Union Civil Protection Mechanism

# Advisory Mission to Ukraine "Solotvyno salt mine area"

## RISK ASSESSMENT REPORT

Figure: Crater Mine No 7

October 2016

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**Executive summary**

## Introduction

This Risk Assessment Report focuses on the technical aspects of the European Union Civil Protection Team (EUCPT) advisory mission to Ukraine. It discusses in detail the following mission objectives:

- *Conduct a comprehensive risk assessment at the Solotvyno salt mines area.*
- *Advise on the development of a monitoring system with local, state and international stakeholders in order to determine milestones for next steps.*
- *Make short, medium and long term recommendations, including potential mitigation and engineering solutions.*
- *Make follow-up observations on immediate measures to be taken by the Ukrainian authorities on recommendations provided by the EUCPT during the scoping mission.*
- *Identify next steps to be taken by the competent authorities and appropriate stakeholders for hand-over of the findings, recommendations and suggestions for further work.*

## Mission context

On 12 January 2016, Hungarian and Ukrainian civil protection authorities addressed a letter to Commissioner Stylianides regarding a cross-border environmental pollution concern at the Solotvyno salt mine complex in Ukraine.

The Union Civil Protection Mechanism (UCPM) was activated on 17 June 2016 and deployed a scoping mission between 2 to 9 July to support the national authorities. The scoping mission produced a technical report shared with Participating States (PS) and Ukrainian authorities (UA) and draft a *"Terms of Reference"* (ToR) for an advisory mission.

Based on the findings of the scoping mission, it was decided to deploy an advisory mission in order to conduct a *"comprehensive risk assessment at the Solotvyno salt mines area"*. The deployment took place from 14 September to 7 October 2016.

The EUCPT are particularly grateful for the exceptionally high level of cooperation of the Ukrainian technical experts from the National Academy of Science (NAS) of Ukraine: Professor D. Khrushchov and Dr Y. Yakovlev, Head Scientific Researcher and corresponding member of NAS of Ukraine, Dr S. Shekhunova. Their professional and open approach to information sharing with a clear focus on the main objective of producing a *"Risk Assessment"* of the Solotvyno mine area was evident at all times.

## Methodology

The advisory mission applied the following methodology and processes to complete the risk assessment report:

Figure 1: Workflow Process

In order to structure the work and tasks, the team followed a practical workflow process, which consisted of the following phases *measurements*, *assessments* (including interviews and fieldwork) *processing of information* (data analysis) and reporting. This was done following a risk assessment model, as per the Commission Staff Working Paper on "Risk Assessment and Mapping Guidelines for Disaster Management".

Following this methodology, the following activities were conducted:

- Pre mission desk research.
- Pre mission technical workshop in Brussels.
- Outputs and review of scoping mission reports and information products.
- Field assessments and investigations.
- Interviews with stakeholders at State, Regional, District and Local level, including members of the public from Solotvyno and surrounding areas.
- Water sampling and on-site measurements
- Chemical analyses were carried out on and off site. Isotope determinations were carried out in a laboratory in Germany as they needed particular requirements.
- Development and use of a risk assessment model
- Development of a dedicated GIS data base to support the mission and inform future actions and programmes.
- Detailed review and research of mining records, mapping, plans, and other historical data products.
- Detailed data and information analysis.
- Daily technical workshops and de-briefings in close cooperation with Ukrainian technical experts.
- Meteorological observations during the mission from the on-site weather station.

The seriousness of the emergency situation at the Solotvyno mine and surrounding areas quickly became apparent to the EUCPT technical experts. The team was able to produce the "*Risk Assessment*" and other mission objectives within the mission timeframe. However, due to the time constraints, it is not exhaustive.

A general determination to address this state of emergency was shown by the different stakeholders which is central in the follow-up of the scoping and advisory missions. A high level of cooperation was demonstrated between the EUCPT, Ministry of Agrarian Policy and Food of Ukraine, Transcarpathian Regional Government, Solotvyno Council Executive Committee (Mayor and Deputy Mayor), Tyachiv district authorities, Solotvyno Mine authorities, and Ukraine State Rescue Service (Mountain Rescue).

The following conclusions were reached after extensive research and investigations within the 24-day deployment-

## Main Conclusions

1. Man-made activities in combination with natural processes have resulted in an overall decay of the mine and surrounding area. This is still ongoing without it being actively managed
2. The overall area is extremely complex in terms of hydrogeological systems and the geological structure, including terrain elevation, karstification and (sub)surface water flows. Therefore, more investigations and assessments are required to get a more credible understanding.
3. The consequences of outdated mining technologies and practises along with uncontrolled and unmanaged mining processes taking place over a number of years have resulted in the general situation and state of emergency. However, the possibility of an effective and environmentally sustainable use of salt resources may be viable.
4. Poorly managed development and land use is contributing to the complexity of the issues and overall situation.

5. Through the risk assessment process, key areas of uncertainty and vulnerabilities were identified and the EUCPT was able to provide a number of recommendations to reduce and address the uncertainties and put in place the next steps and potential further actions/programmes.
6. The requirement for a suitable and viable monitoring system was acknowledged and the recommendations are contained under the coordination of the *pillar* "protecting the environment" of the EU Strategy for the Danube Region (EUSDR).
7. Although the EUCPT has not identified a significant level of salt contribution from the assessed area into the Tisza River, since the ending of mining operations in 2010, further investigation and regular monitoring is required.
8. The tipping of domestic and industrial waste is evident within the mine and surrounding areas (a notable increase has been observed since the scoping mission) and is considered a potential risk for health and environment.
9. The EUCPT was unable to make any conclusive observations on the follow up of the immediate recommendations from the scoping mission. However, Ukrainian Stakeholders (at all levels) expressed a positive encouragement and anticipation for the final advisory mission "Risk Assessment" report to act as a platform to move and address the immediate recommendations and potential future actions to address the situation at the Solotvyno mine and surrounding areas.
10. The EUCPT has developed and captured both a digital archive of legacy data and activated both the Emergency and Risk/Recovery modes of Copernicus Satellite mapping capability, including radar data.

The overall conclusion is that the vulnerability of the population in the hazardous area is high. There are significant uncertainties arising from the mining area, in terms of collapses (craters), sinkholes and potential landslides, which could either, have a direct impact on human life or an impact on buildings, houses and other constructions (infrastructure), as well as consequential effects on society and the economy. An additional finding is that the wide spread propagation of domestic and industrial waste is a potential hazard to health and the environment.

## Recommendations

The recommendations hereafter are thematically ordered, where appropriate, to enhance readability. The EUCPT advises to use the momentum of the cooperation that has been developed at all levels (State, Regional, District, Local and Scientific), to discuss the implementation of the recommendations and the follow up in terms of specific actions and projects.

The following recommendations are considered in the short, medium and long-term context, broadly approximating to 0-2, 2-5 and 5-10 -year time scales

1. ***Implement a long-term monitoring system including:***
    - Monitoring to establish a "benchmark" for the monitoring parameters;
    - Ground movement and ground levels, including landslides delivered to a common platform;
    - Groundwater quality parameters and groundwater levels;
    - Whilst monitoring data is already available, there is a requirement for continuous monitoring of the Tisza River water quality parameters and discharge rates, as well as water levels up and downstream of Solotvyno;
    - Salt and freshwater lake water quality parameters and levels;

- Establishment of a flood plain monitoring network, connected to the alluvium quality and elevation (some use of existing wells);
- A network of monitoring wells and springs between Solotvyno and the Magura Mountain;
- A programme for drinking water quality monitoring (public- and private- wells and springs);
- The sewage drainage system is important for the hydrology in the mining area, and the health of the population, but the system is damaged. Therefore, monitoring and further actions are needed (please see recommendation 8).
- Consideration of monitoring vulnerable critical infrastructure and housing

2. ***Undertake proactive, coordinated, short and medium term mitigation planning in conjunction with the monitoring and vulnerability programmes.***

3. ***Work in proactive collaboration with the EUSDR (short to long term) by:***
    - Establish a regular exchange of data and information;
    - Exploration of funding opportunities for the recommended monitoring system;

4. ***Conduct a detailed geological, hydrogeological, lithological and geomechanical model, including: (short term and ongoing)***
    - Further hazard footprint mapping;
    - The further developing of hydrogeological understanding, including seasonality and karst processes
    - Further investigation of the linkage between Black Moor and the mining area and establishment of a monitoring network, including water level and quality, such as catchment vs precipitation
    - Implementation of a programme to develop the expertise for using ground radar interferometry to monitor ground motion
    - Modelling dissolution rates and time to collapse
    - Further assessment of data archived at the Mining Museum
    - Establish the degree of connectivity between the gas field and the mining area
    - Use the model to contribute to the delivery of recommendations 1, 2, 5, 6, 7 & 8.

5. ***Revise the land use plan as a land use management plan (medium to long term), to include:***
    - A robust application of building codes and the implementation of the construction laws
    - Survey on mitigation by civil engineering programmes
    - Contingency planning for restoring critical infrastructure and business continuity planning
    - Demolish old and unsafe mining infrastructure above surface and capping of old boreholes and shafts (risk assessment).
    - Retaining wall systems
    - Relocation of the inhabitants near Black Moor (hazard zone).
    - Structural database
    - Exclusion zones

6. ***Community safety (short term action, but ongoing)***

- Improve public awareness campaign on the hazards and risks in the mining area and surroundings
- Involve local population in further risk assessments, related to the decision making process
- Continue educational programmes
- Detailed structural vulnerability survey

7. ***Develop, implement and maintain a robust Waste Management Plan (medium to long term), including:***
    - Domestic and commercial waste
    - Sewage system
    - Hydrocarbon underground storage (former soviet military base)
8. **Consider an environmentally sustainable *Economic Development Plan (medium to long term), including*;**
    - The exploration of the Solotvyno mine and surrounding area
    - The leisure (lake) area
    - The effective use of salt resources (brine and rocksalt) for health purposes (hospital: speleotherapy)
    - Consider industrial heritage to conserve old mining industrial archaeology

## More information

For more detailed information, please see the complete Risk Assessment Report which goes into depth regarding technical information, conclusions and recommendations.

## Table of content

## 1. Summary

This technical report is subdivided into two main sections; generic information and technical information.

The generic information describes amongst others, the context of the mission, the presentation of the mission, including the working of the European Civil Protection Mechanism, the cause of the risk assessment, the objectives and deliverables of the mission, the team composition and the country profile. Whereas the technical part goes into the methodology of the risk assessment, the "Solotvyno mine area" observations from a geological and hydrological perspective, findings, risks, conclusions and recommendations.

## 2. Generic information

### 2.1 Acknowledgements

The EUCP-team (EUCPT) would like to express its gratitude to those mentioned hereafter for the excellent support and cooperation throughout the mission:

- *Mrs Kovalova, Deputy Minister of Agrarian Policy and Food of Ukraine*
- *Mr Joo (Ministerial Commissioner to the EU Strategy for the Danube Region)*
- *Mr Mikulin, Deputy Head of Zakarpattia Oblast State Administration*
- *Mr Ukholj, Mayor of the Solotvyno Village Council*
- *Mr Kocherga, Deputy Mayor of the Solotvyno Village Council*
- *Mr Poshtuk, Director of SE Solerudlikvidatsia*
- *Prof. Khrushchov (Geologist)*
- *Dr Shekhunova (Geologist)*
- *Dr Yakovlev (Hydrogeologist)*
- *Mr Volodymyr (Deputy Director of Agrarian Policy and Food of Ukraine)*
- *Mr Pogar (Tyachiv Regional Administration)*
- *Mr Bondarenko (Permanent representative of Ukraine to the EU)*
- *Mr Andras (Permanent representative of Hungary to the EU)*
- *Mr Zaienko ( Deputy Director of the EU Department, Ministry of Foreign Affairs of Ukraine)*
- *Mr Malkov (International Consultant to the UN)*
- *Mr Zayats (Head of Department Civil Protection)*
- *Other representatives of private and public organisations*
- *Mr Luchner, Acting Director, Emergency Management Directorate*
- *The Participating States of the Union Civil Protection Mechanism*

The EUCP-team felt really welcome in the country and is grateful for the information shared by all partners involved in this risk assessment, including maps, technical information and data. Without this support the team would not have been able to produce this report.

The EUCP-team highly appreciates the continuous support and advice from Prof Dmitri Khrushchov (Geologist), Dr Stella Shekhunova (Head Scientific Researcher and corresponding member of NAS of Ukraine, Geologist) and Dr Yevgeniy Yakovlev (Hydrogeologist).

## 2.2 Recipients of the report

Mr Mikola Chechotkin
Head of State Emergency Services of Ukraine

Dr Tibor Tollar
Chief Counselor for Fire Services of Hungary

## 2.3 Introduction of the report

### Context of the mission:

From 2007 to 2010, flooding of two operational mines and formation of huge earth surface gaps and other hazardous geological phenomena took place at the State Enterprise "Solotvynskyi Solerudnyk" activity territory. *See figure 2.3.1.* An expert conclusion of the Ministry of Emergencies of Ukraine has defined this ecological disaster as a state level emergency (Minutes No 14 as of December 3, 2010).

The hydrogeological and geotechnical conditions of the mineral salt deposit in Solotvyno, in the Transcarpathian region of Ukraine, are reported to be precarious. Due to the dissolution process and mining works, a number of underground cavities and sinkholes have formed.

According to official data, the degraded territory covers approximately 300 residential houses, a school, a kindergarten, two municipal institutions, power lines, the gas pipeline network, local roads and a cemetery. A policy of resettlement of 70 residential houses has been initiated, but the inhabitants have not been resettled due to religious or familial reasons; this illustrates the diverse cultural and social currents in the area.

In December 2010, the situation related to these dangerous exogenic geological processes within the territory of Solotvyno salt mines was classified as an emergency by a decision of the Transcarpathian Regional State Administration. Later, this decision was approved by the expert report of the Ministry of Emergency Situations of Ukraine (No. 02- 17292 /165 dated from 09.12.2010). This resulted in the announcement of an environmental disaster at state level by the Ministry.

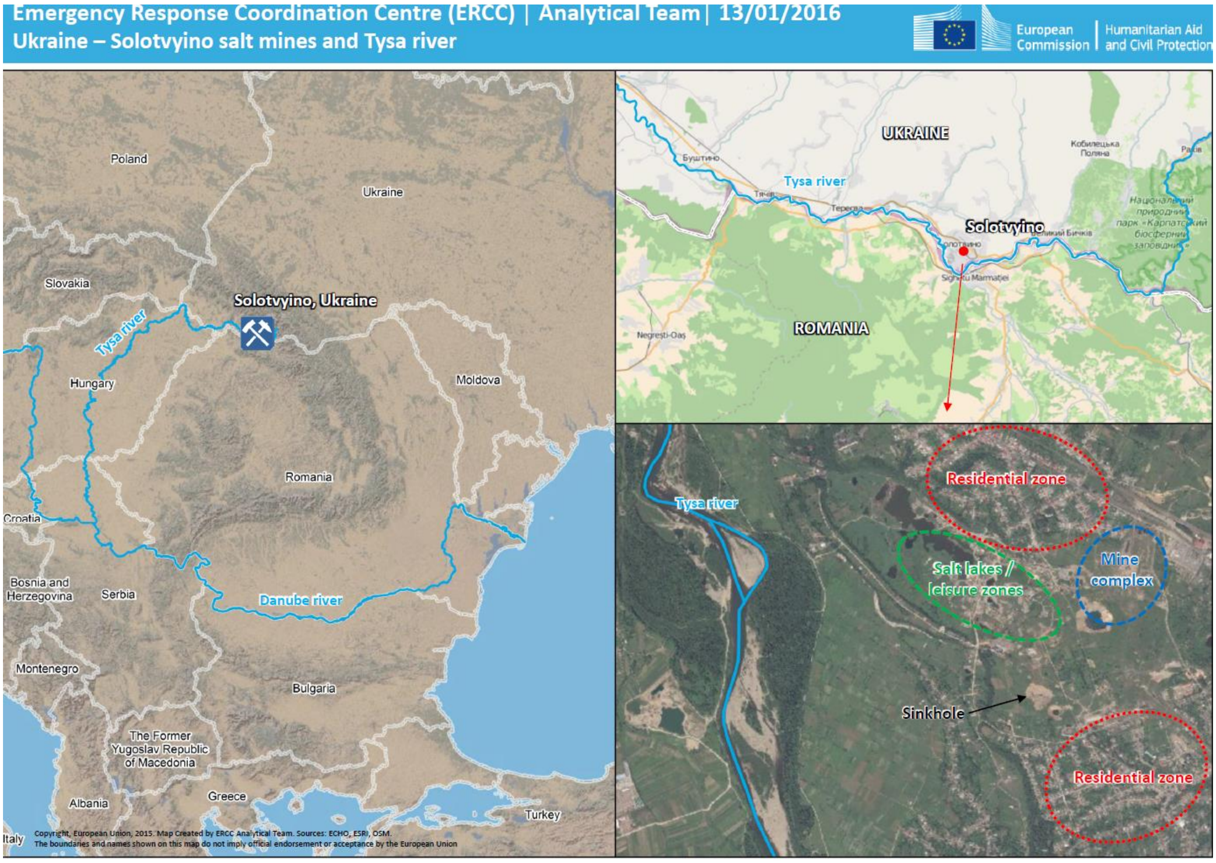



Figure 2.3.1 Overview of Ukraine and Solotvyno (ERCC)

## 2.4 Presentation of the mission

## The European Union Civil Protection Mechanism (UCPM)[1]

In 2001, the UCPM was established, fostering cooperation among national civil protection authorities across Europe. The UCPM currently includes all 28 EU Member States in addition to Iceland, Montenegro, Norway, Serbia, and the former Yugoslav Republic of Macedonia. Turkey has recently signed the agreements to join the UCPM.

