DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2002/27

Groundwater protection and remediation in Donbas region, Ukraine

DANCEE-supported Ukrainian/Danish environmental co-operation project

Dr. Edmund Gosk (editor),
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MINISTRY OF THE ENVIRONMENT

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GEUS

EXECUTIVE SUMMARY

The Geological Survey of Denmark and Greenland (***GEUS***), assisted by Ministry of Environment and Natural Resources of Ukraine (***MoENRU***) and Institute of Geological Sciences of National Academy of Sciences of Ukraine (***IGS NAS***), have prepared and submitted to the Danish Co-operation for Environment in Eastern Europe (***DANCEE***) a Project Document entitled: "Groundwater Protection and Remediation in Donbas Region, Ukraine". Financial support for the project was granted in May 1998. The project has finished in December 2001.

Central part of Donbas Region, where the project activities took place, covers the biggest industrial agglomeration in Ukraine: Donetsk-Makeevka-Horlivka-Yenakievo (***D-M-H-Y***). It is one of the oldest coal mining regions in the world. Majority of mines is 50-60 years old and some of them have been established more than 100 years ago. Metallurgical, chemical and transport industries are well represented in this area and the level of agricultural activities is relatively high.

Environment protection and environmental management at a local level is quite a new experience in Donbas region. However, the Donetsk Oblast State Administration (***DOSA***) actively supported the Ukrainian / Danish project believing that the regional approach to mine closure problem will give valuable results, which can be utilised in the administrative practice. Beside the financial, formal and administrative support the Donetsk Oblast environmental authorities of ***MoENRU***'s division provided essential technical and professional input.

The co-operation among project participants: ***IGS NAS, Geoinform*** and ***GEUS***, and the local consultants were smooth and efficient.

The major outputs of the project are as follows:

- Comprehensive sampling of soils, surface water, groundwater and snow is carried out,
- 3D regional geological and hydrogeological models for the whole mine coal district are developed,
- Prognoses for recovery of groundwater level after numerous coal mine closures are prepared,
- A map of Hot spots in the district is made,
- Database for environmental data is established and transferred for DOSA and local authorities of MoENRU; the structure of the database is ready but considerable amount of data still need to be evaluated and transferred into digital form,
- New essential knowledge about hydrogeology, geochemistry and geodynamical conditions in the district are obtained,
- Vulnerability map is prepared,
- New factors related to recovery of groundwater levels after mine closures such as explosive gas migration and local seismic activity are addressed,
- The ability of IGS NAS, IGEPD and others subcontractors to tackle environmental investigations and processing of information is significantly increased.

The most important results of the project are already widely distributed via *Information Bulletins* issued in Russian. In these bulletins, several regional prognoses for consequences of mine closures are discussed. This work is quite unique in Ukraine and the project results are frequently used in administrative, scientific and political context. The thesis put forward by the project stating that situation in Donbass may turn out to be worse than the situation in Chernobyl area is being seriously discussed at the highest level. After a conference in Donbass in November 2001, a letter stating the gravity of the situation was send to the President, Premier and the head of the Security Council by a member of the Ukrainian Parliament. The facts presented in this letter were based on the results of the project.

In the past the former Ministry of Coal Industry contributed significantly to the budget of the Donetsk Oblast through payment for coal production, dumping of coal mine waste and other waste at the local waste disposal sites. While this source of financing is drying out the problem with contamination of environment by the waste disposal site and ground water level uprising due to coal mine closure becomes more and more actual. Environmental authorities of the district are interested in preventing groundwater resources from contamination in order to secure safe supply of drinking water for the population of the district and in groundwater level uprising prognosis for protective measurements substantiation. The results of the project are important for the future management.

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LIST OF ABBREVIATIONS

DANCEE - Danish Co-operation for Environment in Eastern Europe (DEPA division)

DEPA - Danish Environmental Protection Agency

D-M-H-Y - Donetsk-Makeevka-Horlivka-Yenakievo region

DOEA - Donetsk Oblast Environmental Authority of MoENRU

DOSA - Donetsk Oblast State Administration (administration of the Ukrainian President)

GEOINFORM - State Geological Information Fund of MoENRU

GEUS - the Geological Survey of Denmark and Greenland

IGS NAS - Institute of Geological Sciences of Ukraine, National Academy of Science

IGEPG - Institute of Geo-ecological Problems of Donbas from Donetsk

LUHANSKHIPROSHAHT - regional institute for design of coal mines from Luhansk

MoENRU - Ministry of Environment and Natural Resources of Ukraine

UkerUgleRestrukturyzacja - Ukrainian state company created for solution of problems connected to coal mine closure

USGEI - Ukrainian State Geological Exploration Institute of MoENRU

USGEI DD - Ukrainian State Geological Exploration Institute of MoENRU, Dnepropetrovsk Department

VSEGINGEO - the All Russian Institute of Hydrogeology and Engineering Geology

1. Introduction

The report summarizes work done within the DANCEE-financed project: ***Groundwater Protection and Remediation in Donbas Region, Ukraine.***

The main objective of the Project was an assessment of ecological-geological situation in the central part of Donbas – mainly with regard to groundwater situation. A specific target – identified lately in the project – was assessment of the regional influence of coal mine closure and groundwater level rise.

The project received considerable support from the MoENRU and from the environmental authorities of the Donetsk Oblast.

Following institutions / companies participated in the project: the **Geological Survey of Denmark and Greenland (GEUS)**, **Institute of Geological Sciences of Ukraine, National Academy of Science (IGS NAS)**, the **State Geological Information Fund (Geoinform)** belonging to the **Ministry of Environment and Natural Resources (MoENRU)**, as partners and **Institute of Geo-ecological Problems of Donbas (IGEPD)** from Donetsk together with **ECOTE Ltd**. from Kharkov as subcontractors. Following Ukrainian participants of the project provided major contribution: ***Olga Volyk, Svetlana Azarova, Valeriy Slyadnev, Igor Melnik and Nataliya Yurkova***.

GEUS was responsible for project management and ***Dr. Edmund Gosk*** functioned as Project Manager. ***Dr. Sc. Yevgienij A. Yakovlev*** functioned as scientific leader and ***Prof. Leonid S. Galitskyi*** as co-ordinator of the Ukrainian input. Quality assurance was provided by ***Alex Sonnenborg*** – the Head of the Hydrology Department of GEUS.

A Steering Committee, established for the project, provided an active support for various project activities. The Committee consisted of ***Academician Peter Gozhyk*** - Director of the IGS NAS, ***Dr. Vitaliy Potapov*** - Head of Ecological Policy Department of the MoENRU, ***Dr. Sviatoslav Kurulenko*** - Head of Ecological Safety State Department for Donetsk Oblast, ***Mr. Leonid Mironov*** - Chief Engineer for LUHANSKHIPROSHAHT and ***Dr. Edmund Gosk*** - Senior Adviser from GEUS, Project Manager.

Project started in September 1999 and finished during a DOSA in Donetsk and Seminar held at the premises of the Donetsk county environmental authorities in IGS NAS in November 2001 with presentation of results.

The activities carried out within the project were primarily confined to the central part of Donbas, where the environmental conditions are most disturbed by coal mining and mine closure.

Following task reports were prepared (Russian and English versions):

- *Appendix 1: Data Inventory, Completion report for Task 1,November 2000,*
- *Appendix 2: Hot Spots Mapping, Completion report for Task 2,November 2000,*
- *Appendix 3: Additional Data, Completion report for Task 3, November 2000,*
- *Appendix 4: Characterization and assessment of cartographic and factual data prepared for Hydrogeological model of Donetsk-Makeevka and Central Mining - Industrial Region, Completion report for Task 5 November 2000,*

- *Appendix 5: The action on closing coal mines, geologo-environmental and social consequences, VSEGINGEO, Moscow 2000,*
- *Appendix 6: Present Environmental Problems of Groundwater Remediation under mass closure of Mines in Some Districts of Donbas, Bulletin 1, Kyiv, Donetsk, Luhansk and Copenhagen, 2000,*
- *Appendix 7: Soil Analyses, Donbas Region, Ukraine; Copenhagen, Kyiv, Donetsk, Luhansk, 2002.*

Appendix 7 was prepared in an English version only.

An extended version of a News Bulletin (in Russian only) was prepared and widely distributed to the relevant authorities and industries in the Donbas region. The title of this bulletin was: *INFORMATION BULLETIN No 2: Preliminary assessment of regional influence of mine closure within Donetsk-Makeevka-Horlivka-Yenakievo industrial agglomeration on activation of flooding processes, deterioration of engineering-geological conditions and increase of groundwater vulnerability, Kiev-Donetsk-Copenhagen, 2001.*

Chapters 3.2 is primarily based on material provided by Mr. Vadim Sinakh from the USGEI DD.

The final editing of this report and preparation of *Appendixes 1, 2, 3, 4* and *6* was done by Dr. Sc. Ye. Yakovlev, Prof. L. Galetskiy and Dr. E. Gosk.

Appendix 5 was prepared by the VSEGINGEO.

Appendix 7 dealing with soil samples was prepared by Ms. Agnete Steenfelt, Senior Researcher from GEUS assisted by Prof. Galetskiy, Dr. Sc. Yakovlev and Mr. Dudzik.

2. Project Context

The project can be regarded as a pilot project dealing with problems typical for an industrialized district in the Central Donbas, Ukraine. The investigated area covering the Donetsk-Makeevka-Horlivka-Yenakievo region, see Fig. 1, is characterized by high concentration of industry and agriculture and is suffering from ecological problems connected with coal mining activities. That is why the local authorities are probably more interested in environmental aspects than it is the case in the neighboring districts. It can be mentioned, that the Donetsk Oblast State Administration (DOSA) has a special “Environmental Police” which quite efficient enforces the environmental legislation in the district. A co-operation program with the Ukrainian Academy of Science, running until the year 2020, has been recently signed by the administration.

In spite of high degree of industrialization, the averaged contaminant load in the district is not alarmingly high. It is on the same level as load measured in technogenic over loaded regions in Ukraine. The bigger towns with the associated industries appear as anomalies in the soil and groundwater contamination picture.

Groundwater resources of the district are an attractive target for expansion of water supply systems as ecological safe source. However, our investigations have discovered quite new and complex problem connected to recovery of groundwater table after mine closures. There will be severe water quality problems, explosive gas migration problem and engineering problems within the mining towns and settlements affected by mine closure. These discoveries are quite alarming.

The thesis put forward by the Project stating that:: ***Long term problems of Donbas are much more severe than long term problems of Tjernobyl*** is now being quoted and supported by Ukrainian politicians. Project participants took part in several administrative and political meetings and seminars where future prospects for the region were discussed. It is horrifying to realize, that Donbas region may become a severe economic and social liability after many years when this region was an economical backbone of Ukraine.

There is a pronounced interest from the Ukrainian side in continuation of the project; there are two aspects which seem to have particular interest: regional assessment of consequences of mine closure and site specific evaluation for some particularly dangerous locations.

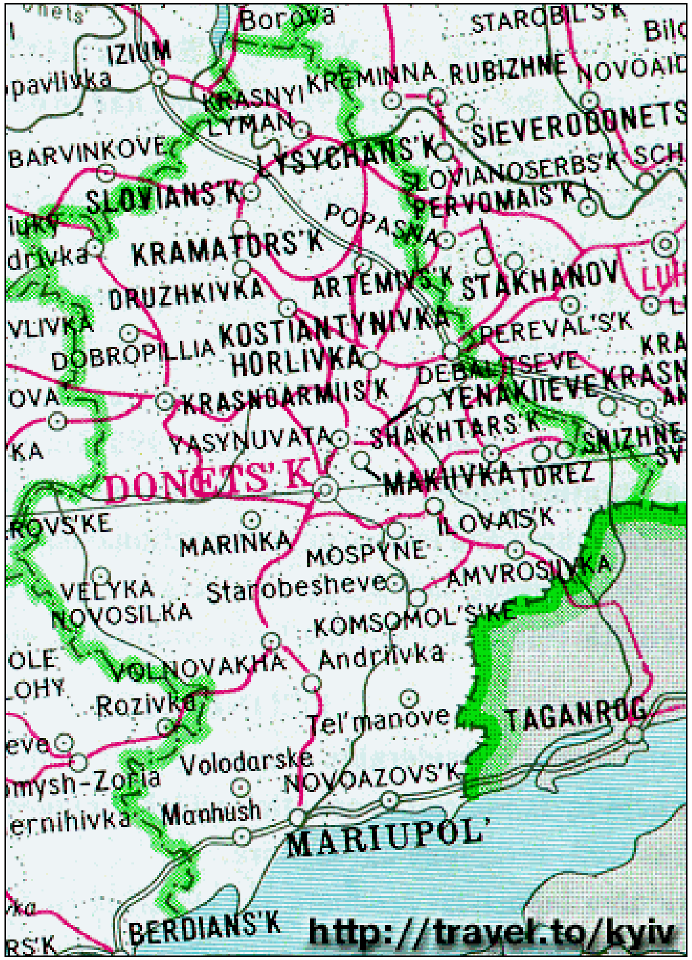


Fig. 1: Schematic map of Ukraine and administrative map of Donetsk Oblast

3. Project Outputs

The major outputs of the Project are as follows:

- An assessment of the connection between groundwater quality changes and technogenic loads,
- Substantiation of the autonomous character of groundwater level recovery after closure of numerous coal mines,
- 3D geological model for the whole coal mine district,
- Calibrated 3D flow model for the whole district,
- New knowledge about the hydrogeology, geochemistry and geo-dynamical conditions in the district,
- Database for environmental data,
- Vulnerability map for the productive aquifers,
- Significantly increased ability of IGS NAS, IGEPD and others subcontractors to tackle environmental investigations and to process environmental information,
- A set of general and specific recommendations regarding environmental management,
- Development of co-operation with DOSA for implementation of the Project results.

The connection between groundwater quality changes and technogenic load is very clear when the mineralization changes map, Fig. 20, is considered. Mining activities have caused a dramatic change of groundwater salinity within the whole mining region, frequently far away from the mining galleries.

The principle of autonomous character of groundwater level recovery was elucidated using the hydrogeological model developed for the investigated area. The message about obeying physical lows valid for hydrogeological systems was communicated strongly during the whole duration of the Project.

3D geological and hydrogeological models for the district were constructed and calibrated which allowed us to calculate the behavior of groundwater level during various mine closure scenarios. The model is a basis for prediction of the pathways of hypothetical and real contaminants within the aquifer system. It is of great importance to further develop these models for use in environmental administration. An evaluation of risks associated with various scenarios of coal mine closure and influence of different factors on environmental conditions are some of the tasks which can be solved using these models.

New knowledge about hydrogeology, hydrochemistry and geo-dynamical conditions is obtained through: 1) analysis of the existing data done together with preparation of the geological and hydrogeological model for the area, 2) new sampling of soils, snow and water and 3) an analysis of the data dealing with the coal mine closure process. New information is collected about some of the existing contaminated sites. Serious problems, which are expected to occur as a result of water table recovery during mine closure, are discussed and evaluated.

Database for environmental data in coal mine closure zone of influence is established first time for the district. The Database is designed to contain practically all information of environmental relevance. Both static information about geology and infrastructure in the area and dynamic information about time series for water levels in groundwater wells and groundwater chemistry is included in the Database. Presently only limited amount of data is incorporated in the Database and significant effort is needed to transform a large amount of existing information into digital form.

Vulnerability map for the complex of Quaternary and Carboniferous aquifers is prepared. Three parameters / conditions were considered during preparation of vulnerability map: 1) travel time of a contaminant through the unsaturated zone 2) specific tectonic density and 3) specific density of river system.

Increased expertise of IGS NAS, IGEPD and specialists from MoENRU – as a result of the project - is particularly evident within the field of computer modeling of environmental cases and within the field of field investigations of soil, snow and aquifer contamination. Delivery of computer software and hardware, purchase of field equipment for groundwater investigations and practical co-operation with the participants of the project contributed to this result.

Recommendations regarding environmental management, given to the local authorities in the Donbas region are already being implemented: the concept of a “rational”, rather than “physical” mine closure becomes important.

Good working relations built on trust and mutual respect have been established with the Donetsk Oblast State Administration (DOSA). Future activities within the field covered by the Project will find a strong support from DOSA.

In the following, all of the outputs corresponding to the 11 tasks (Work Plan, Fig. 2), are described in headings 3.1 to 3.9. Some of the tasks provided input for several headings, while some of the headings may include input from several tasks.

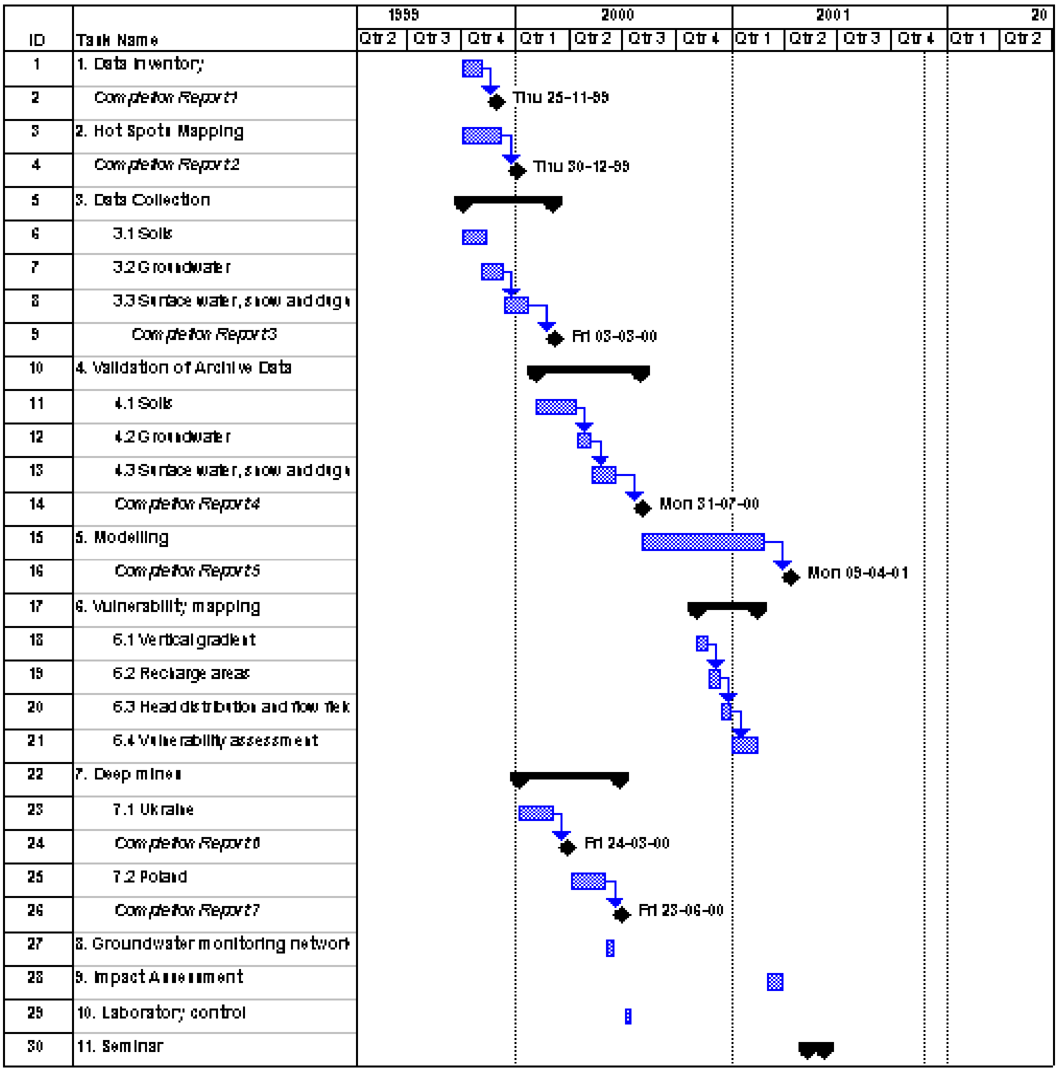


Fig. 2: Time schedule for the Donbas Project

3.1 Geology, hydrogeology and environmental set-up

An assessment and remediation of groundwater contamination in Donbas coal mine region, within the artificially expanded zone of active water exchange, requires good knowledge of: hydrogeology, geology, lithological composition of rocks, contamination sources and groundwater and surface water chemistry. Project activities resulted in substantial increase of our knowledge about all these subjects, first of all about geomechanical and geochemical consequences of groundwater level recovery in mine districts.

3.1.1 General description of the area

The Donetsk-Makeevka-Horlivka-Yenakievo (D-M-H-Y) and the Stakhaniv area, situated in the central part of Donbas, belong to the most industrialized districts in the region. An administrative map showing the extent of the investigated area is shown on Fig. 3. Hydrogeological map for this area and Geological cross section (SW-NE cut) are shown as Figs. 4 and 5 respectively. The investigated area is about 8,600 km^2 and the population is about 1.4 mill. About 90 % of people live in towns and urbanized settlements. In the Donbas region number of people working in the coal industry is the largest in the Ukraine.

Major part of the territory belongs to the Seversky Donets river Basin. The maximum elevations of the earth’s surface are in the north and north-east (245-250 masl) while in the south the surface elevation is close to 150 masl. The minimum elevation, found in the shore zone of the Kalmius River, was determined to about 140 masl.

The average annual precipitation is about 420-450 mm and is about 30-35 % lower than the potential evaporation. Most of the precipitation falls during autumn and winter. The territory is hilly, actively eroded and well drained. The top soil consists of loess and loams - which makes the groundwater recharge difficult. In addition, the active mine drainage is an important factor for groundwater regime.

