, Mikhail A. Ilyushchenko, Trevor Tanton, Paul M. Randall. Groundwater Modeling of Mercury Pollution at a Former Mercury Cell Chloralkali Facility in Pavlodar City, Kazakhstan. In CD: Bruce M. Sass (Conference Chair), *Remediation of Chlorinated and Recalcitrant Compounds—2008.* Proceedings of the Sixth International Conference on Remediation of Chlorinated and Recalcitrant Compounds (Monterey, CA; May 2008). Published by Battelle, Columbus, OH, Paper H-016.
Development and application of a hydro-geological model for risks assessment and prognosis of efficiency of technologies of mercury contamination demercurization in Pavlodar, Kazakhstan.

18. V.Yu.Panichkin, O.L.Miroshnichenko, L.Yu.Trushel, N.M.Zakharova, T.N.Vinnikova. Investigation of processes of groundwater mercury contamination by methods of mathematical modeling. Geology and Subsoil Protection. #2(27), 2008, P. 90-97 (Ru).
Results of mathematical modeling of hydro-geological conditions of Pavlodar industrial region (Kazakhstan) and Kiev city (Ukraine) for prediction of spread of a plume of groundwater mercury pollution were described.

19. V.Yu.Panichkin, O.L.Miroshnichenko, L.Yu.Trushel, N.M.Zakharova, T.N.Vinnikova. Mathematical modeling of processes of groundwater contamination with mercury. Proceedings of VIII International Congress “Water: Environment and Technology” ERVATEK-2008 [electronic resource]. M., ZAO “Firm SIBIKO International”, 2008 (Ru).
Expediency of method of mathematical modeling application for studies of the processes of groundwater pollution with mercury was justified. A system of different-scale interrelated mathematical models of hydro-geological conditions of the northern part of Pavlodar industrial region (Kazakhstan) developed in the Institute of Hydro-geology and Hydro-physics of the Ministry of Education and Science of the Republic of Kazakhstan was described. The purpose of its creation was prediction of spread of the plume of groundwater mercury contamination for assessment of threat of mercury ingress into the Irtysh River and wells of water supply system of Povlodarskoe village and development of measures on the risk minimization. A series of prognosis tasks was solved on the model. Since technogenic factors render prevailing influence on hydro-geological conditions at the area, the necessity to use produced complex as a system of continuously acting mathematical models is explained.

20. V.Yu.Panichkin, O.L.Miroshnichenko, L.Yu.Trushel, N.M.Zakharova, T.N.Vinnikova. Mathematical models of groundwater mercury contamination. Actual Problems of Sciences about the Earth. Proceedings of International Scientific-practical Conference “Satpaev readings” (Kazakhstan, Almaty, 10-11 April, 2008). Almaty, 2008, P. 219-222 (Ru). Results of mathematical modeling of hydro-geological conditions of Pavlodar industrial region

(Kazakhstan) and Kiev city (Ukraine) for prediction of spread of a plume of groundwater mercury contamination, assessment of environmental risks and development of measures on the risks minimization are examined.

21. A.V.Ubaskin, A.V.Eremenko. Pheno-deviants of crucian carp as a results of anthropogenic impact onto water ecosystem. Biological aspects of rational use and protection of water bodies of Siberia. Proceedings of All-Russian Conference. Tomsk. Lito-Print, 2007, P. 59-60 (Ru).
Results of studies of ecosystems of Lake Balkyldak including revealing bio-indicator properties of silver crucian (Carassius auratus gibelio) living in conditions of mercury contamination are provided. Decrease of growth rate, its variability at upward-age fish, decrease of their fatness coefficient, decrease of an index of a body height, increase of driving were recorded. Mass mosaic scales, its "eroshenie", affection of fish skin, ulcers appearance were observed. Bone skeleton deformities were strongly pronounced especially that of fish head. Considerable lengthening or shortening of one of jaw bones, i.e. fish mouth deformation were observed.

22. A.V.Ubaskin, T.N.Derbeneva, N.V.Ubaskina. Mercury impact onto biota of a technogenic water body. VIII All-Russian Scientific-practical Conference of Students and Postgraduates "Chemistry and Chemical Technology in XXI Century", Tomsk, 2007, P. 304-305 (Ru).
Assessment of a studied habitat quality by determining concentration of every pollutant is very expensive and gives few data for understanding negative effect on communities. Testing of a natural habitat using biological objects allows constructing quite simple and accessible quality system. In particular in hydrosphere representatives of ichthyol-fauna as a final element in trophic chain of a water body are good test-objects. At present complex study of the Lake Balkyldak ecosystem is carried out, in particular one of the tasks is revealing bio-indicator properties of fish living in conditions of mercury contamination. The obtained results allow considering hydro-bionts as a reliable instrument for operative environmental monitoring of water ecosystem in conditions of anthropogenic pressure.

23. A.V.Ubaskin, A.P.Bondarenko. Food chains and methods of their study; case of a waste sedimentation pond. Methodical book for students of natural specialties. Kereku, Pavlodar, 2007, 119 p. (Ru).
In the textbook prepared methods of environmental monitoring of closed water bodies and sampling and analysis of hydro-bionts are given; sequence of fish analysis is shown. Detailed methods of assessment of environmental status of water bodies, hydrological and hydro-chemical methods are developed as well as methods of bacteria-plankton monitoring, algae sampling and investigation, determination of fish species diversity, their general morphological characteristics, measurement and special terms. Data on environmental status of a lake - wastewater storage pond are provided. Using case of study of the wastewater storage pond Balkyldak food chains and possibility of pollutants transport through trophic elements are studied. The lake biota can be an example of adaptation of living organisms in man-changed conditions and their inhabiting man-disturbed landscapes. Silver crucian (Carassius auratus gibelio) (Bloch, 1783), carp-sazan (Cyprinus carpio aralensis) and tench (Tinca tinca) are shown to inhabit the lake. Character of the crucians' anomalies in the pond Balkyldak and average morphological parameters of silver crucian from Balkyldak and Krivoe (control water body) lakes are given. Preliminary conclusion has been done that data obtained by now are still insufficient for judgment about processes going in natural conditions of Lake Balkyldak, however they are an evidence that contamination of water environment predominantly with mercury compounds on the background of other pollutants, can result in a number of physiological, biochemical, morphological and environmental changes of fish. Taking into account the fact that at present ecosystem of Lake Balkyldak is under stress conditions as a

result of long intensive technogenic impact, development of a system of biological monitoring is an actual task which requires finding of complex criteria for assessment and prediction of an ecosystem status. The study carried out suggests that under mercury intoxication processes running can become a reason of serious disturbances at all stages of fish life cycle that is necessary to take into consideration when studying natural populations in water bodies subjected to anthropogenic pollution.

24. M. A. Ilyushchenko. Problems of demercurization of industrial objects within the former USSR. Proceedings of International Workshop “Environmental mercury pollution: mercury emissions, remediation and health effects” (Astana, 28 May-1 June, 2007). Program. Abstracts. Astana, 2007. P. 14 (Ru & En). Typical problems arising while closing down chlor-alkali and other large-scale chemical industries using mercury technologies were examined. Projects of remediation of sites of mercury pollution in Kazakhstan are pioneer ones and their experience is valuable for next works on remediation.

25. V.Yu. Panichkin. Risk assessment from groundwater mercury pollution of the Northern area of Pavlodar industrial region by the methods of mathematical modeling. Proceedings of International Workshop “Environmental mercury pollution: mercury emissions, remediation and health effects” (Astana, Kazakhstan, May 28 – June 1, 2007). Program, Abstracts. Astana, 2007, P. 20 (Ru & En). Development and application of a hydro-geological model for risks assessment and prognosis of efficiency of technologies of mercury contamination demercurization in Pavlodar, Kazakhstan.

26. O.L. Miroshnichenko. Methods and technology of creation of the system of mathematical models with different scales for groundwater mercury pollution within the industrial area of Pavlodar city. Proceedings of International Workshop “Environmental mercury pollution: mercury emissions, remediation and health effects” (Astana, Kazakhstan, May 28 – June 1, 2007). Program, Abstracts. Astana, 2007, P. 21 (Ru & En).
Development and application of a hydro-geological model for risks assessment and prognosis of efficiency of technologies of mercury contamination demercurization in Pavlodar, Kazakhstan

27. M.A. Ilyushchenko, R.I.Kamberov, L.V.Yakovleva. Post-demercurization monitoring and risk assessment in the Northern industrial area of Pavlodar city. Proceedings of International Workshop “Environmental mercury pollution: mercury emissions, remediation and health effects” (Astana, 28 May-1 June, 2007). Program. Abstracts. Astana, 2007. P. 22 (Ru & En).
Typical for the former USSR case of mercury pollution in Pavlodar city was examined: history of the pollution, risks assessment and preparation of a project of demercurization, cleanup works, post-demercurization monitoring and new risks assessment, development of biotechnology of mercury cleanup from mercury.

28. S.M.Ullrich, M.A.Ilyushchenko, I.M.Kamberov, T.W.Tanton. Mercury contamination in the vicinity of a derelict chlor-alkali plant. Part I: Sediment and water contamination of Lake Balkyldak and the River Irtysh. The Science of the Total Environment, V. 381, 2007, P. 1-16.
Mercury losses at PCP in 1975-1993 caused a whole series of environmental problems of international value. First of all it was a threat of the Irtysh River pollution. Surface water, bottom sediments and fish from the Irtysh River and its floodplain were investigated, as well as those from the wastewater storage pond of PCP. Risks were assessed, which turned out to be high only for population of Pavlodar outskirt dealing with fishing in the wastewater storage pond.

29. S.M.Ullrich, M.A.Ilyushchenko, T.W.Tanton, G.A.Uskov. Mercury contamination in the vicinity of a derelict chlor-alkali plant. Part II: Contamination of the aquatic and terrestrial food chain and potential risks to the local population. The Science of the Total Environment, V. 381, 2007, P. 290-306.
Risks of mercury pollution of adjacent territory for population of Pavlodar outskirt and PCP personnel were assessed. Main risks came from emission of gaseous mercury and dust from semi-dismantled buildings, wastes storages and an industrial site of stopped chlor-alkali production. It is imperative to continue remediation works.

30. V.Yu.Panichkin, O.L.Miroshnichenko. Application of methods of structural modeling for assessment of a danger of mercury contamination of groundwater within an industrial zone of Pavlodar. Water: resources, quality, monitoring, water use and protection. Proceedings of International Scientific-practical Conference hold within the framework of an Exhibition “Akvaterm – 2007” Kazakhstan, Almaty, 19-21 September, 2007). Almaty, 2007, P. S156-159 (Ru).
Process of creation of a system of different-scale interrelated mathematical models of hydro-geological conditions for assessment of a danger of groundwater contamination with mercury at Pavlodar industrial region is described.

31. V.Yu.Panichkin, O.L.Miroshnichenko, L.Yu.Trushel, N.M.Zakharova, T.N.Vinnikova. Solution of tasks of groundwater protection by methods of mathematical modeling (case of Pavlodar industrial region). Water: resources, quality, monitoring, water use and protection. Proceedings of International Scientific-practical Conference hold within the framework of an Exhibition “Akvaterm – 2007” Kazakhstan, Almaty, 19-21 September, 2007). Almaty, 2007, P. S153-156 (Ru).
Results of mathematical modeling of groundwater mercury contamination at Pavlodar industrial region are analyzed.

32. V.Yu.Panichkin, O.L.Miroshnichenko. Method of structural modeling of processes of groundwater contamination in Kazakhstan. Abstracts at International Symposium “Future of Hydrogeology: contemporary trends and perspectives”, Saint-Petersburg University. Saint-Petersburg, Russia, 2007, P. 111-113 (Ru).
Application of a method of structural modeling for investigation of processes of groundwater contamination, ways of interaction of local and regional models and criteria of assessment of quality of the produced system of the models are described. The developed model was used successfully for producing a system of mathematical models of hydro-geological conditions of Pavlodar industrial region (Kazakhstan) for solving tasks of prediction of spread of a plume of groundwater mercury contamination and assessment of a danger for the environment and the region inhabitants.

33. V.Yu.Panichkin, O.L.Miroshnichenko, T.N.Vinnikova, L.Yu.Trushel, N.M.Zakharova. Study of processes of groundwater mercury contamination in Pavlodar industrial region (Kazakhstan) by methods of mathematical modeling. Abstracts at International Symposium “Future of Hydrogeology: contemporary trends and perspectives”, Saint-Petersburg University. Saint-Petersburg, Russia, 2007, P. 113-115 (Ru).
A system of mathematical models of hydro-geological conditions of Pavlodar industrial region consisting of regional and local model is described. It was created with the purpose of prediction of spread of the plume of groundwater mercury contamination, assessment of a danger for the environment and human health and development of measures on the risk minimization.

34. V.Yu.Panichkin, O.L.Miroshnichenko. Automated technology of geo- migration processes modeling on a system of different-scale models. Proceedings of VII International Congress “Water: the environment and technology” EKVATEK-2006 (Russia, Moscow, 30 May – 2June, 2006). Part 1. P.161 (Ru).
A technology of creation of a system of different-scale interrelated mathematical models using GMS software, which can be used for modeling of the process of groundwater contamination with mercury and oil products at the industrial area of Pavlodar (Kazakhstan), is described.

35. V.Yu.Panichkin, O.L.Miroshnichenko. Automated technology of designing of mathematical models of hydro-geological objects. Izvestiya NAS RK. Geological series. 2006, #3, P. 43-48 (Ru).
Automated technology of designing of mathematical models of hydro-geological conditions developed at Institute of Hydro-geology and Hydro-physics of the MES RK, which was tried out for solving tasks of prediction of the plume of groundwater mercury contamination spread at Pavlodar industrial region (Kazakhstan) and Kiev city (Ukraine) is considered.

36. A.V.Ubaskin, K.U.Bazarbekov, A.P.Bondarenko, A.A.Kalieva, A.V.Ermienko. Experience of bio-indication of contaminations on an example of silver crucian carp in Lake Balkyldak. Vestnik PSU. #4, 2006, P. 104-111 (Ru).
Using characteristics of anomalies of fish from Lake Balkyldak test-objects (bio-monitors) are given as well as biomarkers, which can be included in a system of biomonitoring as complex criteria for assessment and prediction of ecosystem status and purposes of determination of a water body contamination level. Given parameters allow estimating state of hydrobionts and their habitat efficiently.

37. A.V.Ubaskin, A.V.Ermienko, K.U.Bazarbekov, A.A.Kalieva, A.P.Bondarenko , N.N.Bondarenko. Influence of anthropogenic factors of the wastewater storage pond Balkyldak on living organisms. Proceedings of I International Scientific-practical Conference “News of scientific thought - 2006”.T.Z. Dnepropetrovsk, 2006, P. 39-40 (Ru).
Results of the first stage of complex studies of Lake Balkyldak ecosystem were summarized, which allowed regarding hydrobionts as a reliable instrument for efficient environmental monitoring of water bodies in conditions of mercury contamination.

38. A.V.Ubaskin, E.M.Nikitina, A.V.Ermienko, A.P.Bondarenko, V.E.Bokov, Ya.T.Ernazarova. Anomalies of hydrobionts as bio-indicators of contamination of water ecosystems. Informational environmental bulletin “Nature and we”. Pavlodar. 2006, P. 16-18 (Ru).
At present monitoring is needed for objective assessment of consequences of anthropogenic effect on the environment. The environment testing with the help of biological objects allows constructing quite simple and accessible system of control. As a results of the studies carried out some morphological changes at hydrobionts are observed. In particular considerable distortion of clam-shell at shellfish is observed as well as multiple clam-shell excrescences. Structure of clam-shells’ surface from the contaminated water body differs substantially from those from the control water body.

39. A.V.Ubaskin, N.T.Erzhanov. Actual environmental problems of Pavlodar Priirtyshiya. Informational environmental bulletin “Nature and we”. Pavlodar. 2006, P. 19-25 (Ru).
Ecosystems of the Irtysh River region functioning with constant cyclicity of different abiotic variables are quite vulnerable and weakly adapted to evolutionary new anthropogenic factor. The Irtysh River basin experiences the strongest anthropogenic pressure. Contamination is the most powerful anthropogenic factor whose force of effect on biological objects of the river

exceeds summary effect of all other negative variables. Anthropogenic alteration of ecosystems poses a danger for biota larger than direct extirpating of some species of the wildlife. One of the most "painful" environmental problems of Pavlodar Priirtyshie is mercury pollution of its territory. At present complex studies of ecosystems of Lake Balkyldak are carried out, in particular one of the main tasks is revealing bioindicator properties of water flora and hydrobionts (plankton, benthos, fish).

40. P.Randall, M. Ilyushchenko, E. Lapshin, L.Kuzmenko. Case Study: Mercury Pollution Near a Chemical Plant in Northern Kazakhstan. The Magazine for Environmental Managers, N2, 2006, P. 19-24.
The threat of polluting the Irtysh River by mercury was caused by high losses of Hg during 1975-1993 at chlor-alkali production in outskirt of Pavlodar, Kazakhstan. These losses were the highest among similar factories in the former USSR and could be estimated as 1.6 kg Hg per ton of produced caustic soda (total losses of mercury could be estimated as 1310 tons of which 1100 tons were mechanical losses). The majority of metallic mercury concentrated beneath an electrolysis shop formed a hotspot of groundwater contaminated with soluble mercuric chloride. Also losses of Hg-contaminated wastewater from a sewage system, contamination of topsoil and a wastewater storage pond – Lake Balkyldak (having capacity more than 80 million m^3) took place. The closest sites subjected to risk of mercury pollution are Pavlodarskoye village having 200 ha of groundwater fields and the Irtysh River located 3-5 km to the west from chlor-alkali production. Original design of clean-up was developed in 1995. The scope of designed works included excavation and thermal treatment of highly contaminated materials with the purpose to recover marketable metallic mercury. The research carried out during 2001-2005 showed that the extent of Hg contamination posing the risk for the environment and public was much higher than it was thought before. This allowed revising a strategy of management of mercury contamination in Pavlodar. Instead of expensive and non-effective recovery of Hg from wastes the containment strategy was proposed assuming isolation of major hotspots from the atmosphere, surface run-off and groundwater. In 2003-2005 the anti-filtration clay barrier (cut-off wall) was constructed around four major mercury hotspots. The depth of the cut-off wall reached basalt clay at 15-20 m and its width was 0.6 m. The total length of the barrier was 3588 m. Contaminated topsoil was excavated to the depth of 0.5 m and removed to sites isolated by the cut-off walls. The hotspots were covered by clay on total area of 180000 m^2. All buildings contaminated with mercury were demolished and the debris was placed into a 3-m deep pit lined with 0.5-m clay layer. These materials were further stabilized with cement and covered with asphalt layer forming the monolith storage with total area of 15671 m^2 which is stable against the impact of groundwater and surface runoff. Since 2005 local authorities initiated 15-year Program of mercury contamination monitoring in the Northern industrial area of Pavlodar. This Program is expected to answer the question whether the clean-up activities implemented to date are sufficient. US EPA gives a support to this program via ISTC launching three-year project K-1240p since 2006.