The UCPM was set up to enable coordinated assistance from the participating states to victims of natural and man-made disasters in Europe and elsewhere. It means that any country in the world can call on the UCPM for help. Since its launch in 2001, the UCPM has monitored over 300 disasters and has received more than 180 requests for assistance.

The EU Civil Protection legislation was revised at the end of 2013[2] (17 December 2013) to ensure better response to natural and manmade disasters in a swift, pre-planned and effective manner and thus to increase the safety of EU citizens and disaster victims worldwide. With the new legislation in place, any country in the world can request assistance from the UCPM. The United Nations and certain international organisations can also activate the UCPM to request assistance in non EU Member States.

[1] More information about the UCPM can be found at http://ec.europa.eu/echo/what/civil-protection/mechanism_en

[2] Decision No 1313/2013/EU of the European Parliament and of the Council on a Union Civil Protection Mechanism.

In 2014 (16 October 2014), implementing rules[3] operationalized some of the topics included in this new legislation to place greater emphasis on disaster prevention, risk management and disaster preparedness, including the European Emergency Response Capacity (EERC) of pre-committed response capacities by the participating states (PS).

The UCPM also helps in marine pollution emergencies, where it works closely with the European Maritime Safety Agency (EMSA), and consular evacuation, in coordination with the European External Action Service (EEAS) and EU Delegations. When the crisis occurs in developing countries, civil protection assistance typically goes hand in hand with EU humanitarian aid.

The UCPM provides participating countries with the opportunity to train their civil protection teams and experts. By exchanging best practices and learning during training and exercises, experts and teams increase their ability and effectiveness in responding to disasters.

The Emergency Response Coordination Centre (ERCC) is the operational heart of the UCPM. The ERCC collects and analyses real time information on disasters, monitors hazards, prepares plans for the deployment of experts, teams and equipment, works with Member States to map available assets and coordinates the EU- disaster response efforts.

Finally, the European Commission supports and complements the prevention and preparedness efforts of participating states, focusing on areas where a joint European approach is more effective than separate national actions. These include improving the quality of and accessibility to disaster information, encouraging research to promote disaster resilience, and reinforcing early warning tools.[4]

## Team deployment and composition

On 12 January 2016, Hungarian and Ukrainian civil protection authorities addressed a letter to Commissioner Stylianides and the Director-General of DG ECHO, Ms Monique Pariat, concerning a cross-border environmental pollution concern at the Solotvyno salt mine complex in Ukraine.

The Union Civil Protection Mechanism (UCPM) was activated on 17 June 2016 with a view to deploying a small preparatory/scoping mission to support the national authorities. The scoping mission took place between 2 and 9 July 2016, and produced a technical report shared with all PS, as well as Ukrainian authorities.

Based on the findings of the scoping mission, it was decided to deploy an advisory mission in order to conduct a comprehensive risk assessment at the "Solotvyno salt mines area". The deployment took place from 14 September until 7 October 2016.

[3] Commission Decision, laying down rules for the implementation of Decision No 1313/2013/EU of the European Parliament and of the Council on a Union Civil Protection Mechanism and repealing Commission Decisions 2004/277/EC, Euratom and 2007/606/EC, Euratom.

[4] The content about the EU Civil Protection Mechanism in this chapter is based on information provided in the ECHO Factsheet, http://ec.europa.eu/echo/files/aid/countries/factsheets/thematic/civil_protection_en.pdf, from July 2015 and retrieved from ECHO website http://ec.europa.eu/echo/what/civil-protection/mechanism_en on 22 August 2015.

The EUCPT "Advisory mission" consisted of the following members:

| Name | Nationality | Expertise |
|---|---|---|
| Terry Webb | United Kingdom | Team leader |
| Ruud de Krom | The Netherlands | Deputy team leader |
| Edmunds Akitis | ERCC | Liaison officer |
| Istvan Moldovan | Romania | Mine engineer |
| Peter Vojuczki | Hungary | Mine engineer |
| Xavier Daupley | France | Mine engineer |
| Laszlo Perger | Hungary | Hydrogeologist |
| Leonard Stoeckl | Germany | Hydrogeologist |
| Vanessa Banks | United Kingdom | Hydrogeologist |
| Gabriella Zagora | Greece | Civil Engineer |
| Sjirk Meijer | The Netherlands | Risk assessment expert |
| Janos Tatrai | Hungary | Coordination/logistics/safety and security expert |
| Gabor Jenei | Hungary | Regional development planning expert |
| Mark Peters | The Netherlands | Information management expert |
| Markus Lampe | Germany | Technical assistance/ logistics expert |
| Henning Lorch | Germany | Technical assistance/ information management expert |
| Michael Kalbitz | Germany | Technical assistance/ ICT expert |

## 2.5 Objectives of the mission

According to Decision No 1313/2013/EU of the European Parliament and of the Council of December 2013 on a Union Civil Protection Mechanism and the Implementing Decision 2014/762/EU of October 2014, the Commission has established the capability to mobilise and dispatch, short notice, small teams of experts responsible for:

1. *Conduct a comprehensive risk assessment at the Solotvyno salt mines area.*

2. *Advise the development of a monitoring system with local, state and international stakeholders in order to determine milestones for next steps.*

3. *Make short-, medium- and long-term recommendations, including potential mitigation and engineering solutions.*

4. *Make follow-up observations on immediate measures to be taken by the Ukrainian authorities on recommendations provided by the EUCPT during the Scoping mission.*

5. *Identify next steps to be taken by the competent authorities and appropriate stakeholders for hand-over of the findings, recommendations and suggestions for further work.*

## 2.6 Follow up observations from the scoping mission

Information concerning the implementation of recommendations of the European Union mission to Ukraine (3 - 8 July 2016):

Follow up on the immediate Recommendations

The EUCPT scoping mission in July 2016 identified serious concerns about the immediate safety situation at Solotvyno mine area to the local public and infrastructure. It was evident that no or little action had been taken since 2010. This resulted in the immediate recommendations being identified by the EUCPT experts and reported to the Ukrainian authorities.

*"In 2010 the Transcarpathian Regional State Administration classified the territory of Solotvyno salts mines as an emergency. This decision was approved by the Ministry of Emergency Situations of Ukraine (N002-17292/165 9/12/2010). From 2011 the Solotvyno State Enterprise "Board of Salt Production Elimination" has had direct responsibly for the mine complex and reports directly to the Ministry of Agrarian and Food Production. Outside of the immediate mine complex the lakes are owned by the local municipality with the resorts privately owned. The head of the State Emergency Service of Ukraine Mr Chechotkin co-signed the request for assistance at executive level".*

Therefore, the relationship and areas of responsibility between the Ukrainian stakeholders at State, Regional, District and Local level with the addition of the State Emergency Service and State Enterprise "Board of Salt Production Elimination" are complex, bureaucratic and problematic for the Ukrainians to define clear ownership of each of the immediate recommendations to the short time frame from the scoping mission (July 2016) to the advisory mission in September 2016.

The advisory mission received one submission of evidence from the Ukrainian authorities in response the immediate recommendations *"Information concerning the implementation of recommendations of the European Union mission to Ukraine (3-8 July 2016)".* The document refers to a DSNS (State Emergency Service) meeting on 9/2/2016, and makes a number of statements, however does not provide any commentary to evidence progress or metrics against the immediate recommendations. The advisory mission became aware of a public safety awareness event on 29 September focusing on the Solotvyno village and the situation. However, it's important to state that the advisory mission did briefly observe the event, however were not formally invited or de-briefed on the event.

Further informal discussions during the mission cycle with Ukrainian Stakeholders (at all levels) expressed a positive encouragement and anticipation for the final advisory mission "Risk Assessment" report to act as a platform to move and address the immediate recommendations and potential future actions to address the situation at the Solotvyno mine and surrounding areas.

# 3. Technical information

## 3.1 Methodology

The basis of the methodology was derived from the Commission Staff Working Paper "Risk Assessment and Mapping Guidelines for Disaster Management"[5].

Further on, the methodology was developed in order to meet the objectives of the mission. The research performed for the purposes of this report was based on detailed inspections on-site, numerous interviews with the local Authorities, the mine company and the residents of Solotvyno, sampling, measuring, testing, literature research and desk research of data and information.

Following the report of the EUCPT scoping mission a perimeter was set up by the EUCPT for the risk assessment. *See Figure 3.1.1.*

[5] Brussels, 21.12.2010 SEC(2010) 1626 final.


Figure 3.1.1: Assessment perimeter (red shape)


Figure 3.1.2 Working phases

In order to structure the work and tasks, the team followed a practical workflow process, which consisted of the following phases; measurements, assessments, including interviews, all fieldworks, processing of information and reporting, both office works. *See figure 3.1.2.* Many of these phases sometimes overlapped or were conducted simultaneously.

The EUCPT worked in close cooperation with the experts from the National Academy of Sciences in Ukraine Prof Khrushchov (Geologist).
Dr Shekhunova (Head Scientific Researcher and corresponding member of NAS of Ukraine, Geologist) and Dr Yakovlev (Hydrogeologist).

### 3.1.1 Measurements and assessments

#### *Sampling and analyzing water quality*

At each surface water position, a GPS determination of the grid reference was made. A clean jug was used to obtain a sample of the water. Samples were taken as far from riverbanks as safely possible and at approximately 0.50 m depth. All equipment was rinsed with the water to be sampled prior to:

1. Determining the pH with a Hanna Instruments multi-probe
2. Determining the conductivity and temperature using a Hanna Instruments conductivity meter.

Figure 3.1.1.1: Water well measurements and sampling

At each well position, e.g. *Figure 3.1.1.1*, once permission to sample had been obtained, interviews were used to determine how often and who used the supply. In wells without pumps groundwater levels were determined using a graduated electrical dip meter with an alarm to indicate contact with water. A jug sample was used to undertake the physico-chemical analyses (steps 1-3) detailed above and a second sample was obtained for laboratory determinations.

<u>Determination of water chemistry using colourimetric techniques (Palintest Photometer 7100)</u>

1. The selected water samples were filtered using Whatman 25 mm GD/X sterile syringe filters. A separate filter was used for each water sample.
2. 10 ml water samples were prepared in accordance with the Palintest methodology. Dilutions were undertaken using deionized water.
3. The following tests were undertaken on each sample *See Figure 3.1.1.2*:

a) Alkalinity (Alkaphot) method Phot 2
b) Calcium hardness (Calcicol) method Phot 12
c) Chloride (Chloridol) method Phot 46, 51, 101 or 102, depending on dilution).
d) Potassium method Phot 30
e) Sulphate method Phot 32
f) Total hardness (Hardicol) method Phot 15

Figure 3.1.1.2; 6 samples (a-f)

Whilst every effort was made to generate accurate and precise results, the analyses were undertaken in improvised laboratory conditions with field equipment. There are inherent limitations in the technique with significant potential for colour interference due to the mineralization of the water. Therefore, it is considered that the results from this technique provide relative values and are not to be relied upon for decision making. Magnesium determinations were attempted, but there was evidence of masking and the results were not considered reliable, so this test was not generally applied to the samples.

Stable water isotopes
Samples taken in 30 ml glass bottles were sent to the Germany (Federal Institute of Geosciences and Natural Resources) for analysis of stable water isotopes $^{18}O$ and $^{2}H$) using Cavity Ring-Down Spectroscopy (CRDS) by Picarro (Reference: http://www.picarro.com/technology/cavity_ring_down_spectroscopy). The composition of stable isotopes varies between different waters due to processes leading to so called "fractionation" between the "heavy" ($^{18}O$ and D) and the "light" isotopes ($^{16}O$ and H). These processes are various and depend on geographical as well as meteorological condition (e.g. distance to ocean, elevation, temperature, evaporation, etc.). A distinct signature of the stable isotope composition between the different end-members (i.e. shallow and deep groundwater, precipitation, and river water) might thus be used to interpret mixing processes of different waters and determine their origin (Reference: Clark, I. D., and P. Fritz (1997), *Environmental isotopes in hydrogeology*, 328 pp., CRC Press/Lewis Publishers, Boca Raton, FL.).

### *Depth specific sampling and measurement strategies*

Water samples and measurements of electrolytic conductivity as well as temperature were conducted in different depths at several locations. A Ukrainian rescue team was trained and guided by EUCPT for the sampling of the Black Moor, the collapse No 7, and the "2 May 2016" sinkhole on the 24th and 25th of September. A zodiac (boat) was used to enter different locations on the water. LF 196 conductivity meter with a 50 m cable was used to record electrolytic conductivity and temperature values with a maximum vertical resolution of 1 m. These values were manually recorded by the Ukrainian samplers and communicated via VHF to the EUCPT on shore for backup.

A bailer *(See Figure 3.1.1.3)* attached to a 200m cable was used for depth specific water sampling. The device was lowered to the desired sampling depth before a slider was activated which activated a mechanism to capture the water at that depth in the bailer. The water sample was then used, to first rinse a 330 ml sampling PET bottle two times, then filled to the top preventing air entrapment (used for chemical analyses). A second sample was taken in a 30 ml glass bottle (analysis of stable water isotopes, no rinsing needed).

The bailer was additionally used in the mineshafts No 9 and No 8 to obtain samples for stable isotopes as well as chemistry. The conductivity meter WTW with the 50 m cable was further used to conduct depth specific profiles of electrolytic conductivity and temperature in Lake18. It was also applied to measure the water depth at various locations by manually determining the point of resistance when the probe touches the ground (max. depth 50 m). Examples of the sampling activities are shown in *figure 3.1.1.4.*

Figure 3.1.1.3

Figure 3.1.1.4: Sampling of the Tisza River (left and right) and the Collapse of Mine 7

### 3.1.2 Processing and reporting

#### The Risk Assessment Model

The risk assessment of the Solotvyno mining area was guided by the Commission Staff Working Paper “Risk Assessment and Mapping Guidelines for Disaster Management”. As the Solotvyno case is a foremost local issue with possible international consequences the method was adapted to reflect the detail of the multi risk complexity of the research area. The risk assessment focuses first on subsurface processes and progresses to surface hazards.

Since the timeframe of the mission was relatively short the risk assessment is primarily qualitative. Therefore, it is based on the more basic concept of risk as the combination of the consequences of an event or a hazard and the associated likelihood of its occurrence. Consequences are the negative effects of a disaster expressed in terms of human impacts, economic and environmental impacts, and political/social impacts. [ISO 31010][EU Working Paper, 2010]. For risk the basic formula is used.

*Risk = hazard impact * probability of occurrence*

The risk assessment is divided into 5 components, which are steps in the process and parts of the final risk assessment.

**Hazard identification**

Following the preliminary study of the situation in, under and around the study area (July 2016) a combined long list of cause-effect relationships and trigger-events was conceptualised. The key characteristic of the processes was a requirement for it to ultimately link to hazards on the surface. The compiling of the list was a team effort facilitated by discussions based on accepted knowledge, expertise and experience. To better understand the different processes (cause-effect relationships) the Solotvyno area was divided into distinct subareas. The list was used to focus the field, historical, literature and other studies, as well as for the development of a geohydrological conceptual model. From the list it was possible to prioritise hazards defined by the significance of the impact on people, economics and/or environment. The hazards were eventually congregated to five possible hazards to the people, economics and environment.

**Impact analysis**

For the purpose of this assessment three types of impacts were defined and qualitatively assessed. The impacts are:

1. Human impacts (affected people) are the estimate of deaths, severely injured or ill people, and the estimate of permanently displaced people.
2. Economic and environmental impacts are rated on a semi-quantitative scale of, cost of immediate or longer-term emergency measures, costs of restoration of buildings, public transport systems and infrastructure, property, costs of environmental restoration and other environmental costs (or environmental damage), costs of disruption of economic activity, value of insurance pay-outs, indirect costs on the economy, indirect social costs, and other direct and indirect costs, as relevant. For example in 2008 new SWQS (surface water quality) standards were proposed for Chloride (200 mg/l) i.e. the threshold value which defines good surface water quality (Surface Water Quality Regulation in EECA countries: Directions for reform OECD EAP Task Force 2008 Kiev.
3. Political/social impacts are rated on a semi-quantitative scale and include categories such as public outrage and anxiety; infringement of the international position, violation of the democratic system; social psychological impact; political implications, psychological implications; damage to cultural assets, and other factors considered important.