Detailed exploratory investigations on a scale of 1:50,000 in particular areas of the coal bearing part of Donbas, including the investigated area, have been carried out in 1930s. A complex geological survey of the Central Donbas territory was primarily made at the scale 1:50,000 and 1:25,000 from 1950-ties until1980-ties.

In the period 1960 -1980 an exploration of groundwater resources for towns and villages in Donbas was made. In the end of 1980s and early 1990s a detailed exploration of the Donbas well fields was done and water supply system for settlements in the region was established. For the first time the influence of mine drainage was taken into consideration.

Since the mid-1980s, due to a sharp deterioration of water quality in the exploited aquifers in the Central and Eastern industrialized parts of Donbas, the existing regional water monitoring system was extended to provide a better control of groundwater resources.

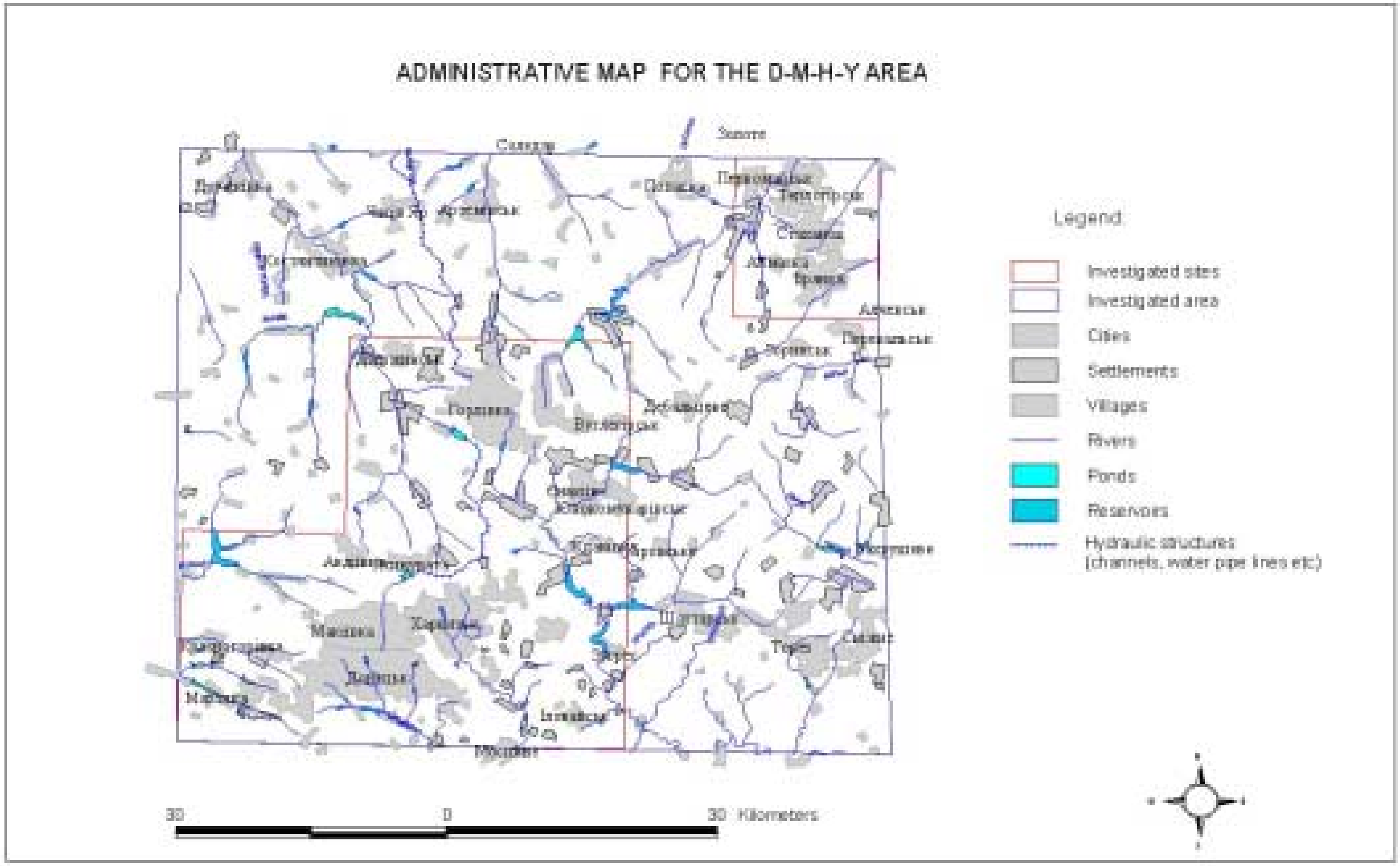


Fig. 3: Administrative map for the D-M-H-Y region

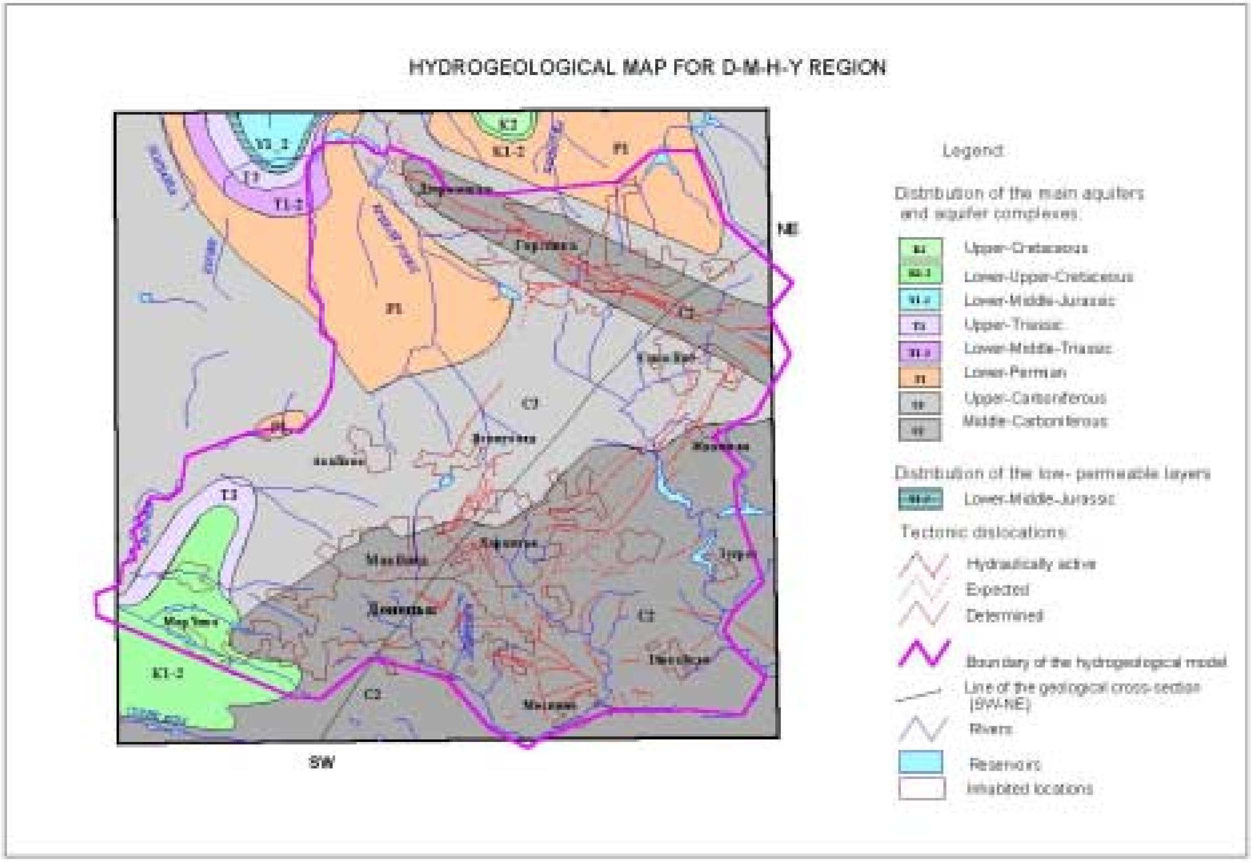


Fig. 4: Hydrogeological map for the D-M-H-Y region; the line of cross-section is indicated

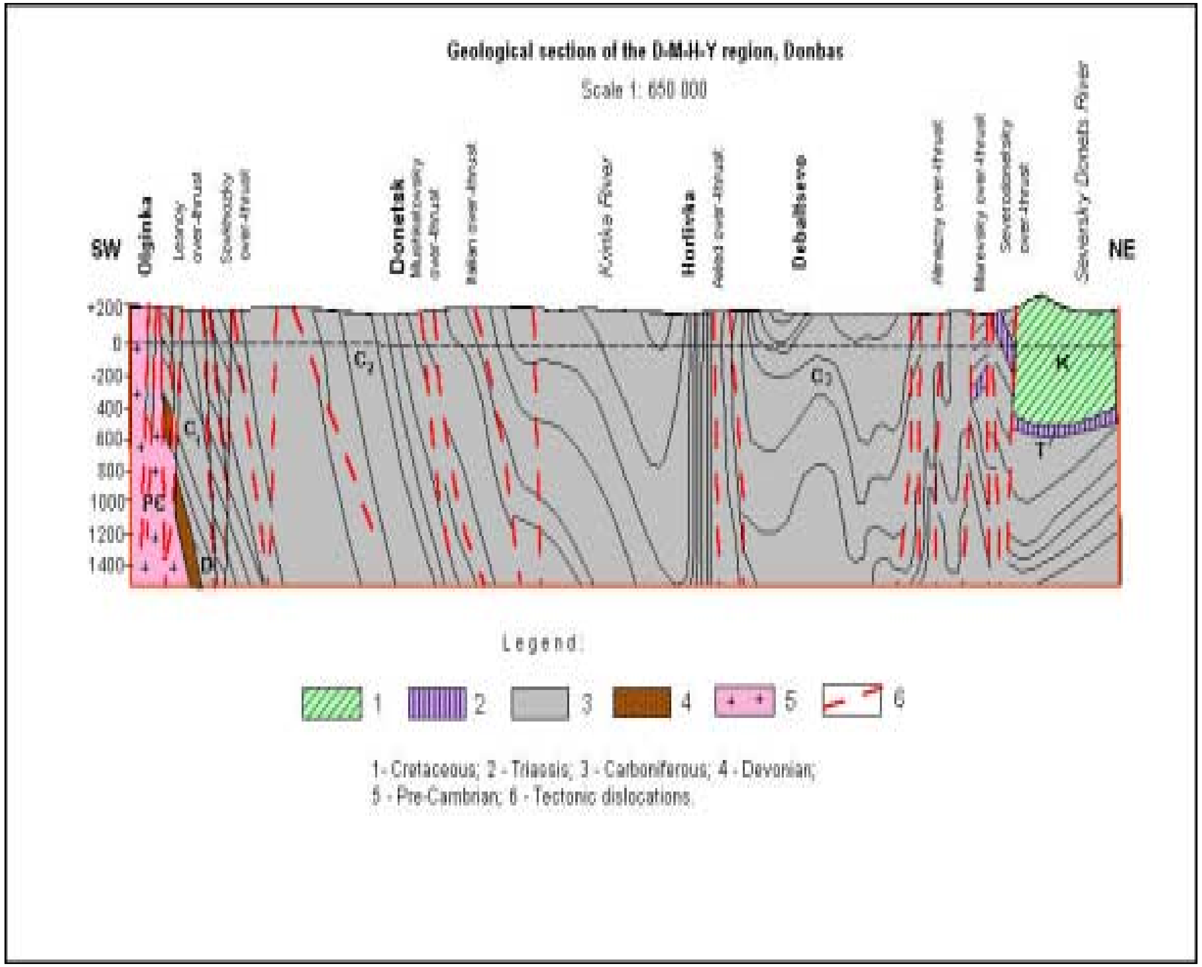


Fig. 5: Geological cross-section for the D-M-H-Y region

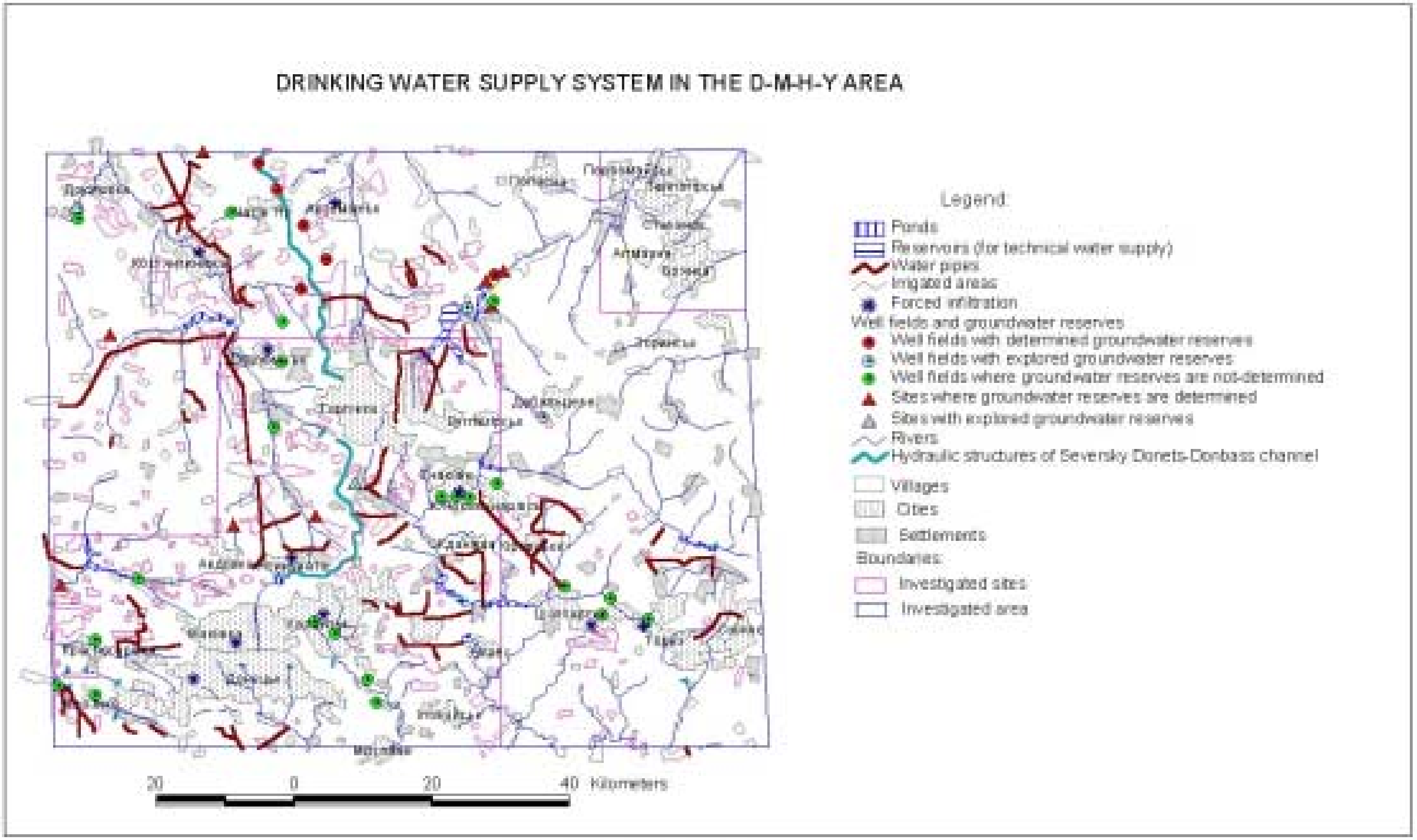


Fig. 6: Drinking water supply system in the D-M-H-Y region

Seversky Donets River (the large right tributary of the Don River) crosses the District from west to east. The river embraces the District in the northern, sparsely populated part covered by arable land, while the southern part is heavily industrialized.

Hydrogeologically, the territory belongs to the central part of the Donbas Hydrogeological Region consisting of Quaternary and Carboniferous sequence of a few relatively isolated aquifers. Within the investigated area groundwater surface is heavily influenced by the operating mines. Lowering of water table down to 1,000 m below ground surface is quite common in the area.

The upper, Quaternary aquifer is frequently drained by rivers while the underlying Carboniferous sediments containing coal mines are characterized by large depressions reaching up to 1,000 m. Outside of the cone of depression created by the coal mines, the deeper, Carboniferous groundwater is drained to the local river system valleys as well. The upper aquifers are drained mainly by the Mius, Kalmius and Seversky Donets Rivers. During the recent decades, due to intensive mine drainage of the Carboniferous aquifers and dumping of this water to rivers and ponds, the surface water system recharges large quantities of water to the upper aquifer. Taking into account that recovery of water table within the mined area results in reduction of the unsaturated zone and storage capability of underground we will witness more frequent and more severe flooding in the future.

The unconfined Quaternary waters are widely used for drinking and technical purposes and for irrigation. The sequence of Carboniferous aquifers is utilized as a local source of drinking water supply in towns and larger settlements. The well fields existing in the area are shown on Fig. 6.

Groundwater in the area is practically unprotected from contaminants penetrating from the surface. This is confirmed by continuous deterioration of water quality during the last 30 years.

3.1.2 Field and laboratory work

The summary of field and laboratory investigations is presented in Table 1. Three types of field data were collected: data about soil, data about groundwater and data about snow. While soil- and groundwater data provide information about degree of contamination, the snow-data gives an information about the actual load and seasonal fluctuations of air-born contamination on the ground surface.

The field data and laboratory works are reported in detail in Appendixes 1, 2, 3 and 7.

To get a more comprehensive picture of contaminant load it would be necessary to investigate contribution of the large dump sites containing chemical-, industrial-, domestic- and mining waste. Settling ponds for mine water and radioactivity contaminated coal mine sludge should be taken into account as well. This activity is planned for selected sites during Phase 2 of this project.

Table 1: Field investigation, summary

Area investigated	Input	Executor and period of investigation	Results
The D-M-H-Y coal mining region	Geochemical survey of soils, groundwater and snow	IGEPD 2000-2001	Eco-geochemical zoning, inter-calibration with the German and the Finnish laboratories
Stakhaniv coal mining region: the active mine closure sites, flooding of the dump sites	Field work and evaluation of geochemical and hydrogeological conditions	ECOTE 2000-2001	Eco-geochemical survey with cross-sections for four profiles about 20-25 km long
D-M-H-Y and Stakhaniv coal mining regions: mines, well fields, hot spots, technogenic load assessments	Compilation and regional analysis of data, complex assessment of eco-geo-chemical situation	Geoinform and IGS NAS 1999-2001	Assessment of groundwater vulnerability, prognosis of seismic engineering-geological situation and changes of explosive gas migration

3.2 Hydrogeological Model of the D-M-H-Y Region

The Hydrogeological Model for Donbas is described in more detail in the Task Report which constitutes *Appendix 4* to this report.

The Donetsk coal basin (Donbas) is one of the most industrially developed regions in the Ukraine and in the world. The coal has been mined for about 200 years. The most intensive exploitation was carried out during the last 50 years. The depth of the most mines achieved 800 – 1,000m. Intensive mining works, water filled mines, filtration from numerous artificial reservoirs (Dnieper-Donbas channel, storage ponds, waste accumulators, etc.) land development and leakage on the territory of industrial and urban agglomerations caused considerable changes in the water balance of the region, first of all of groundwater level and hydrogeochemical regime.

That is why the main purpose of this work was to create a flow model of the D-M-H-Y industrial region and give a forecast evaluation of the hydrogeological situation in the mines flooding conditions. The model was developed with the software MIF, designed in the Hydrogeological Processes Simulation Laboratory, USGEI DD.

The geological structure of the basin is represented by Paleozoic and Neozoic deposits which form Donetsk fold system. Major Paleozoic fold elements are complicated by thick net of tectonic elements, most of them are reflected in the structure of the upper layers.

The aquifer system consists of inter-layered aquifers and confined layers. Sandstone and coal are the main aquifers while shell and argillite layers are confining beds. The slope of beds varies from slightly inclined to nearly vertical. Hydraulic conductivity in natural conditions is decreasing with depth. Low-permeable rocks are anisotropic. The essential parts of the rock massifs within coal mine districts are disrupted by mining works. This process results in destruction of aquiclude layers and in increase of the total permeability within the upper part of geological section.

One of the major factors determining the behavior of groundwater in mining conditions are the so called pillars established at the boundary lines between neighboring mines. Very often these boundaries coincides with major tectonic structures (faults, over-thrusts etc.). The thickness of the pillars (20-100 m) was established in accordance with geo-mechanical conditions valid for dry situation. Full or partial flooding of mines drastically diminishes the protective properties of the pillars.

The mines are usually hydraulically linked. The linkage is frequently provided by abandoned galleries or fissured zones embracing tectonic structures, which typically are characterized by high hydraulic conductivity. Location of numerous old mines closed in previous years is very often unknown. Regional recovery of groundwater level results in a chain of geo-mechanical, local seismic, geo-chemical and others processes. That is why the hydrogeological model – predicting the rate and distribution of water level recovery - is the base for the effective forecast and adoption of protective measures.

3.2.1 Model set-up

The total area of the modelled territory is about 3,500km^2. The model outer boundary is restricted by numerous rivers, streams, watersheds and reservoirs providing discharge- or recharge- type of boundary conditions.