41.M. Ilyushchenko, P. Randall, T.Tanton, A.Akhmetov, R.I. Kamberov, L.Yakovleva. Activities to contain mercury pollution from entering the river Irtysh in Pavlodar, Kazakhstan. Paper S-285, in: Abstracts of Eighth International Conference on Mercury as a Global Pollutant (Madison, Wisconsin; August 6-11, 2006). DEStech Publication, Inc., 2006 (10)
Typical for the former USSR case of mercury pollution in Pavlodar city was examined: history of the pollution, risks assessment and preparation of a project of demercurization, cleanup works, post-demercurization monitoring and new risks assessment, development of biotechnology of mercury cleanup from mercury.

Attachment 2: List of presentations at conferences and meetings with abstracts

1. M.A.Ilyushchenko, L.V.Yakovleva. Change of a concept for technologies of remediation of water bodies and territories contaminated with mercury. In book: Mercury in the biosphere: ecological-geochemical aspects. International Symposium (Russia, Moscow, GEOHI RAH, 7-9 September, 2010). From experience of completed projects of remediation of mercury contaminated areas (Minamata Bay, chlor-alkali production in Pavlodar) efficiency of demercuryzation technologies were considered. Complete cleanup using conventional technologies was shown to be impossible due to economic constraints. Those technologies are perspective which contain mercury hotspots or immobilize mercury as well as microbiological technologies of its recovery.

2. L.V.Yakovleva, M.A.Ilyushchenko. Experience of demercurization of chlor-alkali and acetaldehyde productions in Kazakhstan. In book: Mercury in the biosphere: ecological-geochemical aspects. International Symposium (Russia, Moscow, GEOHI RAH, 7-9 September, 2010).
Comparison of cleanup technologies and results of remediation of cases of mercury pollutions in Pavlodar and Temirtau cities, Kazakhstan.

3. V.Yu.Panichkin, O.L.Miroshnichenko, M.Ilyushchenko, T.W.Tanton, P.Randall. Mathematical model of groundwater mercury contamination at the Northern part of Pavlodar industrial region (the Republic of Kazakhstan). In book: Mercury in the biosphere: ecological-geochemical aspects. International Symposium (Russia, Moscow, GEOHI RAH, 7-9 September, 2010).
Development and application of a hydro-geological model for risks assessment and prognosis of efficiency of technologies of mercury contamination demercurization in Pavlodar, Kazakhstan

4. M.A.Ilyushchenko, L.V.Yakovleva. Change of a concept of remediation in case of mercury contamination. 11-th International UFZ-Deltares/TNO Conference on Management of Soil, Groundwater & Sediments. Consoil 2010 (Salzburg, Austria 22-24 September 2010).
From experience of completed projects of remediation of mercury contaminated areas (Minamata Bay, chlor-alkali production in Pavlodar) efficiency of demercuryzation technologies were considered. Complete cleanup using conventional technologies was shown to be impossible due to economic constraints. Those technologies are perspective which contain mercury hotspots or immobilize mercury as well as microbiological technologies of its recovery.

5. L.V.Yakovleva, M.A.Ilyushchenko. Experience of demercurization of chlor-alkali and acetaldehyde productions in Kazakhstan. 11-th International UFZ-Deltares/TNO Conference on Management of Soil, Groundwater & Sediments. Consoil 2010 (Salzburg, Austria 22-24 September 2010).
Comparison of cleanup technologies and results of remediation of cases of mercury pollutions in Pavlodar and Temirtau cities, Kazakhstan..

6. A.V.Ubaskin, A.P.Bondarenko, B.A.Tuleubaev, G.A.Baimukhanova. Experience of students and schoolchildren participation in an international environmental project in basin of the Middle Irtysh. IV International scientific-practical conference “Actual environmental problems” (Kazakhstan, Karaganda 09-10.12.2010).

Involvement of young people in discussion and popularization of results of studies of risks in sites of mercury contamination in Pavlodar has turned out to be effective way to cut down fishing at the wastewater storage pond – Lake Balkyldak.

7. A.P.Bondarenko, A.V.Ubaskin. Realization of a complex approach when studding a technogenic ecosystem with participation of students and schoolchildren. International conference “Rivers of Siberia” (16-18 April, 2010).
Tasks of the research involved the subjects of contemporary biodiversity of ecosystems, a level of mercury accumulation by different groups of the water body’s biota and mercury redistribution on food chains. Three-year research allowed estimating the current condition of the lake ecosystem being used as a wastewater storage pond and revealing changes in biological and environmental characteristics under influence of pollutants. The project participants could observe and estimate in real field conditions a scale of wildlife transformation caused by industrial activity. Many components of educational process and world view character were realized successfully.

8. M.Ilyushchenko, V.Yu.Panichkin, P.Randall, T.W.Tanton, S.A.Abdrashitova, O.L.Miroshnichenko, L.V.Yakovleva, W.J.Devis-Hoover, R.Devereux. Influence of efficiency of chlor-alkali production cleanup from mercury on groundwater status in Pavlodar City, Kazakhstan. International Symposium on Contaminated Soils and Sediments” RemTech2009 (Ferrara, Italy 23-24 September 2009).
Typical for the former USSR case of mercury pollution in Pavlodar city was examined: history of the pollution, risks assessment and preparation of a project of demercurization, cleanup works, post-demercurization monitoring and new risks assessment, development of biotechnology of mercury cleanup from mercury.

9. M.Ilyushchenko, L.V.Yakovleva. Problems of demercurization of industrial objects within the former USSR. ISTC Science Workshop at the International Conference on Mercury as a Global Pollutant. ICMGP 2009 (Guiyang, China, 7- 12 June 2009).
Typical problems arising while closing down chlor-alkali and other large-scale chemical industries using mercury technologies were examined. Projects of remediation of sites of mercury pollution in Kazakhstan are pioneer ones and their experience is valuable for next works on remediation.

10. V.Yu.Panichkin, O.L.Miroshnichenko, M.A.Ilyushchenko, P.M.Randall, T.W.Tanton. Evaluation of demercurization efficiency of chlor-alkali production in Pavlodar City, Kazakhstan. ISTC Science Workshop at the International Conference on Mercury as a Global Pollutant. ICMGP 2009 (Guiyang, China, 7- 12 June 2009).
Typical for the former USSR case of mercury pollution in Pavlodar city was examined: history of the pollution, risks assessment and preparation of a project of demercurization, cleanup works, post-demercurization monitoring and new risks assessment, development of biotechnology of mercury cleanup from mercury.

11. V.Yu.Panichkin, O.L.Miroshnichenko, M.A.Ilyushchenko, T.W.Tanton, P.M.Randall. Matematical modeling of groundwater mercury pollution (case of Northern industrial area of Pavlodar City, Kazakhstan). ISTC Science Workshop at the International Conference on Mercury as a Global Pollutant. ICMGP 2009 (Guiyang, China, 7- 12 June 2009).
Development and application of a hydro-geological model for risks assessment and prognosis of efficiency of technologies of mercury contamination demercurization in Pavlodar, Kazakhstan.

12. M.A.Ilyushchenko, P.M.Randall, T.W.Tanton, A.V.Ubaskin, G.A.Uskov. Mercury Risk Assessment from a Wastewater Storage Pond in Pavlodar City, Northern Kazakhstan. ISTC Science Workshop at the International Conference on Mercury as a Global Pollutant. ICMGP 2009 (Guiyang, China, 7- 12 June 2009).
Technical characteristics and history of the wastewater storage pond Balkyldak, its pollution with mercury as a result of disposal of wastewater of chlor-alkali production, risks assessment carried out, problems of demercurization and its further exploitation were described.

13. V.Yu.Panichkin, O.L.Miroshnichenko. State-of-the-art technique and technology of hydro-geological modeling (case of a system of mathematical models of groundwater mercury contamination at Pavlodar industrial area). Proceedings of International Scientific-practical Conference “Groundwater – strategic resource of sustainable development of Kazakhstan” devoted to 100th anniversary of B.A.Kenesarina (Kazakhstan, Almaty, 1-3 October, 2008).
Developed methods and technology of hydro-geological modeling using up-to-date information technologies and software which were tried out while producing a system of interrelated different-scale models of groundwater mercury contamination of Pavlodar industrial region were described.

14. M.Ilyushchenko, P.Randall, T.Tanton, R.Kamberov, L.Yakovleva. Demercurization and post-demercurization monitoring in the area of an industrial site of a derilict clor-alkali facility in Pavlodar city, Northern Kazakhstan. ISTC Science Workshop at the International Conference on Contamination Soil, Consoil 2008 (Milan, Italy 3-6 June 2008).
Typical for the former USSR case of mercury pollution in Pavlodar city was examined: history of the pollution, risks assessment and preparation of a project of demercurization, cleanup works, post-demercurization monitoring and new risks assessment, development of biotechnology of mercury cleanup from mercury.

15. K. Arani Kajenthira, Simon A. Jackman, Murray Gardner, Don Porcelli, Tom Scott, Olga Riba, Mikhail A. Ilyushchenko, Rustam I. Kamberov, Jeremy Wingate, Frans De Leij, Tony Hutchings. Bioremediation of Mercury Contamination in Kazakhstan: A Multifaceted Approach. Sixth International Conference on Remediation of Chlorinated and Recalcitrant Compounds (Monterey, CA; May 2008).
Potentiality of the use of technologies of bioremediation foe cases of mercury pollution in Kazakhstan.

16. Mikhail Ilyushchenko, Rustam Kamberov, Lyudmila Yakovleva, Trevor Tanton, Susanne Ullrich, Paul Randall. Monitoring the Effectiveness of Measures to Contain the Primary Sources of Mercury Pollution on the Site of a Former Chloralkali Plant in Kazakhstan. Sixth International Conference on Remediation of Chlorinated and Recalcitrant Compounds (Monterey, CA; May 2008).
Typical for the former USSR case of mercury pollution in Pavlodar city was examined: history of the pollution, risks assessment and preparation of a project of demercurization, cleanup works, post-demercurization monitoring and new risks assessment, development of biotechnology of mercury cleanup from mercury.

17. Vladimir Yu. Panichkin, Oxana L. Miroshnichenko, Mikhail A. Ilyushchenko, Trevor Tanton, Paul M. Randall. Groundwater Modeling of Mercury Pollution at a Former Mercury Cell Chloralkali Facility in Pavlodar City, Kazakhstan. Sixth International Conference on Remediation of Chlorinated and Recalcitrant Compounds (Monterey, CA; May 2008).

Development and application of a hydro-geological model for risks assessment and prognosis of efficiency of technologies of mercury contamination demercurization in Pavlodar, Kazakhstan.

18. M.A.Ilyushchenko. Overview of Environmental Remediation Needs in the Republic of Kazakhstan. Special Session “Environmental remediation opportunities for 21st Century” in the frameworks of 11th International Chemical Weapons Demilitarisation Conference, CWD 2008 (Interlaken City, Switzerland, May 18-22, 2008).
Typical problems arising while closing down chlor-alkali and other large-scale chemical industries using mercury technologies were examined. Projects of remediation of sites of mercury pollution in Kazakhstan are pioneer ones and their experience is valuable for next works on remediation.

19.V.Yu.Panichkin, O.L.Miroshnichenko, L.Yu.Trushel, N.M.Zakharova, T.N.Vinnikova. Mathematical modeling of processes of groundwater contamination with mercury. VIII International Congress “Water: Environment and Technology” ERVATEK-2008.
Expediency of method of mathematical modeling application for studies of the processes of groundwater pollution with mercury was justified. A system of different-scale interrelated mathematical models of hydro-geological conditions of the northern part of Pavlodar industrial region (Kazakhstan) developed in the Institute of Hydro-geology and Hydro-physics of the Ministry of Education and Science of the Republic of Kazakhstan was described. The purpose of its creation was prediction of spread of the plume of groundwater mercury contamination for assessment of threat of mercury ingress into the Irtysh River and wells of water supply system of Povlodarskoe village and development of measures on the risk minimization. A series of prognosis tasks was solved on the model. Since technogenic factors render prevailing influence on hydro-geological conditions at the area, the necessity to use produced complex as a system of continuously acting mathematical models is explained.

20.V.Yu.Panichkin, O.L.Miroshnichenko, L.Yu.Trushel, N.M.Zakharova, T.N.Vinnikova. Mathematical models of groundwater mercury contamination. Actual Problems of Sciences about the Earth. International Scientific-practical Conference “Satpaev readings” (Kazakhstan, Almaty, 10-11 April, 2008).
Results of mathematical modeling of hydro-geological conditions of Pavlodar industrial region (Kazakhstan) and Kiev city (Ukraine) for prediction of spread of a plume of groundwater mercury contamination, assessment of environmental risks and development of measures on the risks minimization are examined.

21. A.V.Ubaskin, A.V.Eremenko. Pheno-deviants of crucian carp as a results of anthropogenic impact onto water ecosystem. Biological aspects of rational use and protection of water bodies of Siberia. Proceedings of All-Russian Conference. Tomsk, 2007.
Results of studies of ecosystems of Lake Balkyldak including revealing bio-indicator properties of silver crucian (Carassius auratus gibelio) living in conditions of mercury contamination are provided. Decrease of growth rate, its variability at upward-age fish, decrease of their fatness coefficient, decrease of an index of a body height, increase of driving were recorded. Mass mosaic scales, its “eroshenie”, affection of fish skin, ulcers appearance were observed. Bone skeleton deformities were strongly pronounced especially that of fish head. Considerable lengthening or shortening of one of jaw bones, i.e. fish mouth deformation were observed.

22. A.V.Ubaskin, T.N.Derbeneva, N.V.Ubaskina. Mercury impact onto biota of a technogenic water body. VIII All-Russian Scientific-practical Conference of Students and Postgraduates "Chemistry and Chemical Technology in XXI Century", Tomsk, 2007.
Assessment of a studied habitat quality by determining concentration of every pollutant is very expensive and gives few data for understanding negative effect on communities. Testing of a natural habitat using biological objects allows constructing quite simple and accessible quality system. In particular in hydrosphere representatives of ichthyol-fauna as a final element in trophic chain of a water body are good test-objects. At present complex study of the Lake Balkyldak ecosystem is carried out, in particular one of the tasks is revealing bio-indicator properties of fish living in conditions of mercury contamination. The obtained results allow considering hydro-bionts as a reliable instrument for operative environmental monitoring of water ecosystem in conditions of anthropogenic pressure.

23. M. A. Ilyushchenko, L.V.Yakovleva. Perspectives of application of remeduation technologies for elimination of consequences of mercury contamination in Pavlodar. Workshop on BIOMERCURY project (Southampton, UK, 22-24 February, 2007).
Typical problems arising while closing down chlor-alkali and other large-scale chemical industries using mercury technologies were examined. Projects of remediation of sites of mercury pollution in Kazakhstan are pioneer ones and their experience is valuable for next works on remediation.

24. M. A. Ilyushchenko. Problems of demercurization of industrial objects within the former USSR. International Workshop "Environmental mercury pollution: mercury emissions, remediation and health effects" (Astana, 28 May-1 June, 2007).
Typical problems arising while closing down chlor-alkali and other large-scale chemical industries using mercury technologies were examined. Projects of remediation of sites of mercury pollution in Kazakhstan are pioneer ones and their experience is valuable for next works on remediation.

25. M.A. Ilyushchenko, R.I.Kamberov, L.V.Yakovleva. Post-demercurization monitoring and risk assessment in the Northern industrial area of Pavlodar city. International Workshop "Environmental mercury pollution: mercury emissions, remediation and health effects" (Astana, 28 May-1 June, 2007).
Typical for the former USSR case of mercury pollution in Pavlodar city was examined: history of the pollution, risks assessment and preparation of a project of demercurization, cleanup works, post-demercurization monitoring and new risks assessment, development of biotechnology of mercury cleanup from mercury.

26. V.Yu. Panichkin. Risk assessment from groundwater mercury pollution of the Northern area of Pavlodar industrial region by the methods of mathematical modeling. International Workshop "Environmental mercury pollution: mercury emissions, remediation and health effects" (Astana, Kazakhstan, May 28 – June 1, 2007).
Development and application of a hydro-geological model for risks assessment and prognosis of efficiency of technologies of mercury contamination demercurization in Pavlodar, Kazakhstan.

27. O.L. Miroshnichenko. Methods and technology of creation of the system of mathematical models with different scales for groundwater mercury pollution within the industrial area of Pavlodar city. International Workshop "Environmental mercury pollution: mercury emissions, remediation and health effects" (Astana, Kazakhstan, May 28 – June 1, 2007).

Development and application of a hydro-geological model for risks assessment and prognosis of efficiency of technologies of mercury contamination demercurization in Pavlodar, Kazakhstan.

28. V.Yu.Panichkin, O.L.Miroshnichenko. Application of methods of structural modeling for assessment of a danger of mercury contamination of groundwater within an industrial zone of Pavlodar. Water: resources, quality, monitoring, water use and protection. International Scientific-practical Conference hold within the framework of an Exhibition “Akvaterm – 2007” Kazakhstan, Almaty, 19-21 September, 2007).
Risks of mercury pollution of adjacent territory for population of Pavlodar outskirt and PCP personnel were assessed. Main risks came from emission of gaseous mercury and dust from semi-dismantled buildings, wastes storages and an industrial site of stopped chlor-alkali production. It is imperative to continue remediation works.