**Probability estimation**

During a team discussion the different causes, triggers and therefore hazards were scaled on likelihood. In this way an expert's view on probability could be elicited. In some cases the impacts are so high that even a very optimistic estimation of likelihood cannot reduce the perception of the risk following normal standards, for example the difference between very high risk and extremely high risk. In such cases an estimate is only roughly made.

**Risk scenarios / "bowtie" analysis**

The situation in Solotvyno is defined by the presence of historic mining activities causing deformation of the surface through aberration of the geologic, hydrogeological and hydrological situation. Possible future incidents may be realised as man-made disasters. The bowtie scenario analysis helps to analyse such scenarios. The bowtie analysis comprises a description and analysis of the risk pathways, from hazards to outcomes, incorporating a review of controls. Here this is achieved by describing the cause-effect relationships as a fault tree leading to a single major event (for example the forming of a sink hole) itself the trigger point for a chain of (parallel) effects and impacts.

**Risk evaluation**

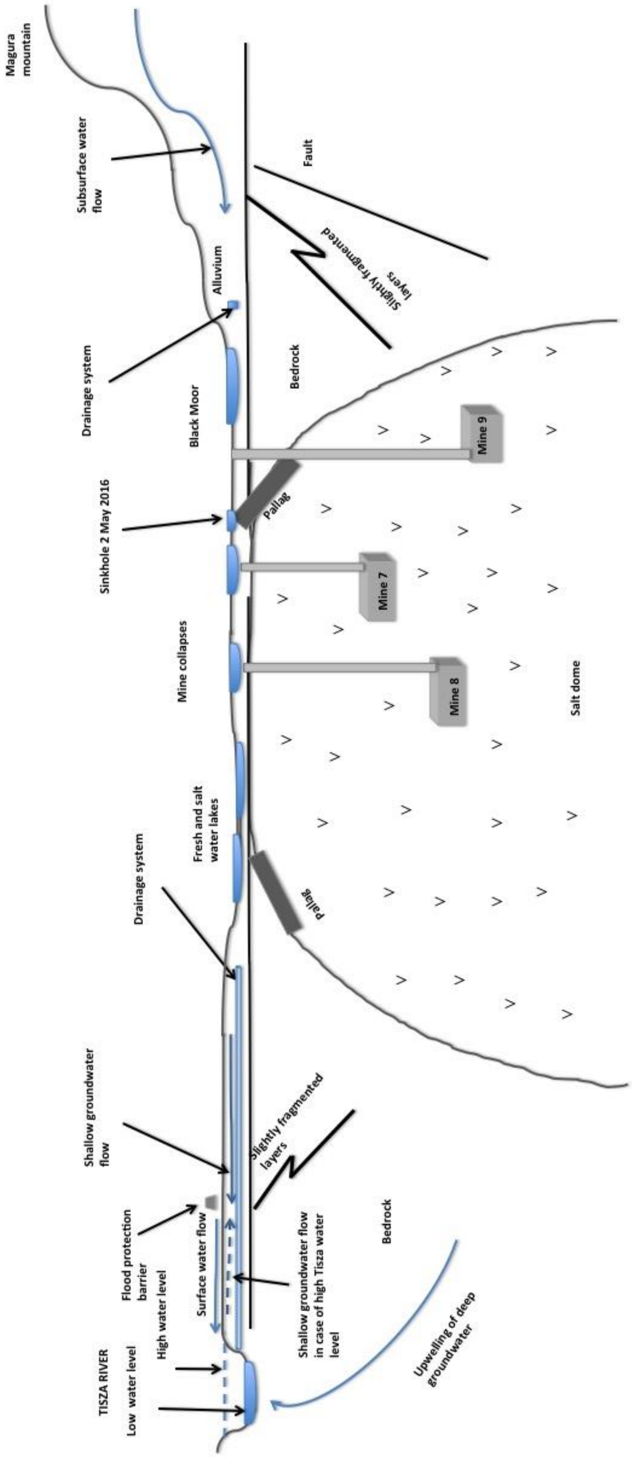
To evaluate the significance of the risks, they were weighted using the common standards of the EU. Some EU member states have quantitative norms, for instance the risk of dying as a consequence of a stationary hazard, which in the Netherlands is a likelihood of less than$10^{-6}$ a year. Because loss of life is unacceptable this norm can be qualitatively interpreted a high probably hazard.

An assessment of possible lines of defence, i.e. measures to block cause-effect relations or prevention and mitigation measures to minimize effects and shorten the recovery phase was undertaken. The lines of defence directly lead to recommendations to eliminate or minimize risks. Finding the most effective lines of defence were derived from the expertise and the personal experience of the specialists. However, the impact and value of the lines of defences are objective verifiable.

## 3.2 Conceptual model

In order to provide a general overview of the hydrogeological situation of the Solotvyno salt mine area, a conceptual model approach was used. This is presented as two-dimensional cross-section from the Tisza River to the Magura Mountain (roughly from SW to NE) is presented in *Figure 3.2.1. Figure 3.2.2 presents the location of the conceptual model (cross section).*

Figure 3.2.1 conceptual model



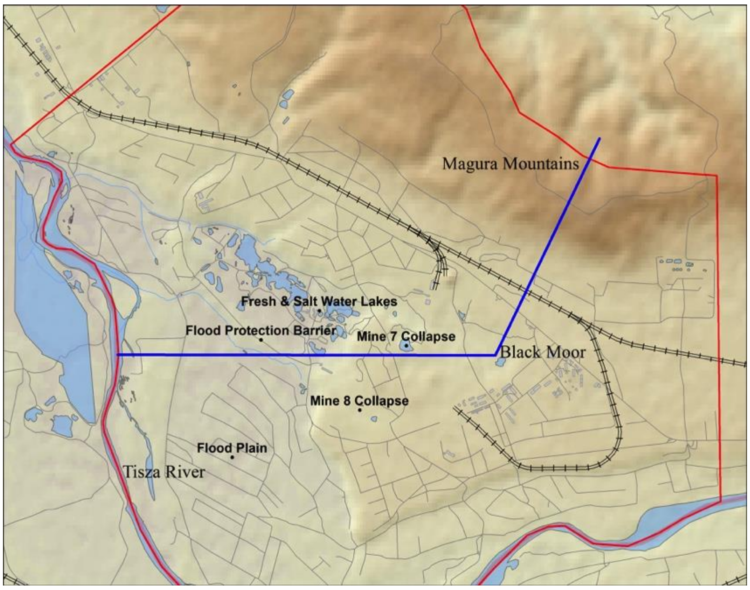



Figure 3.2.2: Conceptual model location (cross section)

The model is conceptual, without scaling such that sizes and objects are indicative. Elements potentially influencing the surface- and subsurface flow in the area, including the input of potentially contaminated groundwater are represented.

Following the model from left to right there is a moderate increase in elevation of about 30 m between the Tisza River at about 252 m to the Solotvyno mine area at about 282 m. Between these points (NE part of the Solotvyno mine area) several fresh- /saltwater lakes are situated at the margin of the salt dome, which are partially a result of mining operations dating back to the 18th century. Between the lakes (south) and the embankment of the Tisza River, a flood protection barrier or dam has been constructed.

The craters of mine No 7 and mine No 8, containing (salt-) water, are located in the southern and central parts of the salt dome (visualized in the centre of *figure 3.2.1*). The rock salt dome comprising is juxtaposed against the host bedrock and both are usually covered by alluvium of a thickness of around 20 m to 30 m (top layer). An intermittent salt-clay layer between the alluvium and the salt dome (locally called "Pallag") forms an impermeable (sealing) layer.

To the East of the salt dome, the area of the Black Moor is a former wetland area that contains freshwater. Further east, a steep increase in elevation forms the Magura Mountain to north of Solotvyno.

Flow paths discharging into the Tisza River with the potential to influence the water quality of the Tisza River downstream of Solotvyno are identified and listed below. *See figure 3.2.1*:

1. *Surface water runoff (small creeks or river water by flooding)*
2. *Shallow groundwater flow in the alluvium*
3. *Flow from the drainage system in the vicinity of the salt dome*
4. *Upwelling of deep groundwater*

5. *Enhanced flow in cracks, faults, or fractures in the bedrock*

The model also indicates the potential, at times of high river discharge, for the direction of the shallow groundwater flow in the alluvium to be reversed towards the salt dome. Cracks and faults are present in the bedrock and possibly hydraulically connected to the salt dome. These disturbances will also have an impact on the ground water flow. Due to the natural head pressure within the bedrock, the potential for upwelling of deep groundwater is also indicated. In the salt dome, over some decades, a number of mines were constructed for commercial purposes. The mining activities ceased some years ago and now the mines are (partly) filled with water. In the mine area, in addition to naturally occurring sinkholes, some major collapses have occurred.

## 3.3 Geology and geomorphology of the "Solotvyno mine area"

### Background

This section of the report provides an overview of the geological setting and the lithological descriptions that underlie the geomorphological, hydrological, hydrogeological, engineering, karst and anthropogenic (man-made) processes or activities that lead to the causal (triggering) factors of the hazards that are assessed in terms of risk in section 3.8. The description is therefore limited in its scope and is not exhaustive. The section starts with a description of the tectonic setting, which is followed by, firstly the stratigraphical context and lithological descriptions of the bedrock, and secondly the stratigraphical context and lithological descriptions of the more recent superficial deposits in the immediate vicinity of the salt dome. The geological descriptions are followed by an introduction to the geomorphology and the evidence for Neotectonic activity in the region of the Solotvyno salt mine.

### Key findings

In this section key findings are presented as follows:

A. Tectonic setting
B. Bedrock geology
C. Superficial geology
D. Geomorphology
E. Anthropocene

#### *A Tectonic setting*

The Miocene salt deposits of Solotvyno occur in the fault-bound Transcarpathian Basin (also referred to as the Transcarpathian Foredeep (Krupsky, 2007) or Transcarpathian Trough (Bukowski, 2009). The form of the salt body (salt dome), which is elongate along a north-west to south-east alignment (*Figure 3.3.A.1*) reflects the tectonic setting. The Basin was formed by compression during the Late Mesozoic Alpine Orogeny and was a consequence of the plate movements that resulted in the closure of the Tethys Ocean. Older sediments, particularly of Triassic, Jurassic and Lower Cretaceous age were incorporated in this mountain building event as both transported bedrock (ophiolites) and as products of weathering and erosion within the developing basin (flysch). Salt deposits were mobilised, metamorphosed and recrystallized during this period. Subduction at the plate boundaries led to volcanic activity, which is reflected in the occurrence of both intruded volcanic rocks and extruded volcanic rocks, such as the tuffs and tuffaceous sandstones within the sedimentary sequence (section 3.3.B), as exposed in the bed of stretches of the Tisza River (section 3.3.B).

The subduction zone was oriented approximately north-west to south-east and this is reflected in structural lineation (or grain), as evidenced by the north-west to south-east alignment of the strike (axes) of the principal faults bounding the region, see the “Northern Fault” on *Figure 3.3.A.1*. Movement along the faults that bound the Transcarpathian Basin were horizontal as well as vertical, i.e. strike slip faulting (Krupsky, 2007). Displacements of up to 20 km are recorded in the northern part of the Solotvyno Basin (McCann, 2000). Antithetic faults occur along a north-east to south-west alignment and one such fault is suspected to cross the salt dome (*Figure 3.3.A.1*). As the volcanic activity subsided, the phase of compression was followed by thermal subsidence of the basin, and crustal relaxation in the basin, leading to a reduction in in-situ stress and consequential tension in the sedimentary basin. During the Pliocene–Quaternary (Cloetingh et al., 2005), resulted in inversion Changes in the stress regime impact on the tightness of the structural faults and joints and this has an influence on their hydraulic conductivity (section 3.4). Lateral variability in fold wavelengths is the result of a marked contrast in rheology between the basinal areas, directly related to the crustal configuration, thermal properties and late-stage collision kinematics with the Carpathians foreland. Similarly, lateral variations in the properties of the downgoing plates largely control the collision mode in the Carpathians and the post-collisional evolution of the entire system. (Cloetingh et al., 2005). The region lies within a zone that has been designated medium seismic hazard risk. http://data.euro.who.int/e-atlas/europe/images/map/ukraine/ukr-seismic.pdf

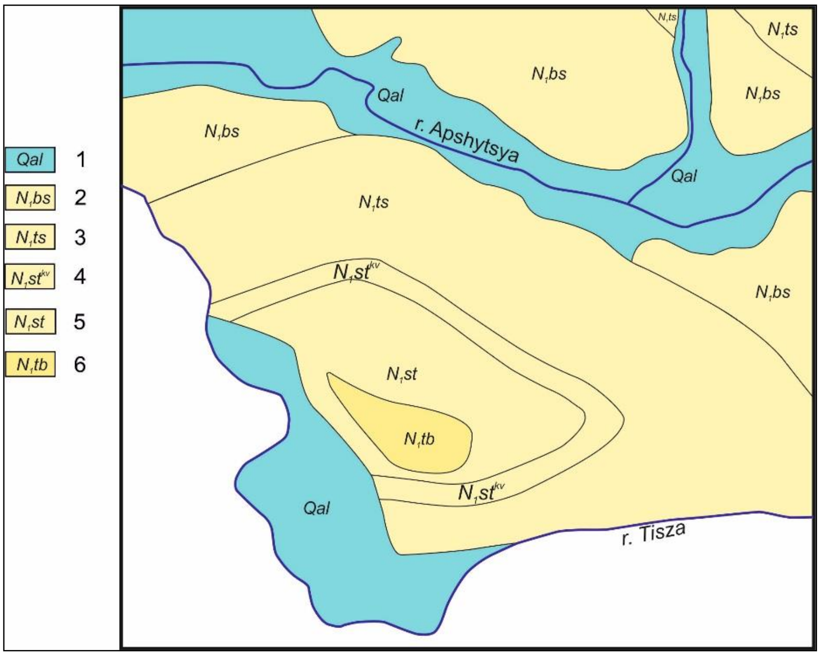



Figure 3.3.A.1: Geology map of the Solotvyno district annotated with suspected fault alignments. Legend: 1 – Quaternary, alluvium; 2 – Miocene, Baskhivska suite. Alternating: clay, sandstone, siltstone and conglomerate; 3 - Miocene, Teresvynska suite of alternating: clay, siltstone, sandstone, and tuff; 4 - Miocene, Solotvynska suite, Kovachskyi level of tuff; 5 - Miocene, Solotvynska suite of alternating: clay, sandstone and siltstone; 6 - Miocene, Tereblynska suite of alternating: rock salt with clays.

### B Bedrock geology

The Transcarpathian trough is a linear feature 150 km long 20-30 km wide. The oldest rocks of the basin comprise the igneous and metamorphic rocks of the Ukrainian Precambrian shield. These rocks were overlain by a sequence of sedimentary rocks. Hryniv et al., (2007) suggest that the Neogene deposits comprise Mesozoic and Palaeogene sediments that rest unconformably on the Palaeozoic rocks. The Solotvyno Basin underwent maximum subsidence during the Badenian (*Figure 3.3.B.1*) when up to 2000 m of sedimentary rocks accumulated (McCann, T., 2000). Although the rock salt is largely pure, layers of clays with subordinate gypsum anhydrites occur (Hryniv et al., 2007). It is reported that bromine can be used as an indicator of primary salt, whereas it is largely absent from the recrystallized salt deposits. The evaporites (Eggenbergite age; Figure *3.3.B.1*) formed within the restricted basins associated with a Paratethys seaway that formed during the Badnian (Bukowski et al., 2007).

Miocene organic rich shales inter-bedded with sandstone reservoirs, siltstones and shales to the north of the Northern Fault form a source rock for gas. The gas generation is thought to have begun in the early Miocene soon after burial, perhaps due to the higher than normal geothermal gradient, which is observed in gas wells.

The bedrock is only rarely exposed in the area of investigation, but where visible it has largely been subject to intense weathering (*Figure 3.3.B.2*). The lithology of the bedrock primarily ranges from sandstone through to siltstone and mudstone with occasional conglomerates and volcanic strata. It is characterised by intense jointing and is commonly calcareous (*Figure 3.3.B.1*).