The investigated area is vertically approximated by 5 model layers. The discretization is based on the fact that hydraulic conductivity decreases with depth. Model layers are attributed to the elevations of the main mining horizons. The first layer has a thickness up to 100m and represents regionally fractured grounds with relatively intensive vertical water flow. The other 4 model layers are characterized by thickness of 200-300m and allow us more precisely reproduce vertical heterogeneity and water inflows to mine workings in accordance with their spatial distribution in various rock complexes.

The model grid is regular with the grid spacing of 2 km (Fig. 7). X axis is oriented along the dominant direction of the Central Region tectonic fractures. This direction coincides with the main anisotropy axis.

The following features have been introduced into the model:

- Hydraulic conductivity and specific yield (with specific values to account for watersheds, river valleys and fractured zones),
- Anisotropy,
- Infiltration and technogenic leakages,

- Groundwater / surface water interaction,
- Boundary recharge/discharge,
- Water inflow to mine workings,
- Wetting and re-wetting,
- Well fields,
- Variation of parameters with time as a result of intensive mining works and regional rock massif deformation.

Pillars and linkages between mine fields have not been taken into consideration because of regional character of the model.

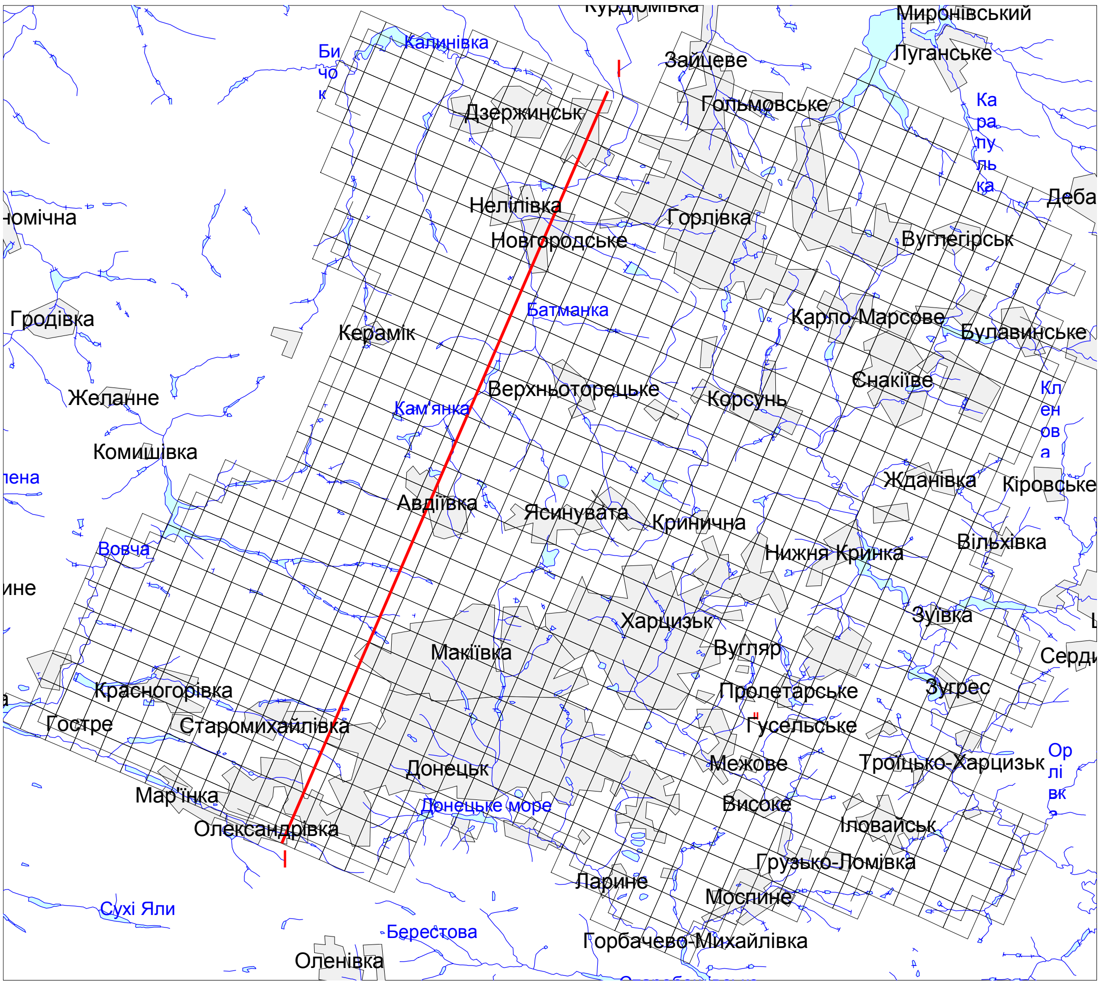


Fig. 7: Model grid; cross-section 1-1 is shown in red

Parameter estimation was performed to test the model sensitivity to changes of parameters and boundary conditions within predefined limits. The estimation testifies that the conceptual model takes into account the main hydrogeological features of the investigated territory. The model is regional and reflects generalized processes and factors, which may lead to considerable difference between model results and observed data on the local sites with specific hydrogeological conditions. More correct results can be observed on the regional flow and structural-geological boundaries.

3.2.2 Steady state solution

Groundwater elevations in the fractured zone for 1967 were taken as control data on the beginning stage of mine work for the steady state problem solution. Total inflow into mines, groundwater elevations from 1991 on the territory of the Central Region and in the vicinity of well fields were taken as control data for the transient problem solution.

By results of steady problem solution for 1944 groundwater elevations in the fractured zone were distributed in the range of 80 - 280m. In profile the elevations were decreasing from top to bottom on the watersheds and from bottom to top in the river valleys (Fig. 8).

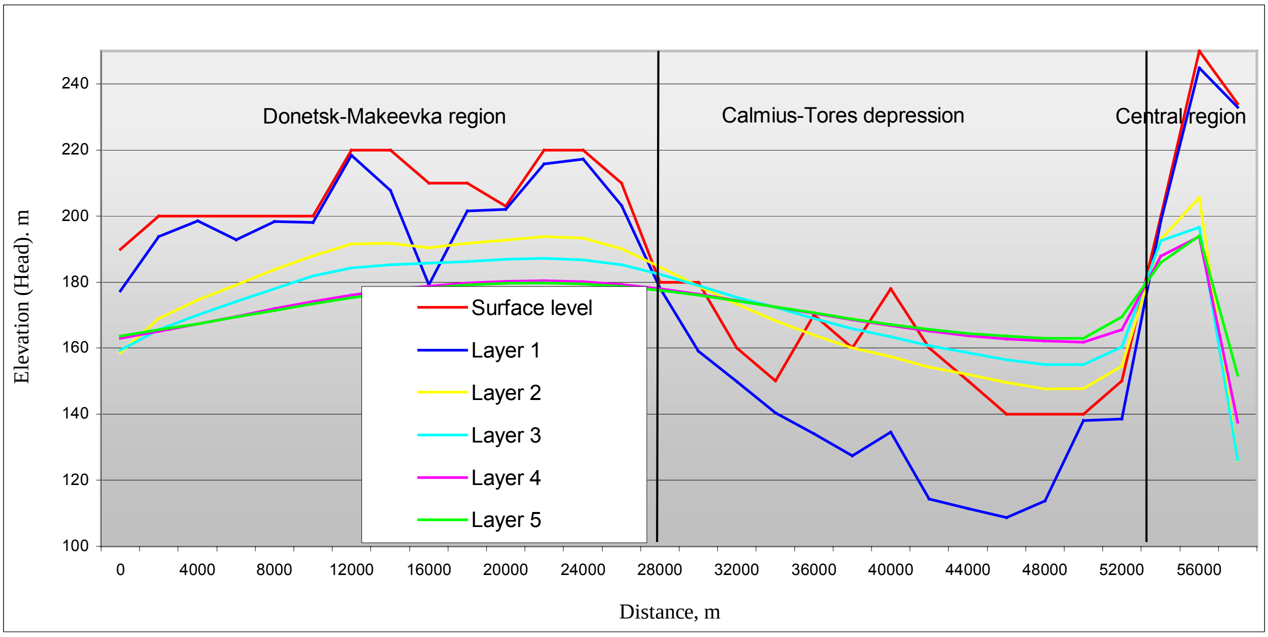


Fig. 8: Groundwater heads in 1944 along the cross-section 1-1

The steady state solution for 1944 was accepted as the initial conditions for the transient problem. The whole time interval for the transient problem (1945-2000) was divided into 5-10 years stress periods. Every stress period is characterized by specific boundary conditions, elevations of mining horizons, mining fields, hydraulic conductivity, groundwater withdrawal, anisotropy coefficients, fluvial conductivity. Corresponding grid arrays were prepared for each parameter varying in time.

3.2.3 Transient solution

For the transient problem the horizontal hydraulic conductivities within the limits of the mining fields were increased 2-5 times compared to the natural conditions. Vertical hydraulic conductivities were increased 2-30 times. Conductivity of the sedimentary rocks within the territory influenced by mining activities within river valleys was increased 10 times. The infiltration within the limits of the mining fields was also increased. With above mentioned parameters the calculated groundwater levels were close to the control data. Water inflows to mines was overestimated 1.3-1.7 times because mining fields were set on the model with their maximal working areas instead of using stepwise input together with mines deepening.

By simulation results groundwater level in the fractured zone decreased to 120-190m. The rocks were fully drained in the limits of some mining fields in the Central and Donetsk-Makeevka regions. On the other territory groundwater levels were close to elevations in natural conditions (Fig. 9). Groundwater drawdowns in the fractured zone during 1944-2000 are related mainly to the mining fields (Fig. 10) Sites with depth of the groundwater occurrence less than 5 m are related mainly to watersheds (Fig. 11).

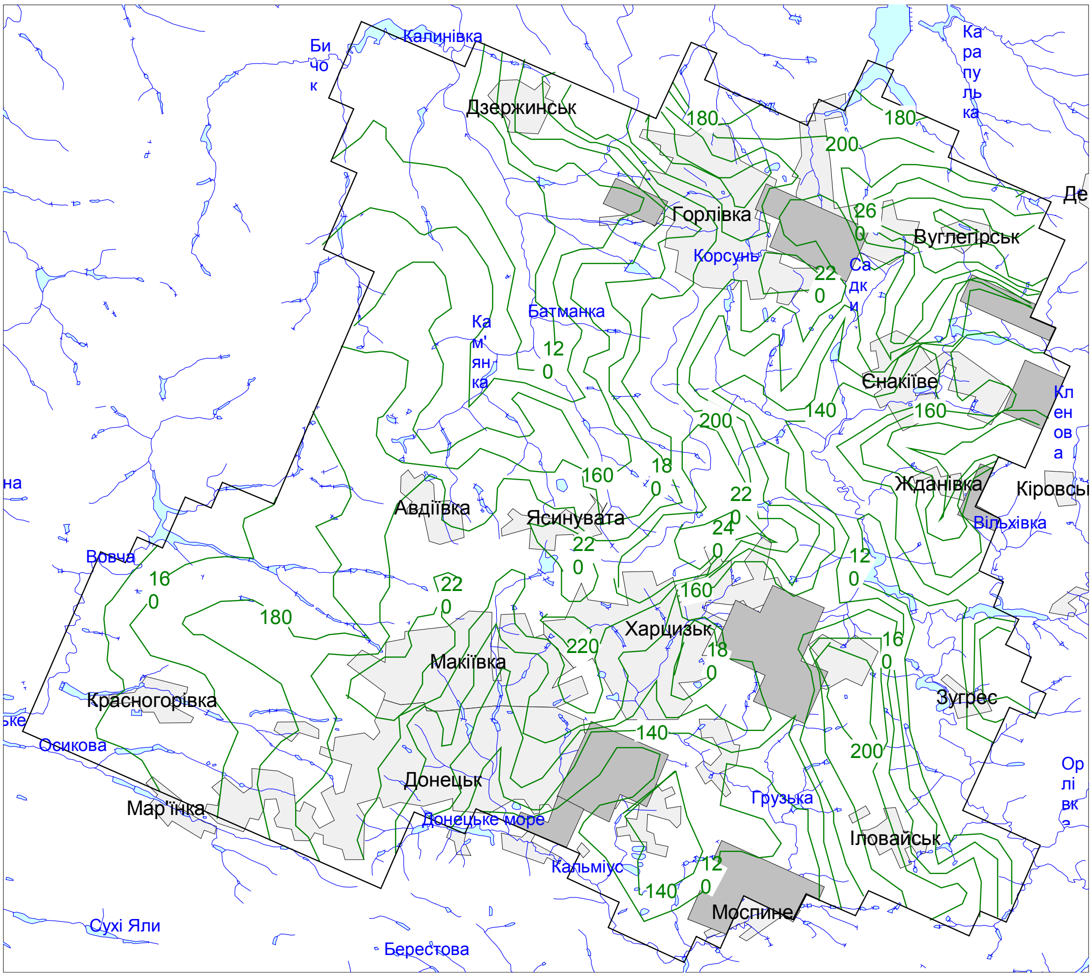
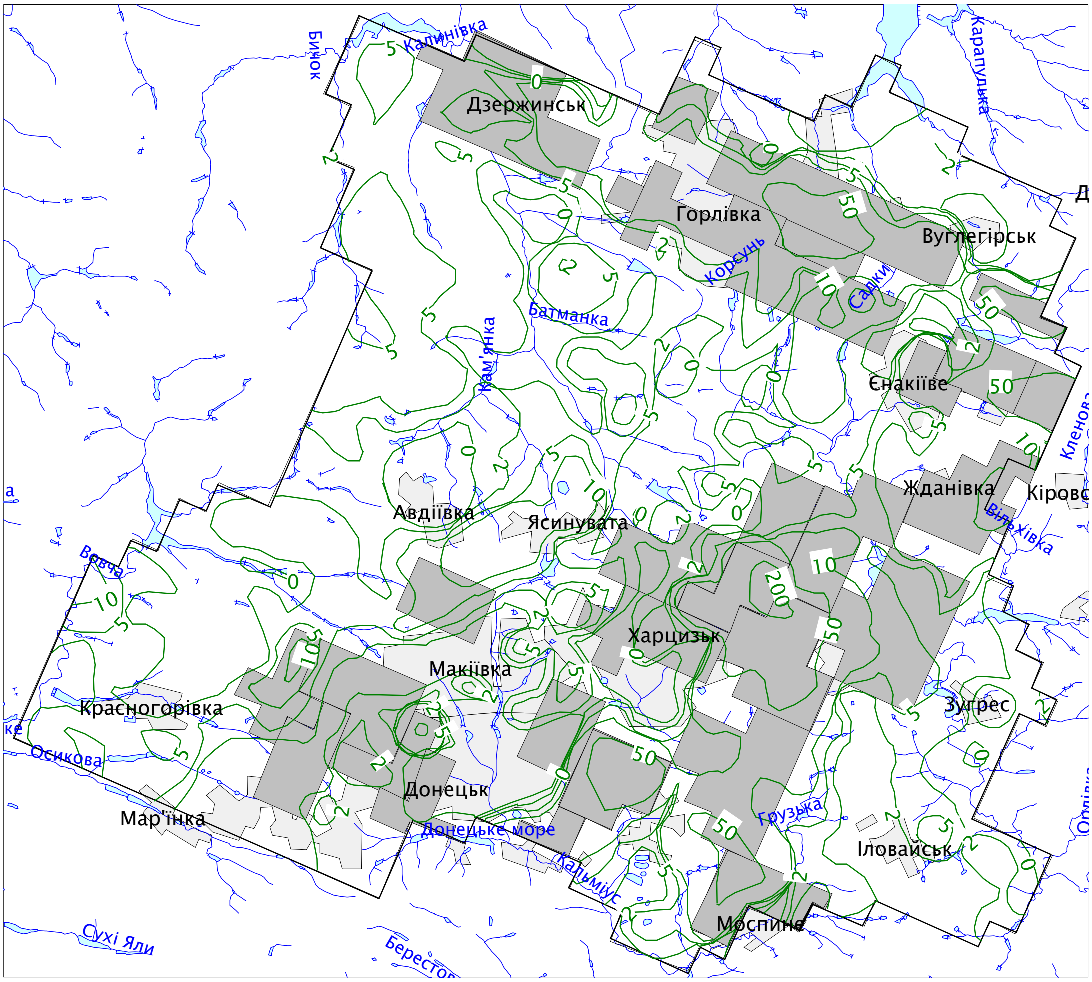


Fig. 9: Groundwater heads in the fractured zone in year 2000



– mining horizons located in the 1st and 2nd model layers

Fig. 10: Groundwater drawdowns in the fractured zone in the period 1944-2000

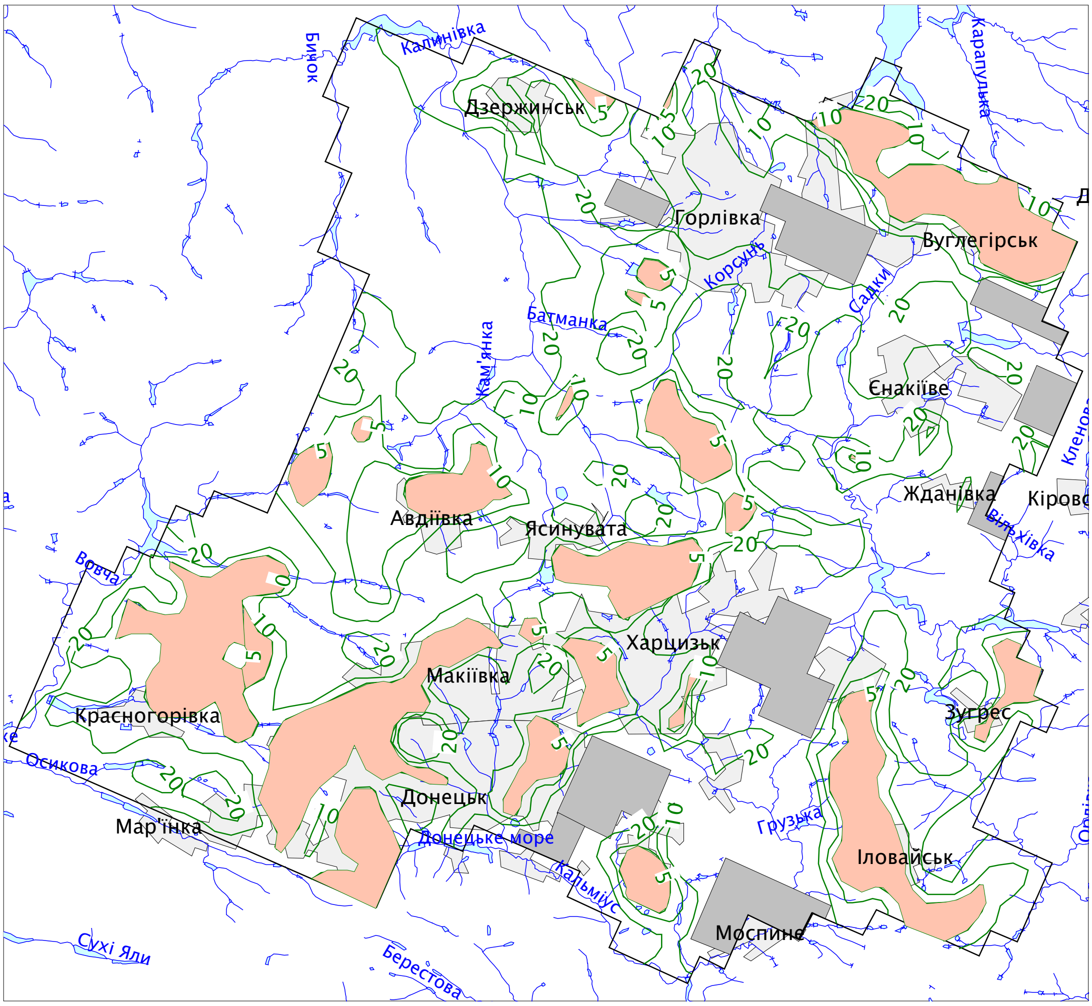


Fig. 11: Depth of the groundwater occurrence in the regional fractured zone in the year 2000

Two separate depressions of the groundwater level were formed within coal mine districts beneath the fractured zone – in the Central and Donetsk-Makeevka regions (Fig. 12).