29. V.Yu.Panichkin, O.L.Miroshnichenko, L.Yu.Trushel, N.M.Zakharova, T.N.Vinnikova. Solution of tasks of groundwater protection by methods of mathematical modeling (case of Pavlodar industrial region). Water: resources, quality, monitoring, water use and protection. International Scientific-practical Conference held within the framework of an Exhibition “Akvaterm – 2007” Kazakhstan, Almaty, 19-21 September, 2007). Process of creation of a system of different-scale interrelated mathematical models of hydro-geological conditions for assessment of a danger of groundwater contamination with mercury at Pavlodar industrial region is described.

30. V.Yu.Panichkin, O.L.Miroshnichenko. Method of structural modeling of processes of groundwater contamination in Kazakhstan. International Symposium “Future of Hydrogeology: contemporary trends and perspectives”, Saint-Petersburg, Russia, 2007.
Results of mathematical modeling of groundwater mercury contamination at Pavlodar industrial region are analyzed.

31. V.Yu.Panichkin, O.L.Miroshnichenko, T.N.Vinnikova, L.Yu.Trushel, N.M.Zakharova. Study of processes of groundwater mercury contamination in Pavlodar industrial region (Kazakhstan) by methods of mathematical modeling. International Symposium “Future of Hydrogeology: contemporary trends and perspectives”, Saint-Petersburg, Russia, 2007.
Application of a method of structural modeling for investigation of processes of groundwater contamination, ways of interaction of local and regional models and criteria of assessment of quality of the produced system of the models are described. The developed model was used successfully for producing a system of mathematical models of hydro-geological conditions of Pavlodar industrial region (Kazakhstan) for solving tasks of prediction of spread of a plume of groundwater mercury contamination and assessment of a danger for the environment and the region inhabitants.

32. V.Yu.Panichkin, O.L.Miroshnichenko. Automated technology of geo- migration processes modeling on a system of different-scale models. VII International Congress “Water: the environment and technology” EKVATEK-2006 (Russia, Moscow, 30 May – 2June, 2006).
A system of mathematical models of hydro-geological conditions of Pavlodar industrial region consisting of regional and local model is described. It was created with the purpose of prediction of spread of the plume of groundwater mercury contamination, assessment of a danger for the environment and human health and development of measures on the risk minimization.

33. A.V.Ubaskin, A.V.Ermienko, K.U.Bazarbekov, A.A.Kalieva, A.P.Bondarenko , N.N.Bondarenko. Influence of anthropogenic factors of the wastewater storage pond Balkyldak on living organisms. I International Scientific-practical Conference “News of scientific thought - 2006”. Dnepropetrovsk, 2006. Using characteristics of anomalies of fish from Lake Balkyldak test-objects (bio-monitors) are given as well as biomarkers, which can be included in a system of biomonitoring as complex criteria for assessment and prediction of ecosystem status and purposes of determination of a water body contamination level. Given parameters allow estimating state of hydrobionts and their habitat efficiently.

34. M.A.Ilyushchenko, N.Mikhailenko. Assessment of risks of the environment pollution as a result of 25-year operation of chlor-alkali production in Pavlodar. Workshop on BIOMERCURY project (Prague, Czhech Republic, 18-19 May, 2006). Typical problems arising while closing down chlor-alkali and other large-scale chemical industries using mercury technologies were examined. Projects of remediation of sites of mercury pollution in Kazakhstan are pioneer ones and their experience is valuable for next works on remediation.

35. M. Ilyushchenko, P. Randall, T.Tanton, A.Akhmetov, R.I. Kamberov, L.Yakovleva. Activities to contain mercury pollution from entering the river Irtysh in Pavlodar, Kazakhstan. Eighth International Conference on Mercury as a Global Pollutant (Madison, Wisconsin; August 6-11, 2006).
Typical for the former USSR case of mercury pollution in Pavlodar city was examined: history of the pollution, risks assessment and preparation of a project of demercurization, cleanup works, post-demercurization monitoring and new risks assessment, development of biotechnology of mercury cleanup from mercury.

36. M. A. Ilyushchenko. Activities for Prevention the Threat of Mercury Pollution in the River Irtysh in Pavlodar, Kazakhstan. 29th AMOP Technical Seminar. (Vancouver, British Columbia, Canada, 6-8 June, 2006).
Typical for the former USSR case of mercury pollution in Pavlodar city was examined: history of the pollution, risks assessment and preparation of a project of demercurization, cleanup works, post-demercurization monitoring and new risks assessment, development of biotechnology of mercury cleanup from mercury.

37. M. Ilyushchenko. Is commercialization of research projects on the environmental monitoring and risks assessment possible? ISTC Workshop “Commercialization of the results of scientific and technical developments in Kazakhstan (Almaty, 19-20 September, 2006).
Commercialization of environmental research projects is possible only in case of development of an environmental technology and only at final stages of pilot trials.

38. M. Ilyushchenko, P. Randall, T.Tanton, A.Akhmetov, E.V.Lapshin, R.I. Kamberov. Activities for Prevention the Threat of River Irtysh Mercury Pollution in Pavlodar. Annual Meeting at the American Institute of Chemical Engineers (AlChE) (Cincinnati, Ohio, US, 30 October – 4 November, 2005).
Typical for the former USSR case of mercury pollution in Pavlodar city was examined: history of the pollution, risks assessment and preparation of a project of demercurization, cleanup works, post-demercurization monitoring and new risks assessment, development of biotechnology of mercury cleanup from mercury.

Attachment 3: Information on patents and copy rights (List and describe patents and copyrights which were obtained or may be obtained as a result of the project)

Table 1

Dynamic of total mercury concentration change in groundwater of Northern industrial area of Pavlodar (on the results of mercury monitoring of 2008-2004)

N N	Borehole name	Total mercury concentration, ng/l 2004	Total mercury concentration, ng/l 2005	Total mercury concentration, ng/l 2006	Total mercury concentration, ng/l 2007	Total mercury concentration, ng/l 2008
1	**C-16-03**	129		144	121	Not tested
2	**C-17-03**	223		171	71.2	80.8
3	**C-18-03**	36		46	42.3	Not tested
4	**C-19-03**	175		229	98.1	93.9
5	**C-20-03**	97		140	83	246
6	**C-21-03**	4425		1630	734	535
7	**C-SLED**	3195		Impossible to pump out	Impossible to pump out	Not tested
8	**C-22-03**	1400		1200	593	731
9	**C-24-03**	2995		Impossible to pump out	Impossible to pump out	Not tested
10	**C-26-03**	19		Impossible to pump out	Impossible to pump out	Not tested
11	**C-29-03**	58		Impossible to pump out	Impossible to pump out	Not tested
12	**C-30-03**	45250		23500	19100	19800
13	**C-SLED-2**	90650		Impossible to pump out	Impossible to pump out	Not tested
14	**C-28-03**	5390		Impossible to pump out	Impossible to pump out	Not tested
15	**C-23-03**	648		Impossible to pump out	Impossible to pump out	Not tested
16	**C-25-03**	2455		2180	1160	**C-25-03**
17	**C-27-03**	24450		12500	11900	**C-27-03**
18	**C-15-03**	1625		11800	15000	**C-15-03**
19	**C-14-03**	2875		7450	12600	**C-14-03**
20	**C-13-03**	6175		4700	4080	**C-13-03**
21	**C-11-03**	29550		16400	7400	**C-11-03**
22	**C-12-03**	28850		31500	20600	**C-12-03**

23	**C-8-03**	35400	43500	38000	**C-8-03**
24	**C-9-03**	27200	17600	14400	**C-9-03**
	C-NN3-03	6025	Impossible to pump out	Impossible to pump out	Not tested
25					
26	**C-34-03**	80	86	57	47.2
27	**C-35-03**	171	737	387	118
28	**C-33-03**	943	941	536	719
29	**C-32-03**	43850	40600	49300	129000
	63-02	5050	3950	3190	2060
30					
31	**62-02**	35	21	22.9	15.2
32	**C-6-03**	21	138	235	Not tested
33	**84-02**	28850	30800	33600	44500
34	**67-02**	854	493	439	326
35	**83-02**	798	493	445	322
36	**72-02**	69	44	31.9	32.3
37	**90-02**	140	140	74.2	67.5
38	**74-02**	1435	338	164	Not tested
39	**87-02**	9315	6150	3990	4580
40	**70-02**	105	307	232	Not tested
41	**73-02**	479	744	763	1560
42	**79-02**	126	919	2760	3200
43	**55-02**	50	59	163	28.3
	89-02	76	38	Very low flow rate of the well	Not tested
44					
45	**88-02**	468	504	262	Not tested
	682	3160	Impossible to pump out	Impossible to pump out	Not tested
46					
47	**P-6**	50	10	10.3	21.50
48	**565-00**	29	52	35.5	20.8
49	**522-00**	<5	<5	<5	10.6
50	**78-02**	32	111	?	330
51	**81-02**	14	9	13.8	5.60
52	**566-00**	3055	5100	2870	2690
53	**86-02**	1775	287	104	63.2
54	**85-02**	6	<5	<5	<5
55	**P-1**	23	83	56.3	9.75
56	**6-P**	39	29	32.1	32.6
57	**5-P**	12	<5	6.19	10.7
58	**C-5-03**	121	160	200	213
59	**C-4-03**	517	354	195	722
	P-3	24700	14700	low flow rate of the well	Not tested
60					
61	**C-2-03**	137000	36500	42700	48500
62	**C-1/1-03**	2135	5600	3820	2990
63	**B-22**	1255	4780	2240	3290
	8-P	<5	Impossible to pump out	Impossible to pump out	Not tested
64					

65	**7-P**	3875		2490	2810	1770
66	**B-23**	946		442	440	626
67	**C-1-03**	212		Impossible to pump out	Impossible to pump out	Not tested
68	**B-14**	4030		Impossible to pump out	Impossible to pump out	Not tested
69	**B-13**	2845		724	215	255
70	**P-4**	159		72	28	51.2
71	**75-02**	166		364	273	Not tested
72	**76-02**	8		<5	9.25	27.9
74	**61-02**	17600		5420	2260	1880
75	**B-21**	12150		27300	33300	35900
76	**60-02**	15		Impossible to pump out	Impossible to pump out	Not tested
77	**C-10-03**	41300		39300	40900	37800
78	**B-21a**	126000		Out of operation	Out of operation	Not tested
79	**567-00**	47000		23400	48900	58200
80	**P-8**	102750	18000	14200	14500	23400
81	**82-02**	57550		44600	34500	42200
82	**66-02**	85300		167000	108000	90400
83	**59-02**	41100		32400	24900	14600
84	**68-02**	36700		57200	65200	71700
85	**69-02**	153500	165000	154000	137000	81200
86	**29-P**	not tested		449	Out of operation	Not tested
87	**165-04**	not tested		10500	8980	7220
88	**166-04**	not tested		3380	2830	4170
89	**167-04**	not tested		3310	2420	2580
90	**169-04**	not tested		28200	32300	31400
91	**170-04**	not tested		6880	7970	16000
92	**168-04**	not tested		7220	7410	6880
93	**171-04**	not tested		270	95.2	65.1
94	**162-04**	not tested		295	Impossible to pump out	Not tested
95	**164-04**	not tested		123	139	375
96	**529**	not tested		44	61.6	42.5
97	**64-02**	not tested		7	27.4	21.8
98	**24-91 (93)**	not tested		71	87	62.7
99	**77-02**	not tested		<5	9.49	<5
100	**23-91 (92)**	not tested		11	21	5.87

Comments to the table 1: “Borehole name” column: red borehole names indicate increase in mercury concentration, green – decrease in mercury concentration, blue – absence of any dynamics; “Total mercury concentration” column: red figures indicate exceeding the sanitary standard (500 ng/l).

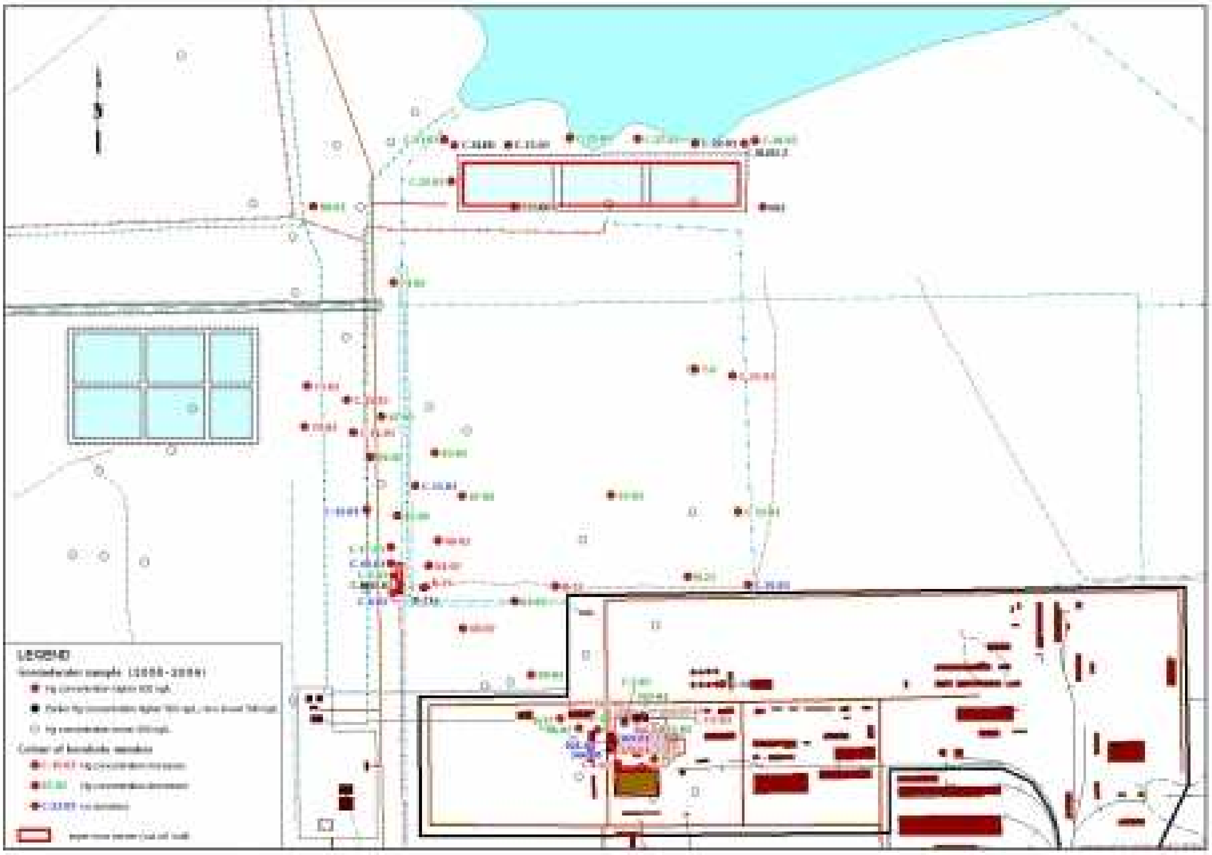


Figure 1. Dynamic of total mercury concentration change in groundwater of Northern industrial area of Pavlodar (2008-2004)

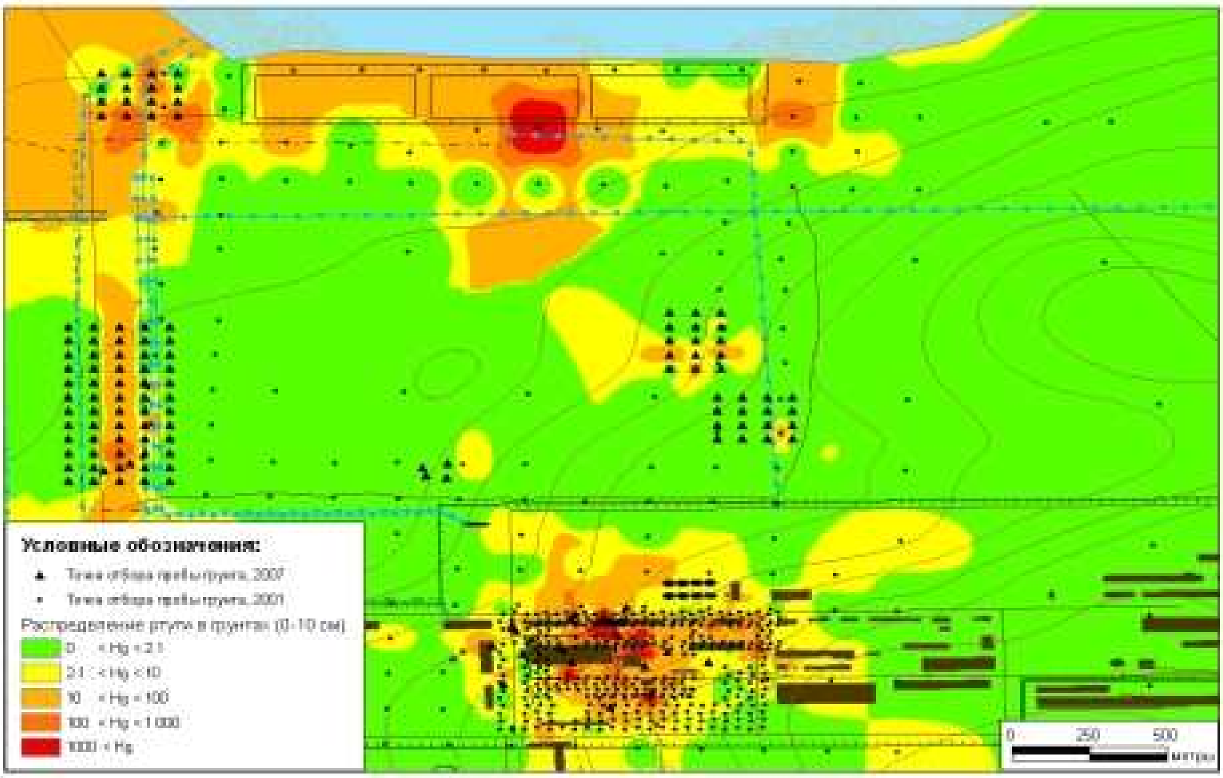


Figure 2. Map of soil mercury contamination (topsoil 0-10 cm) in Northern industrial area, Pavlodar completed with data of 2007 on 111 sampling points.