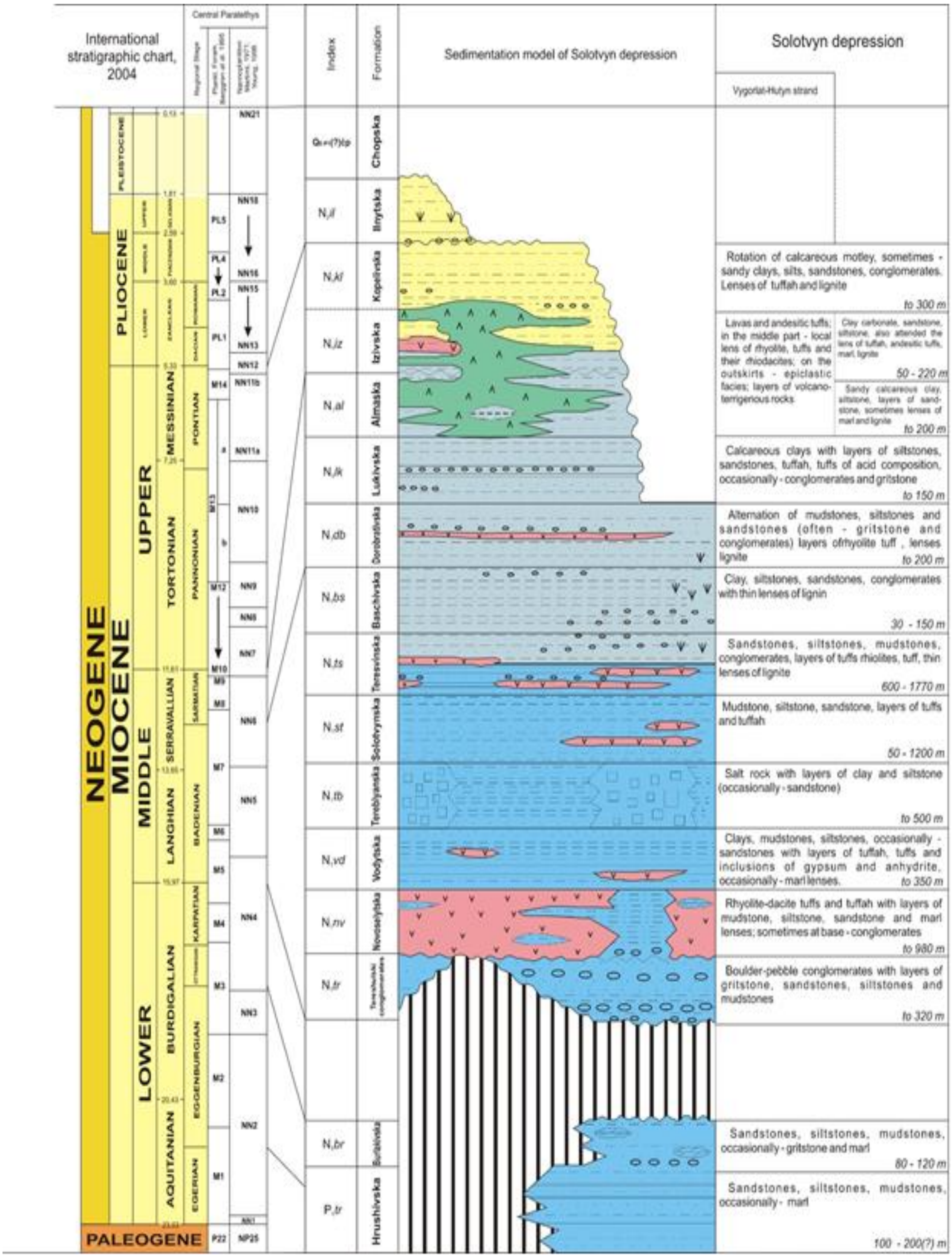



Figure 3.3.B.1: Stratigraphical and lithological context of the Neogene deposits in the Solotvyno district (Grygorovych et al., 2009).

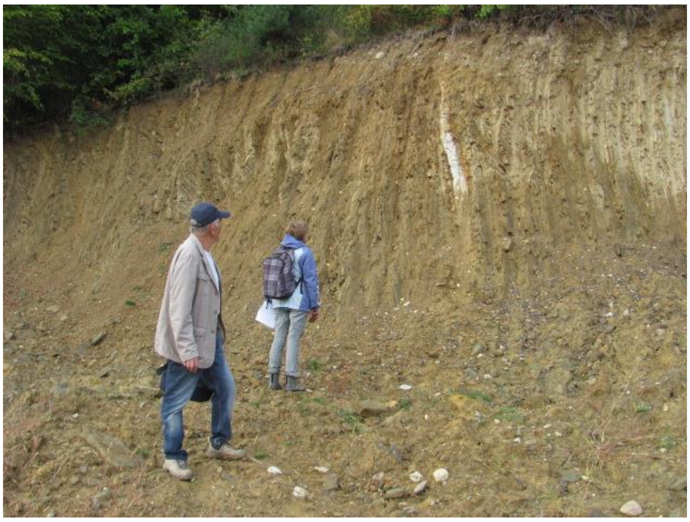


Figure 3.3.B.2: Weathered, deformed bedrock

The Solotvyno salt dome is north-west to south-east orientated. It has risen diapirically within the sediment profile. The inferred presence of faulting on its northern flank suggests that faulting may have contributed to this process. The fault system is described as brachial and this has implications for the potential for fluid movement in the fault zone.

Further detail regarding the geology and its implications for applied can be found in the references of Khrushchov, Shekhunova and Bosevskaya cited in Annex D.

### *C Superficial geology*

The superficial deposits (*Figure 3.3.C.1*) comprise a sequence of Quaternary, largely alluvial, river terrace deposits overlying the weathered salt and capped by loess or residual soil (*Figure 3.3.C.1)* The Quaternary deposits cover the surface of the salt dome with a thickness ranging from 0 to 10 m in elevated areas and up to 40 m river valleys (Shekhunova et al., 2016 personal communication).

Where undisturbed, loess deposits cap all of the terraces, locally reaching 1.5 to 2.0 m in thickness. The river terrace deposits were laid down by the Tisza River at a time of higher discharge than today. Three terraces have been identified above the current alluvium of the river (*Figure 3.3.C.2*), the formation of which is attributed to Neotectonic uplift. The breadth of the river terrace deposits reflects both the historical discharge of the river and its former course (section 3.3.D). The distribution of the pallag (*Figure 3.3.C.1*) that underlies part of the floodplain is limited to the near surface distribution of the salt from which it is forming. The thickness and rate of formation of the clay reflects the rate of dissolution of the salt as well as the anthropogenic erosional effects described in section 3.3.E.

| **Lithology** | **Description** | **Reference** | **Image** |
|---|---|---|---|
| Loess/ residual soil | Cohesionless fine grained (silt) deposit characterised by the presence of mica particles | Apparently not previously noted in the literature. |  |
| River Terrace Deposits and Alluvium | Beds of slightly clayey silty sandy fine to coarse gravel with cobbles. Cobbles are rounded to subrounded and comprise flysch and Miocene sandstone, quartz, chert, rarely schists and volcanic rocks (Shek. This deposit is generally 10 – 30 m in thickness and is ubiquitous in its distribution except in the upper reaches of the streams. | |  |
| Pallag | Residual clay deposit derived from dissolution of the salt. Primarily clay with subordinate sand and gypsum. Up to 20 m or more in thickness. | |  |
| Weathered salt margin | The "wet" rind and zone of leached and brecciated salt, which locally extends to 200 m in thickness. | Khrushchov et al., 2016 |  |

Figure 3.3.C.1: Superficial geology of the Solotvyno district.

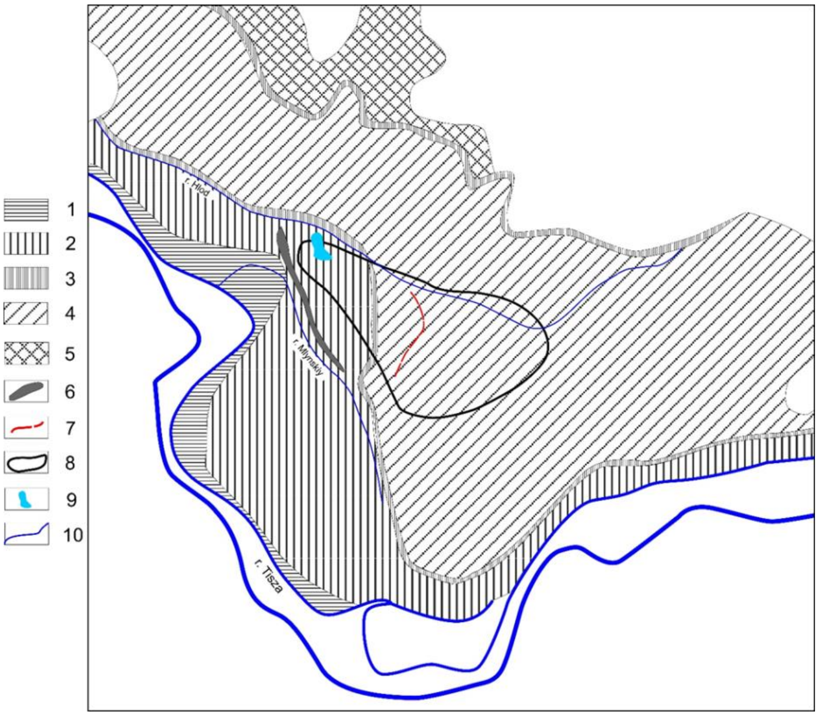



Figure 3.3.C.2: Geomorphological map of Solotvyno. Legend: 1 – Floodplain of Tisza river; 2 – 1-st river terrace; 3 – edge of terraces; 4 - 2-nd river terrace; 5 – 3 river terrace; 6 – dam; 7 – old quarry wall; 8 – salt dome; 9 – salt lakes; 10 – rivers, streams. (Elizarov A.F)

### *D Geomorphology*

The geomorphological characteristics of the Solotvyno district can broadly be traced along a transect from north-east to south-west and comprise: (i) the relatively steep, partially wooded, Magura Mountain, which rises above the floodplain and terraces of the former course of the Tisza River; (ii) the transition zone which forms the route corridor; (iii) naturally occurring sinkholes in the area of Black Moor, comprising cone shaped karst features with a relatively mature cover of vegetation, close to the former course of the Tisza River; (iv) collapse features associated with the abandoned mine workings; (v); fertile land of the terrace deposits (*Figure 3.3.C.2*), and (vi) the extensive floodplain of the Tisza River, which is commonly rimmed with trees. The river, which flows from east to west, meanders and bifurcates around channel bars in the floodplain. The principal geologically related geomorphological features of the research area are shown on *Figure 3.3.C.2*. The geomorphology reflects the balance between salt uplift and dissolution, the neotectonic setting of the alluvial deposits, karst processes, piping of the loess and landslides and anthropogenic activity (section 3.3.E). Shupikov (1970) reported on the elevation the terraces above the river bed (*Figure 3.3.D.1*).

| Terrace | Elevation (m Above Baltic Sea Level) |
|---|---|
| Floodplain | 248-250; 1-2 m in thickness; |
| 1 | 256-282; 5-7 m in thickness; extends to the north-western outskirts Solotvyn salt dome ("Zaton") |
| 2 | 250-295; 20 m thick**;** widespread in central and south-eastern part of the dome |
| 3 | 30 -40 m in thickness |

Figure 3.3.D.1: River Terrace Deposit elevation (after Shupikov, 1970).

One of the main features of the geomorphological map (*Figure 3.3.C.2*) is the edge of the terraces. It is suspected that this marks the former route of the Tisza River, which has migrated in a southerly direction, possibly in response to rising ground levels in the area of the salt dome. Examination of the topographical maps of the area suggests that it is plausible that valleys draining the Magura Mountain form tributaries of the former route of the river. This, in turn, indicates that there is a potential for preferential groundwater flow paths in the River Terrace deposits.

There are traces of weathering and dissolution (karstification) of the salt, which results in the development of relief in the salt. This reflects the potential for active dissolution where surface or groundwater can make contact with the salt through natural or anthropogenic hydrological windows through the superficial deposits. Ivancheko, (1985) suggested that erosion of salt results in a series of elevations separated by depressions with funnel shaped karst forms and salt ponds. The development of hydrological windows is evident in both geological sections provided by the Mining Office and the distinctive geomorphology of the Black Moor area.

Another distinctive geomorphological feature that characterises the area is the development of landslides both within the sinkholes and collapse features (section 3.3.E) and on the steep slopes of the Magura Mountain where translational landslides develop as a consequence of crack propagation and piping breaching the loess and facilitating tension gap development (*Figure 3.3.D.2*).

Figure 3.3.D.2 and 3 Landslides on the Magura Mountain and in the Black Moor respectively.

It has been noted that the tensional setting of the Magura Mountain landslides figure 3.3.D2 could be indicative of deformation resulting from salt withdrawal (Ge and Jackson, 1998), as suggested by Shekhunova et al. 2016 (verbal communication) and/or the tectonic setting. Landslide styles differ between the collapse features and the sinkholes, reflecting both the triggering process and the characteristics of the mobilized materials. The deeply weathered nature of the bedrock and the deformable nature of the superficial deposits are such that all types of landslides may be subject to reactivation.

### *E. Anthropocene*

Clearly, the most significant geomorphological impact of human activity is the mining impact; which has resulted in: underground voids with varying degrees of saturation; focused leakage from supporting infrastructure, particularly the drainage channels; mounds of material remnant from phases of abandonment and collapse, and most significantly a series of collapse features where upward stoping of the mine workings has propagated to the surface, e.g. *Figure 3.3.E.1*.

Figure 3.3.E.1: Collapse subsidence above Mine No 7.

In the area of Lake Kunigunda it is evident that human activity has increased the rate of naturally occurring karstification by: (i) breaching the pallag with the development of salt pools and houses; (ii) through the indirect focusing of water from leaking services in these areas, and (iii) facilitating water exchange within the abandoned mines by the exploitation of abandoned mine water as a source of brine for the ponds. Hydrogeological windows have also been formed by the quarrying of the river terrace deposits for use as a building resource. Such exploitation of the alluvium is particularly evident in the floodplain of the Tisza River where the activity leaves a series of depressions within the floodplain.

Another feature of the Anthropocene is the extensive use of the collapses and sinkholes for the unregulated disposal of waste, e.g. *Figure 3.3.E.2*.

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Figure 3.3.E.2: Use of collapse features for waste disposal

## 3.4 Hydrology and Hydrogeology of the "Solotvyno mine area"

### Background

This section of the report provides an overview of the hydrological and hydrogeological setting and the implications for the causal (triggering) factors of the hazards that are assessed in terms of risk. The description is therefore restricted in its scope and is not exhaustive. The section starts with a description of the meteorological conditions, then describes the hydrology of the Tisza River, and the hydrogeological context of the district.

Hydrology

Average precipitation is lowest in March (42 mm) and highest in June (101 mm) with an average annual recharge of around 744 mm/a. The average temperature is lowest in January (-3.5 °C) and highest in July (18.8 °C) with an annual average temperature of 8.8 °C (http://en.climate-data.org/).

The Tisza River is the main tributary of the Danube River. Its length is close to 1000 km (966 km), it has an average discharge at its confluence with the Danube River of 825 $m^3$/s (1946-2006) The source of the Tisza River is the Carpathian Mountains, thereafter it flows through five countries: Ukraine, Romania, Slovakia, Hungary, and Serbia.

According to the report Integrated Tisza River Basin Management Plan, 2011, compiled and published by the International Commision for the Protection of the Danube River (ICPDR), Vienna, Austria: "*The Tisza River Basin is blessed with rich biodiversity, including many species no longer found in Western Europe. The region has outstanding natural ecological assets such as unique freshwater wetland ecosystems of 167 larger oxbow-lakes and more than 300 riparian wetlands.*"

These assets are strongly connected to the Tisza River. Nature conservation is an important economic component in the Upper Tisza River Basin in Ukraine. The protected areas occupy 1,600 km2, or more than 12% of the Zakarpatska Oblast area (Source: Tisza River Basin Analysis 2007, published by ICPDR, Vienna, Austria).

The important water uses and services are: Water abstraction (for industry, irrigation and household using), drinking water supply, wastewater discharge (municipalities, industry), dredging and gravel exploitation, recreation and various ecosystem services.

The targeted Tisza River section is intrinsically connected with Ukraine, Romania, Hungary and Slovakia. Any common action for protecting of the Tisza River may be potentially promoted by the HUSKROUA ENI Cross-border Cooperation Funding Programme.


Figure 3.4.1: Tisza River course

Hydrogeology

In addition to the geological understanding outlined above and summarized in terms of the hydrogeological characteristics below (*Figure 3.4.3*), a number of research lines offer the potential to contribute to the understanding of the hydrogeology. These are described below.

(i) The regional hydraulic gradient is considered to be from the north-east towards the south-west, i.e. Magura Mountains to the Tisza River. However, an historic hydrogeological map provided by Dr Shekova (*Figure 3.4.2*), indicates that the local hydraulic gradient varies across the area of the Solotvyno mine area. This map shows that there are significant local changes in the hydraulic gradient. The groundwater levels are relatively shallow and broadly reflect the changes in ground level. Groundwater levels determined during this mission have been used to provide a coarse validation of the groundwater level contours. The groundwater contours steepen significantly in the area of Black Moor and the palaeo-channel, indicating that the natural karstification of the salt, probably during the Pleistocene has had a significant impact on the groundwater regime.