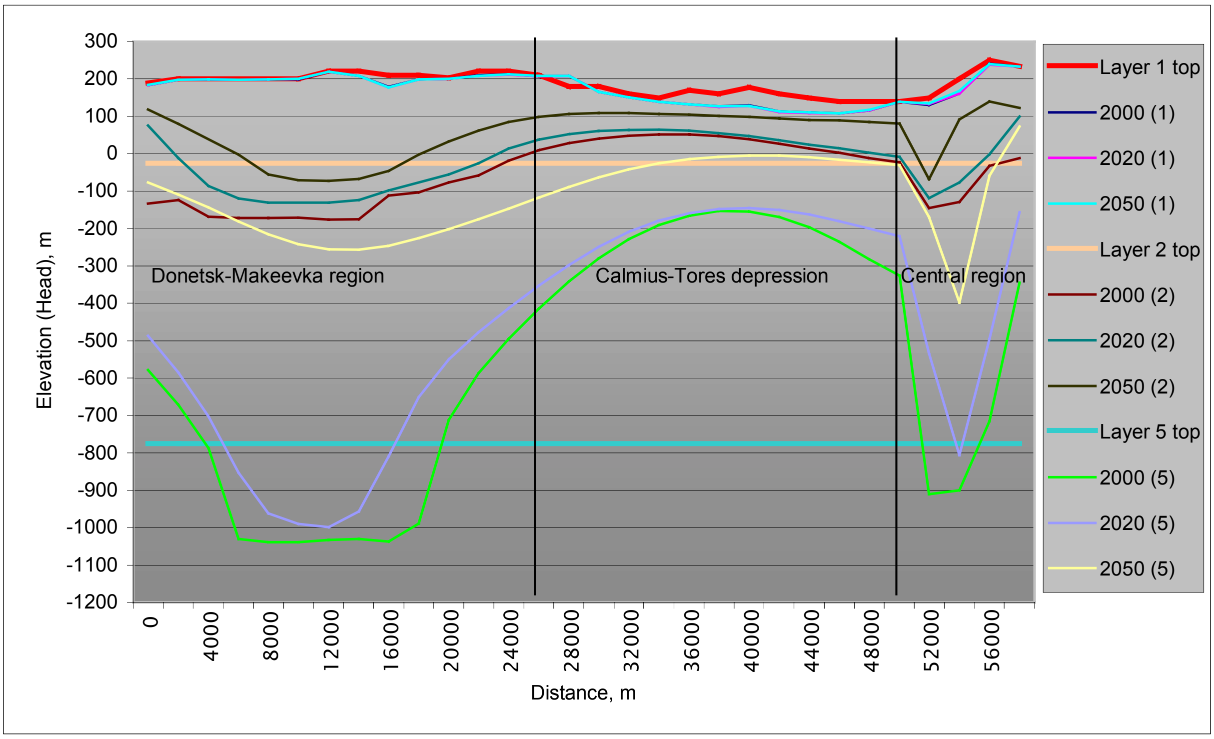
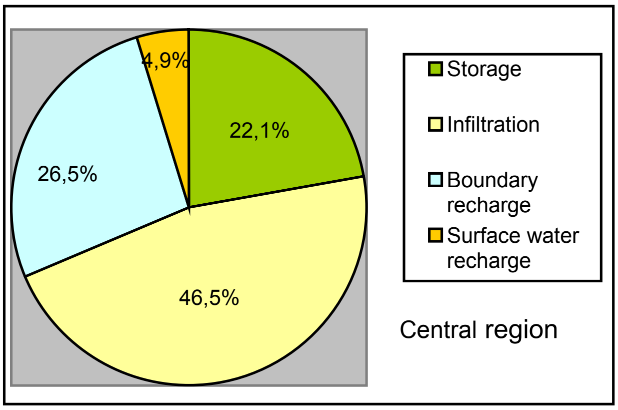


Fig. 12: Groundwater elevation (head) in the year 2000, 2020 and 2050 along the cross-section 1-1 (1st, 2nd and 3rd model layers)

Main components of water inflow to the coal mines in 2000 are given in the Table 2 and Fig. 13.

Table 2: Water inflow to mines in the fractured zone in year 2000

Region	Water inflow to mines, m^3/day	Balance components, m^3/day			
		Storage	*Infiltration*	*Boundary re-charge*	*Surface water recharge*
Central	6688	1483	3110	1770	325
Donetsk-Makeevka	24556	911	12005	5389	6251



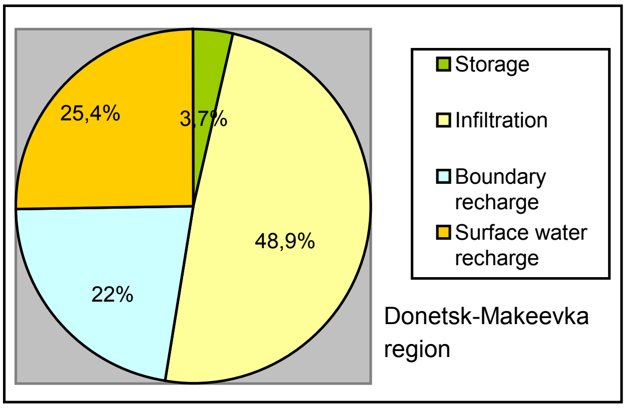
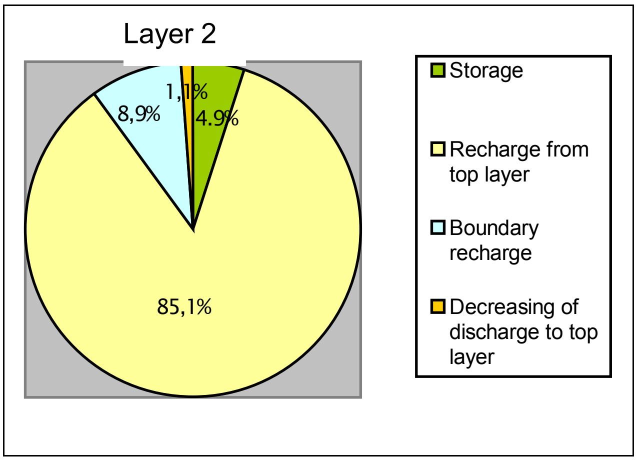


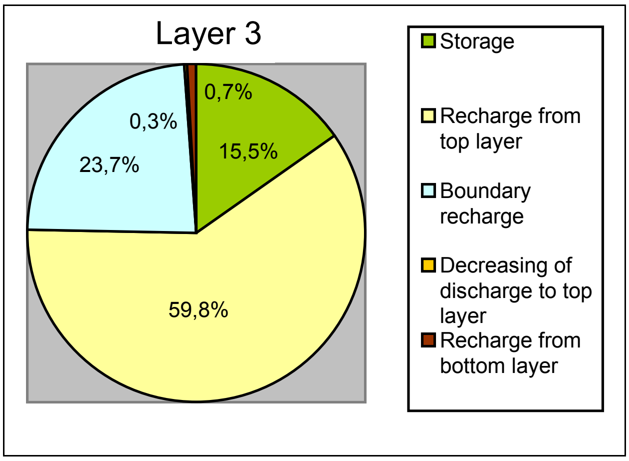
Fig. 13: Water inflow to coal mines in the regional fractured zone in year 2000

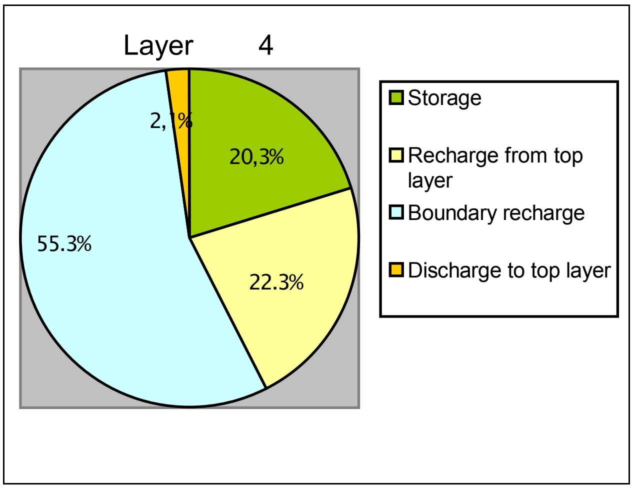
The main balance components in the mine inflow coal beneath the fractured zone are given in the Table 3 and Fig. 14. All the obtained balance components of water inflow to mines are averaged in the limits of mining fields.

Table 3: Water inflow to mines beneath the fractured zone in 2000

Layer No.	Water inflow to mines, m^3/day	Balance components, m^3/day				
		Storage	Recharge from top layer	Boundary recharge	Recharge from bottom layer	Decreasing of discharge to top layer
2	133,028	6,550	113,258	11,753		1,467
3	123,907	19,180	74,092	29,415	880	340
4	90,601	18,370	20,210	50,100	1,921	
5	18,694	3,865	4,111	10,718		







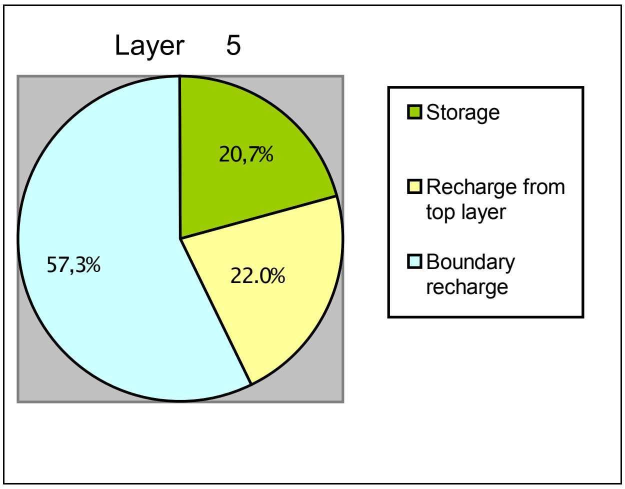


Fig. 14: Water inflow to mines beneath the regional fractured zone in year 2000

3.2.4 Prognoses

Three runs have been made for a period of 5, 20 and 50 years with simultaneous flooding of all the mines. Two sets of parameters were used in the prediction:

1. Parameters, obtained by the transient inverse problem solution for 2000;
2. Parameters, increased in 20% compared with ones obtained by the steady inverse problem solution for 1944. This variant takes into account loose rocks consolidation in time.

According to the simulation results the groundwater level elevations in the fractured zone within the limits of the mine fields will rise during 2000-2005 by 12m (1st variant) and 20m (2nd variant). The area with the depth of groundwater occurrence less than 5m, which has the essential engineering-geological effect, will greatly increase (Fig. 15).

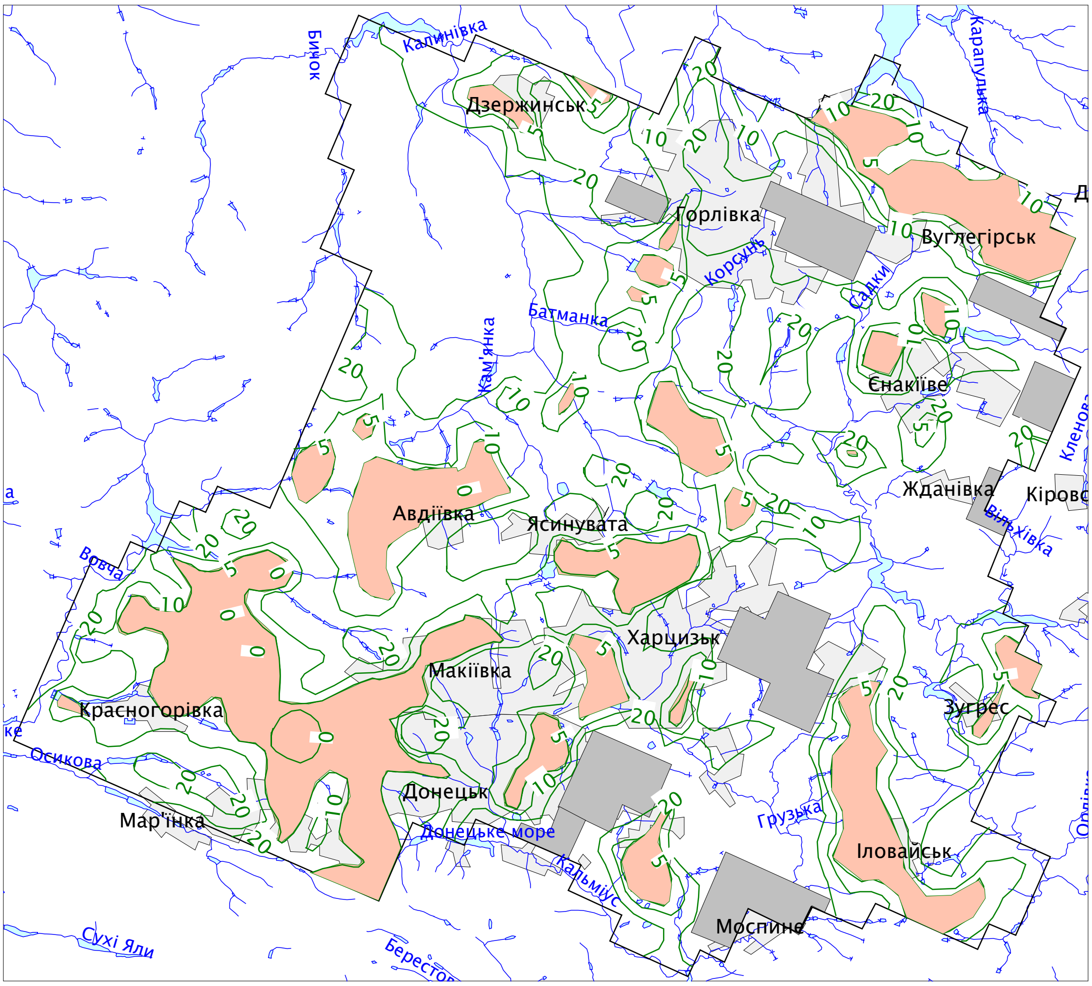


Fig. 15: Depth of the groundwater occurrence in the fractured zone in 2005 (2nd prediction variant)

Groundwater level depth in 2005 will decrease by 0.5-10m compared with 2000 on the boundaries of mining depressions. Taking into account subsidence of the ground surface due to removal of large quantities of coal-bearing rocks those territories are the most endangered for technogenic and natural flooding. The rise of groundwater head beneath the regional fractured zone will be 230-360m (1st variant, Table 4) and 210-360m (2nd variant, Table 5). Groundwater heads will continue to decrease in the area between mining depressions, close to water divide. It is due to more active discharge in the mining space as compared to infiltration.

During 2000-2020 years groundwater elevations in the limits of the mining fields in the regional fractured zone will rise on 10-40m (1st variant) and 70m (2nd variant). The square with the depth of groundwater occurrence less than 5m will continue to increase. Groundwater heads rise beneath the regional fractured zone will be 270-670m (2nd variant, Table 4, Table 5 and Fig. 12). High speed of the groundwater level rising within fractured zones is connected local development of permeable fractured zones and its shortening with depth.

Table 4: Groundwater level (head) changes in situation with all mines flooded (1st variant)

Layer No.	5 years		20 years		50 years	
	Max rise	*Max decrease*	*Max rise*	*Max decrease*	*Max rise*	*Max decrease*
1	12	5	43	29	99	21
2	227	6	289	11	429	N/A
3	261	20	523	26	650	N/A
4	289	19	728	18	903	N/A
5	358	52	548	24	1110	N/A

Table 5: Groundwater level (head) changes in situation with all mines flooded (2nd variant)

Layer No.	5 years		20 years		50 years	
	Max rise	*Max decrease*	*Max rise*	*Max decrease*	*Max rise*	*Max decrease*
1	20	2,5	76	11	171	12
2	208	5	268	3	370	N/A
3	163	10	519	25	591	N/A
4	222	19	666	22	808	N/A
5	358	54	529	28	1013	N/A

During 2000-2050 years groundwater elevations within coal mines fields in the regional fractured zone, which has the regional expansion will rise up to 100m (1st variant) and 170m (2nd variant). Groundwater heads rising beneath the fractured zone will be 370-1000m (2nd variant, Table 4, Table 5, Fig. 12). Configuration of the mining depressions leave nearly the same, but their depth and size will decrease, first of all from the outer parts.

Fast groundwater rising will begin after the groundwater flow conditions become confined. Steady state will be reached approximately in 80-100 years (Fig. 16).

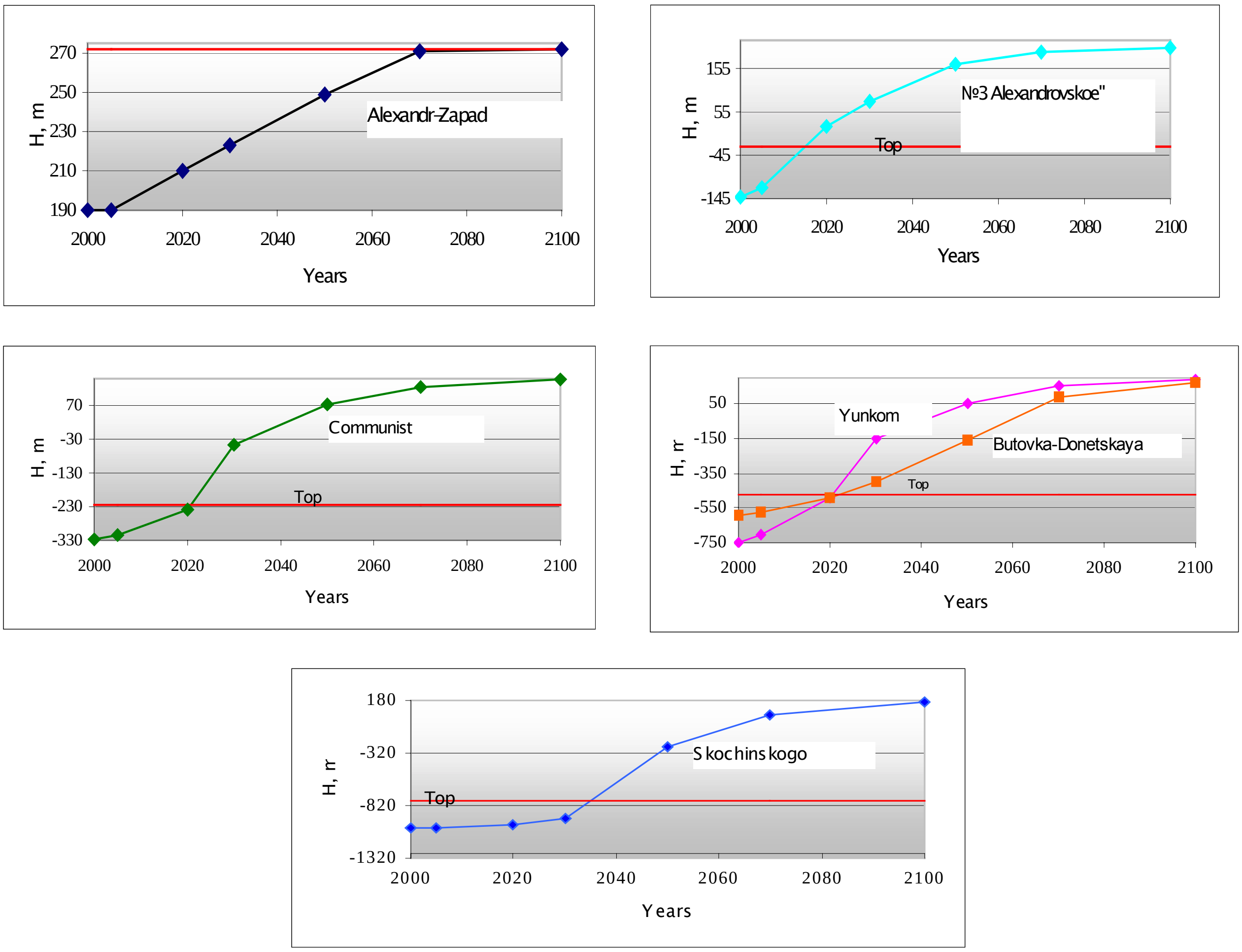


Fig. 16: Head recovery in situation where all the mines are flooded (2nd variant)

The following conclusions could be done based on the simulation results:

1. In natural conditions the active water interchange was attributed to the fractured zone only; leakage to low permeable coal bearing rocks beneath the regional fractured zone could nearly be neglected (less than 5% of infiltration).
2. Depressions formed by intensive drainage of the mining works have rather complex spatial form and depend on tectonics, boundaries of mining fields, vertical distance between mining horizons, flow parameters, leakage from surface sources and interaction with hydrogeological boundaries.
3. Flooding of all the Donbas mines would cause considerable groundwater rise and reduction of the storage capacity of the unsaturated zone; that would increase frequency and severity of flooding at the boundaries of mining depressions.
4. it is possible to utilize the model for further studies of selected sub-areas; in such cases boundary conditions for the sub-areas would be defined by the large model.

There are nearly no observation data about groundwater recovery after flooding of the mines. It's necessary to create monitoring system to control groundwater level and quality. Mines flooding should be accompanied by interval observations of groundwater free table and heads in observation wells, which uncover vertical profile from earth surface to mine working. The observation wells should be located in the limits of mining fields as well as outside them – near the pillars between mining fields and within watershed areas. Systematic hydrological investigations should be organized on the rivers and streams in the limits of mining fields.

The obtained results show that the model may be useful for parameters estimation, preliminary evaluation of water balance components, selection of the sites which need protection from technogenic and natural flooding and for assessment of groundwater pollution and dangerous hydrogeomechanical processes.

3.3 Hot Spots

High technogenic load on ground surface and on surface water within the investigated area is primarily caused by "Hot Spots" – locations characterized by high rate of emission of contaminating compounds.

Detailed discussion of hot spots is included in Task report, *Appendix 2*. This appendix contains table with characteristics of the individual sites and background information relevant for an assessment of environmental hazard associated with hot spots. In here only brief description is included. The hot spots are plotted on Fig. 17.

The total number of hot spots defined within the investigated area is about 700. Hot spots may be divided into four groups:

1. About 300 mining areas of which 113 are situated within local settlements and towns; out of the 113 mines 57 are in operation, 28 are closed by dry conservation and 28 are closed by wet conservation or by whole flooding.
2. About 215 surface hot spots including 114 waste water ponds, 12 pesticide storage sites and 77 terricones.
3. Towns and settlements which are regarded as sources of contamination with heavy metals, oil products and chemical compounds.
4. About 126 sites containing liquids and water saturated wastes; the total volume of contaminants stored at these sites is 81.2 mill m^3 and the total area is 14.6 mill. m^2; that gives an average depth for a typical dump site of 6 m.