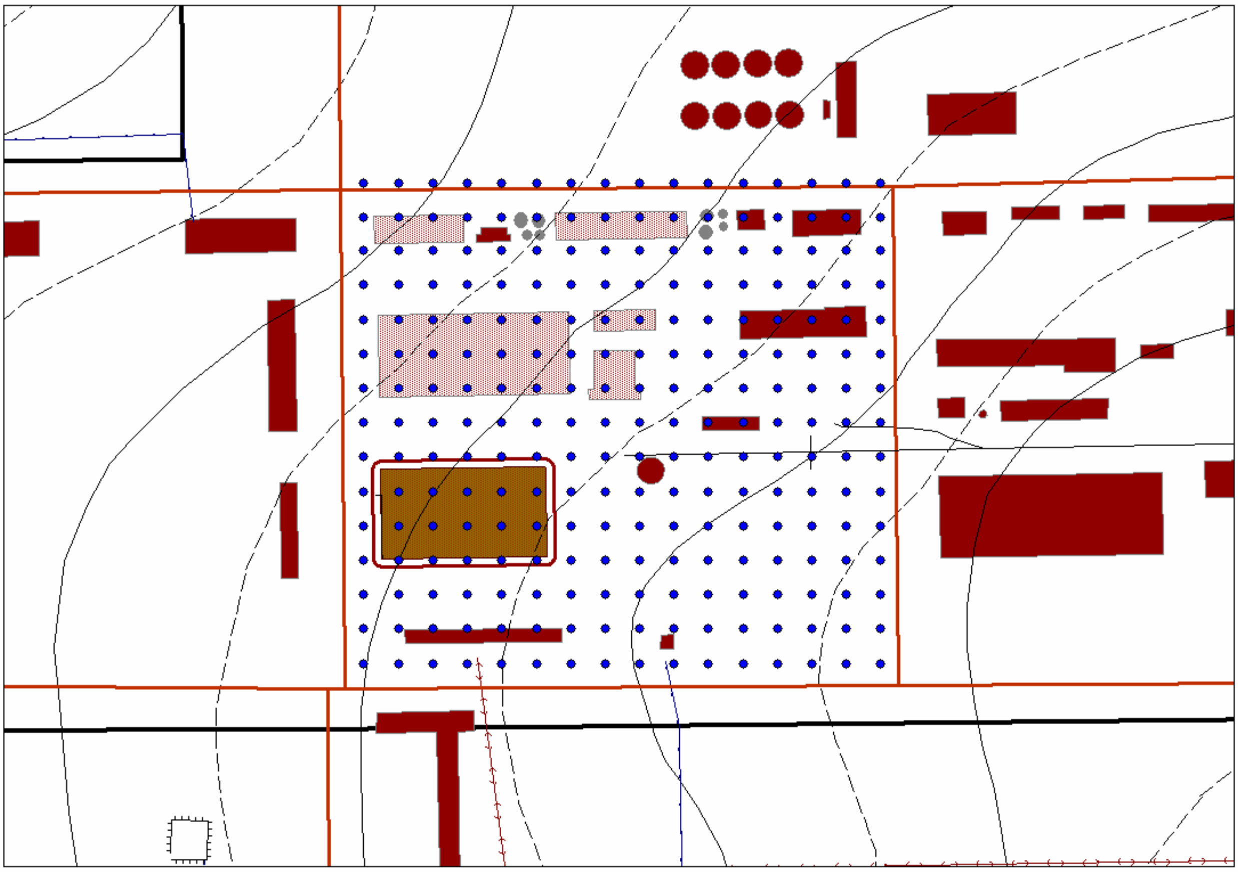


Figure 3. Soil sampling plan from three layers: 0-10, 10-20, 20-50 cm deep at the area of a former chlor-alkali facility of PCP ("territory of demercurization")

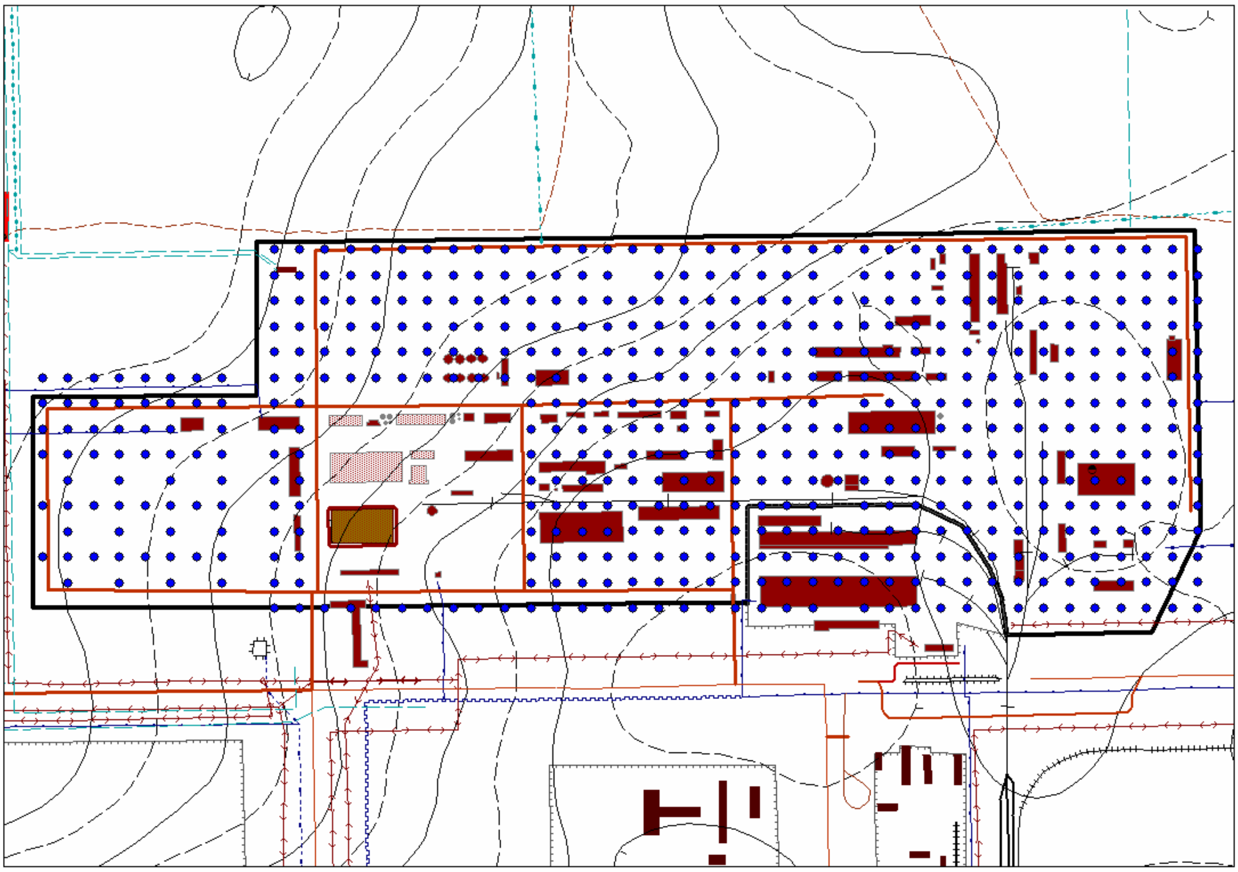


Figure 4. Soil sampling plan from three layers: 0-10, 10-20, 20-50 cm deep at the area of industrial site # 1 of PCP

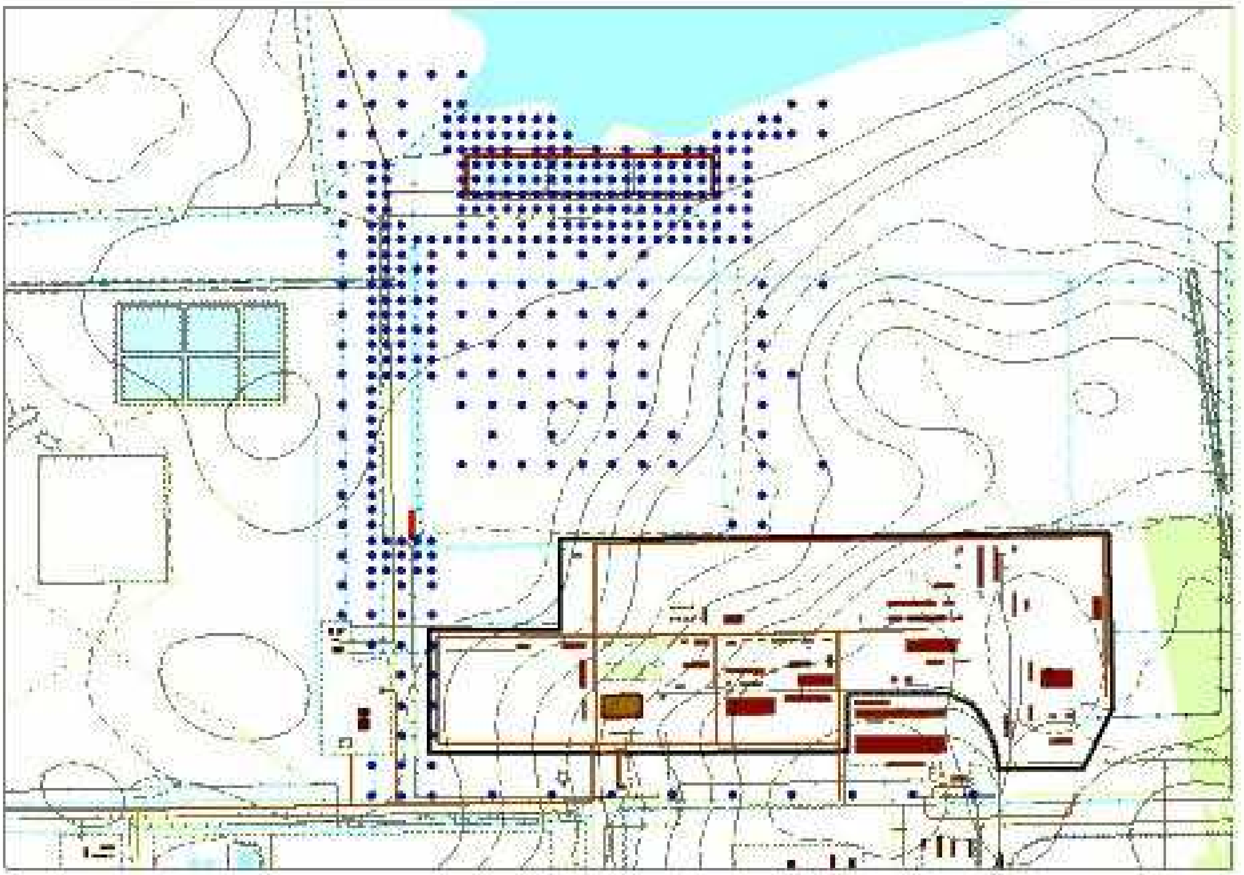


Figure 5. Soil sampling plan from three layers: 0-10, 10-20, 20-50 cm deep at the territory around the industrial site # 1 of PCP

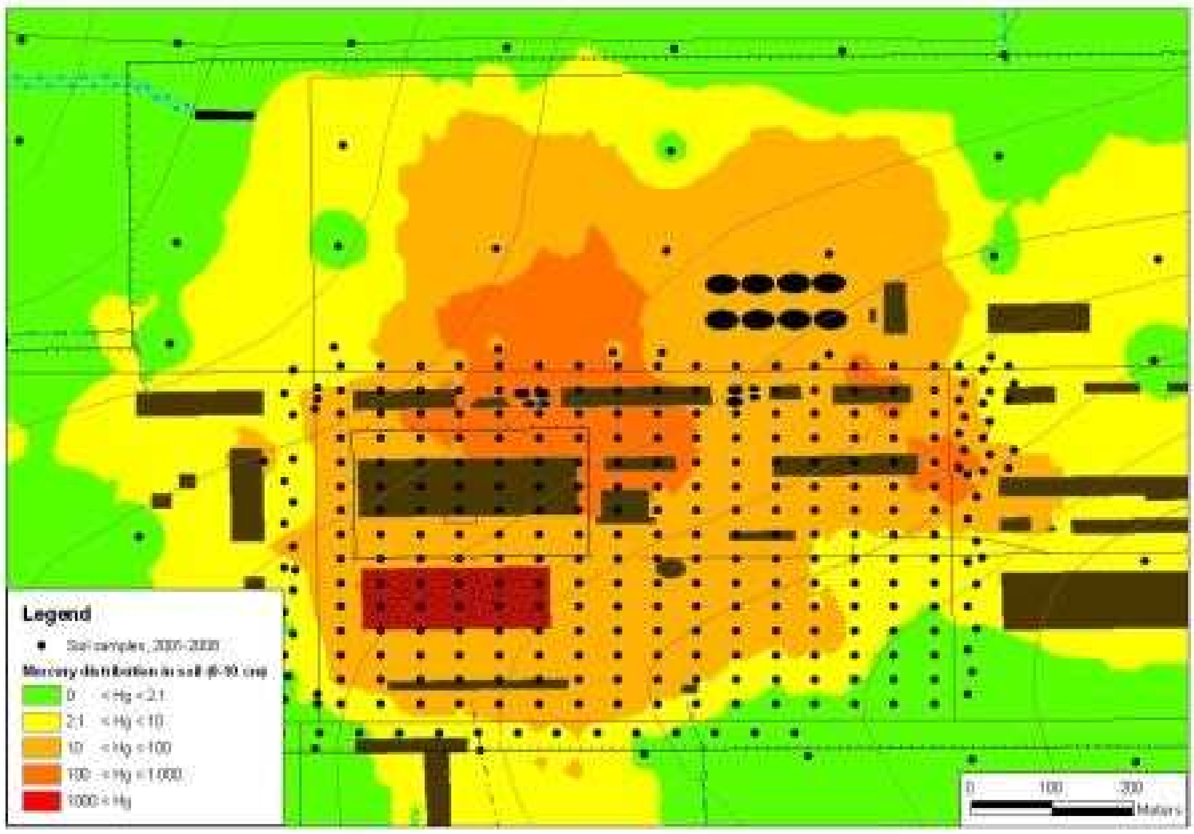


Figure 6. Map of topsoil (0-10 cm layer) mercury contamination at the industrial site of the former chlor-alkali production of PCP, produced on the results of soil sampling of 2008.

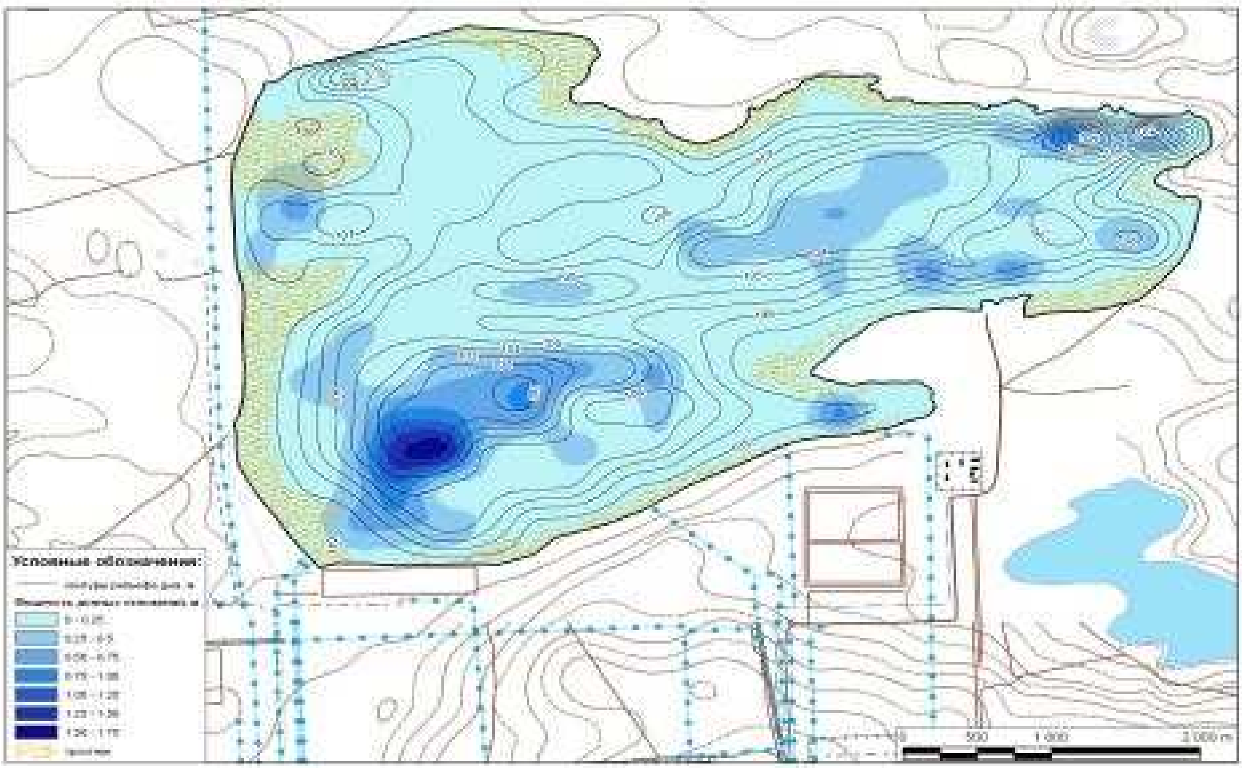


Figure 7. Map of depths and thickness of bottom sediments of wastewater storage pond – Lake Balkyldak