(ii) A number of exploratory wells were drilled in the area of the Magura Mountain and gas was discovered beneath the salt. Borehole records with groundwater levels would provide constraint on the likely driving head for this system in the mountains, which is required for understanding the hydrogeological context and will be required for any future groundwater modelling. It was not possible to access such records during the course of the mission. For this mission the base of the system comprises the Tisza River at an elevation of about 257 m relative to sea level.

(iii) Whilst some houses are supplied by mains water, many are reliant on private well supplies. The wells form useful access points to the water table and have been used both for groundwater level measurement and for a restricted number of chemical parameters, as well as the physico chemical parameters: pH, electrolytic conductivity and water temperature.

(iv) Mine shafts and collapse features provide access to the groundwater, and where possible, these have been accessed and sampled. However, it should be noted that access to mine-related water features is problematic because of the associated health and safety issues, particularly the potential instability of the collapse features and similarly the mine shaft structures, which are largely in a state of significant disrepair.

(v) The faulting and associated jointing that is suspected to cross the region (NW-SE structural grain; geology section) have the potential to form groundwater flow paths. Currently, whilst groundwater flow associated with fault zones is suspected, the evidence base has not been established.

(vi) Hydraulic windows in the pallag occur as a consequence of both natural and anthropogenic processes. These areas comprise zones of higher susceptibility to karst processes. An initial estimate (courtesy of information provided by Professor Khrushchov) indicates a reduction in the surface cover of the pallag of at least 25%. Whilst the formation of pallag is a naturally occurring, self-protecting process and the extent of the cover is likely to change with time, it can be relied upon as a protective measure once karst processes have been initiated.

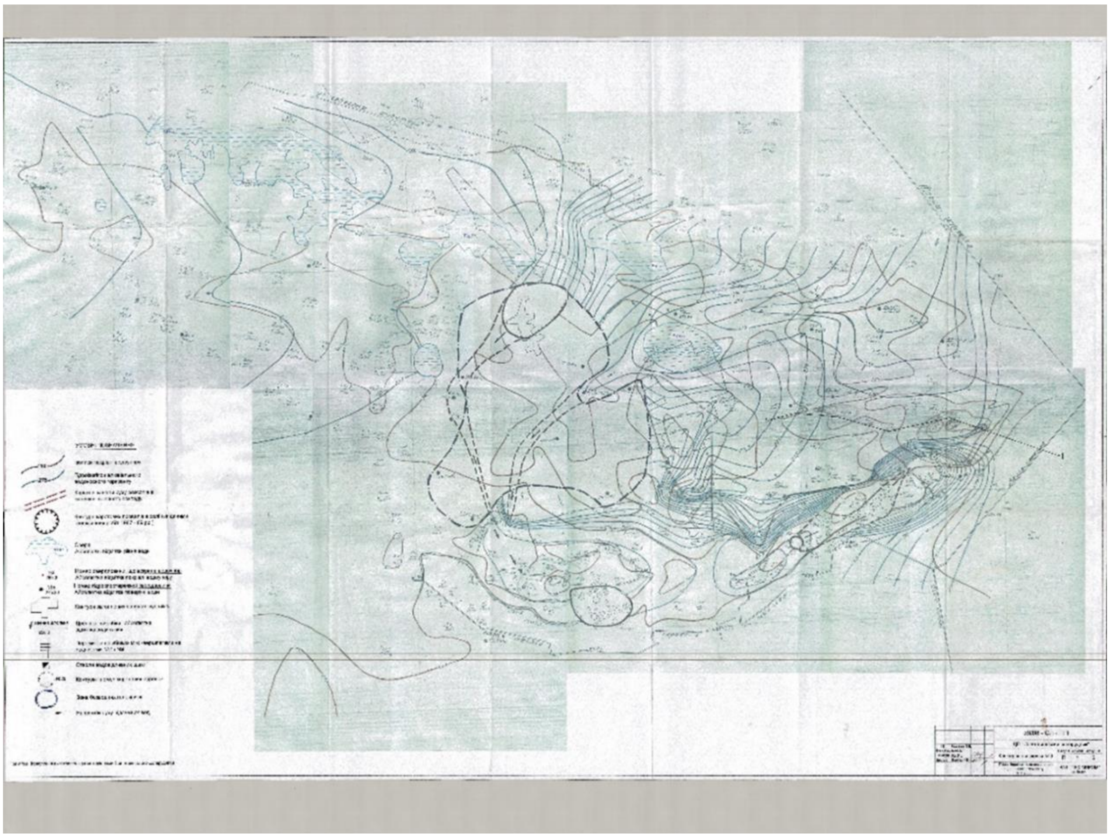

Figure 3.4.2: Groundwater contour map

It has not been possible to characterize the hydrogeological properties at the site, owing to the time constraints, accordingly only preliminary observations have been made and are summarized below (*Figure 3.4.3*). The bedrock geology comprises interbedded tuff, clays and sand, that form interbedded aquifers and aquitards. Exposures seen during the mission indicate that the bedrock is heavily weathered with steeply inclined beds and jointing. The overlying alluvium reaches thicknesses of several tens of metres, accommodating the flow of shallow groundwater flow from the Solotvyno mine area to the Tisza River. Further information would be required to assess the hydraulic and engineering properties of these beds.

| **Lithology** | **Description** | **Hydrogeological properties** | **Potential hydraulic conductivity (m/sec; Domenico and Schwartz, 1990)** |
|---|---|---|---|
| Loess/ residual soil | Cohesionless fine grained (silt) deposit characterised by the presence of mica particles | Largely cohesionless silt grade material, prone to fissuring and to collapse on wetting | $1 \times 10^{-9}$ - $2 \times 10^{-5}$ |
| River Terrace Deposits<br><br>and<br>Alluvium | Beds of slightly clayey silty sandy fine to coarse gravel with cobbles. Cobbles are rounded to subrounded and comprise flysch and Miocene sandstone, quartz, chert, rarely schists and volcanic rocks (Shekonova). This deposit is generally 10 – 30 m in thickness and is ubiquitous in its distribution except in the upper reaches of the streams. | Channel deposits comprising thickly bedded silty sands, sandy gravels and coarse gravels with cobbles. | Variable hydraulic conductivity suspected:<br><br>$2 \times 10^{-7}$ - $3 \times 10^{-2}$ |
| Pallag | Residual clay deposit derived from dissolution of the salt. Primarily clay with subordinate sand and gypsum. Up to 20 m in thickness ( | Dark coloured clay | $1 \times 10^{-9}$ - $1 \times 10^{-11}$ |
| Weathered salt margin | | The “wet” rind and zone of leached and brecciated salt, which locally extends to 200 m in thickness. | Salt erosion rates can vary considerably between about 1 and 100 mm/year<br><br>The salt is primarily thought to be an aquitard to water, however |

| | | | |
|---|---|---|---|
| | | | fracture flow associated with faulting of the dome, should not be overlooked. |

Figure 3.4.3: Hydrogeological characteristics of the superficial deposits.

## Key findings

### 1. Tisza River

River discharges, as well as water quality parameters are measured at two gauging stations downstream of Solotvyno. These two stations are Tiszabecs/Vilok and Zahony/Chop. At both locations, measurements are taken at the right and the left bank of the river by the Hungarian and Ukrainian authorities. Monthly water quality data in broad scale of elements are available at these locations for the time period between 2004 and 2015 provided by the Upper Tisza Regional Water Directorate, Nyíregyháza, Hungary.

Chloride [mg/l] and electrolytic conductivity [µS/cm] data is shown in *Figure 3.4.4* and *Figure 3.4.5* for the two locations, respectively. However, chloride measurements are not available prior to 2009.

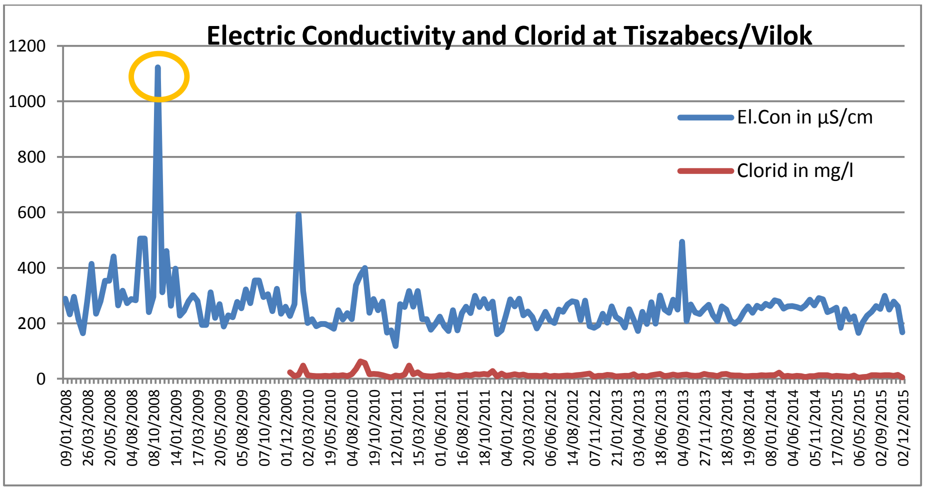


Figure 3.4.4

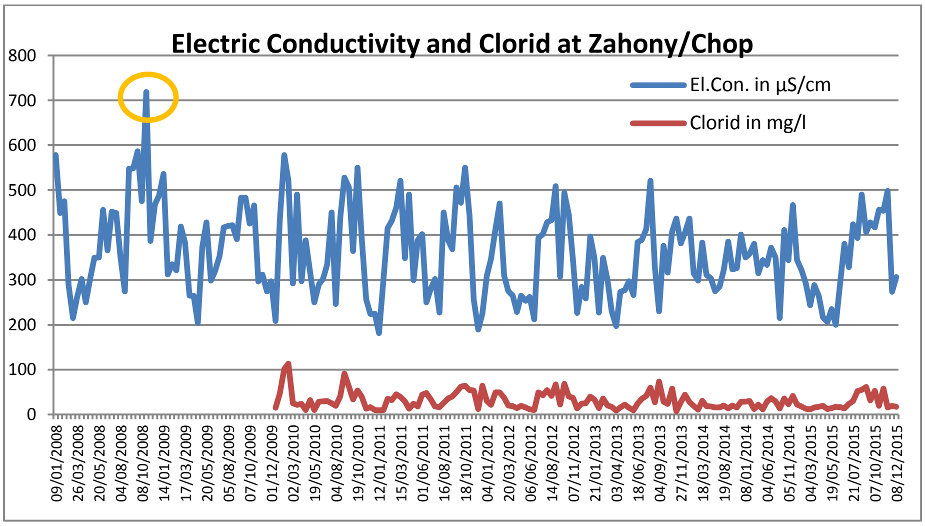


Figure 3.4.5

The threshold value of Chloride in the river water reflects the use. The EU 75/440/EEC standard concerned with Chloride in case of Abstraction of surface water for Drinking Water Supply, is 200 mg/l, and in accordance with the EU 78/659/EEC, the standard for the Protection of Fish Life is not yet been prescribed. Unfortunately, there are not yet any Chloride standard threshold values for water flora and Bentic Invertebrata fauna.

In 2008 a new SWQS (surface water quality standard) standard was proposed for Chloride - 200 mg/l-, as threshold value for the designation of good surface water quality, such as in the section of the Tisza River at Solotvyno (Surface Water Quality Regulation in EECCA countries: Directions for reform, OECD EAP Task Force 2008, Kiev).

Measurements by the Upper Tisza Regional Water Directorate (Nyíregyháza, Hungary) showed maximum chloride concentrations above this threshold in 2008. *See Figure 3.4.6.* This is reflected in the electrolytic conductivity data for 8.10.2008 at the two other stations mentioned above *Figures 3.4.4 and 3.4.5*. This threshold exceedance was assumed to be triggered by the mining activity at Solotvyno.

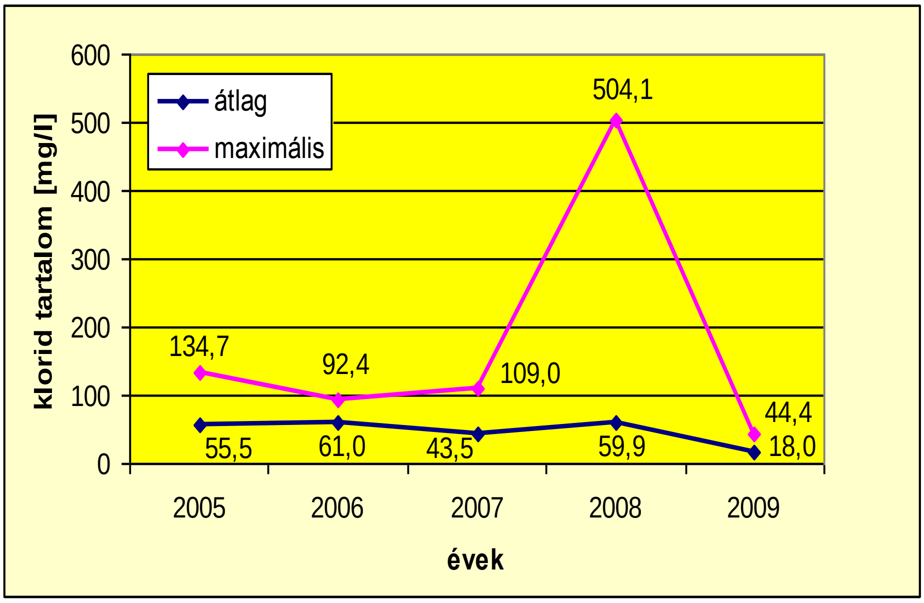


Figure 3.4.6: Maximum and average chloride (klorid tartal) per year (évek) content at the section of the Tisza River (Tjachiv, 35 river km downstream from Solotvyno)

Source: (Official letter to the Hungarian Governmental Commissioner authorized for Cross-border Water Issues between Hungary and Ukraine on the on-site mission in Solotvyno, in the subject of salt contamination of the Tisza River, on 15 May 2009).

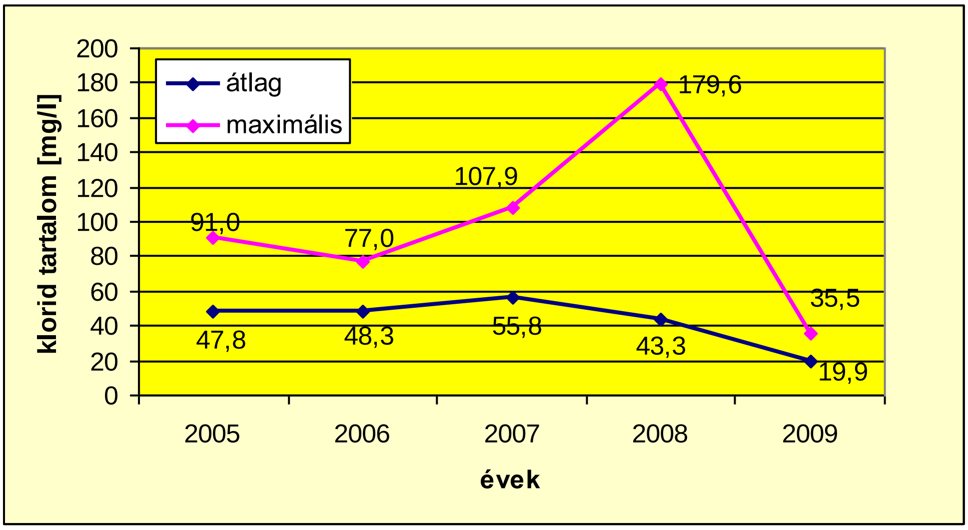


Figure 3.4.7: Maximum and average chloride content at the section of the Tisza River (Vilok-Tiszabecs, 104 river km

Source: (Official letter to the Hungarian Governmental Commissioner authorized for Cross-border Water Issues between Hungary and Ukraine on the on-site mission in Solotvyno, in the subject of salt contamination of the Tisza River, on 15 May 2009).

Annual average chloride concentrations [mg/l] provided by SEIU (2016; *Figure 3.4.8*) show concentrations at three different locations (i.e. Solotvyno (green; exact location not known and assumed to be located just upstream of Solotvyno on the left river bank), Tjachiv (red) 35 km downstream of Solotvyno; and Tiszabecs (blue) 104 km downstream of Solotvyno. The average annual data for Tiszabecs however, shows a slight difference to the data from the Hungarian authorities presented above. This difference might be explained by duplicate measurements on each of the right and left hand side of the Tisza by both countries, Hungary and Ukraine. This data is available until the year 2016 and suggests a decreasing trend in the average annual chloride concentration for both stations downstream of Solotvyno. A stable, or slightly increasing trend can be observed in the data measured at, or upstream of, Solotvyno. The second observation drawn from this data set is the higher concentration measured at the two downstream locations, compared to Solotvyno, particularly before 2010 (excluding the data from 2016, where part of the data is still missing at the time being).