The area occupied by hot spots equals about 20% of the investigated area; if area occupied by mine field is included, almost 50% of the area will belong to the hot spots category.

The contamination picture determined during the project can hardly be explained by the plotted contaminant sources only. Particularly, groundwater and surface water contamination by toxic metals, oil and others organic compounds seems to be much more widespread than the shown hot spots can explain.

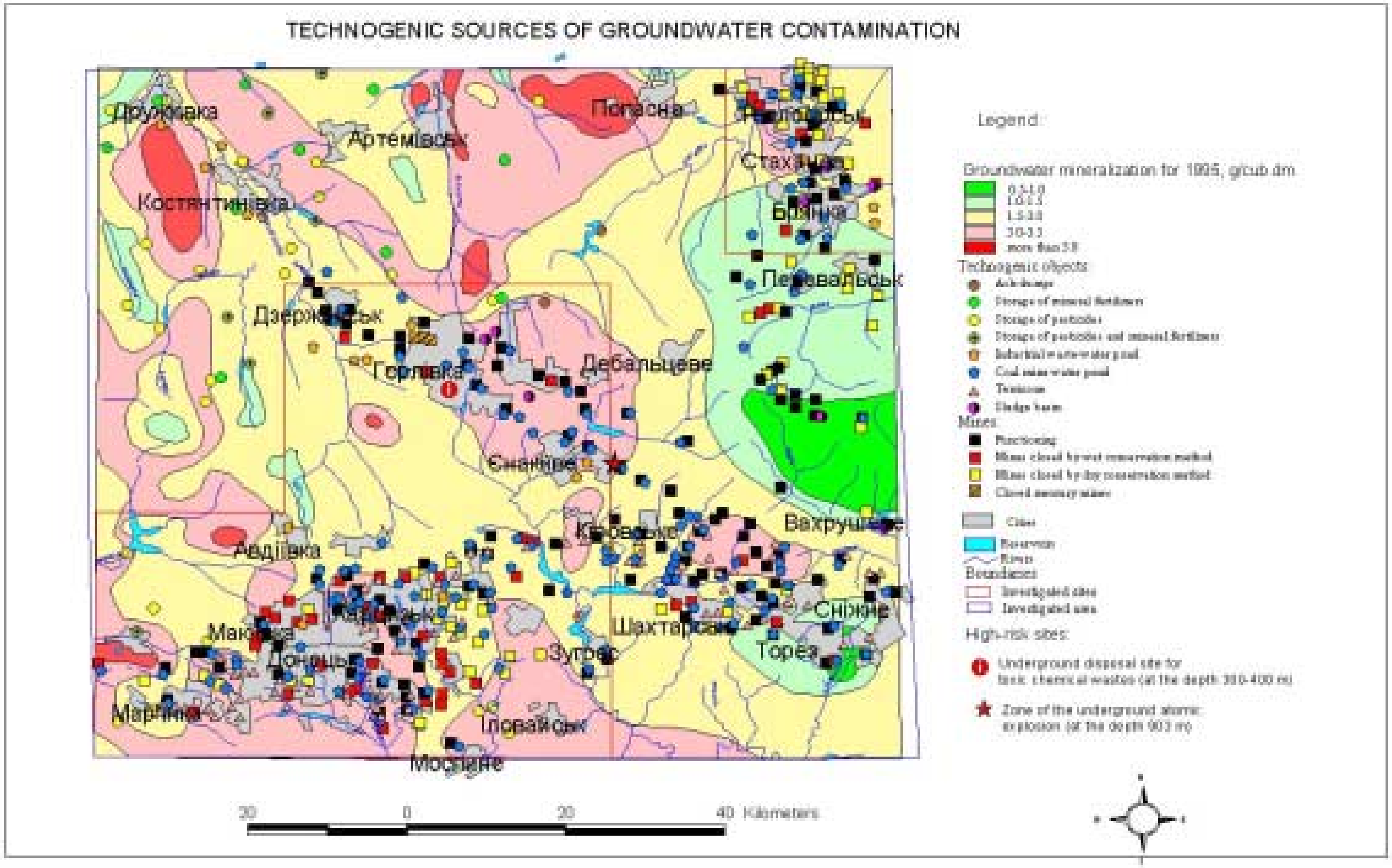


Fig. 17: Hot spots defined in the D-M-H-Y region

First of all the existing contamination picture can be related to the change of drainage pattern caused by mining activities. In the future the contamination pattern will be primarily defined by the methodology selected for mine closure.

In addition to the mentioned sources of contamination, there are some very serious additional environmental hazards such as Horlivka Chemical Plant and Yuncom coal mine with large amount of highly radioactive (hundreds of REM) liquid and solid waste stores at the depth of 903 m. This waste was created in 1979 during an atomic explosion designed to improve mining condition of methane-bearing coals. In the present situation the system is relatively stable but groundwater rise during mine closure may change this situation dramatically.

3.4 Snow contamination

In the areas characterised by a high dust load, snow measurements of dust deposition are very realistic measure for soil contamination. The natural background dust fall-out is about 0.01 g/(m^2day). The dust fall-out within the investigated area exceeds the background level 10-50 times (up to 87 times at the Horlivka region). The high values of dust fall-out are co-related to high concentration of Hg, Ag, Pb, Zn and Ge. It is calculated, that the annual fall-out within the Horlivka region amounts to: Zn-31.4 kg/km^2, Pb-9.5 kg/km^2, Hg-0.137 kg/km^2 and Ge-0.371 kg/km^2.

3.5 Soil contamination

Donbas is the region where huge amount of rocks and chemical compounds are being moved, processed and dispersed in the atmosphere, surface water and on the soil surface.

The findings regarding soil contamination were based on:

- Information from earlier surveys, exploration and mining works,
- Data from geochemical monitoring,
- Specific geochemical investigations carried out within the Project, inclusive inter-calibration of an Ukrainian laboratory with three western laboratories.

The basic information for an assessment of soil contamination was an existing map entitled: “Complex evaluation of the regional technogenic changes of hydrogeomechanical conditions within Donetsk and Luhansk Oblast, scale 1:200,000. Grid density for soil sampling in towns and industrial areas was 2x2 km and for agricultural land 4x4 (or 8x8 km). Geochemical parameters for soils within natural reserves (Honujtovkij steppe and Velikoanadolsky and Kamennomogilsky steppe) within the Donetsk Oblast were adopted as representative background.

The level of technogenic contamination of the soil was determined as a ratio between the concentration of selected contaminants in the contaminated samples (c_i) and the concentrations of these compounds in reference samples (c_r): $K_c = c_i / c_r$. A value of “Hygienic index” – Z_c, is normally calculated as a sum of K_c values for a number of parameters: $Z_c = (\Sigma K_c) - (n-1)$, where n is the number of parameters considered.

In accordance with the recommendation of the Ministry of Health, following characteristics of the area was adopted:

$Z_c < 16$:	permissible,
$16 < Z_c < 32$:	moderately dangerous,
$32 < Z_c < 128$:	dangerous,
$Z_c > 128$:	very dangerous.

In some cases the soil contamination classification was done using: $Z_{pc} = \Sigma c_i / c_{pc}$, where c_{pc} represents permissible concentrations for the various parameters.

About 15% of the Donbas soils is characterised by the very dangerous level of contamination (K_c>128). The main reason for such high values is high rate of dust deposition either from the local industry or from more distant sources – all depending on the predominant wind direction and the way of dust emission. It should be stressed, that high K_c values indicate strong air pollution which is very dangerous for the inhabitants of such areas.

The results show that soil contamination with Hg, Sb, and As in the Horlivka-Yenakiyevo agglomeration is significantly higher than in the Donetsk-Makeevka agglomerations. The network used for sampling of soil, groundwater and snow is shown on Fig. 18.

3.5.1 Sampling and analysis of soil data

The detailed discussion of sampling results and procedures for the Soil sampling-task is given in the *"Soil analyses"* report, *Appendix 7*. In here only the major findings are described.

The assessment of soil contamination in a given area is commonly based on a number of soil analyses and comparison of the measured concentrations with established background levels, i.e. concentration levels obtained in uncontaminated land. The establishment of background levels must be based on reliable analytical data that can be compared with and calibrated to match international geochemical reference data. There are three objectives for the work done on soil samples within the Project:

1. To provide Ukraine with international reference material,
2. To create a set of 25 national reference soil samples, and
3. To examine the quality of existing Ukrainian soil analyses.

It is important that the chosen reference material cover the range of expected element concentrations. The project has bought NIST references 2710 and 2711 (contaminated soils) to cover high values, and CANMET references STSD 2 and STSD 4 to cover background values. The reference material should be used in the future to monitor new soil analyses. 25 large soil samples and three stream sediment samples were collected in the Donetsk-Makeevka province of Ukraine, from uncontaminated as well as contaminated sites.

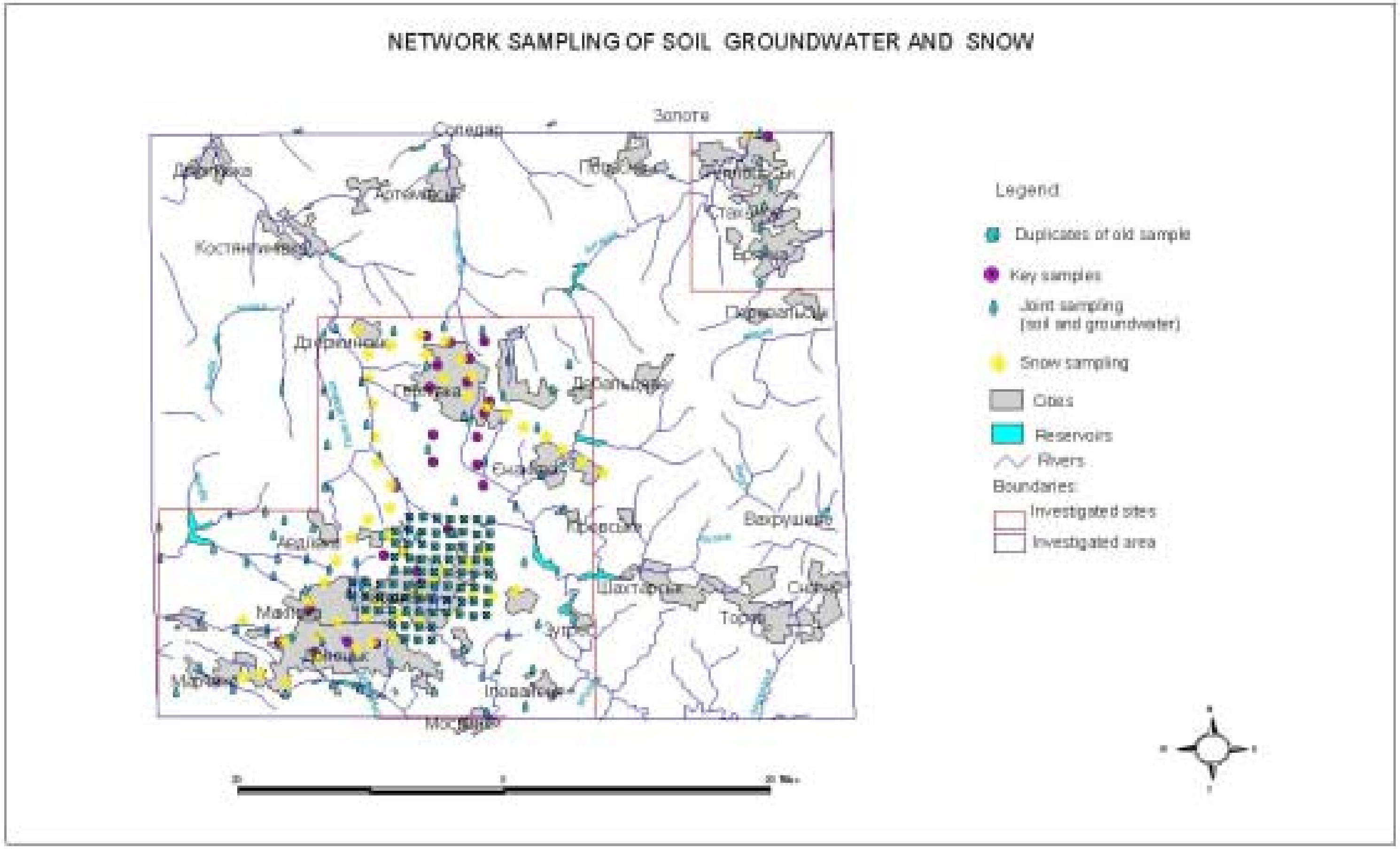


Fig. 18: Sampling network for soil, groundwater and snow

The concept used for the reference soil samples is to treat the samples from Ukraine in much the same way as samples from within the European FOREGS (FORum of the European Geological Surveys Directors) programme for establishing common European geochemical baselines. The main principle is that samples from all over Europe should be treated and analysed in the same laboratories to avoid the bias that is known to exist in previously obtained data when different analytical methods or laboratory routines have been used. Further information on the FOREGS geochemical work may be obtained from the FOREGS web site http://www.pgi.waw.pl/foregs/.

The samples were received at GEUS, and they were sent to the Geological Survey of Slovak Republic for homogenising and splitting, and submission of splits for analysis. The samples were analysed at the Geological Survey of Finland (Geologian Tutkimuskeskus, GTK) by inductively coupled plasma mass spectrometry for 35 elements, and at the Geological Survey of Germany (Bundesanstalt für Geowissenschaften und Rohstoffe, BGR) by X-ray fluorescence spectrometry for 41 elements plus loss on ignition (l.o.i.). These two laboratories are in charge of the FOREGS soil samples.

3.5.2 Comparison of existing Ukrainian soil analytical data with new analytical data

The aim of this part of the study is to examine how analyses performed in Ukraine compare with analyses of present international standard. A batch of 78 samples, collected and previously analysed by Optical Emission Spectrography at the Institute of geo-ecological problems of Donbas in Ukraine, was submitted for analysis at Activation Laboratories Ltd. (Act), Canada. The analytical method was chosen so that as many of the elements determined by OES in Ukraine were included. The choice was '4litho' using lithium metaborate/tetraborate fusion and subsequent ICP-MS, in which 63 elements were determined, including 32 of the 34 elements determined in Ukraine. Selected reference samples were included and also the four international standards (reference materials) provided by the project. The analytical procedure involves duplicate analyses and the analyses of additional international standards so that there is ample data sets documenting the precision and accuracy of the analytical results.

The comparison of results provided by the Activation Laboratories and the FOREGS results shows that most of the concentrations determined by Act are closely comparable to those of GTK, where the same analytical method has been used. The major element oxides by Act are close to those determined by BGR.

A comparison of the Ukrainian and the Act results was made. The two data sets have 26 elements in common, for which concentrations are above the lower limit of detection. These data are displayed in scatter diagrams, Fig. 18. It follows from an examination of the data and diagrams that for each element the range of concentrations measured in the 78 samples is more or less the same for the two methods. Also, there is a general agreement between the two data sets on anomalous samples, i.e. an unusually high value in one data set corresponds to a high value in the other. However, the correlation coefficients between the data sets are low for most elements and it will not be possible to make a reliable calibration between the data using a regression method, except for the elements Mn, Ca, Ba, Ge and Zn. The reason is that the resolution in Ukrainian analytical data is poor compared to the analyses by Act.

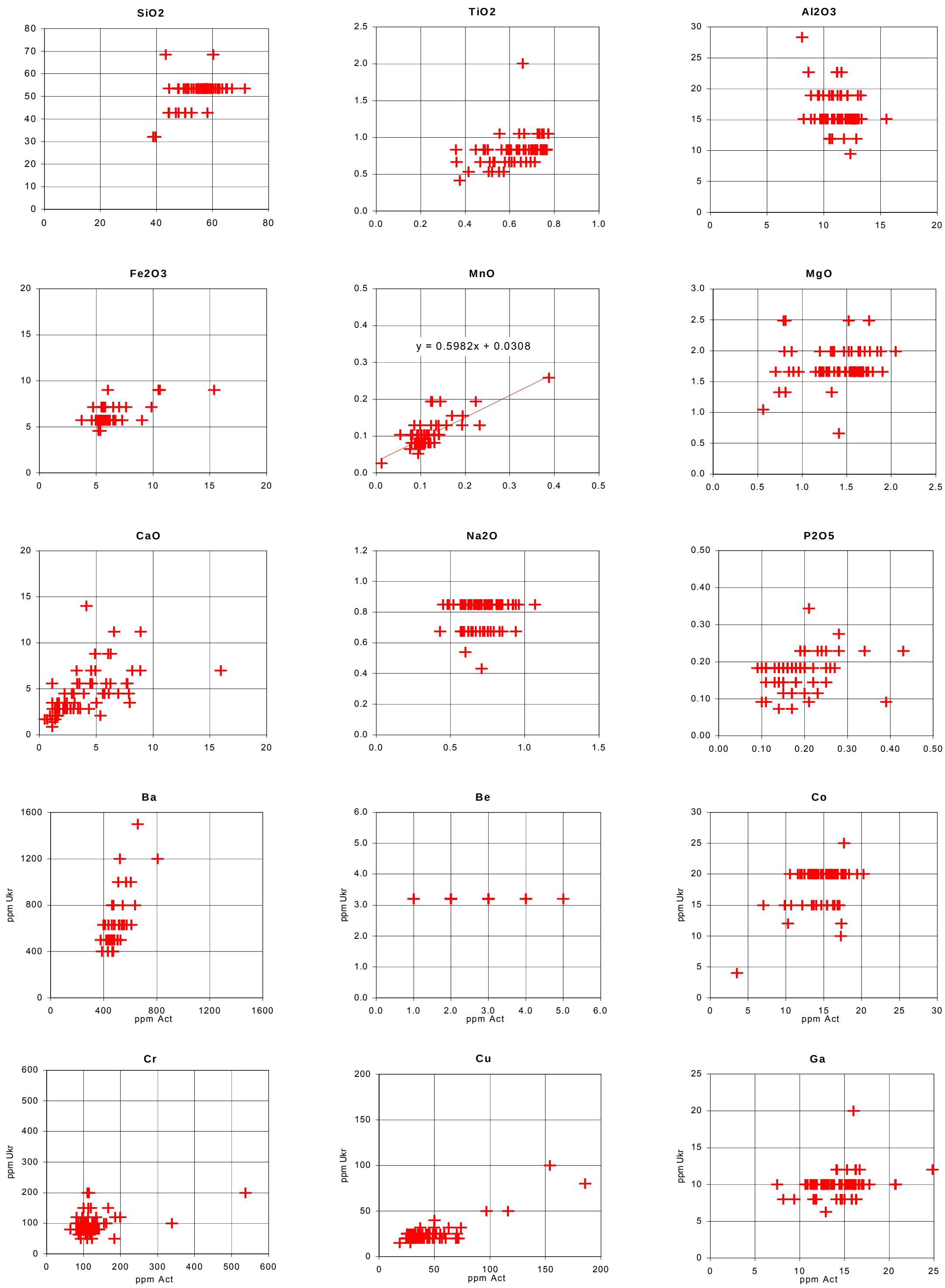


Figure 19. Compatibility of element concentrations determined in 78 samples by Optical Emission Spectrography in Ukraine (Ukr, y-axis) and by Inductively Coupled Plasma Mass Spectrometry at Activation Laboratories Ltd. (Act, x-axis).

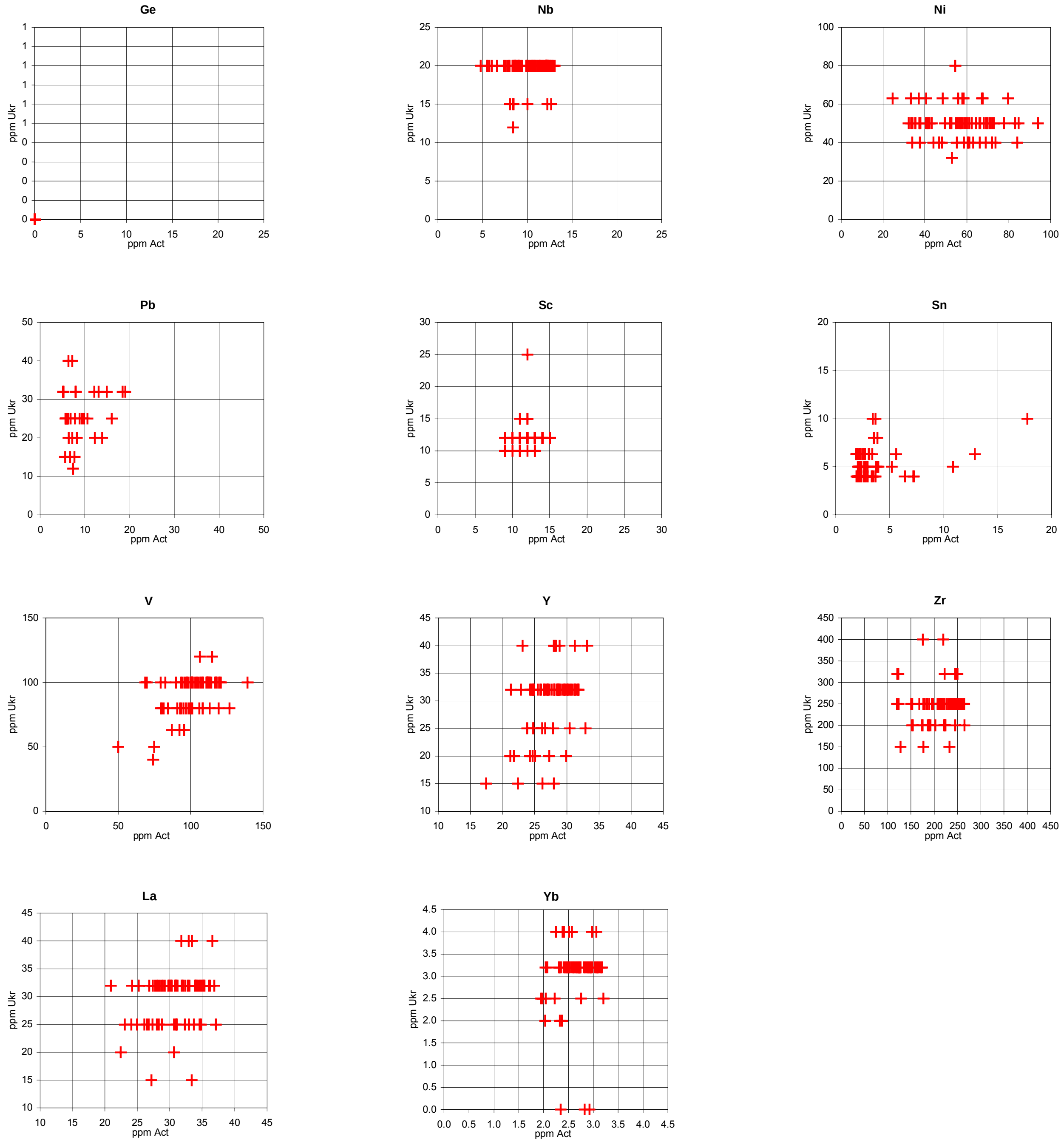


Figure 19 continued. Compatibility of element concentrations determined in 78 samples by Optical Emission Spectrography in Ukraine (Ukr, y-axis) and by Inductively Coupled Plasma Mass Spectrometry at Activation Laboratories Ltd. (Act, x-axis).