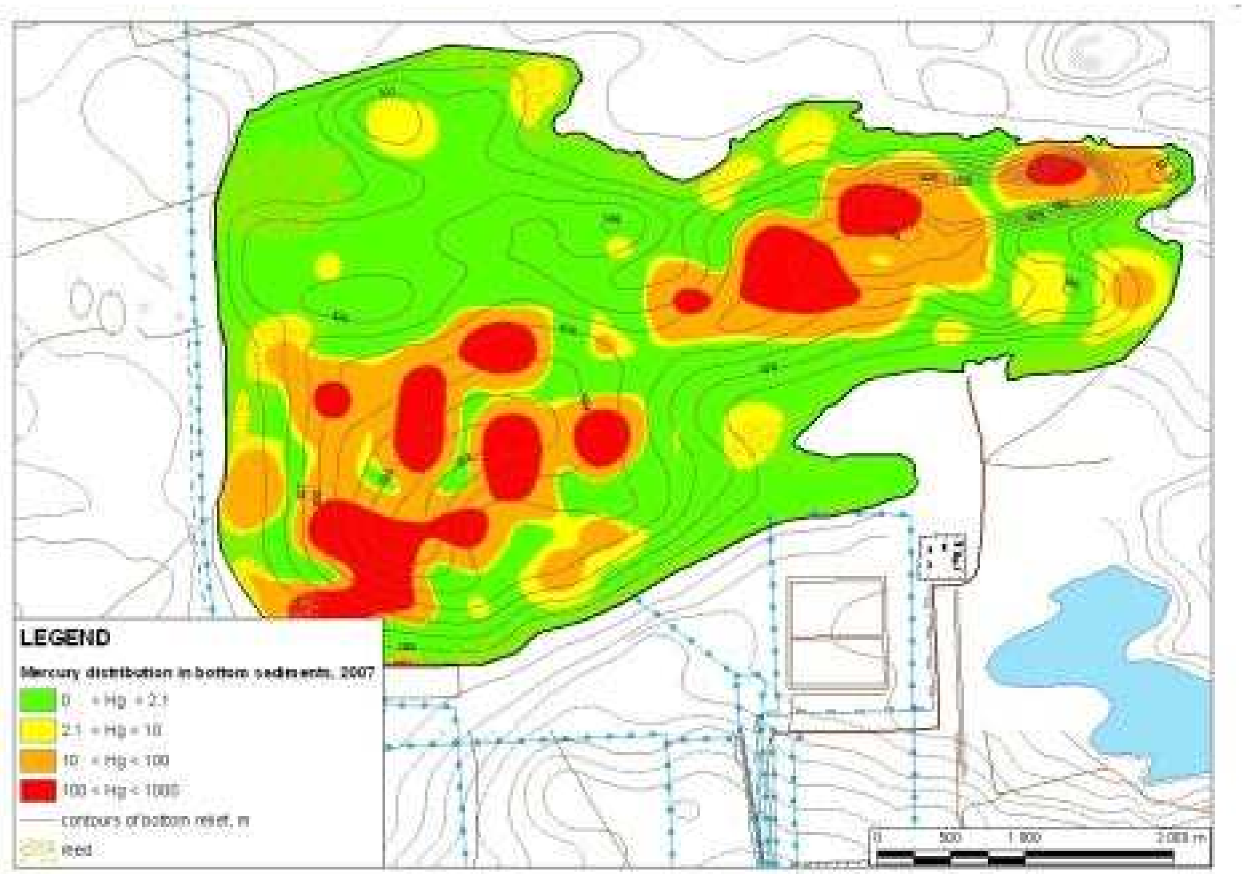


Figure 8. Map of the wastewater storage pond Balkyldak bottom sediments mercury contamination

Figure 9. System of hydro-geological models of Northern Industrial Area of Pavlodar 1. Area of groundwater mercury contamination, 2. Regional model of hydro-geological conditions of the Northern industrial area of Pavlodar city, 3. Local model of groundwater mercury contamination

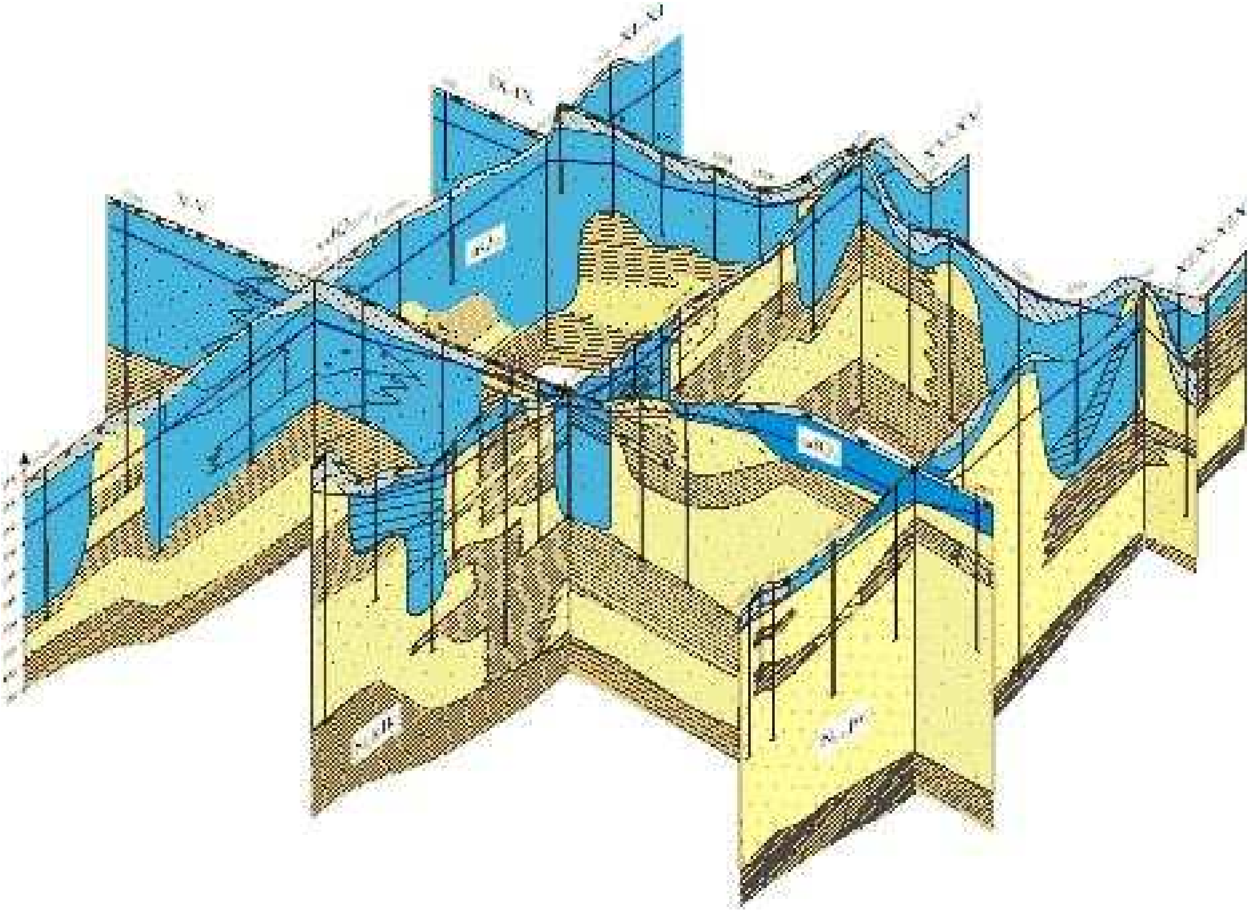


Figure 10. 3D diagram of lithologic structure of simulated Northern industrial area of Pavlodar

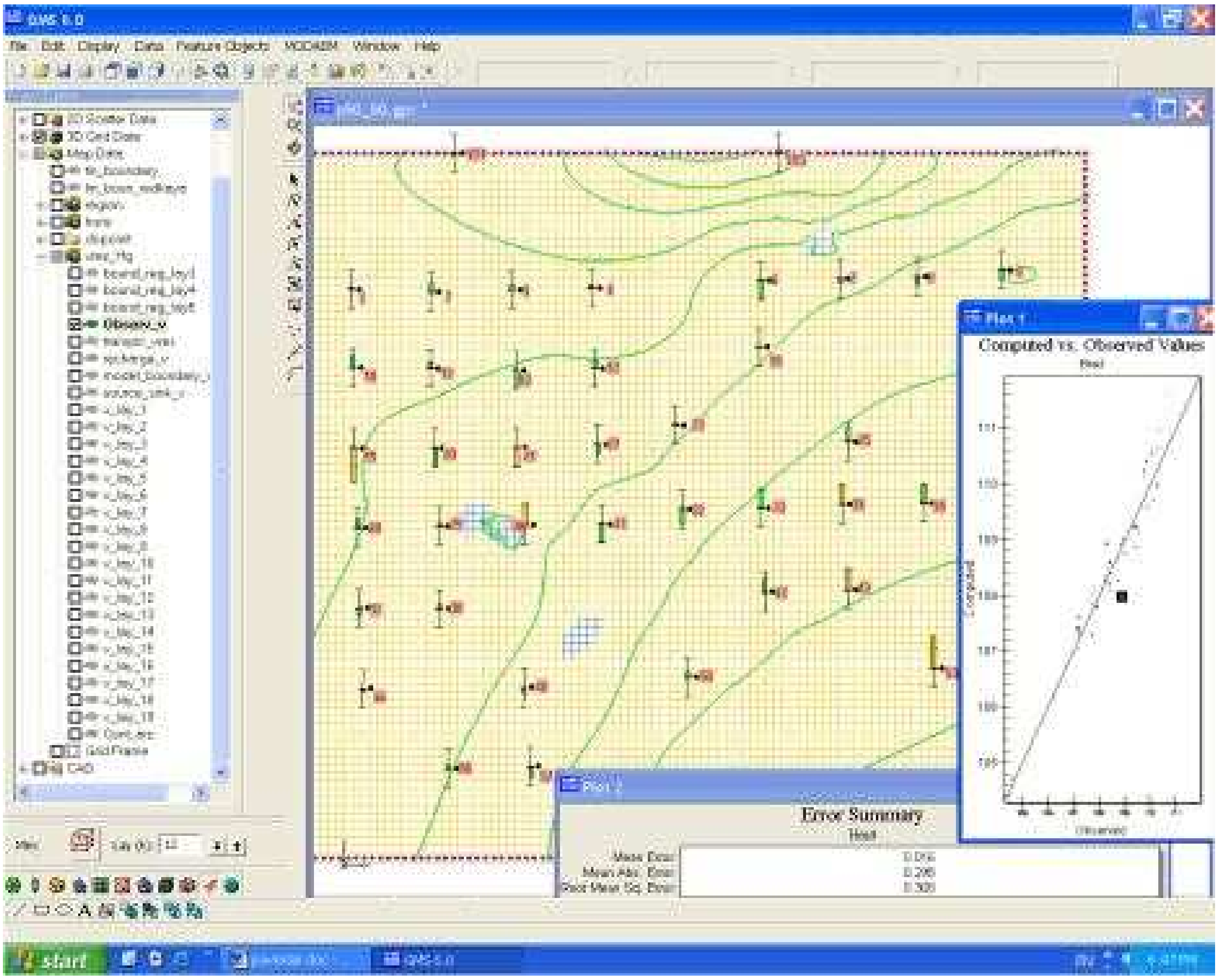


Figure 11. Result of solution of inverse stationary task on hydro-dynamic model of Northern industrial area of Pavlodar

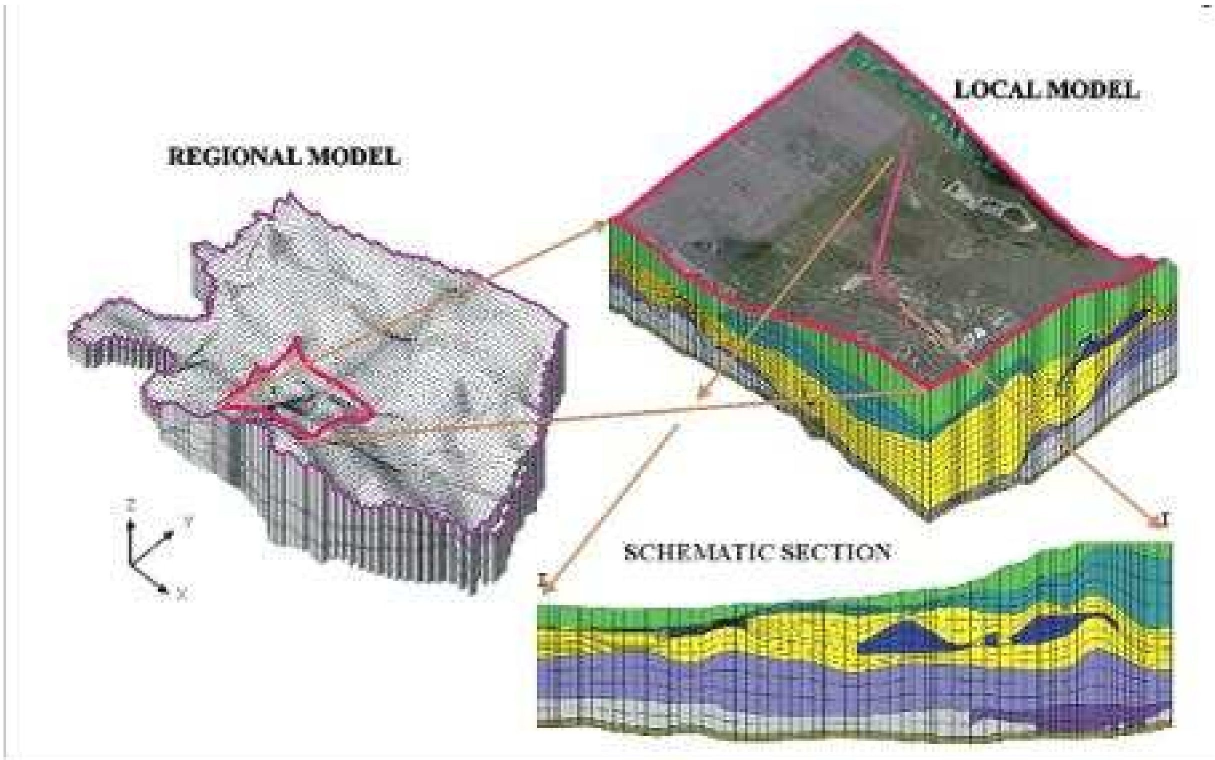


Figure 12. Structure of system of models of hydro-geological conditions in the Northern industrial area of Pavlodar