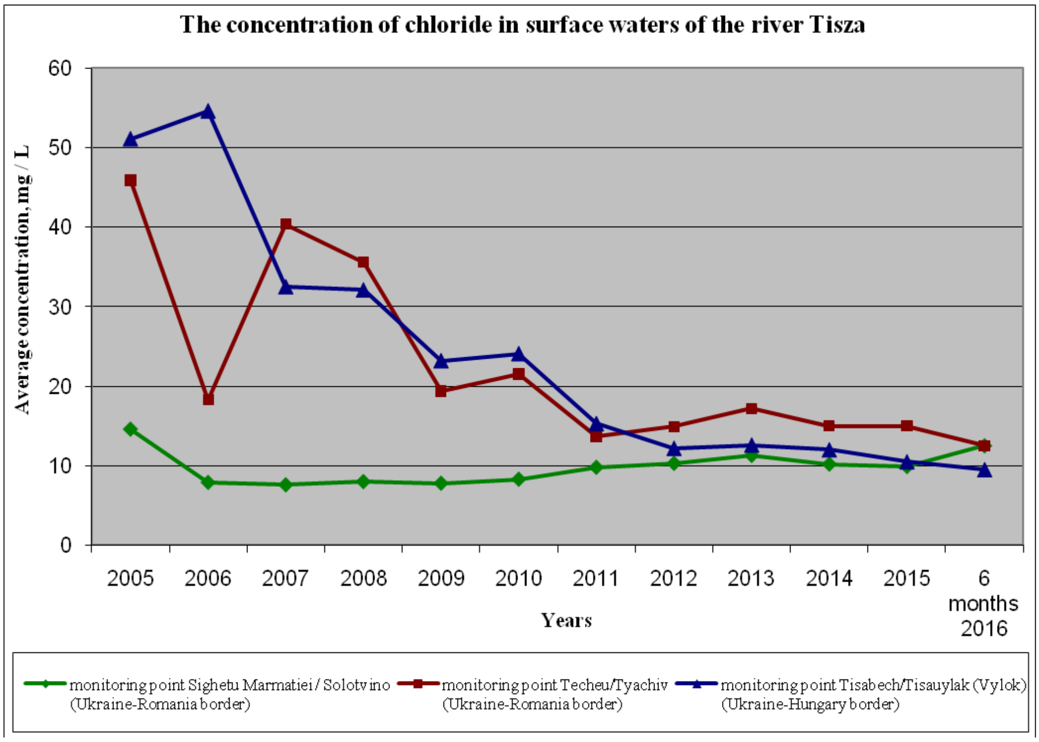


Figure 3.4.8 Annual average chloride concentrations at three different locations (green: just upstream of Solotvyno, red: 35 km downstream of Solotvyno; blue: 104 km downstream of Solotvyno (source: SEIU, 2016)

## 2. Local scale hydrology of the Tisza River

As shown in the conceptual model, different flow paths into the Tisza River, originating from the Solotvyno Mine area, exist. To determine local water inflow into the Tisza River a survey along the River course was conducted.

Measurements were conducted on the 27th of September 2016 starting in the East of Solotvyno, where a small stream with slightly higher conductivity of around 1265 µS/cm enters the River. The profile was finished at a bridge crossing the Tisza River in the South of Solotvyno, approximately 6 km upstream of the starting location. A slight increase of electrolytic conductivity (about 300 µS/cm to 600 µS/cm) was observed from up- to downstream.

Two days later three conductivity and temperature measurements were taken approximately 5 km and 6 km downstream of Solotvyno, as well as at the starting location two days earlier. The downstream locations both indicate a low mineralization of the river water (344 µS/cm and 342 µS/cm, respectively) with temperatures of 18.1 and 16.7 °C, respectively. Temperatures may deviate due to water depth because shallow water flows are more susceptible to changes in air temperature. However, the electrolytic conductivity measurement repeated at the starting location of the profiling conducted 2 days before showed a lower electrolytic conductivity of 330 µS/cm and a temperature of 16.2 °C. This suggests a temporal increase at the day of profiling the river (27.09.2016), possibly due to upstream activities resulting in an increase of mineralization at Solotvyno over time. This hypothesis is supported by the chemical analyses, which did not show an elevated Cl- content in the water. Thus, no direct impact on the water quality of the Tisza by water release from the Solotvyno mine area could be proved. However, it is known that the drainage canals release water into the Tisza River close to where the higher mineralization was measured i.e. at the starting location, see above. A further consideration is that the time of this survey coincided with the end of the "dry period". The river water level was very low, as indicated by the large dry gravel floodplains and flood margins observed along the river course. It is likely that water input and mineralization entering the Tisza River during the wet season might be substantially different. Additional salt load might partially be compensated by the overall higher flow volumes and dilution in the Tisza River. The conceptual model suggests that the Tisza River (in general a gaining river) might be losing water under high flow conditions. This would lead to a temporal reversal in shallow groundwater flow from the river towards the Solotvyno mine area. Such a scenario might lead to elevated chloride concentrations in the base flow at the end of the wet season (or after a flooding event), when the shallow groundwater flow is directed towards the river again.

## 3. Flow processes at Solotvyno mine area

Contact of under-saturated freshwater with salt leads to dissolution. The salt dome of Solotvyno is the main salt deposit in the area. The different paths that may facilitate contact between fresh water (or under-saturated water) with the salt dome have been described below:

1. Carpathian Mountains (deep groundwater flow)
2. Recharge in the Magura Mountain (shallow groundwater flow)
3. Tisza from up-stream (hyporheic – surface and shallow groundwater flow)
4. Direct precipitation
5. Tisza flooding events
6. Leaking water supply (and waste water)
7. Agricultural irrigation

The high Carpathian Mountains are assumed to be a major groundwater recharge location, due to their elevation and generally increased precipitation. This affects the deep groundwater flow in the Solotvyno area, which is assumed to flow from NE to SW. No water level measurements have been obtained from depths greater than 50 m due to a general lack of boreholes penetrating the bedrock in this area. Due to the (suspected) lower hydraulic conductivity properties of the bedrock, it is concluded that deep groundwater flow has a relatively low impact on the surface water quality in the Solotvyno area (i.e. Tisza River). Deep groundwater flow is generally slow, thus long contact times with the prevailing salt in greater depths will lead to high mineralization of these waters. Compared to fresh water, such brines are characterized by high densities, e.g. 1.164 g/cm³ 22 % NaCl salt by weight at some ambient temperature (Lide, 2005). Consequently, freshwater is generally located above the saltwater. However, different processes can lead to mixing of fresh and salt-water (e.g. dispersion, diffusion, upwelling of deep groundwater along faults, influence of geomorphological disturbances e.g. due to mining activities).

## 4. Mine Craters

### Crater No 7 and 2 May sinkhole (24.09.2016)

Both of the main craters of Mine No 7 and Mine No 8 are filled with water. Crater No 8 is still developing (see *Figure 3.4.9*) and was not sampled for safety reasons. In crater No 7, however, water level measurements and water quality analysis were conducted with the help of the Ukrainian Mountain Rescue Team. The maximum water depth measured was 28 m, at the center/west side of the crater. The temperature decreased over depth from 24.4 °C at the surface to 14.2 °C. *See Figure 3.4.10.* Electrolytic conductivity seems was stable with depth, showing values between 248,000 µS/cm and 256,000 µS/cm with a slightly elevated conductivity of 277,000 µS/cm in the upper meter. These values indicate saturation of the water. The remaining roof of the old cavern of mine No 7, consisting of rock salt can be seen clearly at the sides of the crater. The first value (0 m) of around 277,000 µS/cm is assumed to be higher due to anthropogenic influence, e.g. waste diposal. The deepest measurement of the profiling location (center/north in the crater) was conducted at 25 m and shows a significantly lower electrolytic conductivity (73,000 µS/cm). This decrease can be explained by clogging of clay in the sampling device, which was noted after the sampling campaign. This is possibly an indication of the development of Pallag at the bottom of the crater No 7, alternatively it might be alluvial sediment. Three samples were taken with a bailer at a depth of 2 m, 8 m, and 16 m, for chemistry and stable isotope analyses (data analyses not available at the time of final report).

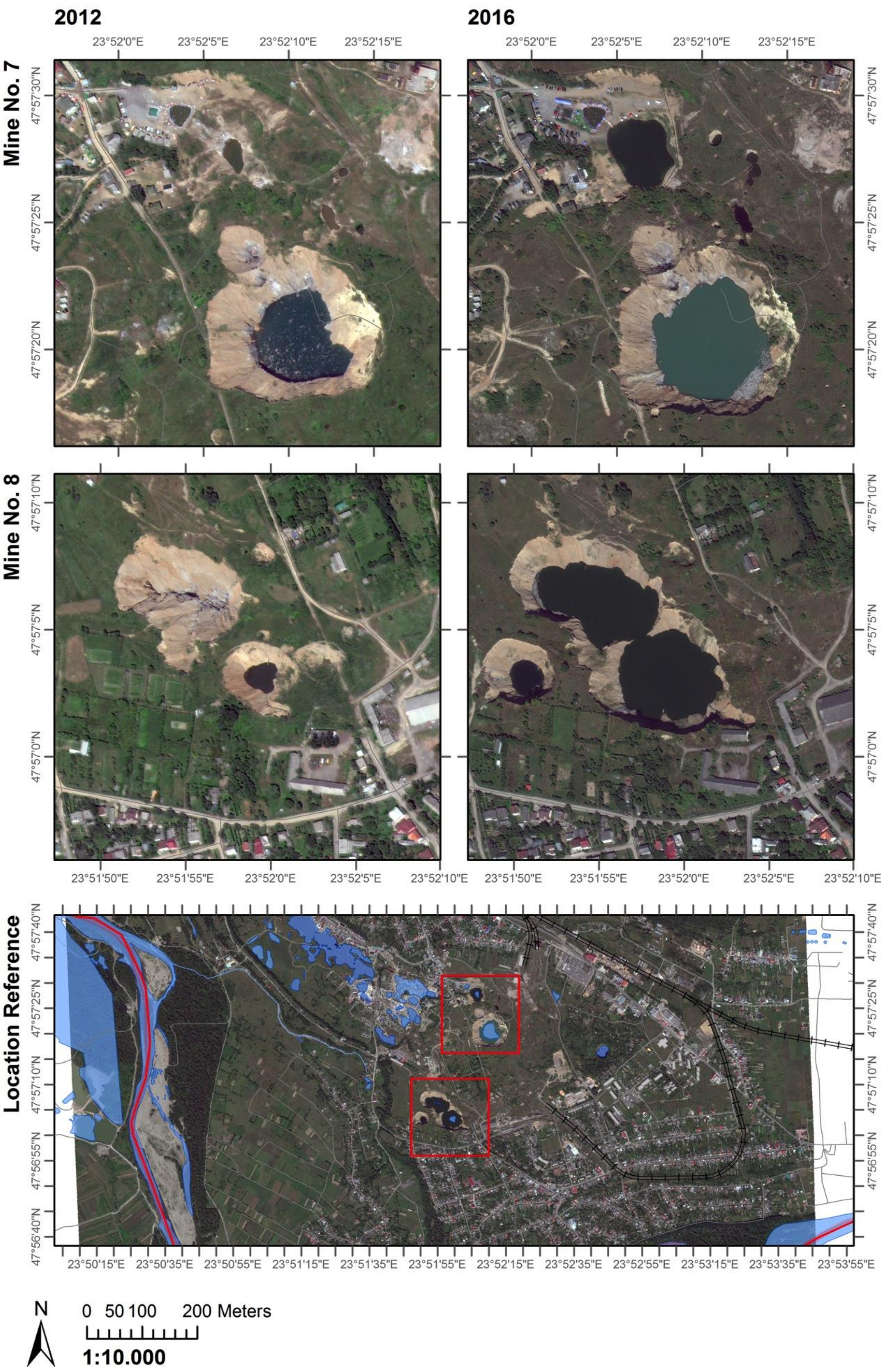
2012
2016
Mine No. 7
Mine No. 8
Location Reference
23°52'0"E
23°52'5"E
23°52'10"E
23°52'15"E
47°57'30"N
47°57'25"N
47°57'20"N
47°57'10"N
47°57'5"N
47°57'0"N
23°51'50"E
23°51'55"E
23°52'0"E
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Figure 3.4.9

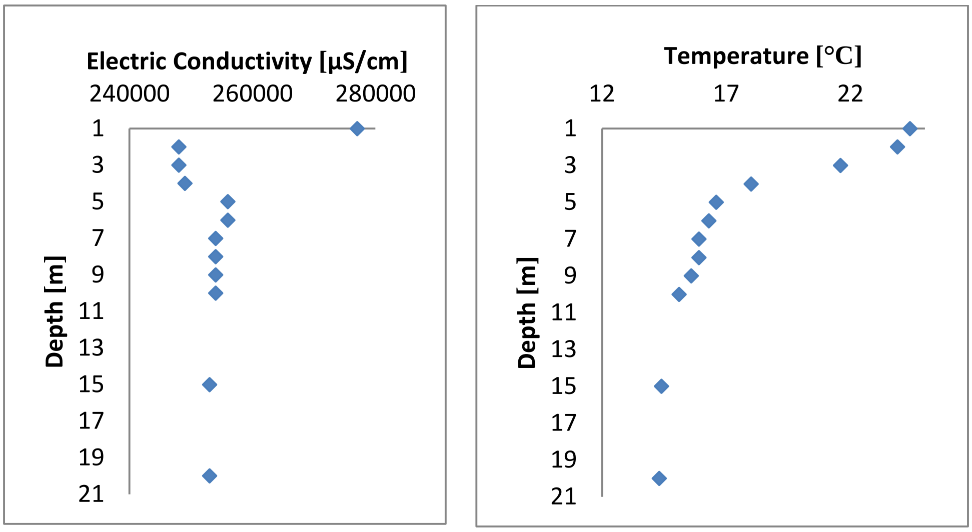


Figure 3.4.10: Electrolytic conductivity and temperature profiles at Crater No 7

The sinkhole, which developed on 2 May 2016 had a water depth of around three meters. The water level was estimated to be 7 m below ground surface. Measurements and samples were taken by spanning a cable above the crater from which the conductivity meter and the bailer were lowered into the water. Results displayed in *Figure 3.4.11* indicate high mineralization and an increase of both, electrolytic conductivity as well as temperature over depth.

| Depth [m] | EC [µS/cm] | Temp. [°C] |
|---|---|---|
| 0 | 49,200 | 19.1 |
| 1 | 74,800 | 25.6 |
| 2 | 129,700 | 26.8 |
| 3 | 115,700 | 24.6 |

Figure 3.4.11: Measurement results of the 2 May Sinkhole

**Shaft 10 (mine No 9) and Shaft 8 (mine No 8) (24 and 26.09.2016)**

Shaft No 10, called "skip-shaft" by the local population, was used for material transportation. Its original depth is around 525 m, but only the last 30 m are believed to penetrate the salt dome according to correspondence with the mining staff. The water level was approximately 3 m below surface. *Figure 3.4.12* shows a depth profile of electrolytic conductivity, which indicates fresh water over the complete measurement range (up to 298 m below water level). Slight mineralization is indicated at a depth of 198 m; however, here pieces of iron from the shaft irons were found in the water, which was coloured red. This may not reflect the "natural" water composition, as the bailer hit the shaft construction several times. The temperature remained constant throughout. The three deepest measurements in *Figure 3.4.12* were achieved by taking a sample with the bailer. Due to the subsequent measurement of temperature after pulling the bailer up and sampling procedure, a temperature rise of around 1 °C may have occurred.