3.5.3 Conclusion

The task planned for this subproject has been carried out according to the agreement. Ukraine now has four international standards, two for monitoring background values and two for monitoring contaminated samples. In addition, a set of 28 soil samples has been analysed according to the requirements for the European FOREGS geochemical mapping programme. These samples can be used in the future as national reference material, which can be linked to a European (and global) network of inter-calibrated national reference samples.

The existing analytical data for the Donbas region are adequate in quality to define a coarse background level and to outline anomalous sites. However, they are not suited to form a basis for geochemical mapping of background variations, and some of the element determinations in the Ukrainian data have very low reliability.

3.6 Aquifer contamination

The contaminant originating at the ground surface may: a) continue through the unsaturated zone to groundwater, b) get absorbed (or adsorbed) to the top soil, within the unsaturated zone or in the groundwater zone or c) may end up in rivers and get removed from the investigated area. Build-up of contaminant concentrations in the bottom sediments of lakes, rivers and streams should cause great concern due to possibility of mobilizing of these contaminants with changes of geo-chemical conditions.

The anthropogenic influence on water exchange pattern (mine drainage, well fields producing drinking water) is the main factor influencing contaminant migration in the unsaturated zone and in the aquifers.

The changes of groundwater quality from year 1966 to year 1996 are shown on Fig. 20. During this period of time the are covered by groundwater with salinity <0.5 mg/l decreased from 1,350 to 150 km^2 and for salinity interval 0.5 to 1.0 g/l the area was reduced from 1,300 to 500 km^2. At the same time the areas of groundwater within higher salinity intervals: 1.0-1.5, 1.5-3.0 and 3.0-7.0 g/l expanded 1.7, 3.7 and 5.0 times respectively. The middle, area-weighted mineralization, has increased more than 50%, from 1.4 g/l in 1966 to 2.2 g/l in 1996.

The main factors for such a change of groundwater quality are:

1. Active infiltration of waste water from ponds and pipe lines.
2. Geochemical contamination of large territories due to industrial sites, towns and agricultural activities.
3. Increased infiltration (2-5 times) within coal mine drainage zone and within cones of depression created by well fields.

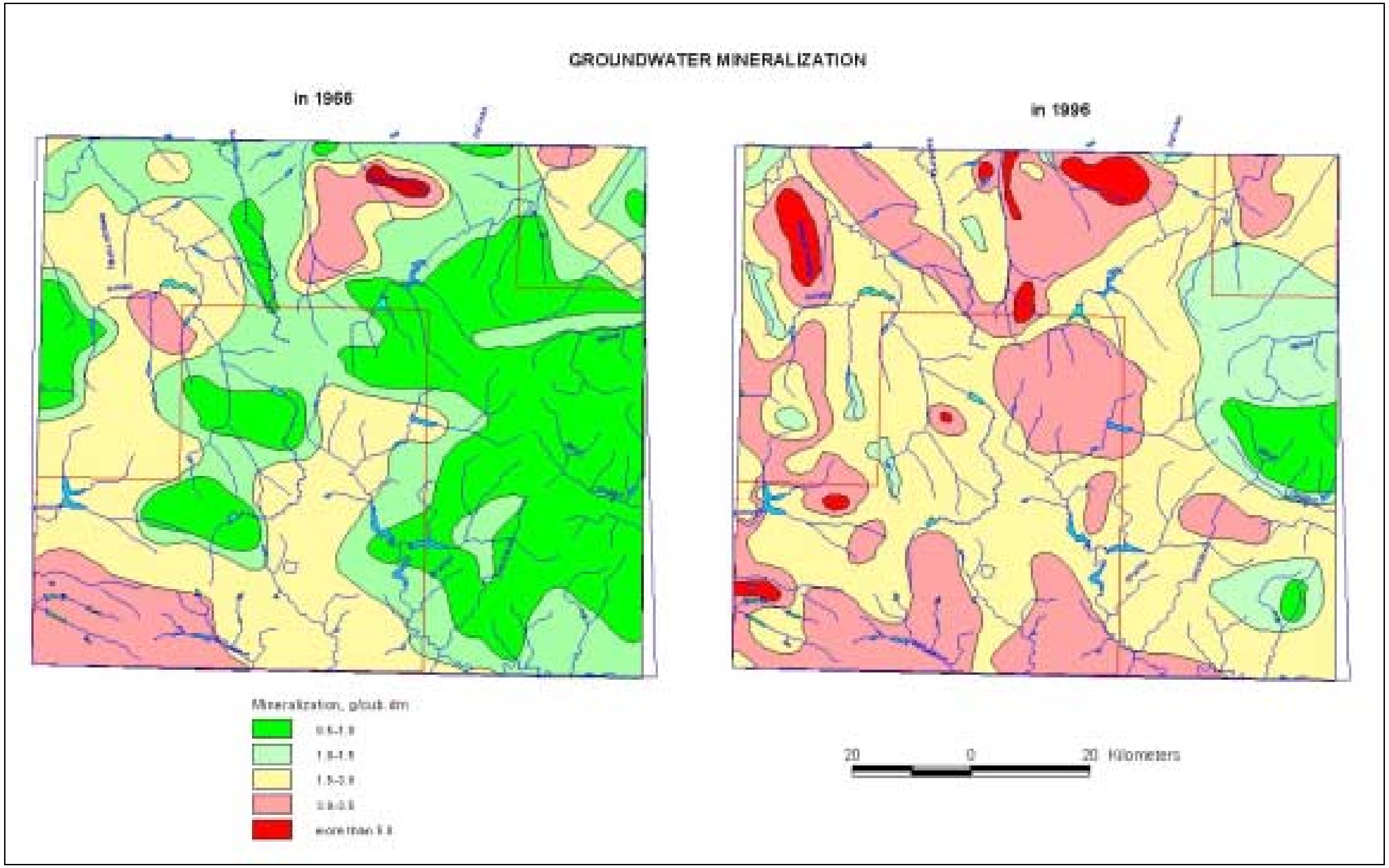


Fig. 20: Groundwater mineralization in 1966 and 1996

Based on the analysed data following trends in development of conditions relevant for the future groundwater quality may be expected:

- Local occurrences of very high salinity, 10-20 g/l or more, will be established due to intrusion of saline water from greater depths,
- Development of micro-components contamination within town agglomeration will accelerate,
- Increase of contaminant migration within locations where water table comes close to the surface will take place,
- Number of sites with aggressive groundwater will increase,
- Reduction of protective abilities of the unsaturated zone due to additional land subsidence and flooding of the mining-affected territories will take place.

3.7 Consequences of mine closure

Active phase of mine closure process within Ukrainian part of Donbas has been going on for the last 4 years. Total number of mines in Donbas region is 240. 70 of these are designated for closure and 20 are physically closed. The remaining 50 mines, plus 10 mines not specified as yet, will be closed within the next 5-10 years. In the D-M-H-Y area no mine closure has been done yet but several mines are practically, but not formally taken out of exploitation. This creates very difficult situation for these mines because the income is very little (or none) while maintenance and running cost are high - particularly if these mines have to pump additional amount of water on account of the neighboring mines.

During mine closure a transformation of relatively stable “mine-geological medium” system into a new, less stable system - where several parameters are changed into non-desired direction - takes place.

The negative mine closure influence results in:

- Flooding of territories,
- Additional subsidence of ground surface,
- Development of dangerous geo-chemical, geo-dynamical and others processes,
- Creation of new pathways for migration of explosive gas due to flooded mine barrier effect, relaxation of tectonic structures etc.

The above-mentioned processes taking place in the geological media can be reversible or irreversible.

The most important reversible processes are:

- Rise of groundwater level,
- Activation of drainage processes by river system,
- Discharge of deep salt water.

The most important irreversible processes are:

- Land subsidence,

- Reduction of geo-mechanical strength of rocks, including the pillars,
- Destruction of regional aquifers,
- Development of volumetric hydro-geo-mechanical tensions, local hydro-geo-mechanical blows and local antropogenically induced earthquakes.

Two figures (Fig. 21 and Fig. 22) summarize the danger posed by water level recovery in the deep mine area: the first showing the area where water level will rise to less than 5 mbs, and the second showing deterioration of geotechnical properties of rocks as a result of water level recovery. Shallow groundwater will disrupt communication lines, foundation of the houses and will increase the risk of flooding.

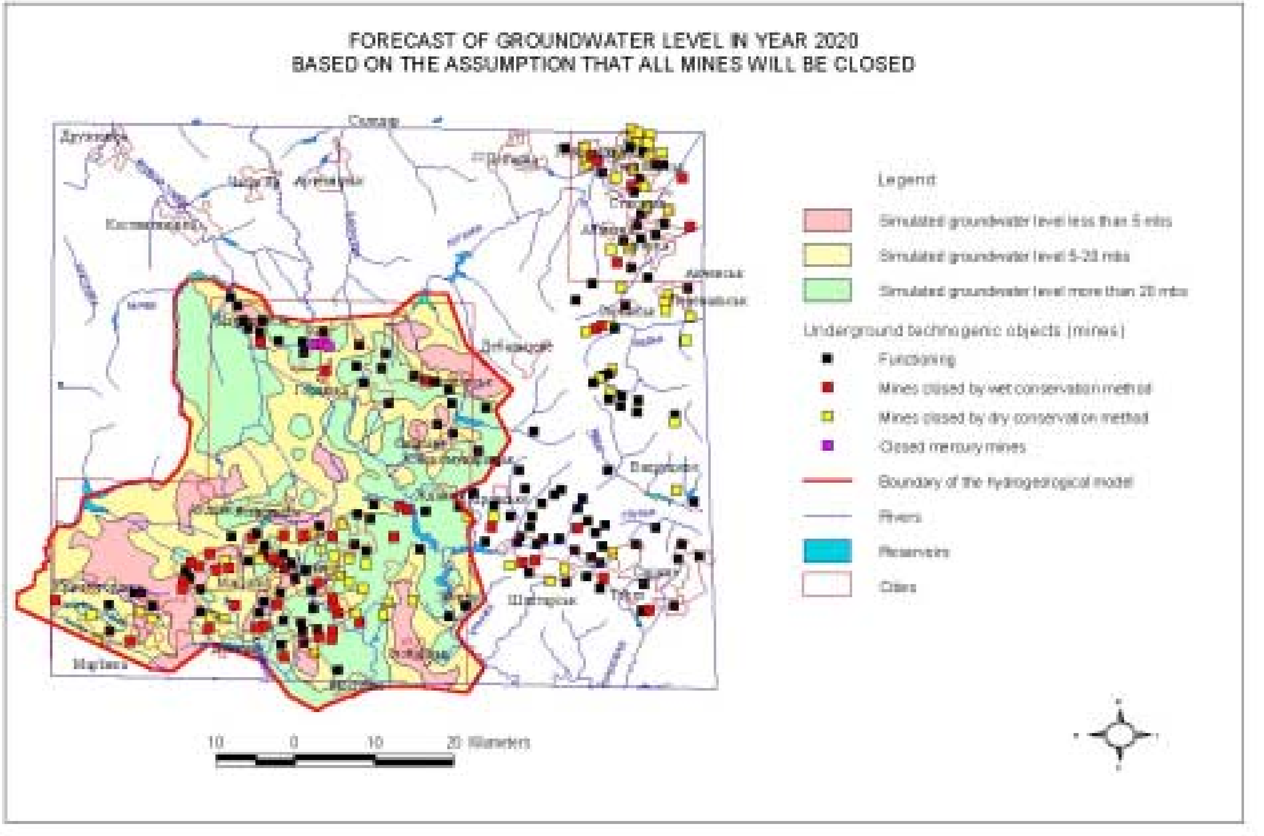


Fig. 21: Calculated groundwater level in year 2020, all mines assumed to be closed

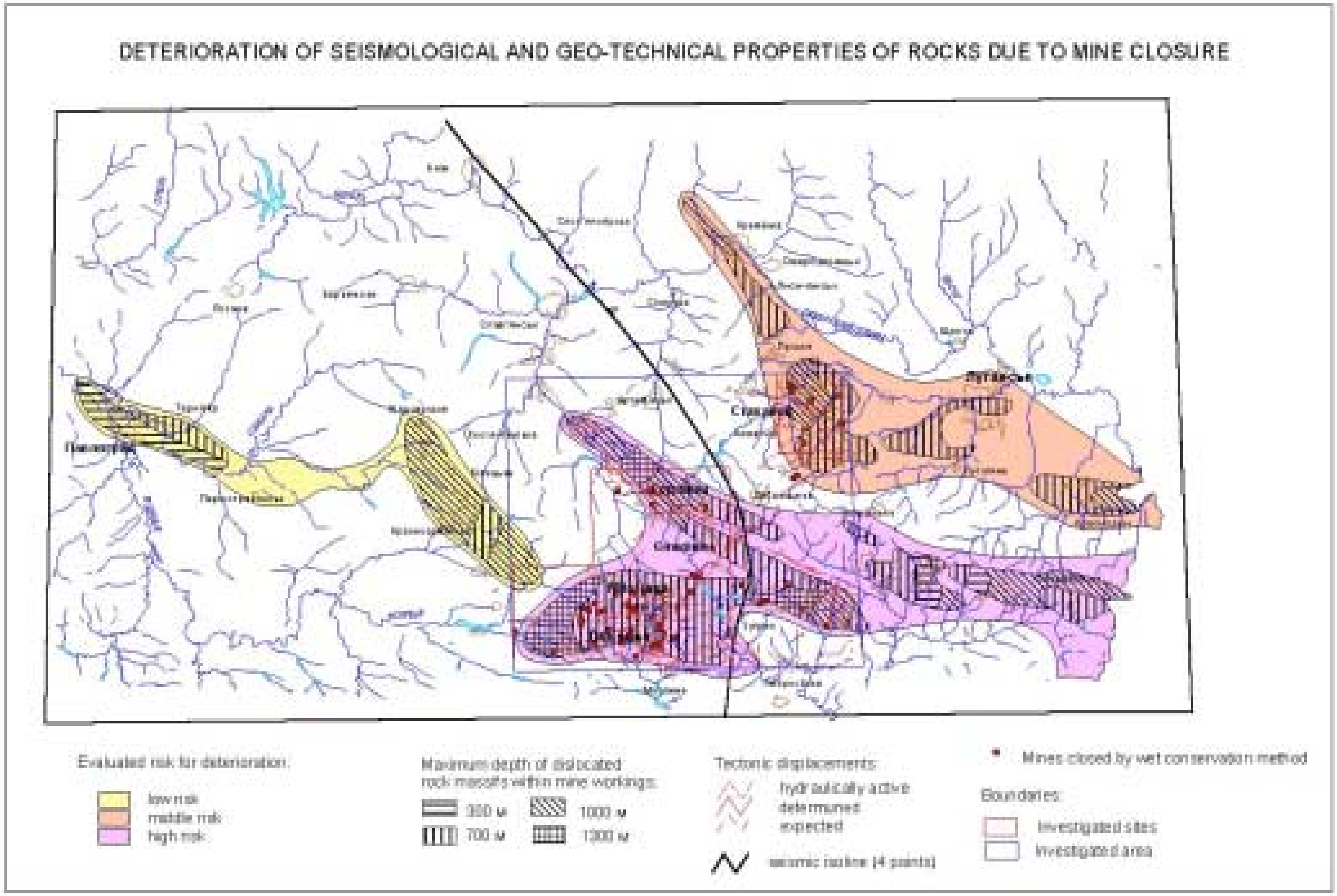


Fig. 22: Deterioration of seismological and geotechnical properties of rocks due to mine closure

3.7.1 Change of the geo-dynamical situation

New geo-dynamical processes caused by mine closure are detected on the territories of the Stakhaniv and Horlivka industrial agglomerations. Such processes are: land subsidence, land surface deformation and hydro-geo-mechanical-blows. On average, land subsidence in Donbas amounts to about 85-90 % of the thickness of the removed rocks. The total amount of rocks removed within Donbas is about 12 km^3, which correspond to about 2 m of land subsidence within the contours of the mine fields.

With increase of water saturation the geo-mechanical equilibrium in the weakened, undermined rock massif begins to be distorted. Main factors of this process are:

- Increase of water saturation of rocks results in reduction of friction and rock strength,
- Swelling of clay creates an additional tensions,
- Movement of rocks in the zone of the abandoned galleries,
- Redistribution of hydrogeomechanical tension in the volume of water saturated rocks and galleries which is very dangerous for stability of pillars and barriers between interacting mines.

About 50 % of investigated area is characterized by multiple ground surface subsidence due to undermining of rock massifs in different periods.

Model forecast for rise of groundwater level until year 2020 was used for assessment of the changes of geo-dynamical conditions between the year 2001 and the year 2020. The results obtained for 4 classes of the geo-dynamical risk connected with the land subsidence and ground surface deformation processes are summarized as follows:

1. The area with low level of geodynamic risk will decrease 2.5 times (from 2,000 km^2 to 800 km^2); this area is characterized by deep groundwater (> 10m) and low ground surface subsidence (< 2m).
2. The area with moderate level of geodynamic risk will be practically unchanged (about 1,200 km^2); this area is characterized by medium depth of groundwater (10-5m) and high ground surface subsidence (>2m).
3. The area with high level of geodynamic risk will increase 2 times (from 750 to 1,500 km^2); this area is characterized by shallow depth of groundwater (<5m) and high ground surface subsidence (>2m).
4. The area with very high level of geodynamic risk within town industrial agglomerations will increase 2.1 times: from 450 to 950 km^2; this area is characterized by shallow depth of groundwater (<5m) and high ground surface subsidence (>2m).

The results summarized above indicates continuous expansion of the area with high and very high level of geo-dynamical risk.

More active form of geodynamical changes of undermined rock massifs is the volume hydrogeomechanical blows. An assessment of changes of potential energy in the geological environment done by Prof. A. Luchshik and Dr. E. Yakovlev illustrate that systems changes created during mine closure result in accumulation of large amount of potential energy within water saturated abandoned galleries and undermined rock massifs. This energy will increase the strength of future earthquakes.

During the last 3 years about 10 quakes (3-5 points on the MKS-64 scale) were observed within the Stakhaniv coal mine district. This region is characterized by high speed of mine flooding and great depth of mines (1.2 – 1.3 km). In addition the region is characterized by a long operation period (more than 100 years) which resulted in removal of large volumes of coal and rocks.

Preliminary analysis of geo-dynamical situation indicates that the risk of land subsidence, ground surface deformation and micro-earthquakes will increase significantly during the mine closure process. The main factors responsible for geodynamic instability in the Central Donbas area are the hydraulically active connections between various mines and the large volumes of coal and rocks removed.

3.7.2 Migration of explosive gases

Main source for creation of explosive gas mixture is the methane from the coal bearing rocks. Regional changes of hydrogeological and geo-dynamical conditions are the main factors for the restructuring of the geochemical gas fields within every mine, coal mine district and whole geological structure. The gas viscosity, as well as density, is about 1,000 times smaller than waters and therefore the methane distribution is very sensitive even to small changes of rock massif saturation with water or its inner tensions. Besides, the tectonic structures are the essential factor for creation of pathways for methane gas migration.

Today an increase of explosive gas migration is observed. Mainly it is connected with big depth of the processing mines (700-1,300 m) and increasing number of fully or partially flooded mines which results in shortening of active gas drained territories. This process will promote the drainage influence of the remaining processing mines. It is known, that the highest concentrations of explosive gas occur at large depth, where their natural concentrations are highest.

Screening effect of flooded mines for gas flows and additional opening of the tectonic structures due to water saturation will increase the local heterogeneity of the gaseous fields, first of all near the processing mines. Main consequence of such situation can be an increased risk of a blast due to higher chances of obtaining an explosive gas mixture.