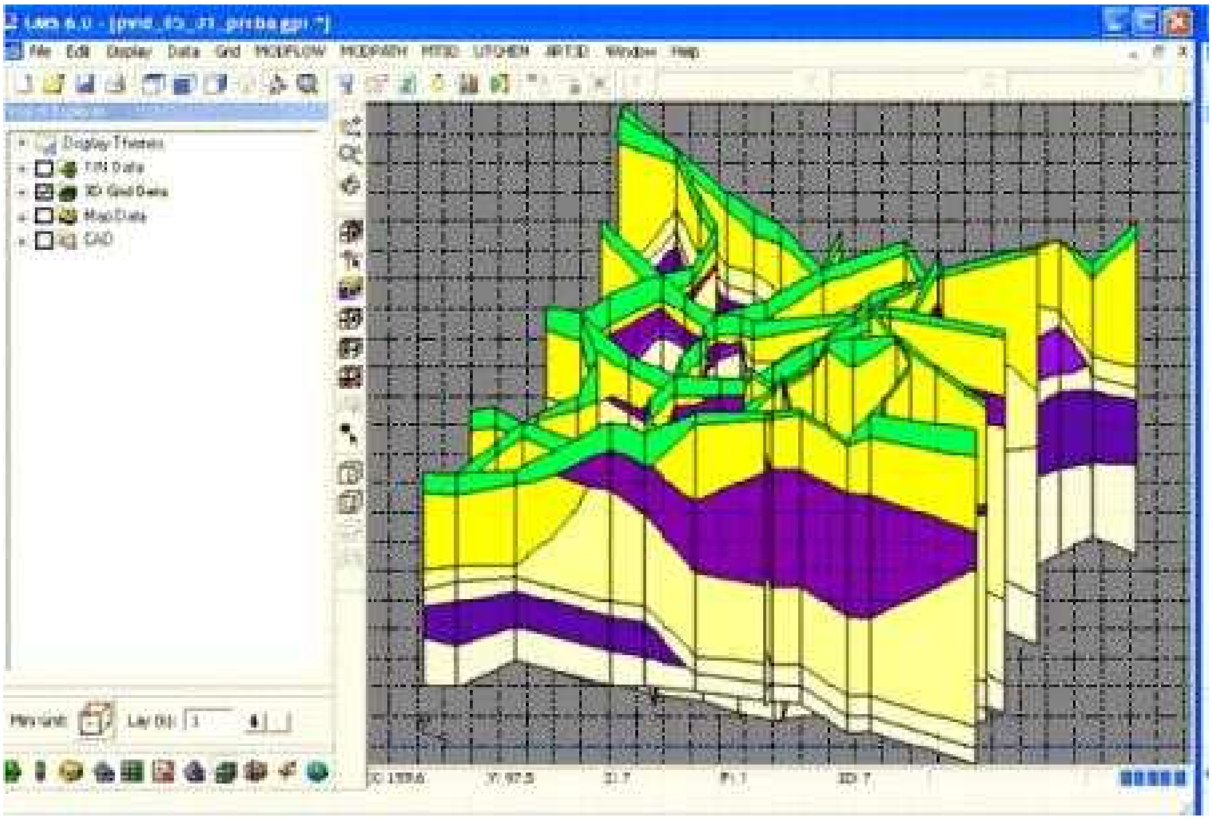


Figure 13. 3D stratigraphy model

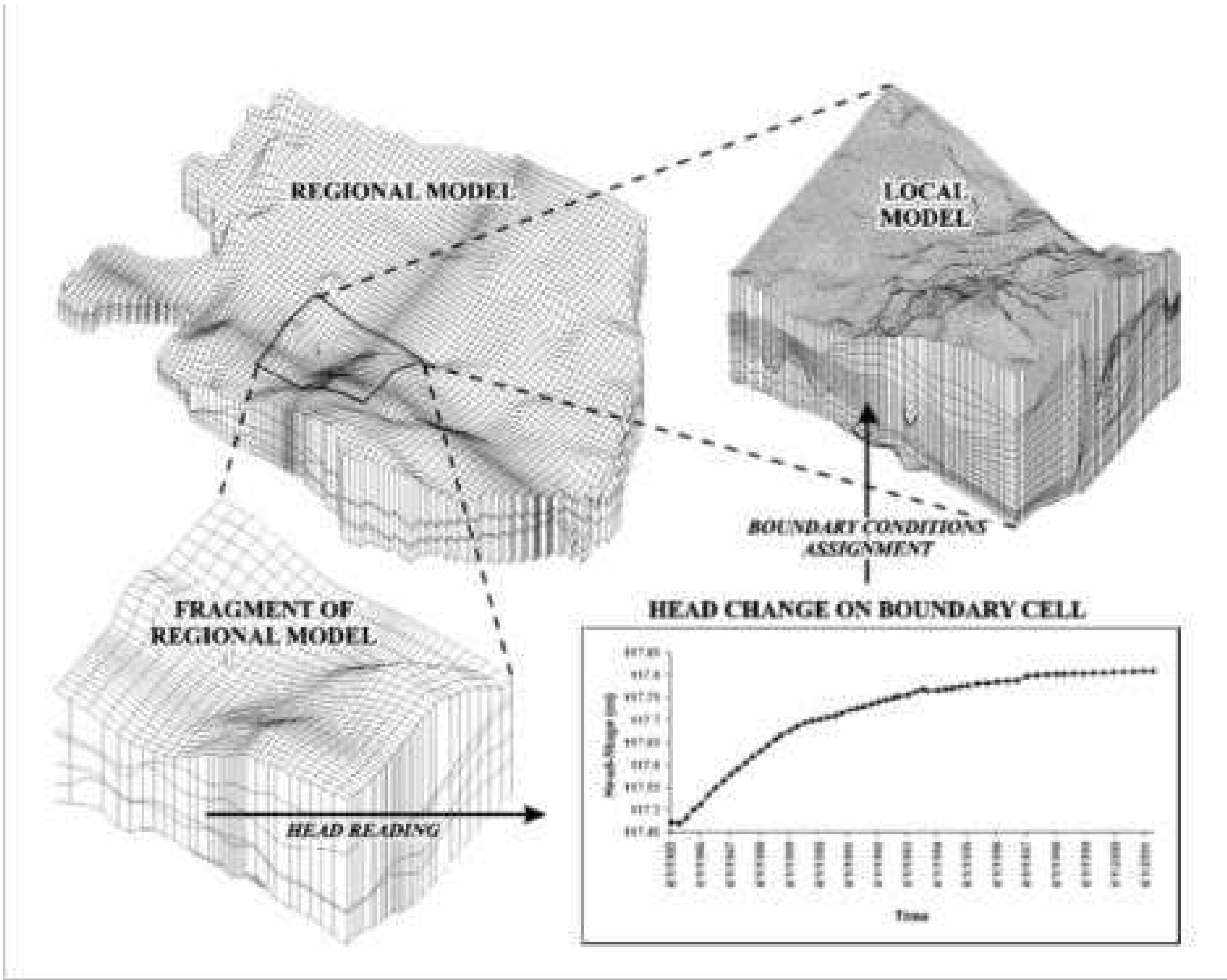


Figure 14.Establishment of absolute groundwater marks on outer boundaries of local model

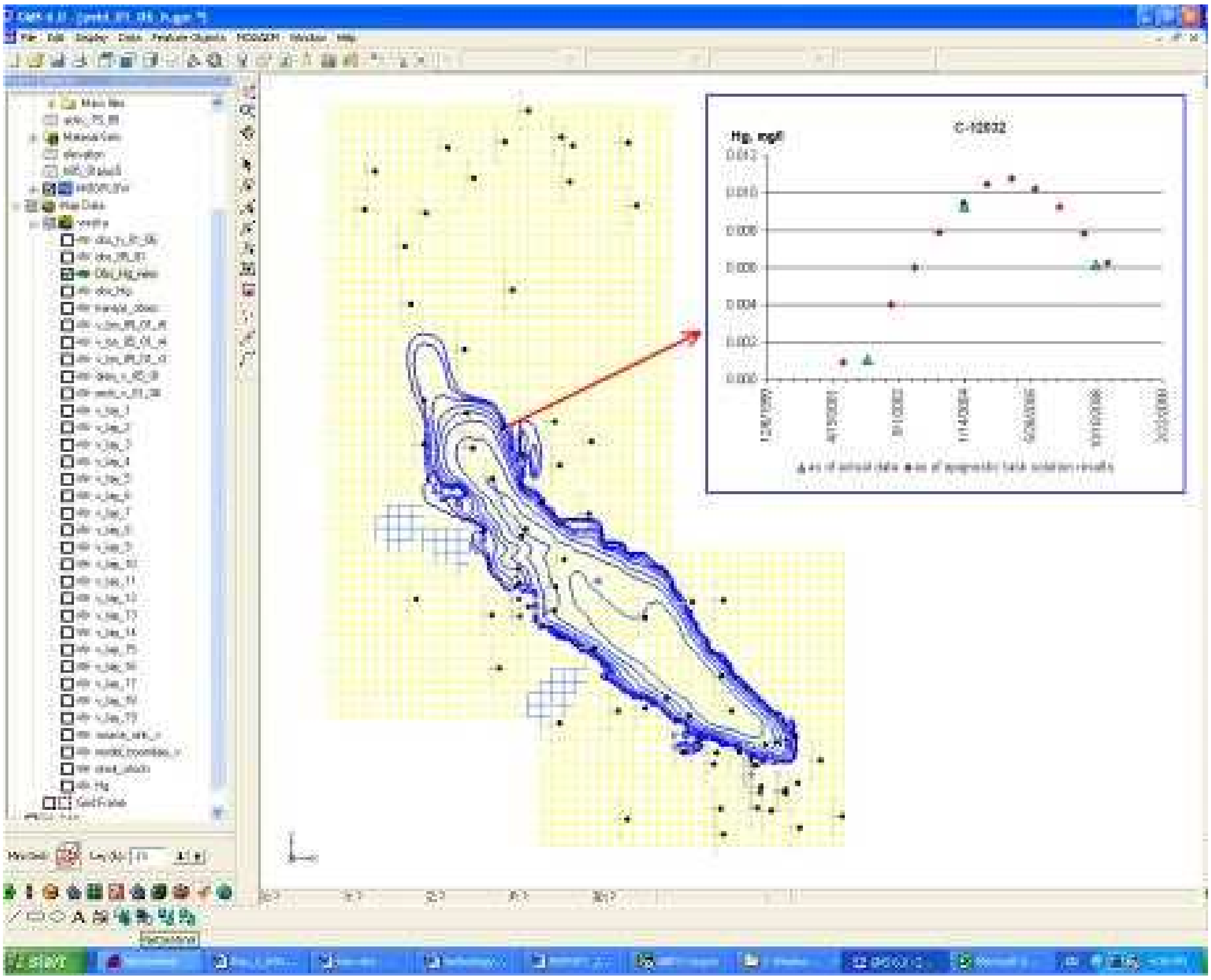
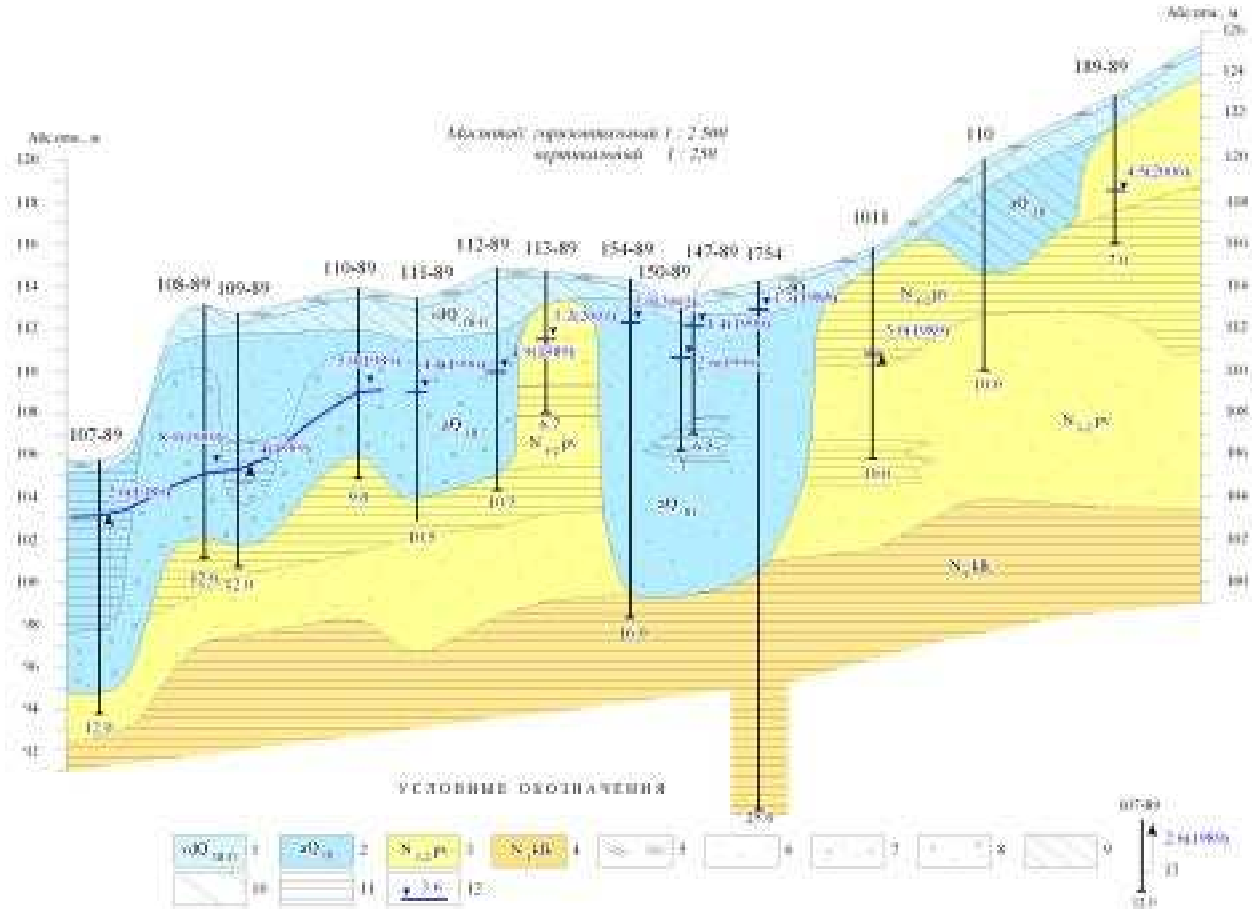


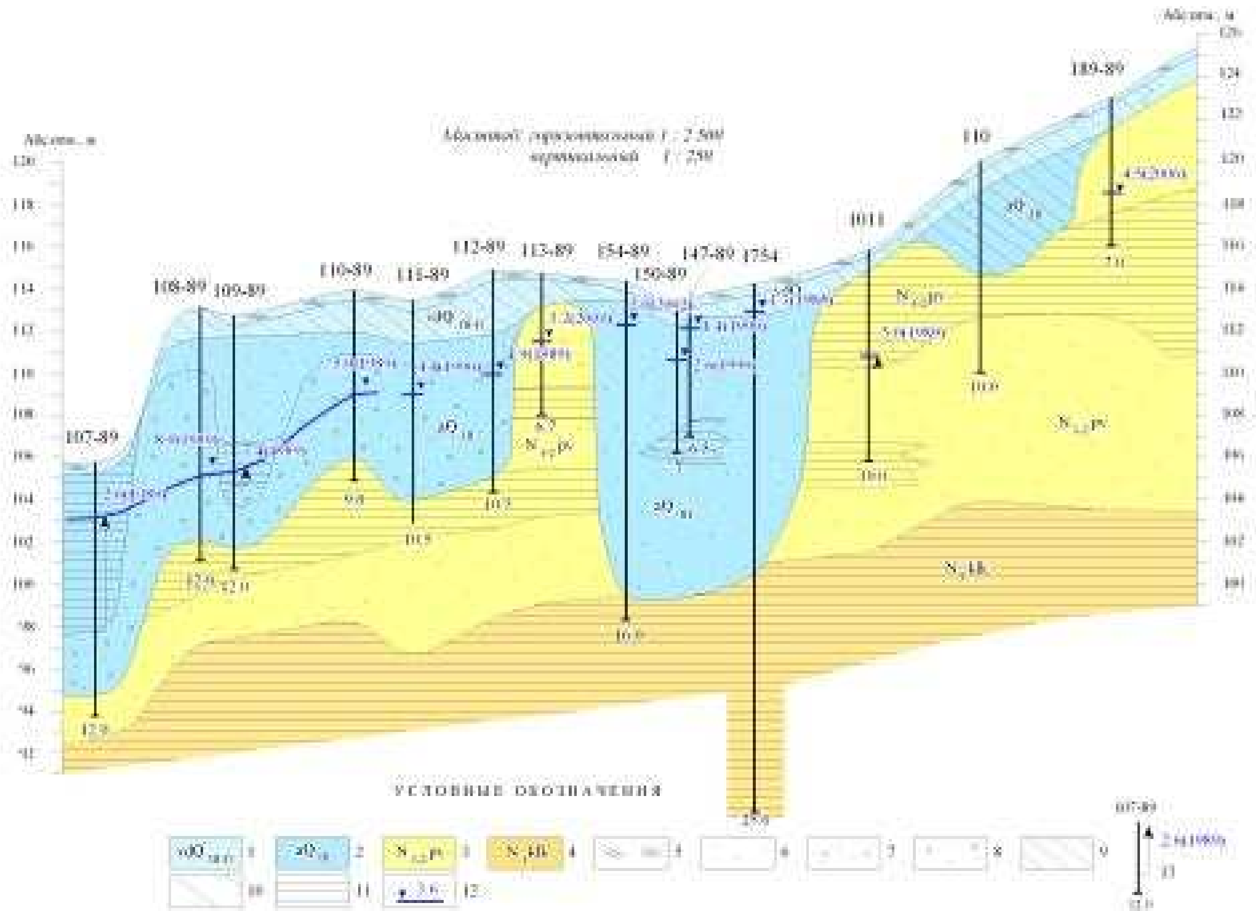
Figure 15. Improvement of the local hydro-geological model

Figure 16. General map of the Norther industrial area of investigation in Pavlodar. 1. General map of working area; 2. Regional model of hydro-geological conditions of the Nirthern industrial area of Pavlodar; 3. Local model of groundwater contamination with oil products



1 – Water permeable, but in fact waterless Upper-Quaternary and recent deposits; 2 – water-bearing horizon of Upper-Quaternary alluvial deposits; 3 – water-bearing complex of Lower-middle-Pliocene, Upper-Miocene deposits of Pavlodar series. 4 – waterproof rocks of Lower-middle-Miocene of Kalkaman series. Lithologic composition of rocks: 5 – soil-vegetation stratum; 6 – sand; 7 – clay sand; 8 – gravel sand; 9 – loam sand; 10 – loam; 11 – clay; 12 – groundwater table with free surface, m; 13 – hydro-geological borehole. Numerals: on top – borehole number (name); at the bottom – borehole depth, m; by the arrow – depth of occurrence of piezometric level, m; in brackets – a year of observation.

Figure 17. Hydro-geological cross section on the line V-V



1 – Water permeable, but in fact waterless Upper-Quaternary and recent deposits; 2 – water-bearing horizon of Upper-Quaternary alluvial deposits; 3 – water-bearing complex of Lower-middle-Pliocene, Upper-Miocene deposits of Pavlodar series. 4 – waterproof rocks of Lower-middle-Miocene of Kalkaman series. Lithologic composition of rocks: 5 – soil-vegetation stratum; 6 – sand; 7 – clay sand; 8 – loamy sand; 10 – clay; 11 – groundwater table with free surface, m; 12 – hydro-geological borehole. Numerals: on top – borehole number (name); at the bottom – borehole depth, m; by the arrow – depth of occurrence of piezometric level, m; in brackets – a year of observation.