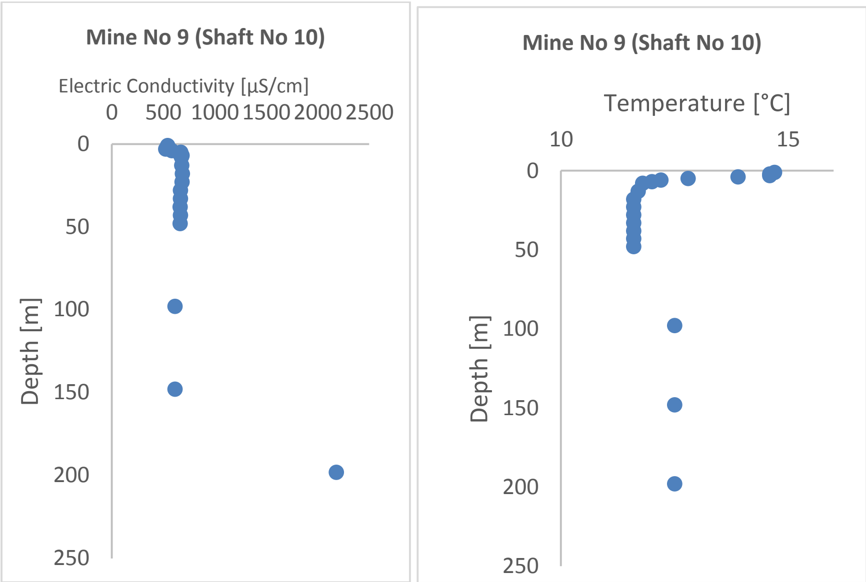


Figure 3.4.12: Electrolytic conductivity and temperature at shaft No 10 (skip shaft of mine No 9)

At Shaft 8 (mine No 8, to the rear of the mining office), the water level was around 33 m below surface. The water mineralization at shaft 8 was around 6,000 to 7,000 µS/cm in the upper first 10 m with a rapid increase (sharp interface) over the next several meters up to a value of 23,000 to 24,000 µS/cm, *see Figure 3.4.13* Three additional samples were taken with the bailer, from which the last one was rejected, due to water intake in the bailer (malfunctioning?). The second sample taken at a depth of 5 m below water level should also be interpreted with care, as it might also have been influenced by the bailer malfunction. It was probably also disturbed by the bailer, which was lowered to a depth of 117 m for the first sample. At this depth, the electrolytic conductivity of 158,000 µS/cm indicates strong mineralization. Temperatures increased over depth in both, the first meters, as well as in the deepest sampling location (117 m, 14 °C).

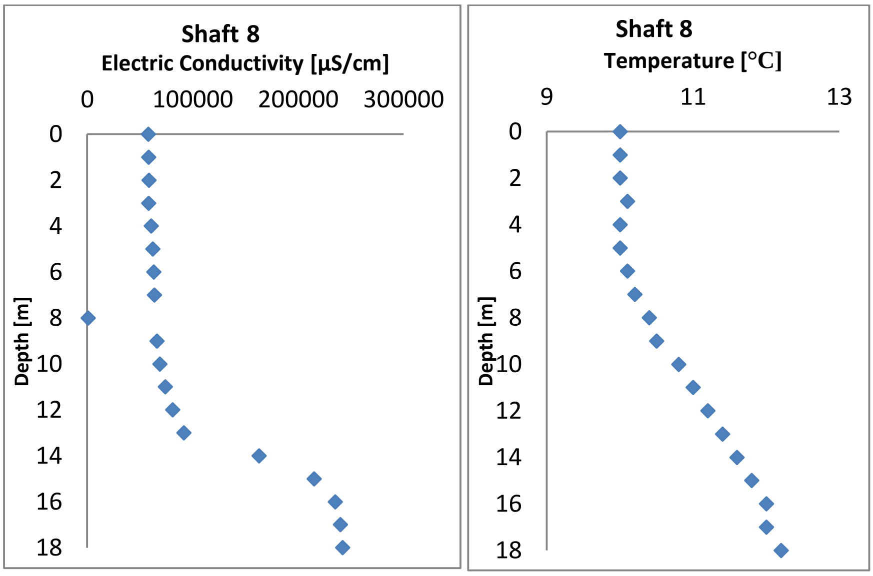


Figure 3.4.13: Electrolytic conductivity and temperature profile at shaft 8 at mine No 8. Water level was (approximately) 33 m below ground level.

Three additional samples were taken with the bailer, from which the last one was rejected. *See Figure 3.4.14.*

| Sampling No. | Meters below water level | Electrolytic conductivity [µS/cm] | Temperature [°C] | pH-Value |
|---|---|---|---|---|
| EUCPT_26 | 117 | 158,000 | 14 | 7 |
| EUCPT_27 | 5 | 61,000 | 11.4 | 7.25 |
| - | 22 | 94,200 | 11.6 | 7.25 |

Figure 3.4.14

**Black Moor**

Two locations at the side and the centre of the Black Moor were selected for measurements of electrolytic conductivity and temperature as well as for depth specific sampling with subsequent chemical and isotopic analyses. These measurements were taken from the boat. The side location (approximately 10 meters from where the Zodiac boat was lowered into Black Moor, had a maximum depth of 3.3 m showing a stable conductivity of around 1550 µS/cm indicating mineralized fresh water. The same trend was observed at the central location, but electrolytic conductivity increased with depth, reaching its maximum of 3110 µS/cm at a depth of 8.3 m. Temperature at the side location at Black Moor was significantly lower in the upper three meters (11.9 °C) compared to the central location (17.9 °C). With increased depth the temperature decreased in the central location, reaching its minimum of 10.0 °C at a depth of 8.3 m. *See Figure 3.4.15*. As the temperature at the surface tends to be higher (at this time of the year) due to contact with the atmosphere, the lower temperatures are assumed to be more groundwater influenced. This suggests, that fresh groundwater with a significantly lower temperature enters the Black Moor from the NW side (side of the overall shallow groundwater flow direction). Depth specific isotope analyses for this location were not available at the time of reporting, but would be beneficial for future interpretation of this situation.

If there is active freshwater inflow into Black Moor, there must be a source. From interviews with locals, it is known that the Black Moor suddenly became dry (literally over night) on two historical occasions. A historic photo dates the first incident to the 02.12.2005. This highly dynamic situation suggests a direct connection either to one of the mines or a karst chamber formed by dissolution. The Black Moor is not situated directly above one of the mine chambers, however, karst conduits are likely to develop. This is especially the case, because of extensive pumping at the mines No 8 and No 9 for dewatering.

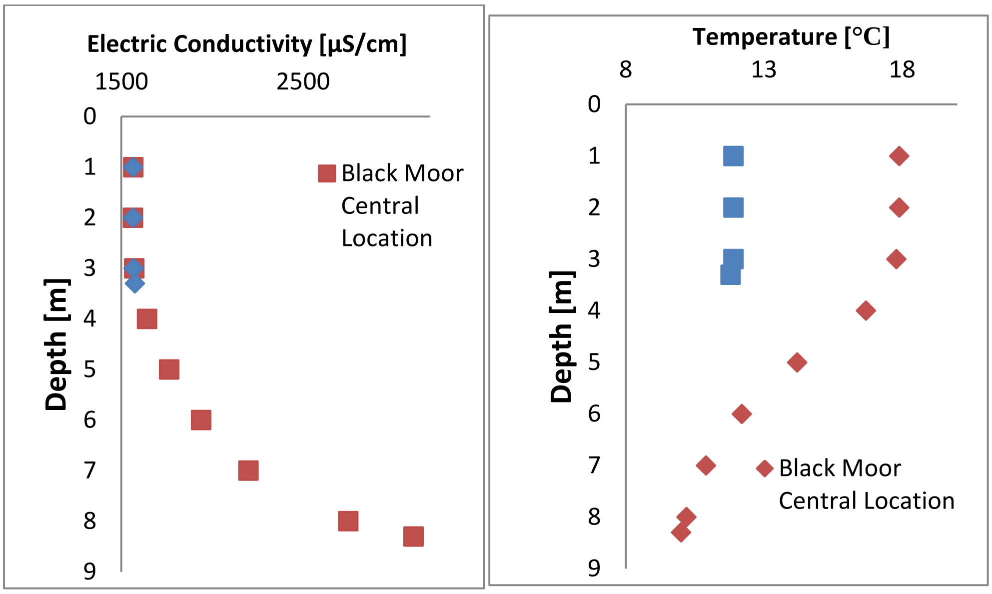


Figure 3.4.15

## Lake Area

The largest lake in the area is Lake 18 (mistakenly declared "Lake Kunigunda" in several sources including google earth), situated in the NW of the Solotvyno mining area. Smaller lakes, which generally show higher salinity values, are situated SE of Lake 18, from which Lake Kunigunda was visited. Here, salt outcrops could be observed. During the time of the mission, the salt outcrop was significantly altered, presumably by anthropogenic mining by the local population on a very small scale, to sell it to tourists. *See Figure 3.4.16.*

Figure 3.4.16: Same perspective of the salt outcrops at Lake Kunigunda at the beginning (left) and end (right) of the mission

Additional anthropogenic influence results from the discharge of water from one "sub"-lake (divided by small dams) to another, when water levels are relatively low, according to local interviews. Lake Kunigunda serves as a recreational area for tourists, thus there is a requirement to maintain the water level (at an unknown level, but assumed to be in the range of less than 3 m). The lakes are situated at the margin between the salt dome and the adjacent bedrock. Lake 18 has a long term, lower salinity according to interviews with locals. This is also reflected in the measurements taken during this mission: Salinity concentrations at Lake Kunigunda (three “sub”-lake measurements) are at saturation, as electrolytic conductivity measurements were approximately 250 mS/cm at a depth of 30 cm. At Lake 18 on the other hand, where a maximum depth of 5.8 m was measured, a clear stratification in electrolytic conductivity as well as temperature was observed. *See Figure 3.4.17.*

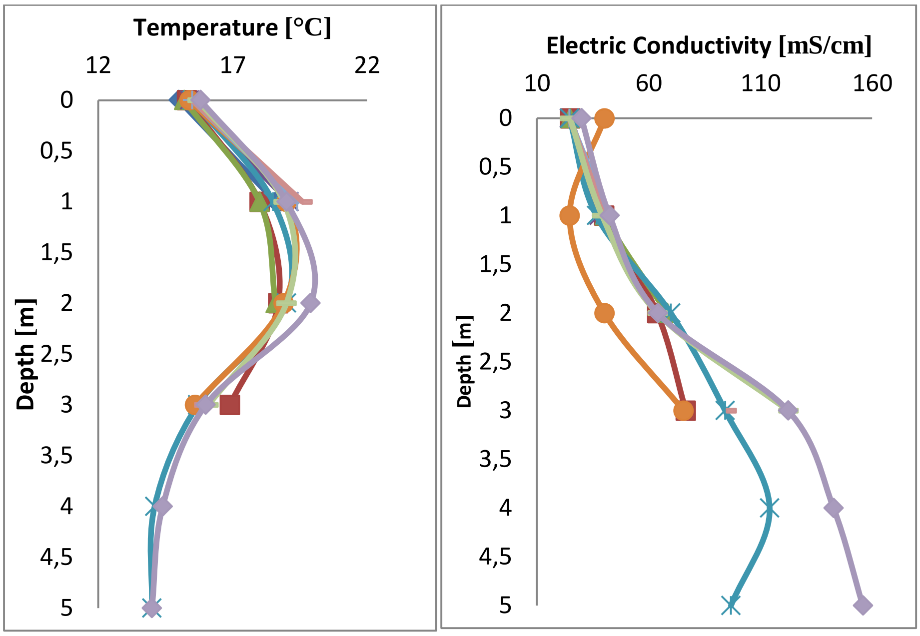


Figure 3.4.17: Electrolytic conductivity and temperature profiles of Lake 18 for ten different sampling locations

### 5. Stable Water Isotopes

Stable isotope samples were analysed by the Federal Institute for Geosciences and Natural Resources during the time of this mission. Plotting this data in relation to the Vienna Mean Standard Ocean Water (VSMOW), a differentiation in stable isotope composition can be made according to the distinct sampling locations (*See colours in Figure 3.4.19.).* The black dots indicate sampling locations of wells (with open shafts), as well as several depth specific samples from Shaft 10 at Mine No 9 (*See figure 3.4.18*). The orange colour represents samples from the collapse of Mine No 7 as well as the Shaft 8 of Mine No 8 from several depths. The light green dots represent water samples from the Black Moor (central location) at a depth of 4.5 m and 6.5 m. The dark green dots show a more “heavy” isotope composition in samples taken from the surface of the Black Moor (1.5 m, central and side location), as well as from the 2May Sinkhole. These analyses clearly show the influence of evaporation from the water surface, which leads to fractionation. The evaporation trend would be visible if a Regional Meteoric Water Line could be established, but this was not possible during the time of this mission. For this, stable isotope data from local precipitation would be necessary. Still, the evaporation is reflected in a less depleted signal compared to the VSMOW (dark green dots).

Water samples from the Tisza River (blue) and the water supply well (red) show a "light" isotopic composition, which commonly represents groundwater. It is assumed that the water well abstracts bank filtration water from the Tisza River given its proximity to the river. Whilst isotopic composition from the Tisza River water, might be subject to evaporation, it carries a "lighter" or "more depleted" isotope composition, possibly due to its origin from the high Carpathian Mountains (plotted in blue in *Figure 3.4.19*).

These values of the Tisza River water can be explained by the fact that the river is at base-flow conditions at this time of the year (end of dry period). Further interpretation of this isotope data is necessary for a better understanding of the complex hydro(geological) flow processes.

| Location | d18O | Sd | d2H | sd |
|---|---|---|---|---|
| Private well | -9.96 | 0.06 | -69 | 0.3 |
| Groundwater spring | -9.8 | 0.09 | -68.2 | 0.2 |
| Pumping Station reservoir | -10.49 | 0.02 | -72.7 | 0.2 |
| Public supply well (shaft) | -9.94 | 0.06 | -69.1 | 0.2 |
| Tisza River | -10.31 | 0.1 | -70.3 | 0.2 |
| Private well near Black Moor | -9.53 | 0.18 | -67.7 | 0.3 |
| Southern drainage outlet | -9.61 | 0.12 | -68.2 | 0.5 |
| Tisza River | -10.35 | 0.11 | -70.5 | 0.2 |
| Northern drainage outlet | -9.69 | 0.08 | -68.1 | 0.2 |
| Black Moor side location_2.5m | -7.04 | 0.08 | -55.9 | 0.1 |
| Black Moor center_1.5m | -7.09 | 0.05 | -55.6 | 0.2 |
| Black Moor center_4.5m | -9.21 | 0.02 | -65.3 | 0.1 |
| Black Moor center_6.5m | -9.13 | 0.09 | -65.2 | 0.4 |
| Mine#7_2m | -8.42 | 0.07 | -63.0 | 0.1 |
| Mine#7_16m | -8.39 | 0.05 | -63.4 | 0.2 |
| 2May2016_Sinkhole_1.5m | -6.97 | 0.09 | -55.4 | 0.2 |
| Mine9_Shaft10_98m | -10.04 | 0.08 | -69.4 | 0.3 |
| Mine9_Shaft10_148m | -9.90 | 0.04 | -69.0 | 0.3 |
| Mine9_Shaft10_198m | -9.91 | 0.10 | -68.9 | 0.4 |
| Mine8_Shaft8_117m | -8.92 | 0.05 | -63.7 | 0.2 |
| Mine8_Shaft8_5m | -8.73 | 0.04 | -62.2 | 0.2 |

Figure 3.4.18: Stable isotope analyses at nine locations of Solotvyno with $\delta^{18}O$ and $\delta^{2}H$ being the stable isotopes concentration relative to the Vienna Standard Mean Ocean Water (‰ VSMOW) and Sd being the standard deviation (%).

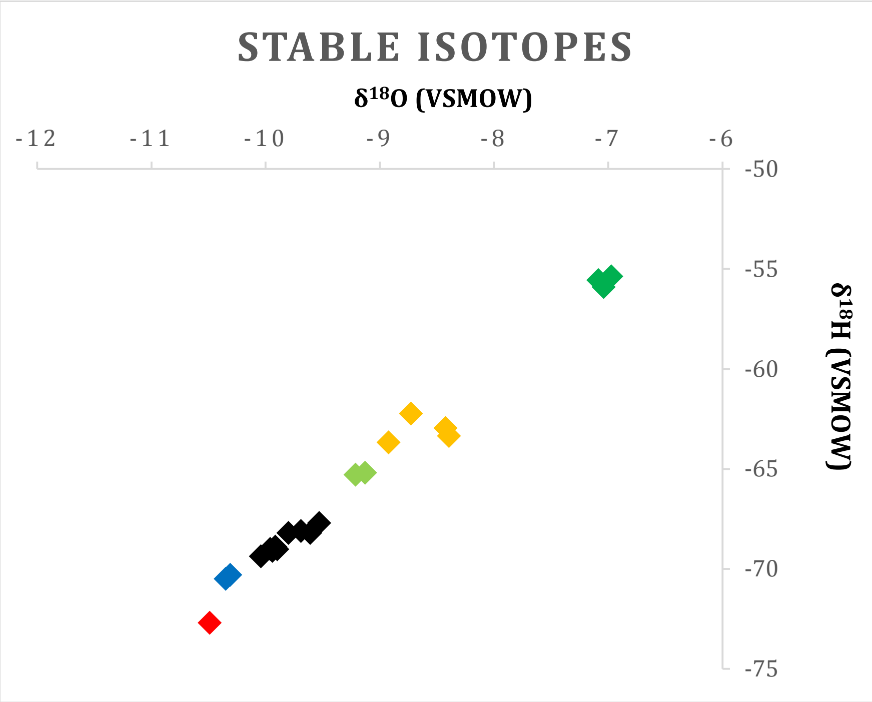


Figure 3.4.19: Stable isotope data analysis of the first nine samples taken during the mission.