Taking above mentioned processes into consideration we believe that gas desorbtion is increasing during regional changes of seismic tensions, or under influence of the hydro-geo-deformation field (Prof. Vartanyan G., VSEGINGEO, Prof. Lushchik A., USGEI of MoENRU) and the influence of frost and water saturation in the upper zone of geological section during winter period should be investigated.

Gas explosions occurring in Donbas mines during the last 3 years were investigated. Statistical analyze shows, that gas explosions are more frequent during winter months: about 60 % during January-March and 80 % during January-May period. However, during late autumn months, there could be large amount of rain, which combined with cold weather, increases the screening ability of upper zone of rock massifs and may prevent the gas from escaping to the atmosphere. This may result in gas explosions. However, we do not know exactly all the pathways of the explosive gas migration: abandoned galleries between neighboring mines and changes of permeability of rocks due to seismic tensions, may lead to unexpected occurrences of gas explosions.

Taking into account the increasing risk of mine gas explosions, following recommendations can be given:

1. An assessments of mine closure influence on the gas-explosion safety of processing mines should be made.
2. The remote sensing technologies should be used for delineation of territories with low concentration of methane in the near-surface air - which can be correlated with its dangerous accumulation in galleries.
3. Hydrogeological models should be used to learn about the structure of groundwater flow between the flooded and processing mines in order to forecast its influence on the explosive gas migration.

Practically the first attempt to make an assessment of explosive gas migration during mine closure process within Donbas was done within the Danish-Ukrainian project. This problem has attracted big attention from DOSA and scientific specialists, because a pattern of gas explosions starts to emerge.

Methane of coal bearing rocks is the important factor of ecological safety for both the processing mines and during the closure process.

3.7.3 Change of geochemical situation

Donbas is the region with the big complex of the principal changes of geochemical situation. Practically all types of landscapes are under technogenic stress connected with mining, development of industrial agglomerations and agricultural activities. The geochemical equilibrium in the upper part of the geological section in more than 90 % of territory has been destroyed. The present depth of contaminant migration is exceeding 1 km – the depth of galleries under the chemical plant in Horlivka.

Major part of the solid and liquid waste disposed on the surface is geochemically incompatible with the soil and underlying rocks and rise of groundwater level, accompanied by an increase of moisture content in the unsaturated zone, will accelerate migration of the contaminants accumulated in soils.

Regional groundwater rise will be one of the main factors influencing groundwater and surface water quality within the next decades.

Project findings and model simulations forecast following development of the geochemical and hydrogeochemical situation:

1. Decrease of the area with an active vertical migration of soil contaminants to groundwater (Fe, Pb, Cu, NO_3, SO_4, Mg, Ca, Al, Zn and others).

2. Increase mobility of chemical contaminants, oil and organic compounds in the soil due to increase of moisture content in the unsaturated zone affected by groundwater level rise – mainly within the zones affected by mine closure.
3. Activation of biogeochemical transfer of soil pollutants and possibility of contamination of agricultural products.

When the groundwater level will reach the critical depth of about 3-5 m principal changes in the ecological situation will occur and the soil-cleansing process will take place.

Project data prove, that recent changes of groundwater chemical composition are primarily connected to macro-components such as mineralization, nitrates and sulfates. It is due to predominantly vertical migration of mine waste water within the industrial zone of Donbas. As the active water exchange exceeds the natural infiltration by a factor of 3, some contaminant take part in a regional circulation.

In some regions the concentration of nitrate measured in various types of wells exceeds the permitted value (45 mg NO_3/l) in 90 % of samples.

After massive mine closure and rise of groundwater level, the wash-out of soil contaminants will have a disperse character. There will be a transition period in the process of soil, surface water and groundwater contamination. The inflow of mineralized mine water into river system will decrease and salinity of surface water will be gradually reduced. But after groundwater table start approaching the critical depth (3-5 m) the frequency of flooding will increase and sites containing heavily contaminated soils and waste will be flooded more often and for longer periods of time. The contaminants mobilized during these events will be transferred towards well fields producing drinking water.

Aquifer contamination will have a regional character due to:

1. High density of hot spots within the Donbas region.
2. Low degree of water exchange within the aquifer caused by low permeability of layers when horizontal flow is concerned.
3. Large storage of contaminants within the soil and unsaturated zone.

The type of groundwater contamination within the active water exchange zone will change character: from being caused by macro-ions to being caused by micro-elements (Cr, Ge, Ni, Cu and others). Content of these microelements within some of the industrial sites exceeds the permissible concentrations by a factor of 20-40.

Reduction of mineralization of surface waters will not result in full recovery of water quality. On the contrary: surface water will further deteriorate due to increased inflow of microelements which are presently to some degree immobilized in the unsaturated zone and in surface dumps. Project data allow to conclude, that we are facing a ***regional process where contaminants are being redistributed from soil into surface water and to groundwater***. An accumulation of contaminant in various crops will take place.

3.7.4 Change of aquifer conditions and water supply situation

Soils and groundwater are the main storage for large amount of various contaminants. These contaminants may get mobilized as a result of processes triggered by recovery of groundwater level as a result of mine closure. In spite of essential regional differences of geochemical and hydrogeomechanical structure within the investigated region, some general features can be observed:

- Increase of mineralization practically everywhere,
- Change of groundwater composition in the direction of mine waste water and technogenic water (mineralization, hardness, sulfates, chloride, nitrate, Pb, Ni, Cu, Mn and Fe ions),
- Continuous deterioration of groundwater used for drinking water supply when the well fields are located within mine and industrial agglomerations.

It is shown, that the Hygienic Index (Σ (c_i/c_{pc}) for some investigated wells and springs can be as high as 44; c_i and c_{pc} are the actual and permissible concentration of the component “i”.

Donbas is the region with water consumption exceeding water resources by a factor of 4.5. This strange figure is explained by re-infiltration of groundwater pumped for mine drainage. The main source of water supply is surface water from the river Dnieper and the channel Dnieper-Donbas.

Major part of hot spots is situated in depressions of the ground surface (local ravines, slopes of river valleys) and these locations are most vulnerable to flooding. The most dangerous hot spots in the flooding situation are those containing liquid waste. Every flooding will generate in such location a huge influx of a wide range of contaminants into the aquifers. This plume will flow towards well fields collecting water from several km^2 and water quality will deteriorate.

Well fields may be contaminated by inflow of mine water through permeable, tectonic structures. It is known, that mine water from abandoned galleries is polluted by heavy metals, organic compounds and chemical compounds.

Change of pH of precipitation and change of moisture content within the unsaturated zone may lead to creation of new, mobile form of contaminant. The restructuring of industry may change the composition of exhaust gases which can disturb the geochemical equilibrium in soils and in the unsaturated zone.

3.8 Vulnerability assessment

Presently no standard procedure for vulnerability mapping is agreed upon. In our project a dynamic approach to the concept of vulnerability is adopted, where the existing (modeled) groundwater flow field and its interaction with nature and technogenic factors plays an important role.

3.8.1 Principles for construction of vulnerability map

An assessment of groundwater vulnerability was carried out and groundwater vulnerability map - combining different types of information into few vulnerability classes - is constructed. Each parameter was divided into five intervals and a numeric value ranging from 1 to 5 was assigned to the various intervals. The small numeric parameter values are lowering vulnerability while the high parameter values are increasing vulnerability (vulnerability is obtained by addition of the numeric values of the parameters used for vulnerability definition). Parameter values are assigned for each $2^x 2$ km cell – in agreement with discretization of the regional hydrogeological model.

Construction of vulnerability maps was done in following steps:

- Parametric maps for the selected parameters were prepared and a fixed value for every node in the modeled area was assigned,
- For each 2x2 km cell parameter values for the three parameters were added,
- Three “vulnerability classes” were defined and “low”, “medium” or “high” vulnerability value was assigned for each cell.

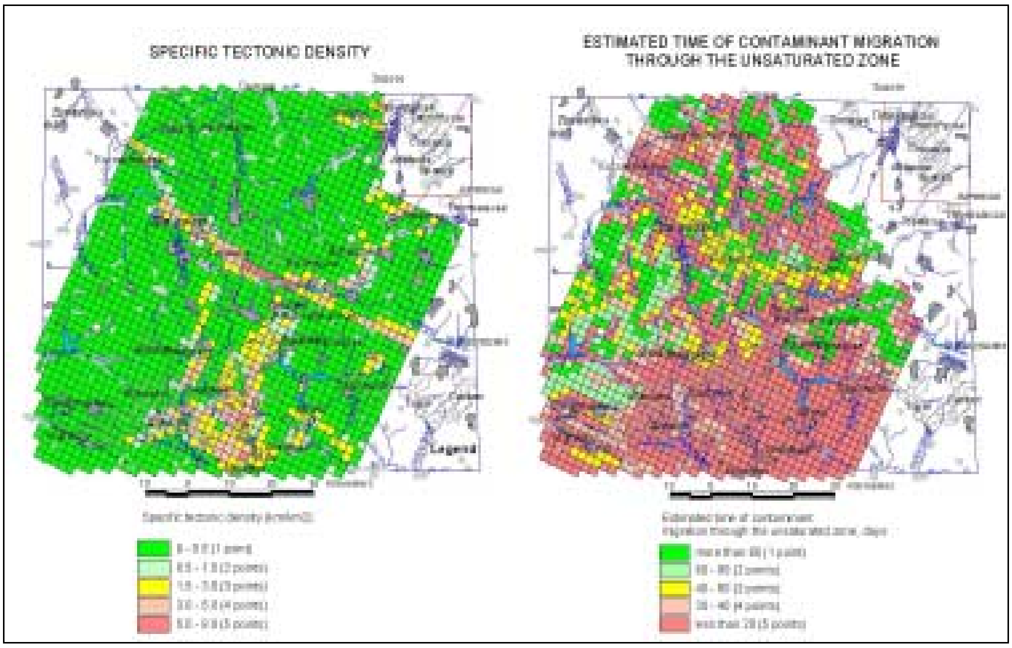
3.8.2 Vulnerability map

Following three parameters were used for construction of the aquifer vulnerability map: *specific density of tectonic structures*, the calculated *travel time of the contaminant through the unsaturated zone* and *specific density of river system*, see Fig. 23.

Specific density of tectonic structures is one of the major factors influencing vulnerability. High density of tectonic structures increases aquifer vulnerability due to high vertical permeability within fault zones and high risk of contamination of upper (fresh) groundwater reserves with deeper (brackish or saline) water flowing along active faults. This parameter is defined as a ratio of the total length of faults within a cell to the area of the cell. For the major part of the investigated area value of this parameter is less than 0.5 km^{-1}. There are only few cells where this parameter exceeds 5 km^{-1}.

Travel time through the unsaturated zone is the most frequently used parameter in vulnerability assessment. High travel times correspond to low vulnerability and low travel times to high vulnerability. It is due to the fact, that sorption and transformation of contaminants is favored by longer residence time. For large part of the investigated area travel time is estimated to less than 20 days which correspond to high vulnerability. For relatively small percent of the area travel time is longer than 80 days which correspond to low vulnerability. Travel time values for the investigated area are quite atypical: normally 80 days will be regarded as relatively short period of time. But in our case the natural water exchange is destroyed by heavy pumping and excessive, forced infiltration which has been practiced in this region during the last 100 years.

A **B**



C **D**

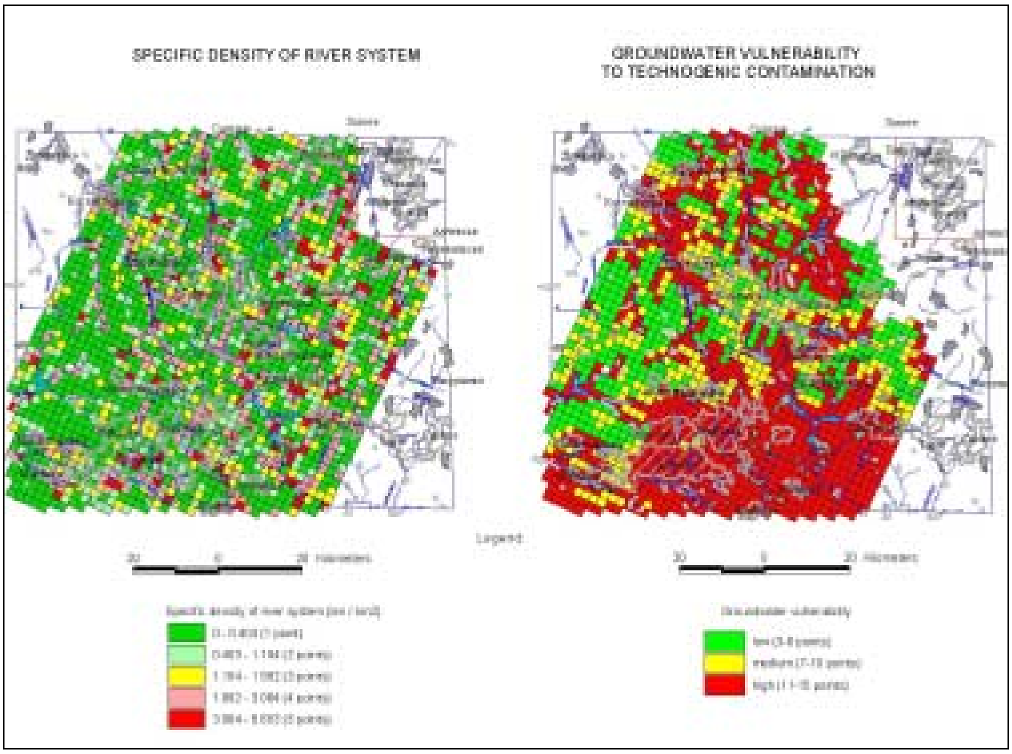


Fig. 23: Groundwater vulnerability as a function of three parameters: A: specific tectonic density, B: migration time through the unsaturated zone, C: density of the river system

Specific density of river system is the third parameter used to define aquifer vulnerability. In the Donbas case high density of rivers correspond to high vulnerability, while low density will lower vulnerability rating. In majority of cases the valuation of this parameter would be opposite – the rivers normally drain aquifers and protect groundwater from contamination. In Donbas region majority of rivers normally discharge contaminated water and contribute to groundwater pollution. For that reason: more km of rivers per km^2 results in higher vulnerability rating. Further more, infiltration ponds and channels are taken into account during preparation of this parametric map.

"Vulnerability values" (three-parameter vulnerability map) for the sequence of Quaternary and Carboniferous aquifers complex were obtained by addition of parameter values in the nodal points, are within interval 3-15. Vulnerability classes of the aquifers complex are as follows:

- Low ("vulnerability values" less than 6),
- Medium ("vulnerability values" between 7 and 10) and
- High ("vulnerability values" between 11 and 15).

As it was to be expected, the vulnerability trend coincides with the major tectonic features in the region, especially within the coal mines fields. There are some similarities between parametric maps valid for the specific density of tectonic structures and the river system. That is why the most part of undermined territories and local towns are placed close to the most vulnerable spots.

The vulnerability map would be different if other scenario (and/or) other parameters were chosen. For the scenario assuming closure of all (or selected) mines in the region two new parameters should be added: the vertical gradient, groundwater quality in the lower strata (for salt intrusion from below) and quality of water infiltrating from above (mainly with regard to micro-pollutants).

3.9 Other outputs

In addition to the primary outputs of the project described above, there are some additional outputs which are more difficult to quantify.

3.9.1 Increased expertise of Ukrainian institutions

One of the important outputs of the project is a significant increase of IGS NAS, GEOINFORM and IGEPD abilities with regard to performing regional ecological and hydrogeological investigations. It is due to introduction of new investigating procedures and due to technical facilities provided by the project. It is obvious, that the significant interest in Project findings is partially due to the computerized data processing of environmental information and the regional modeling carried out within the Project.

IGS NAS, Ukrainian State Geological Survey Institute and IGEPD are the natural choice when location of the new Database and the hydrogeological model created within the project is considered for such complex region as Donbas.

Another possible field, where these Institutes can offer competitive expertise, are the field of soil and groundwater contamination investigations. The training in application of a specific software dealing the geological media transformation during coal mine closure process is of great value for these institutes and offers an essential advantage in attempts to solve specific problems of Donbas.

3.9.2 New approach to handling ecological problems in mining regions

Project activities were subjected to a high public interest due to the importance of mine closure problem for the local population. The approach adopted by the Project had a regional and comprehensive character which allowed to look at the consequences of actions taken at one site on the environmental situation in adjacent areas. The idea about a real assessment of the situation – rather than “physical closure” of some selected mines – is now more accepted by the environmental authorities and the administrative body responsible for mine closure and distribution of public money assigned for this task.

3.9.3 Implementation of new computer hardware and software

New computer software and hardware was purchased for the Project funds. Presently, the Ukrainian partners of the Project are fully compatible with foreign institutes working within the hydrogeological/environmental field. GIS, computer network and specialized database were implemented in Kiev.

3.9.4 Groundwater monitoring network

Presently, there is no systematic groundwater monitoring in Donbas region. No institution is responsible for data collection and practically no wells are available which can be used for this purpose. The district environmental authorities are expecting in the near future a significant increase of demand the information about ecological parameters for groundwater and therefore there is considerable interest and will to implement various types of groundwater monitoring.

A decrease in groundwater withdrawal due to numerous coal mine closures will result in increase of the stress on aquifers and in such situation a well-functioning groundwater monitoring network is required. There is a need to establish a general type of a monitoring systems at a regional level and a local level around coal mine fields. In addition, several specific monitoring systems for control of water level recovery (within and outside mine fields) and for control of contamination from existing and potential contaminant sources: flooded landfills, chemical plants etc.

During the project a detailed information about Danish experience with groundwater monitoring was provided and Danish equipment and methodologies demonstrated in field conditions.

UkerUgleRestrukturyzacja propose co-operation with design and implementation of a monitoring system related to mine closure process.

3.9.5 Seminar and conferences

Project key persons participated in following seminars/conferences:

Table 6: Contribution of Project staff to various seminars and conferences

No	Date and location	Project-relevant subjects discussed	Participants
1	12.06. 01 Meeting at the Donetsk Oblast State Administration	❑ Deterioration of groundwater quality during mine closure ❑ Other consequences of mine closure: geochemically aggressive soils, local earthquakes, explosive gas migration	Dr. Sc. Yakovlev, Prof. Galetskiy, Mr. Madsen and Dr. Gosk, Officials from the state administration
2	17-21.09.01 International Conference: Regional Ecological Emergencies in Ukraine, Crimea	❑ Irreversible ecological changes within the mining areas ❑ Problems connected to water table recovery ❑ Groundwater vulnerability in mining regions	Dr. Sc. Yakovlev
3	26-27.10.01, Donetsk, Central Ecological State Administration and Geological Exploration Institute of Ministry of Environment Lectures for directors of coal mines	❑ Geological conditions and environmental situation within mine “Yankom” where nuclear bomb was exploded at 903 mbs in 1979 ❑ Possibilities for an assessment of ecological risks associated with flooding of the mine, using the hydrogeological model developed within the Project	Dr. Sc. Yakovlev, Mr. Slyadnev,
4	09.11.01, Kiev Session of Parliamentary Commission for Radioactive Protection	Radiological risk connected to flooding of an underground cavern in Donbas region containing large quantity of highly radioactive material	Dr. Sc. Yakovlev presented the report for the 14 members of the National Commission
5	16.11.01, Kiev Session of Ecological Parliamentary Commission	Regional problems of flooding within mine districts of Ukraine	Dr. Sc. Yakovlev
6 6.1 6.2 6.3	20-21.11.01, Donetsk. International Conference: “Donbas-2020: Protection of environment and ecological safety” 3 session reports 2 lectures at the local Institute Information about the Danish-Ukrainian Project presented for Horlivka District State Administration and 12 directors of the local coal mines	❑ Main factors and conditions which have to be considered during mine closure and ecological safety issues ❑ Consequences of mine closure ❑ Horlivka and Yenakiyevo mine districts as examples of high ecological hazards in the light of the Project findings	Dr. Sc. Yakovlev, Dr. Gosk and Mr. Slyadnev, local politicians and MPs from Kiev, local environmental administration, scientists and leaders of private enterprises

3.9.6 Visit to Denmark

In June 2000 eight person Ukrainian delegation visited Denmark for a four days period. The group consisted of Prof. Galetskiy L.S. (IGS NAS) – Chairman of the delegation, Dr. Sc. Yakovlev Ye.A., Dr. Melnik I.V. (Geoinform of MoENRU), Dr. Babaev M.V., Dr. Magmedov V.G. (Water ecological laboratory of MoENRU), Mr. Slyadnev V.A., Ms. Yurkova N.A. (Geological Fund of MoENRU) and Ms. Volyk O.S. (IGS NAS).

There were two main items on the program for this visit: meetings in GEUS, and a field trip to a famous Danish Chalk outcrop: Møns Klint.

The visit at GEUS was dealing mainly with the problems of storage and processing of environmental data and with logistics and techniques of groundwater monitoring. The visitors had the opportunity to discuss specific issues with the different departments of GEUS.