Figure 18. Hydro-geological cross section on the line XVII-XVII

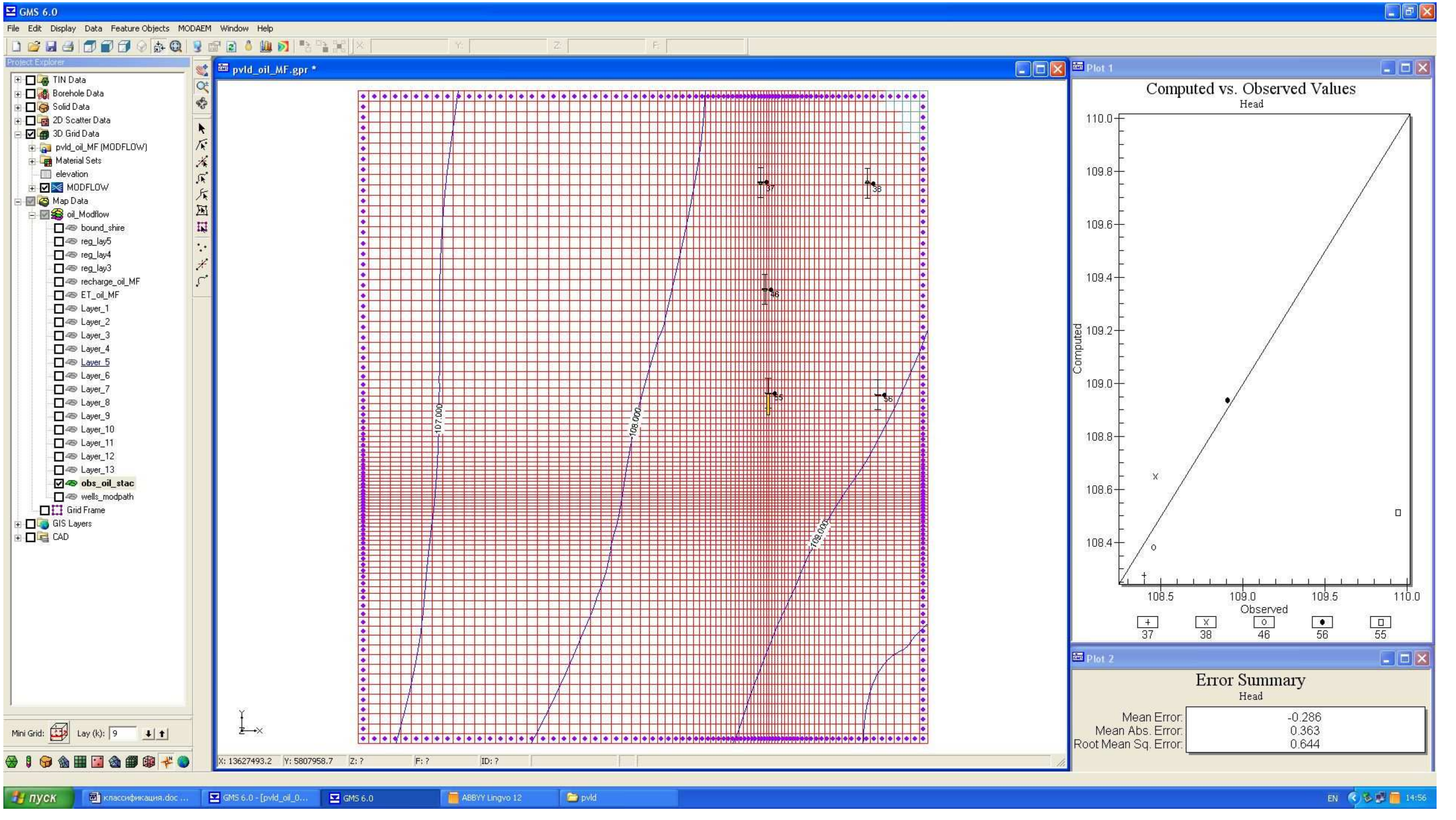


Figure 19. Result of solution of inverse stationary tasks

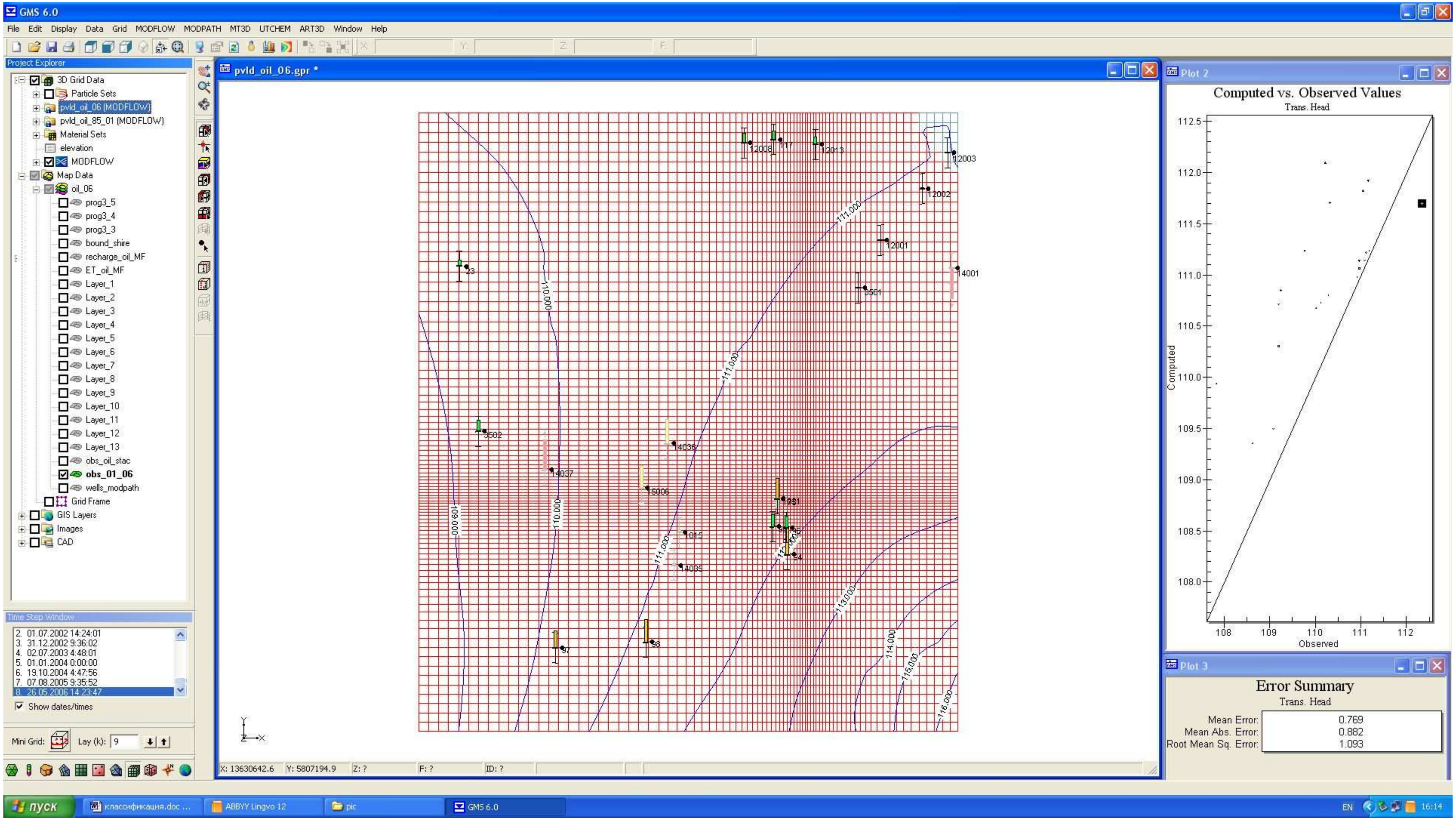
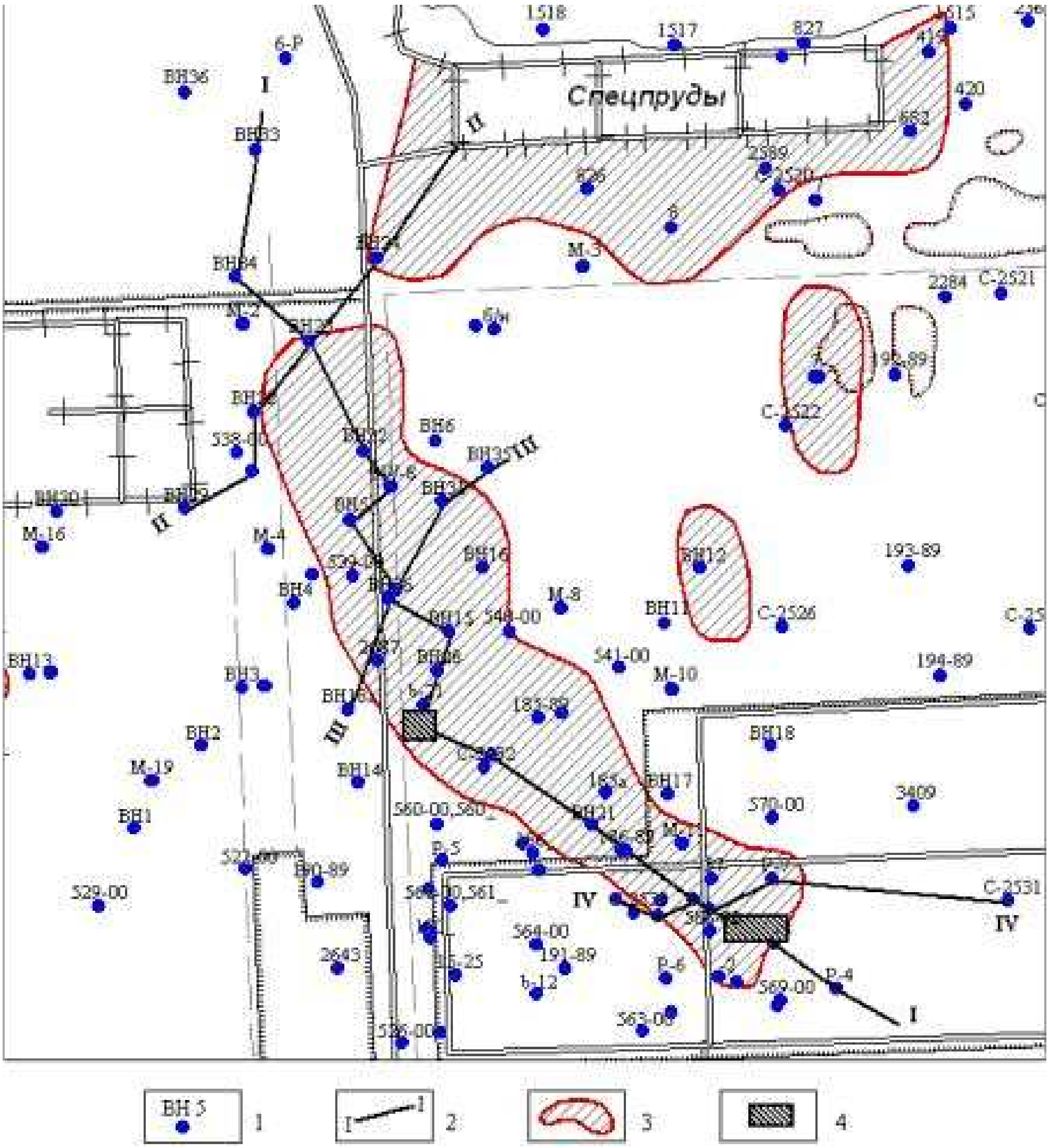
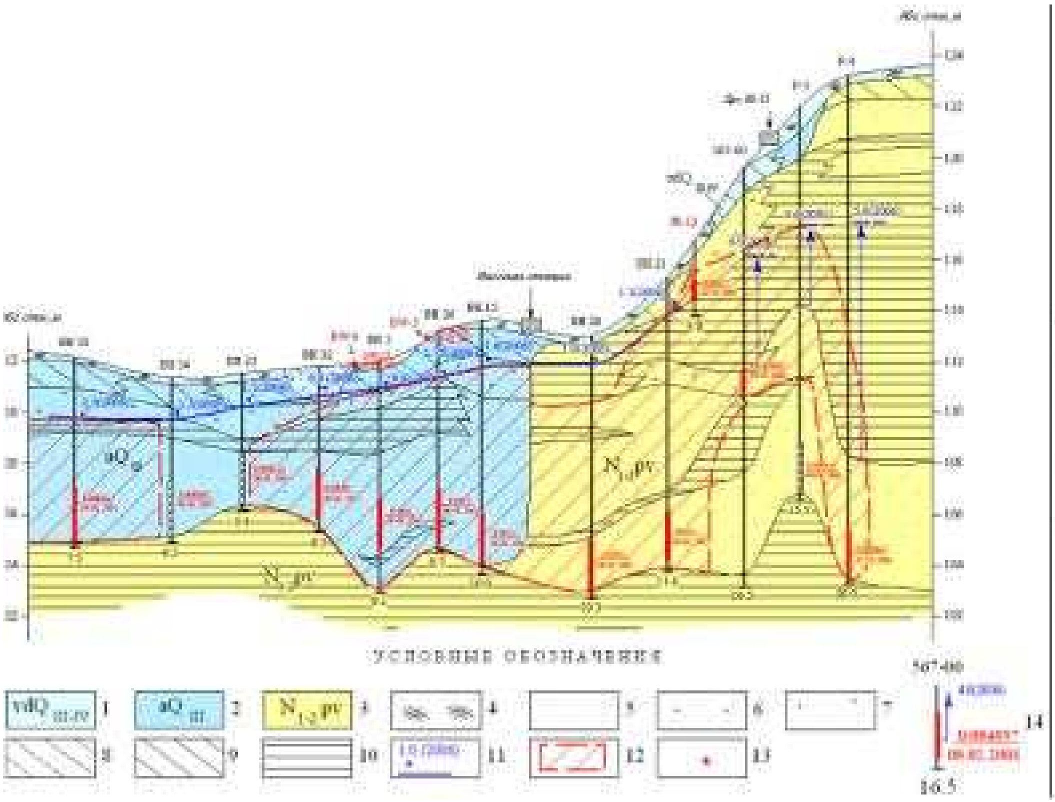


Figure 20. Result of solution of inverse non stationary tasks



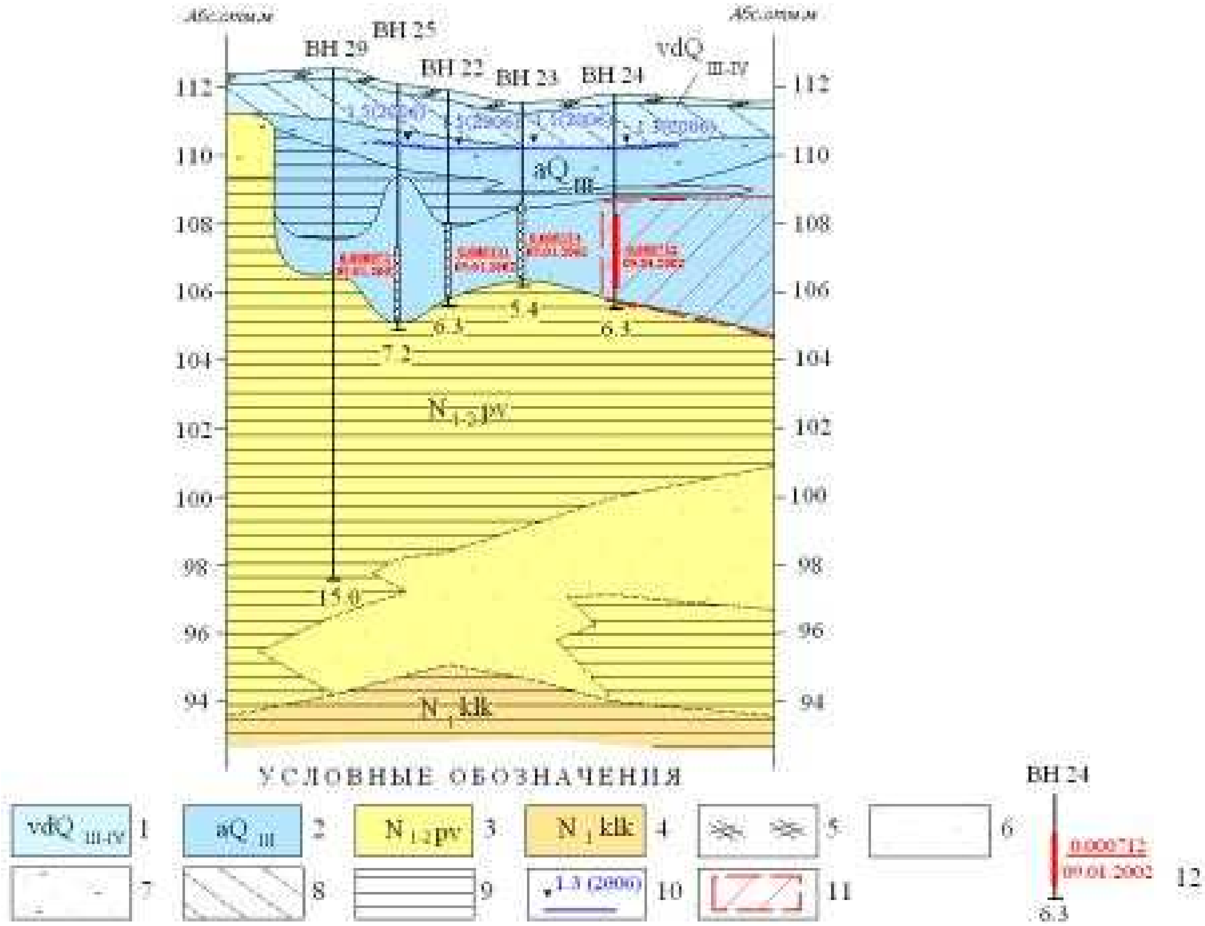
1 – hydro-geological borehole and its name, 2 – hydro-geological cross section line and its number, 3 – groundwater mercury contaminated area, 4 – main sources of mercury pollution.