4. Project inputs

The primary project inputs consisted of:

- 12 man-months from the Danish side
- 130 man-month from the Ukrainian and Russian side
- Computer Hardware
  Work station (N.B. Mitac 6133) (one)
  Transportable PC (one)
  Pentium PC (three)
  Canon FC-220+E16 (one)
  Printer Epson Photo EX (two)
  HP Scanjet 5200C (one)
  Modem GVC 56000 V.V.90, extended with cable (two)
  Plotter HP 450C A1 (one)
  Computer network
- Computer software
  ArcView 3.1 for Windows
  ArcView Spacial Analyst for Windows
  ArcView 3D Analyst for Windows
- Chemical analyses of soil, water, snow
- Complete analysis at certified lab. of ”key” samples
- Purchase of internationally certified standard soil material
- Consumables (paper, analytical glassware, ink, etc.)
- Travel and accommodation

5. Project sustainability

Project sustainability depends mainly on two factors: sincere interest and possibilities of the local authorities in providing financial and administrative support necessary for practical implementation of the project results and availability of the local expertise necessary for carrying out the work.

We have all the reasons to believe that the level of Oblast State and Ecological Administrations support - achieved during Project time - will get even higher during the next phase of the Project. IGS NAS, State Institute of Geological Survey of MoENRU and IGEPD are perfectly capable of continuation of the work.

Several results of the project are already being discussed by the authorities, local project and scientific institutes specialist and various steps are considered. A translated and modified version of the Completion Report will be prepared and distributed among the relevant bodies as first and principally new example of a proper assessment of environmental situation at a regional level.

The alarming results of some of the chemical soil analyses – mainly with respect to high degree of contamination by heavy metals and prognoses for groundwater rise – has triggered plans about promoting groundwater monitoring in the district. Besides the obtained results of groundwater vulnerability assessment had given the principally new information about environmental hydrogeological conditions within the Central Donbas.

Database created within the project and the results of hydrogeological modeling are going to be utilized in assessment of groundwater level regime changes within coal mine closure zone of influence – a task which is supported by the Donetsk Oblast State Administration, ecological authorities, scientists and specialists of MoENRU. In this context we were lucky to have support of the Chairman of the Steering Committee, L.F. Mironov, who is a recognized authority in the ecological reconstruction of closed coal mines in Donbas region and author of several publications dealing with this subject. He has promoted co-operation and co-ordination with the on-going activities and will assure that results are utilized in the future work.

The Steering Committee and the local and central environmental authorities found the approach adopted by the project to be practically oriented and feasible for the conditions not only of Ukrainian part of Donbas but for the neighboring Donbas region of Russia.

The substantial assistance from the project in providing technical means for conducting of the work and the substantial training of the IGS NAS and Ukrainian State Geological Survey Institute of MoENRU personal in utilization of the “state of the art” computer hardware and software created a lot of good will and contributed to the sustainability of the project.

It is important, that groundwater protection and safe coal mine closure process within Donbas Region can be supported by the complex hydrogeological investigations carried out within the Project. The authorities are aware of high vulnerability of their water supply system and the risks involved with various dangerous geological processes taking place in the mine closure situation.

The attitude of the administration of the district is essential for the sustainability of the project and we were very pleased, that the Oblast State Administration and Ecological authorities took active part in the implementation of the project result among the coal mine companies and organizations. Besides, the authorities actively support the plans for the next phase of the project in the geologically most complicated and environmentally most threatened central part of Donbas.

6. Impact assessment

The impact of our project can be evaluated in different contexts: as an impact due to introduction of new approaches to the solution of the coal mine closure problem, as an impact on development of professional relations between the parties involved and as an impact of project results on the environmental practice in the investigated Central Donbas Area.

The Danish-Ukrainian teamwork performed smoothly and all the tasks were solved to full satisfaction of all the parties involved with the necessary adjustments of investigation caused by a wish of the Ukrainian side to put more emphasis on one of the most urgent problems facing Ukraine: the consequences of mine closure in the Donbas area. The professional relations are strong and the good will created during the project can and will be used in the future co-operation. The skills acquired during reconstruction assessment of the old mining region are very important for more deeper understanding of the ecological consequences and for reduction of the negative impact of mine closure.

There are two types of results provided by the project: the "expected" and the "surprising" results. The impact is different for these two groups of results. The definitely positive impact is related to the "expected" and predictable results, like: construction of complex geological, hydrogeological and geodynamical model for the district, construction of groundwater vulnerability maps, mapping of the existing contaminated sites, transfer of technology and know how, assessment of the influence of chemical and mechanical changes of geological media on environment etc. The "surprising" results are related to our sampling round across the district and discovery of a wide-spread contamination of groundwater by heavy metals, oil products and others organic compounds. These foundings are very important for the forecast of the influence of chemical parameters within zones of regional groundwater level recovery after mine closures. Project assessment shows continuos deterioration of engineering-geological parameters for soils and significant increase of aggressiveness of groundwater. And this discovery represents a serious problem for the community and for the environmental authorities of the district. It may be necessary to revise the existing mine closure schemes if the alarming results of our last model forecast, together with the geochemical, groundwater vulnerability and geomechanical assessments will be taken into consideration.

The Donetsk and neighboring Luhansk Oblast State Administration as well as MoENRU are satisfied with the results of our project and with the wide distribution of information in form of Bulletins to the local authorities in other districts.

Donetsk Oblast State Administration expressed its support for the next phase of Danish-Ukrainian investigation in the mine closure process with the co-operation in some local program.

It should be noticed, that the results provided by our Project are utilized by people at the top political level in Ukraine. Mr. J. Samoilenko, the chairman of the "Tjernobyl Committee" of the Supreme Council of Ukraine, wrote a letter to the Ukrainian President L.D. Kutchma to the Prime Minister and to the head of the National Security Council of Ukraine about the problems facing Donbas. The letter refers to the findings of our project as presented by Dr. Sc. Y. Yakovlev during a meeting in Donetsk in November 2001, see chapter 9.3.

7. Recommendations

The recommendation for future activities in the Donbas coal mine district were discussed on several occasions. The Steering Committee of the Project, project management and the Oblast administrative and environmental authorities agree about priorities for the future activities for the Danish/Ukrainian co-operation. Mr. V. Vasylchenko - the Program Coordinator from the DANCEE participated frequently in these discussion and it seems that he supports the ideas that the physical mine closure have to be preceded by an assessments of environmental situation. The model developed within the Project should be used for this purpose. It was pointed out by the DANCEE representative that present project for Central Area of Donbas has high priority: He advised, that the next phase of the Project would be more effective if co-financing and direct co-ordination within the local environmental program was provided by the Ukrainian side. Project involving direct investment into contamination-preventing and/or contamination-reducing activities will have Danish priority.

It is recommended that following activities continue in Phase II:

1. Preparation of guidelines for procedures leading to a rational mine closure,
2. Risk assessment for the probably most dangerous Hot Spot in the Donbass region: the Horlivka dump site containing 300.000 tones of chemical and military waste in abandoned galleries at 300 m depth,
3. An evaluation of the Yenakievo site containing large amount of highly radioactive water at 900 m depth,
4. Improvement and extension of the existing hydrogeological model for the region which will make it possible to perform detailed modeling for Horlivka and Yenakievo locations,
5. Establishment of a pilot monitoring system for control of water and gas movement at selected, high risk location,
6. An assessment of consequences for various mine closure scenarios; technical, social, economical and health risk factors should be taken into account,
7. Creation of a geo-environmental data base for the Central Donbas Area containing information about principal geological media transformation during the mine closure process.

Both the central and the local environmental authorities have expressed an interested in establishment of monitoring networks in the Donbas region. Such interest was expressed by the UkerUgleRestrukturyzacja - Ukrainian state company created for solution of problems connected to coal mine closure. Therefore it should be expected, that these authorities will act as possible Ukrainian source of co-financing of the second phase of the Danish-Ukrainian project.

The Ministry Environment and Natural Resources of Ukraine - in accordance with the Cabinet of Ministry and Supreme Soviet decisions - will finance several large-scale investigations of environmental situation in Donbas and others old mining regions. This will represent an essential contribution to the solution of the tasks, planned to be carried out within joined Danish-Ukrainian project.

8. Lessons learned

Donbas is a region where the hydrogeological situation is changing rapidly and due to influence of coal mine closure. Our Project is the first methodological and practical attempt to investigate this new situation at a regional scale.

At the project start there were few delicate issues connected to the possible problems in relation between the various participants of the project. IGS NAS and GEOINFORM have always been the main reference for all the geological and hydrogeological institutes in the whole Ukraine, preparing manuals for all the others to follow. In our project all participants had to be partners and the progress of the project could be obtained only if the interests and origin of the different partners was not an issue. We have learned, that our worries were unfounded and it was, for example, perfectly al right to send IGS NAS, GEOINFORM and ECOTE people to GEUS (Denmark) for training in use of specialized modeling and contamination-related software. Sharing of the information and results among all the participants of the Project is a key issue for success.

The decision about adopting all the information originating from different sources into one coordinate system and one type of computer processing software was justified. This made it possible to present results in a unified form.

A lot of effort and energy was spend on information to and consultation with the Oblast State Administration and Environmental authorities. That resulted in powerful feed-back and efficient dissemination of our results (*Information Bulletin 1* and *Information Bulletin 2*).

As everywhere, it is difficult to assure participation of the best local personnel on a permanent basis for a period of two years. Therefore the possibility to regulate the participation of local personnel through monthly payments is very valuable and highly appreciated tool in the hands of the Danish Project Manager.

In spite of the very applied and practical approach to the problems solved by the project, there was a space for a new development in the scientific field: the recently introduced concept of “Dynamic Vulnerability” of groundwater was extended to take into account conditions specific for the Donbas region: tectonic density and river density. This aspect proves that strong synergy exists when approaches from different professional environments are combined.

Strong and practically oriented Steering Committee is an asset for a project. Good will and professional guidance from our Committee helped us to streamline our approach and make it compatible with the expectations of the future users of our results.

9. Annexes

Annexes prepared within the project are divided in “Appendixes” – task reports describing the various project activities and translations of various correspondence relevant for the project activities already conduced and for plans for the future.

In addition some letters of support and letters relevant for the project are included in translated version.

9.1 Task reports

Seven reports dealing with various task have been prepared within the project. Two of these reports (Nos 5 and 7) are included with the Completion report, while the other task reports have been delivered earlier.

- *Appendix 1: Data Inventory, Completion report for Task 1,November 2000,*
- *Appendix 2: Hot Spots Mapping, Completion report for Task 2,November 2000,*
- *Appendix 3: Additional Data, Completion report for Task 3, November 2000,*
- *Appendix 4: Characterization and assessment of cartographic and factual data prepared for Hydrogeological model of Donetsk-Makeevka and Central Mining - Industrial Region, Completion report for Task 5 November 2000,*
- *Appendix 5: The action on closing coal mines, geologo-environmental and social consequences, VSEGINGEO, Moscow 2000,*
- *Appendix 6: Present Environmental Problems of Groundwater Remediation under mass closure of Mines in Some Districts of Donbas, Bulletin 1, Kyiv, Donetsk, Luhansk and Copenhagen, 2000,*
- *Appendix 7: Soil Analyses, Donbas Region, Ukraine; Copenhagen, Kyiv, Donetsk, Luhansk, 2002.*

Appendixes 5 and 7 were prepared in English version only. An extended version of a News Bulletin (in Russian only) was prepared and widely distributed to the relevant authorities and industries in the Donbas region. The title of this bulletin was: *INFORMATION BULLETIN No 2: Preliminary assessment of regional influence of mine closure within Donetsk-Makeevka-Horlivka-Yenakievo industrial agglomeration on activation of flooding processes, deterioration of engineering-geological conditions and increase of groundwater vulnerability, Kiev-Donetsk-Copenhagen, 2001.*

The final editing of this report and preparation of *Appendixes 1, 2, 3, 4* and *6* was done by Dr. Sc. Ye. Yakovlev, Prof. L. Galetskiy and Dr. E. Gosk.

Appendix 5 was prepared by the VSEGINGEO.

Appendix 7 dealing with soil samples was prepared by Ms. Agnete Steenfelt, Senior Researcher from GEUS assisted by Prof. Galetskiy, Dr. Sc. Yakovlev and Mr. Dudzik.

9.2 Letters of support

Project activities and the idea about continuation of the Project is receiving strong support from the Ukrainian authorities and from the Donbas industry. Translations of the letters from the Mr. A.P. Beliy - the vice-president of the Donetsk Oblast State Administration and from Mr. S.A. Taruta – the Chairman of the Board of Directors of the "Industrial Alliance of Donbass" are included below.

15.10.2001 No. 7-12-2764

To Mr. Martin Ghisler,, the General Director of the Geological Survey of Denmark and Greenland (GEUS)

On desirability of conducting
the 2nd phase of the Danish - Ukrainian Project

Dear Mr. Ghisler

In 2001 the government of Ukraine has adopted the state program "Ukrainian coal", which concludes, that coal is one of the major energy resources of Ukraine. This program is provided for 2001-2010 years. The program foresees the reduction of the total number of operating mines within the Donetsk region by 49 until to the end of 2001. Mine closure resulted in an improvement of the environmental parameters for these 49 mines..

At the same time the difficult conditions of mining operations in Donetsk area lead to the development of the following processes: flooding, land subsidence, contamination of well fields etc. All these problems are observed during the process of mine closure. The difficult conditions in the Donetsk region are primarily created by a lot of mineralized water flooding the mines and migration of methane gas. The methane gas of carboniferous rocks is considerable energy source itself, the usage of which can increase ecological and economic efficiency of depth usage and decrease technogenic load on the natural environment.

The Donetsk Oblast State Administration repeatedly considered the perspective of industrial extraction of methane from the carboniferous rocks with the purpose to decrease the hazard of explosions in mines and increase the energy potential in the region. At the same time the mine closure leads to decrease of water saturation of carboniferous rocks and decreasing of gas production of the rocks.

The results of regional modeling, carried out within the framework of the Danish-Ukrainian project ***"Groundwater Protection and Remediation in Donbass Region, Ukraine",*** showing raise of groundwater levels and flooding of closed mines, confirm the possibility of changes of methane movement and accumulation. The obtained results can be used in projects dealing with placing and construction of the wells for methane mining. The regional estimations of the water saturation of carboniferous rocks owing to mine closure within the Donetsk-Makeevka-Horlovka-Yenakievo agglomeration have been obtained according to modeling. Such results allowed to increase reliability for area forecasting of the risk of explosion in the mines.

In connection with above-stated points, we consider the 2nd phase of the Danish-Ukrainian project will be important for detailed forecasts of groundwater levels variations within the Central mining region and the adjacent regions. These regions are characterized by complexity of the geological conditions, different level of gas content of carboniferous rocks, and also underground burial of highly-toxic wastes.

The support of the Geological Survey of Denmark and Greenland (GEUS) for the 2nd phase of the Project will promote progress of scientific, technical and business cooperation between two countries, and also the growth in integrated approach and ecological and economical efficiency of the Danish-Ukrainian works in the Donbass mining region.

Yours faithfully,
vice-president of the Donetsk Oblast State Administration Beliy A.P.

11.10.2001, No. 337/9177

To Mr. Martin Ghisler, the General Director of the
Geological Survey of Denmark and Greenland (GEUS)

On desirability of conducting
the 2-nd phase of the Danish - Ukrainian Project

There are more than 240 mines at depth 800-1300 m within the Ukrainian part of the Donetsk coal basin. Difficult conditions of mining conditioned by mineralized waters flooding in mines and explosion-dangerous methane gases, result in unprofitable mines closure and their flooding. At the same time methane gas of carboniferous rocks is considerable energy resource. Using such energy resource will promote increasing of integrated approach of depth use and solution of complex ecological and economical problems of the region.

The "Industrial alliance of Donbass" carries out complex of economical and technological mining for industrial extraction of methane from carboniferous rocks with the purpose to decrease risk of explosions in mines of Donbass and to develop new sources of energy within the region. The Corporation has spent 30 million US $ on initial experimental and industrial work taking into account considerable methane resources of coal bearing rocks, their high energy potential and ecological and economical efficiency.

The information provided by modeling of regional raise of groundwater levels causing flooding of closed mines - which have been obtained within the framework of the Danish-Ukrainian project ***"Groundwater Protection and Remediation in Donbass Region, Ukraine"***, is of great practical importance for a determination of methane movement and accumulation. The obtained results can be used in projects that deal with placing and construction of the wells for methane mining. The regional estimations of the water saturation of carboniferous rocks - owing to mine closure within the Donetsk-Makeevka-Horlovka-Yenakievo agglomeration - have been obtained from the modeling results. Such results allowed to increase reliability for area forecasting with increased explosive risk in mines.

In connection with the above-stated points, we consider the 2nd phase of the Danish-Ukrainian project to be rational continuation of the 1st phase. It is necessary to make detailed forecasting estimations of groundwater levels variations within the Central mining region and the adjacent region as well. These regions are characterized by complexity of geological conditions, different level of gas content of carboniferous rocks, and also underground burial of highly-toxic wastes.

The support of the Geological Survey of Denmark and Greenland (GEUS) for the 2nd phase of the Project will increase environmental and economical efficiency of the Danish-Ukrainian co-operation in the Donbass mining region.

Yours faithfully,
The Chairman of the Board of Directors of the
"Industrial Alliance of Donbass" Taruta S.A.

9.3 Letters to the Ukrainian president and to the head of the Ukrainian Security Council

Project staff participated in several meetings dealing with present and future environmental situation in the Donbas region. During one of these meetings in Donetsk in November 2001, consequences of uncontrolled and uncoordinated mine closures were presented by Dr. Sc. Y. Yakovlev – the leading scientist in our Project. Mr. U. Samoilenko, the head of the “Tjernobyl Committee” of the Supreme Council of

Ukraine, who participated in this meeting, have send a letter to the President, L.D. Kutchma to the Prime Minister and to the Secretary of the Security Council of Ukraine describing the expected emergency situation which will occur in connection with present style mine closure.

Translation of this letter is included below:

To Mr. L.D. Kuchma
The PRESIDENT of UKRAINE

About ecological consequences of mines closure and warning with regard to deterioration of environmental conditions within the Donbass region

Dear Leonid Danilovich,

On execution of Resolution of the Supreme Soviet (Ukrainian parliament) from November 15, 2001 № 2815-Ш "About the report of the Cabinet of Ministers of Ukraine concerning socio-economic consequences of mines closure", the Committee has analyzed the changes of ecological state within the Donbass region during 1998-2001. An essential worsening on the conditions for majority of mining territories, as the result of mines closure and flooding, is observed. Increasing of number of mines, which are closed by the method of wet conservation, had result in: an increase of saturation for the ground resulting in increase of frequency and duration of flooding within the Stakhanov, Krasnodon and other mine-urban agglomerations, accelerated land subsidence, creating new pathways for the salty and contaminated groundwaters, explosive gases migration in the functioning mines and within the boundaries of settlements.

Raising of groundwater level outside (5-10 km and more) the technical boundaries of the separate mine fields is the main factor causing deterioration of the ecological state of the territory. The increase of risk of ground saturation and flooding is created within the undermined territories with essential subsidence of the day surface from 2 to 7 m within an area of about 8,000 km^2; the total area of mining works is about 15,000 km^2. High population density and high concentrations of industry and polluting sites will result in severe consequences of flooding of inhabited and industrial areas. Town-creative character of the majority the mining regions within Donbass is predetermined the flooded area increasing and worsening an ecological state of massifs by a housing and industrial massives, where the big quantity of the ecological dangerous plants are situated and higher density of population is observed. Already today there is a real threat of non-governed flooding the chemical wastes within the Gorlivka and zone of the underground atomic explosion on mine "Yunkom" (town Yenakievo) with possibility of the regional surface and underground water intakes, coastal zone of the Azov sea contamination.

Preliminary estimations of the Institute of geologic sciences of National Academy of Sciences of Ukraine and Ukrainian state research institute of the Ministry of Environment and Natural Resources the area of flooding within the coal industrial and urban agglomerations of Donbass can increase till 25-35% of their total territory during next 8-10 years (during closure 30-40 % of operating mines).

Failure to take account of regional influence of separate mines and their groups closure in the projects, which one will be realised by Ministry of fuel and energy, is connected with the absence in the Resolution of the Cabinet of Ministries of Ukraine from 12.01.99 №31 " About measures of a solution of ecological-hydrogeological problems, which one arise in a consequence of mine plants, mines and quarries closure" of the corresponding assignments(orders) concerning ecological security of territories, which are neighboring with the boundaries of mine fields.

As a whole, dear Leonid Danilovich, on our view in Donetsk region the very alarming ecological tendency is developed, which one can have extraordinary social and economical consequences for the state. Practically the speech can go about impossibility of constant and ecologically safe existence of the big quantity of industrial - urban agglomerations within Donbass as soon as possible.

In connection with above-mentioned the Committee regards the necessary to address to you with the following propositions:

1. To charge to the Council of National Security and Defence of Ukraine to check the implementation by Ministry of fuel and energy, Ministry of ecology and natural resources, regional state administrations of the Resolution of the Cabinet Ministry from 12.01.99 № 31 " About measures of a solution of ecological-hydrogeological problems, which one arise of in consequence mine plants, mines, and quarries closure" and to evaluate the effectiveness of measures under the warning of negative consequences for neighbouring territories, their housing and industrial objects.
2. To charge to the Cabinet Ministries of Ukraine to prepare the draft of the State Program about urgent measures on prevention of regional ground water levels and salted mine waters raising and its influence on ecological and socio-economic situation within industrial - inhabited agglomerations in Donbass and Ukraine as a whole.

We are considering, that the accelerated implementation of the above mentioned measures will promote the prevention of a further heightening of the social stress and originating of extraordinary ecological situations connected with the mass closure of mines in the technogenic overloaded regions of Donbass. On our view, it will allow also to stabilize of the ecological situation within region and to increase the effectiveness of state and domestic budgets use.

Yours faithfully,

Chairman of Committee Yu. Samoylenko