Figure 21. The map produced on the basis of the material available



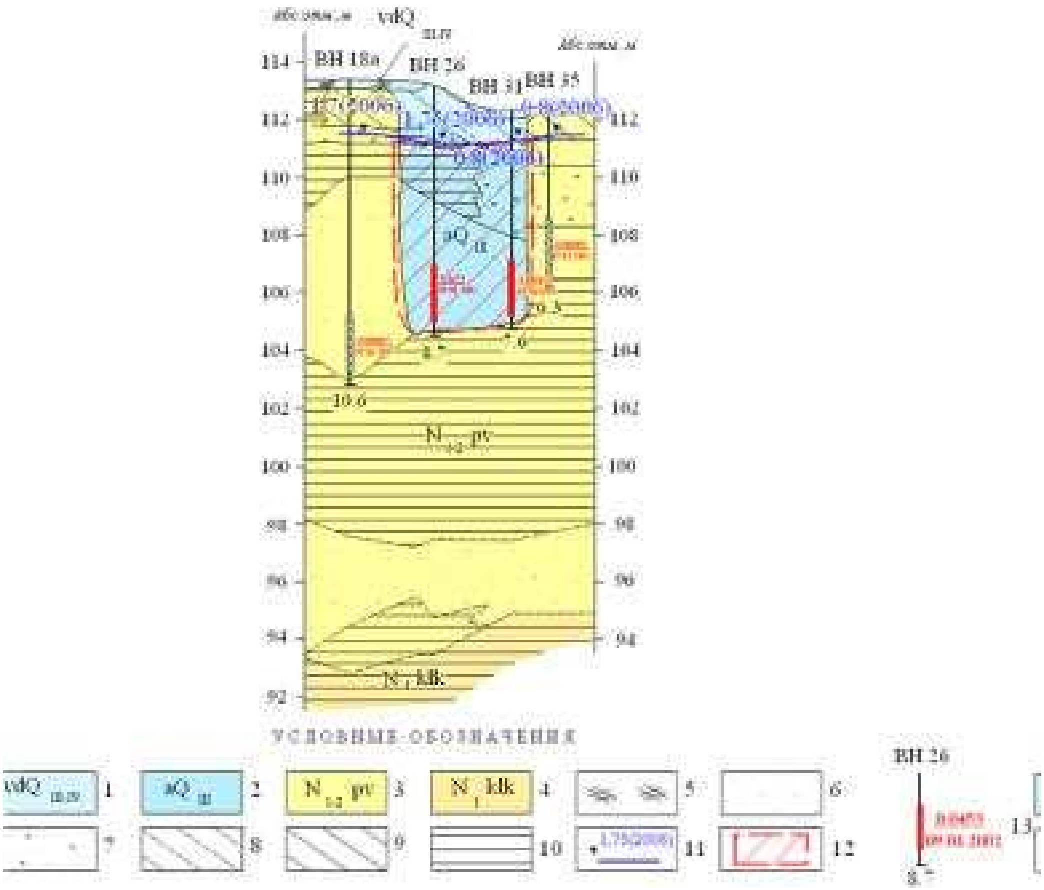
1 – Water permeable, but in fact waterless Upper-Quaternary and recent wind deposits; 2 – water-bearing horizon of Upper-Quaternary alluvial deposits; 3 – water-bearing complex of Lower-middle-Pliocene, Upper-Miocene deposits of Pavlodar series. Lithologic composition of rocks: 4 – soil-vegetable stratum; 5 – sand; 6 – clay sand; 7 – gravel sand; 8 – loam sand; 9 – loam; 10 – clay; 11 – table and depth of groundwater occurrence, m; in brackets – a year of observation. 12 – the area of groundwater mercury contamination. 13 – surface water sampling points. 14 – hydro-geological borehole. Numerals: on top – borehole number (name); at the bottom – borehole depth, m; on the right: in numerator – mercury concentration in water – mg/l; in denominator – sampling date. Hatched area – sampling interval. Red colored boreholes – the ones where mercury concentrations are more than MPC (0.0005 mg/l). By the arrow – occurrence depth of piezometric level, m; in brackets – a year of observation.

Figure 22. Hydro-geological cross section on the line I-I



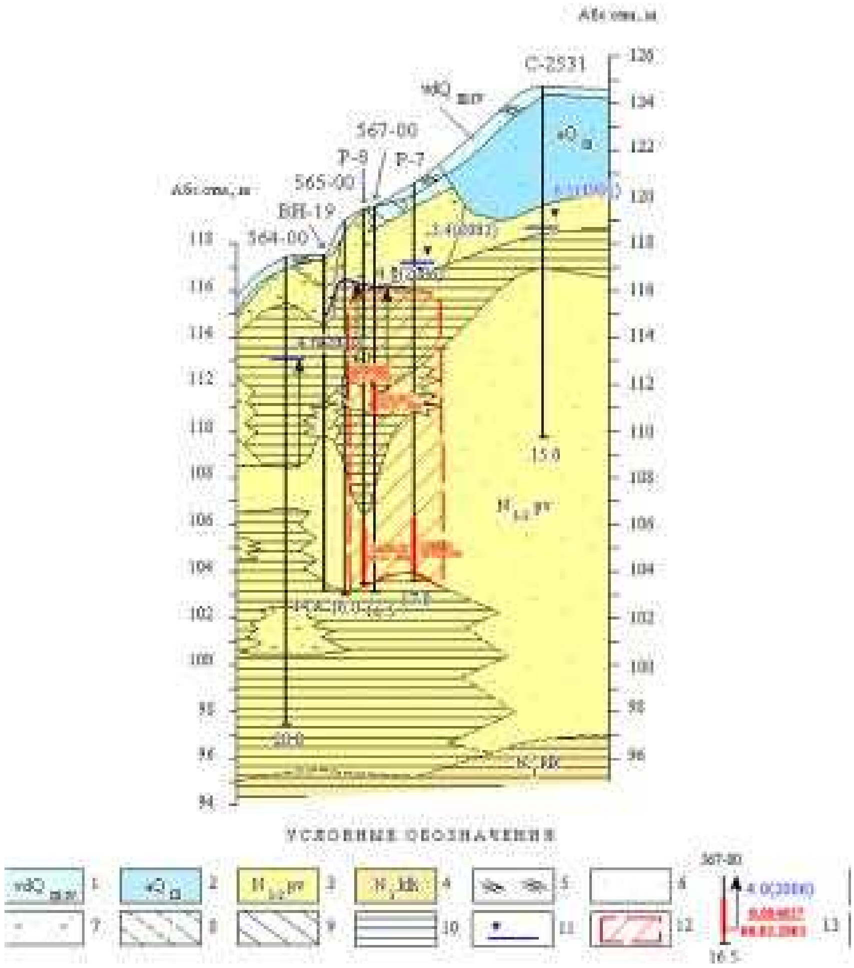
1 – Water permeable, but in fact waterless Upper-Quaternary and recent wind deposits; 2 – water-bearing horizon of Upper-Quaternary alluvial deposits; 3 – water-bearing complex of Lower-middle-Pliocene, Upper-Miocene deposits of Pavlodar series; 4 – waterproof rocks of Lower-middle-Miocene of Kalkaman series. Lithologic composition of rocks: 5 – soil-vegetable stratum; 6 – sand; 7 – clay sand; 8 – loamy sand; 9 – clay; 10 – table and depth of groundwater occurrence, m; in brackets – a year of observation; 11 – the area of groundwater mercury contamination. 12 – hydro-geological borehole. Numerals: on top – borehole number (name); at the bottom – borehole depth, m; on the right: in numerator – mercury concentration in water – mg/l; in denominator – sampling date. Hatched area – sampling interval. Red colored boreholes – the ones where mercury concentrations are more than MPC (0.0005 mg/l).

Figure 23. Hydro-geological cross section on the line II-II



1 – Water permeable, but in fact waterless Upper-Quaternary and recent wind deposits; 2 – water-bearing horizon of Upper-Quaternary alluvial deposits; 3 – water-bearing complex of Lower-middle-Pliocene, Upper-Miocene deposits of Pavlodar series; 4 – waterproof rocks of Lower-middle-Miocene of Kalkaman series. Lithologic composition of rocks: 5 – soil-vegetable stratum; 6 – sand; 7 – clay sand; 8 – loamy sand; 9 – loam; 10 – clay; 11 - table and depth of groundwater occurrence, m; in brackets – a year of observation; 12 – the area of groundwater mercury contamination. 13 – hydro-geological borehole. Numerals: on top – borehole number (name); at the bottom – borehole depth, m; on the right: in numerator – mercury concentration in water – mg/l; in denominator – sampling date. Hatched area – sampling interval. Red colored boreholes – the ones where mercury concentrations are more than MPC (0.0005 mg/l).

Figure 24. Hydro-geological cross section on the line III-III



1 – Water permeable, but in fact waterless Upper-Quaternary and recent wind deposits; 2 – water-bearing horizon of Upper-Quaternary alluvial deposits; 3 – water-bearing complex of Lower-middle-Pliocene, Upper-Miocene deposits of Pavlodar series. 4 – waterproof rocks of Lower-middle-Miocene of Kalkaman series. Lithologic composition of rocks: 5 – soil-vegetable stratum; 6 – sand; 7 – clay sand; 8 – loam sand; 9 – loam; 10 – clay; 11 – groundwater table with free surface, m; 12 – the area of groundwater mercury contamination. 13 – hydro-geological borehole. Numerals: on top – borehole number (name); at the bottom – borehole depth, m; on the right: in numerator – mercury concentration in water – mg/l; in denominator – sampling date. Hatched area – sampling interval. Red colored boreholes – the ones where mercury concentrations are more than MPC (0.0005 mg/l). By the arrow – occurrence depth of piezometric level, m; in brackets – a year of observation.

Figure 25. Hydro-geological cross section on the line IV-IV

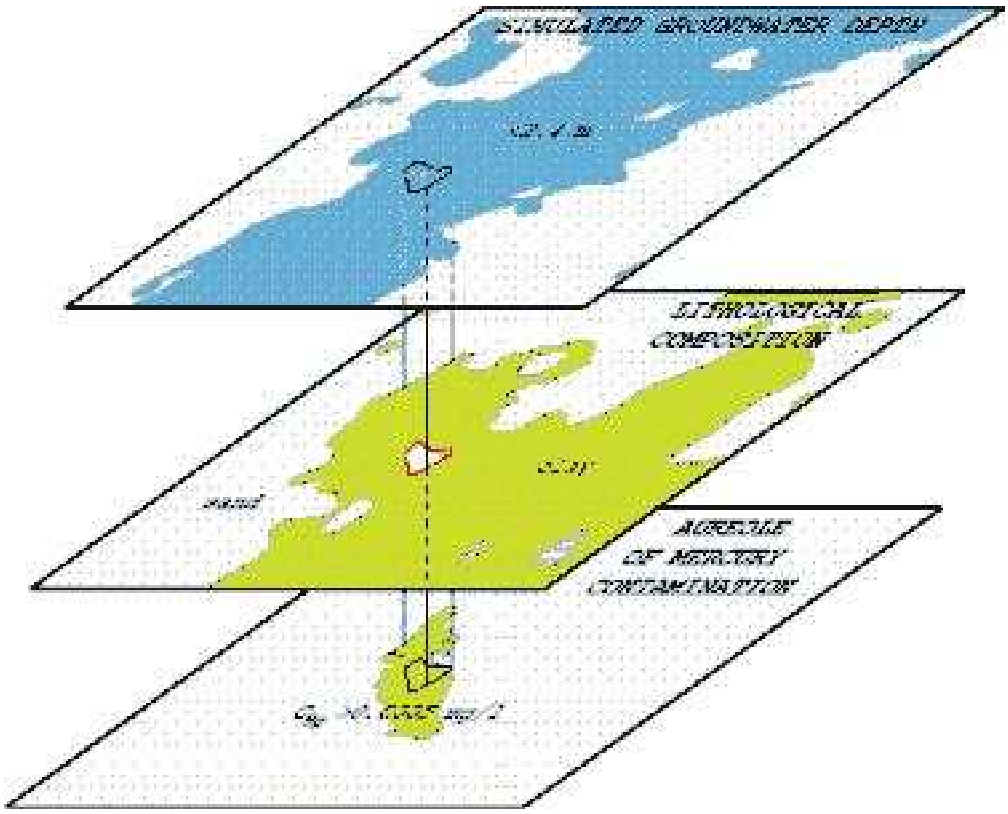


Figure 26. Zoning of the area of investigation according to groundwater depth of occurrence, lithologic structure and mercury concentration in groundwater

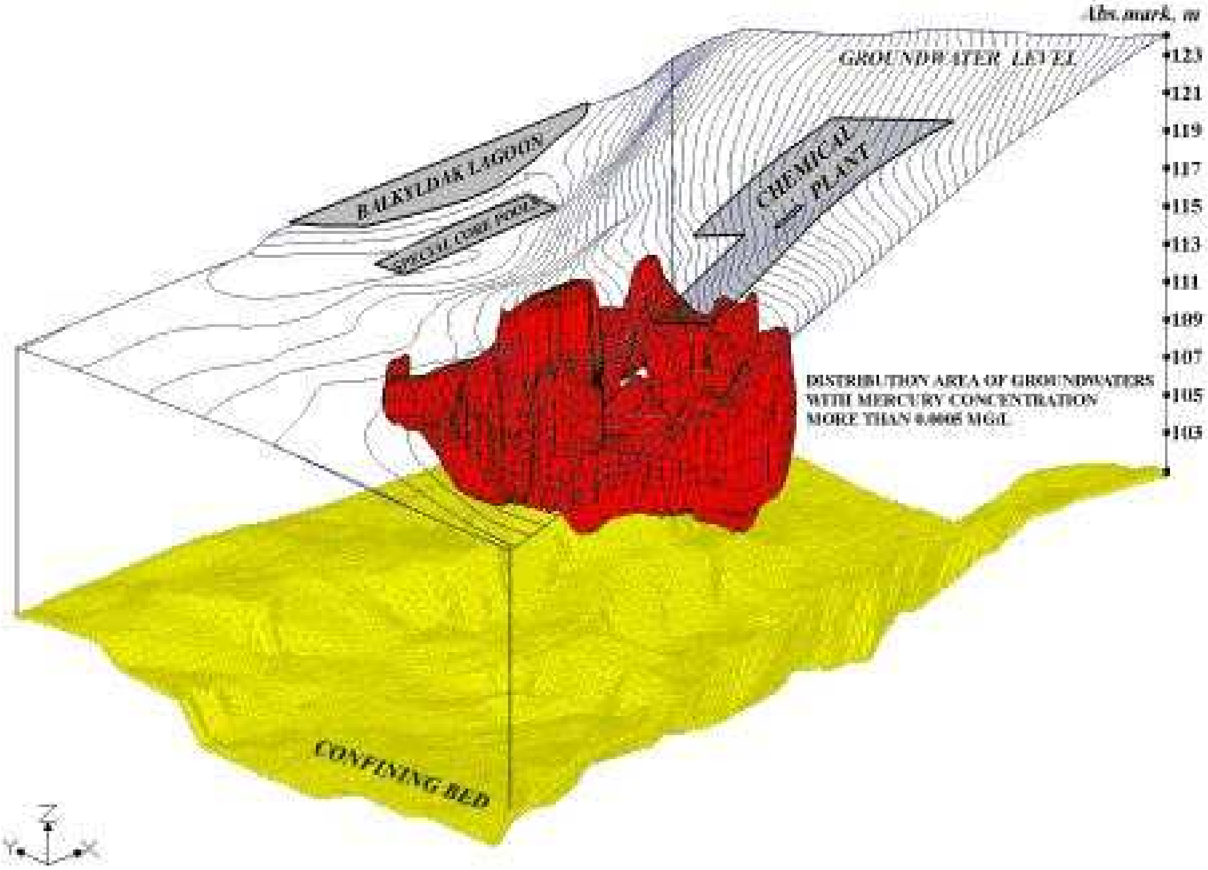


Figure 27. 3D diagram of groundwater mercury contamination spread based on the results of modeling of 2006.

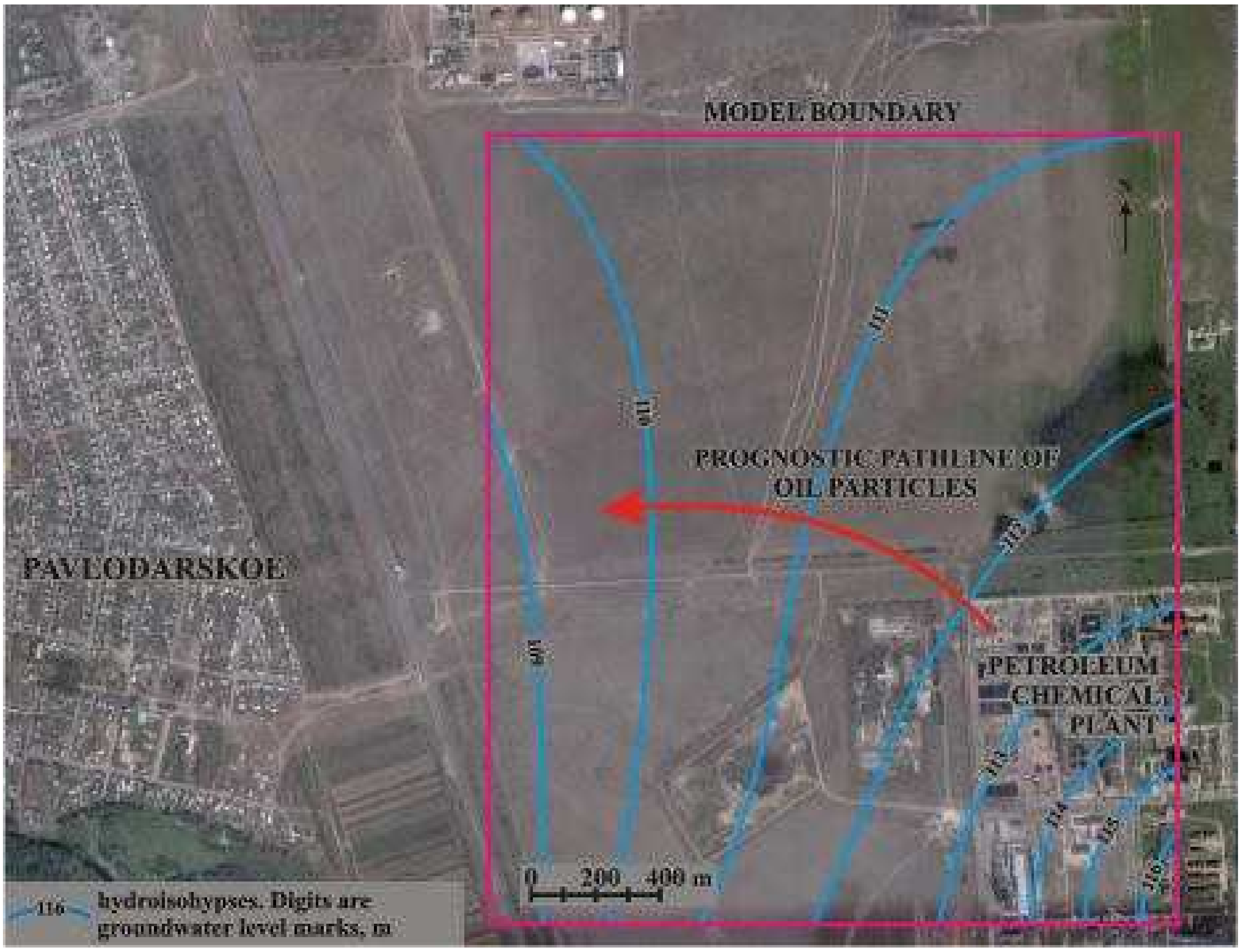


Figure 28. Prognosis trajectory of oil products movement with groundwater (according to results of the modelin