## 3.5 Environmental situation

### Background

**Flood management to protect Solotvyno leisure and resort area (connecting to the Upper-Tisza Valley flood management)**

**Overview**

Due to the high Carpathian Mountains of Zakarpattia Oblast, high floods are to be expected. Discharges can be high, and fast water flow can reach the lower part of the Tisza River causing rapid flooding. Forecasting of flows in rivers has become more and more problematic year by year due to climate change and deforestation. The area is subject to higher precipitation in wintertime and dryer spells in summer periods. Winter precipitation can also be of greater intensity. The prediction of amounts and flows on mountain slopes is more difficult to forecast. Forest management has radically changed the hydrology in the region (Zakarpattia Oblast). During the 1930's the region was covered by > 80% of forest. Today this has been reduced to 45% due to deforestation. Therefore, an early warning system is a vital component for the future (flood forecasting). *Figure 3.5.1* is a snapshot of a flooding event of the region in March 2001. Such events are attributed to deforestation and its consequences (i.e. rapid flows and very low infiltration).

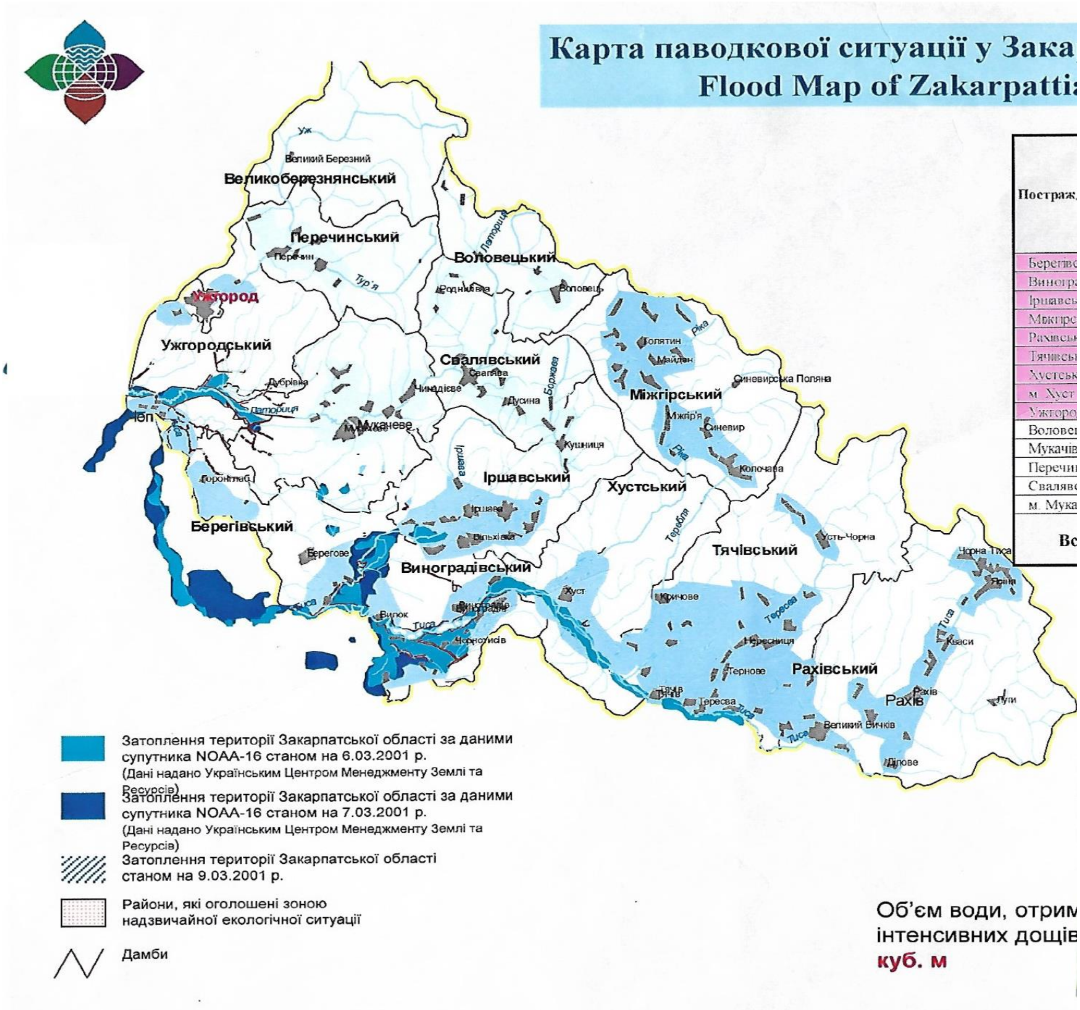


**Figure 3.5.1 Inundation map Zakarpattia Oblast (Region) (provided by Dr Y. Yakovlev)**

Figure 3.4.16: Same perspective of the salt outcrops at Lake Kunigunda at the beginning (left) and end (right) of the mission

## Flood management in Solotvyno

There is no credible data on flood events at Solotvyno. However, the geomorphology and extent of the alluvial sediments and the flood-line show clearly that the area is sensitive to flooding. Solotvyno is located on the former Tisza floodplains The permeability of the alluvium is high, providing easy movement for water from and to the river. In *Figure 3.5.1* the deepest part the floodplain is visible at the western part of Solotvyno. Here, the Tisza River is braided, thereby loosing velocity. These branches are very close to the freshwater lakes (several hundred meters). It is highly probably that there is a subsurface hydraulic connection between the lakes and the Tisza River increasing the risk of flooding consequence. The fresh and saltwater lakes are part of the resort area and served as allergology medical treatment as well. A dam was constructed between 1920-1939 [by the Czechs] to protect the former mining area (now the lakes resort area).

**Flood Barrier**

To protect the mines in the eastern part of the salt down from flooding, the Czechs built a flood barrier of about 10 metres high. It stretches from the elevation of the mining area of mine No 8 to the elevation on which the state hospital is situated. The barrier has a clay core (*Figure 3.5.8*).

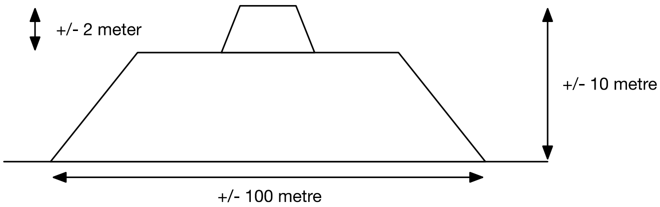


Figure 3.5.8 schematic profile of flood barrier on bases of rough estimates (aerial photo and on site observation).

The flood barrier was assessed by the EU-team on 24-9-2016 and 2-10-2016. The flood barrier looks well designed. The lowest point, at the northern end of the Lake 18, can be protected if higher water levels are forecasted. It is not known at which water level the flood barrier will be topped. It is also unknown whether is hydraulic connection beneath the barrier. It is likely that if flood water enters the basin formed by the salt lakes and lake 18 water behind the flood barrier will be retained for some time before it drains back into the Tisza riverbed as the river level recedes.

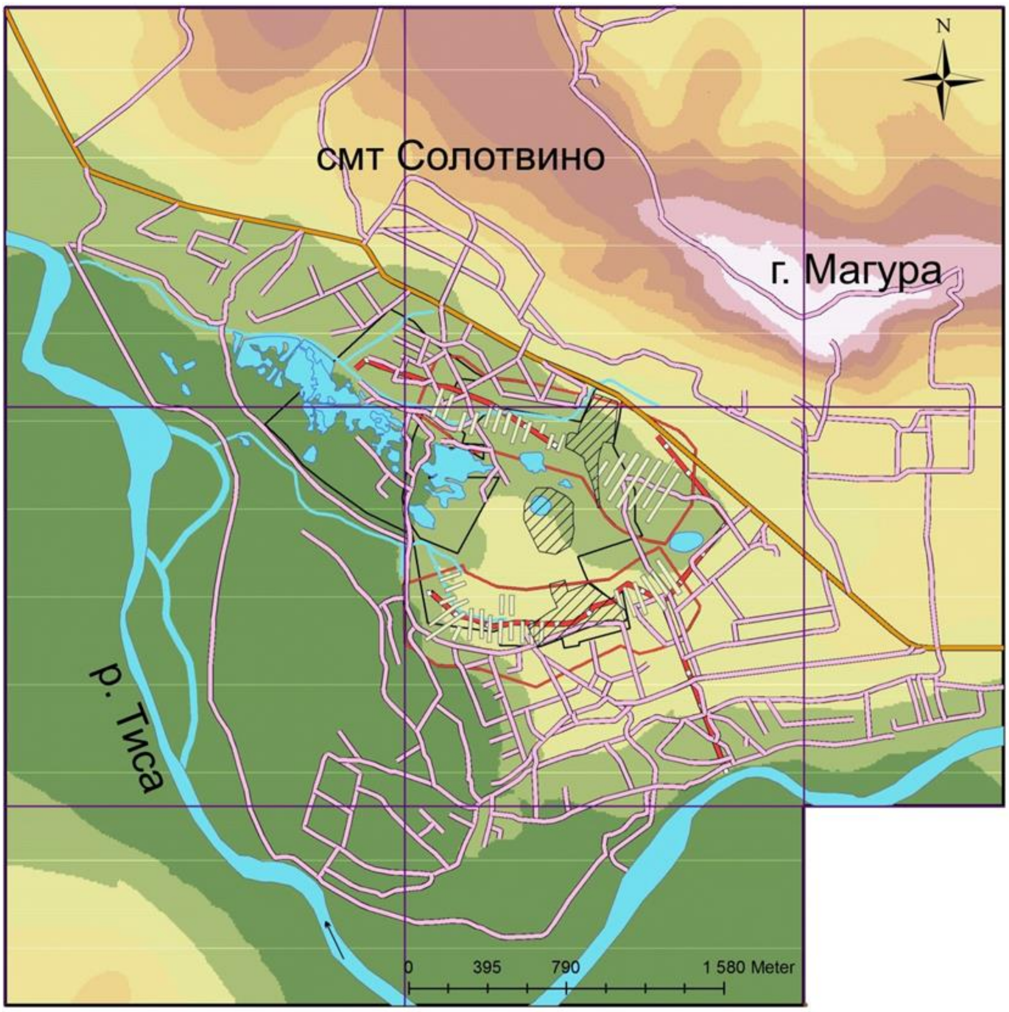


Figure 3.5.2

Figure 3.5.8 schematic profile of flood barrier on bases of rough estimates (aerial photo and on site observation).

The potential impact of these environmental changes requires:

1) A rethinking of the flood management of the floodplain area, focusing on the freshwater and saltwater lakes area and implementation of an early warning system in conjunction with effective flood forecasting.
2) Rethinking of water management in the leisure and resort area focusing on
    a. The drinking water network
    b. The sludge line system
    c. Management planning of salt water use and handling
3) More effective waste management, perhaps through the implementation of rules and technical facilities.

## Key findings

In order to establish an understanding of the groundwater levels across the site, the depth to water level was measured in eleven private and two public water supply wells and sampled. Electro-chemical analyses were recorded and subsequently basic chemical analyses were undertaken and are summarised in *Figure 3.5.3.*

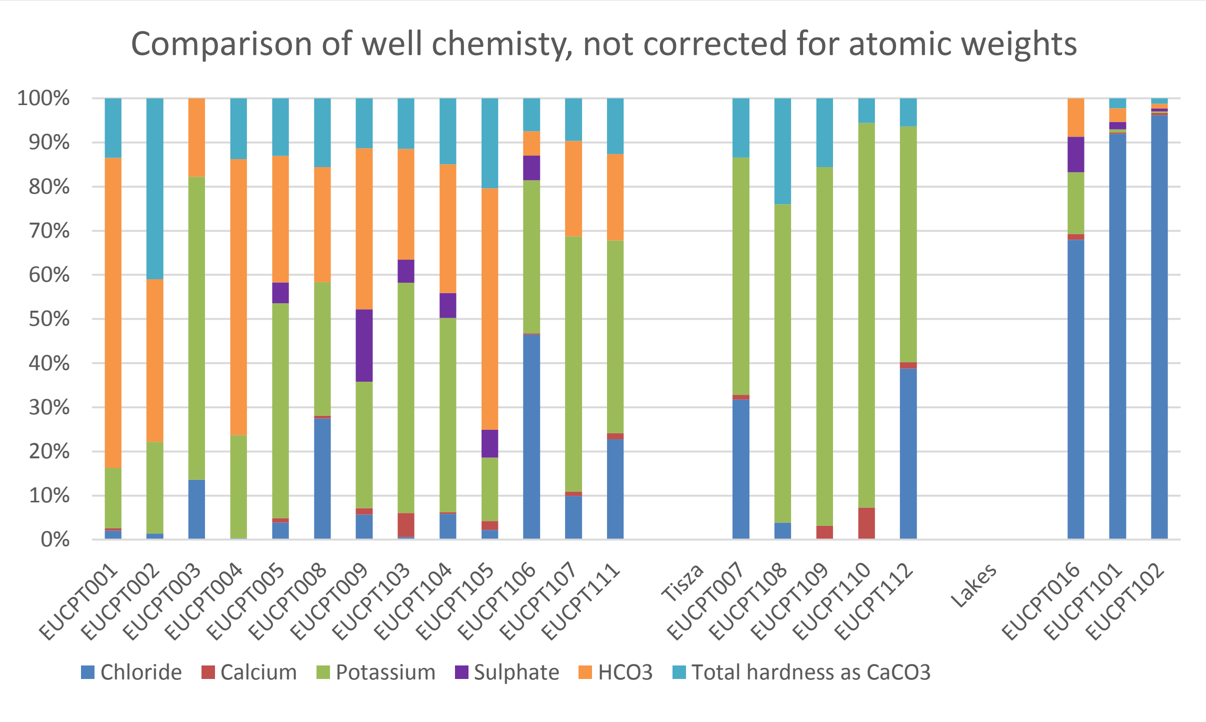


Figure 3.5.3

Chloride concentrations were generally low in the well samples that were analysed and they contrast with samples from the lakes in the recreation area. The water well samples being richer in bicarbonate and sulphate. A maximum concentration of 375 mg/l was determined for sample EUCPT106, which was a newly constructed well and 290 mg/l chloride was determined for well EUCPT008, (*Figure 3.5.4*); the remainder were well below the trigger value of 300 mg/l. The water supply is primarily derived from the River Terrace deposits, which provides a natural filtration.

Figure 3.5.4 Well sampled at EUCPT008.

From this data it has also been possible to plot coarse resolution profiles approximately along the line of the conceptual model. Chloride and calcium profiles are presented below (*Figure 3.5.5 and 3.5.6*). These results show the influence of the salt dome on the groundwater chemistry (chloride concentration) and may show the influence of the northern fault on the well chemistry, i.e. elevated calcium outside the area of the dome.

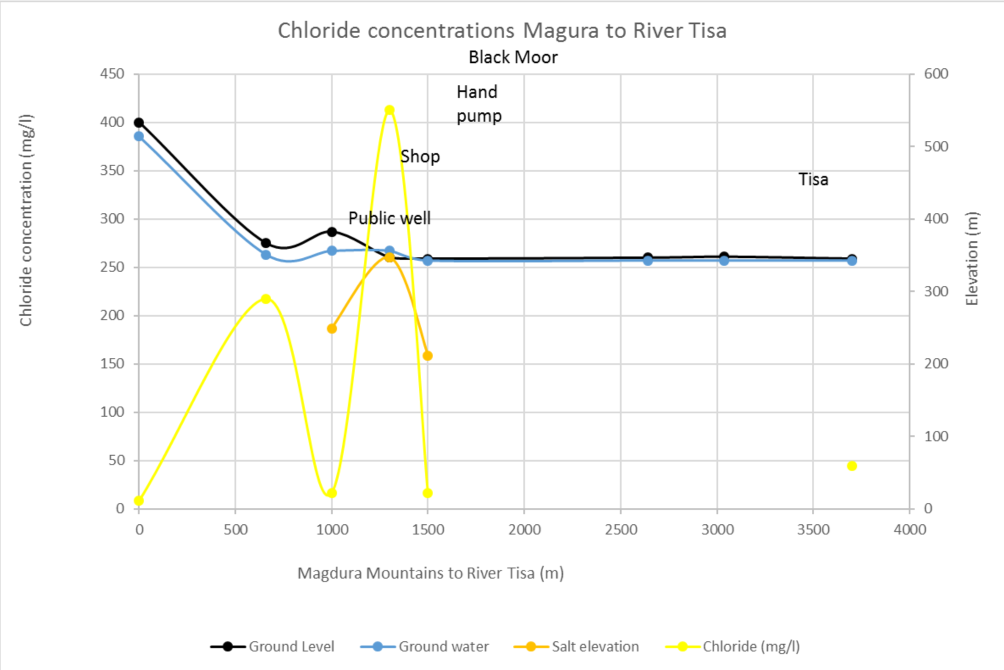


Figure 3.5.5: Profile of spot chloride concentrations from Magura Mountain to the River Tisza

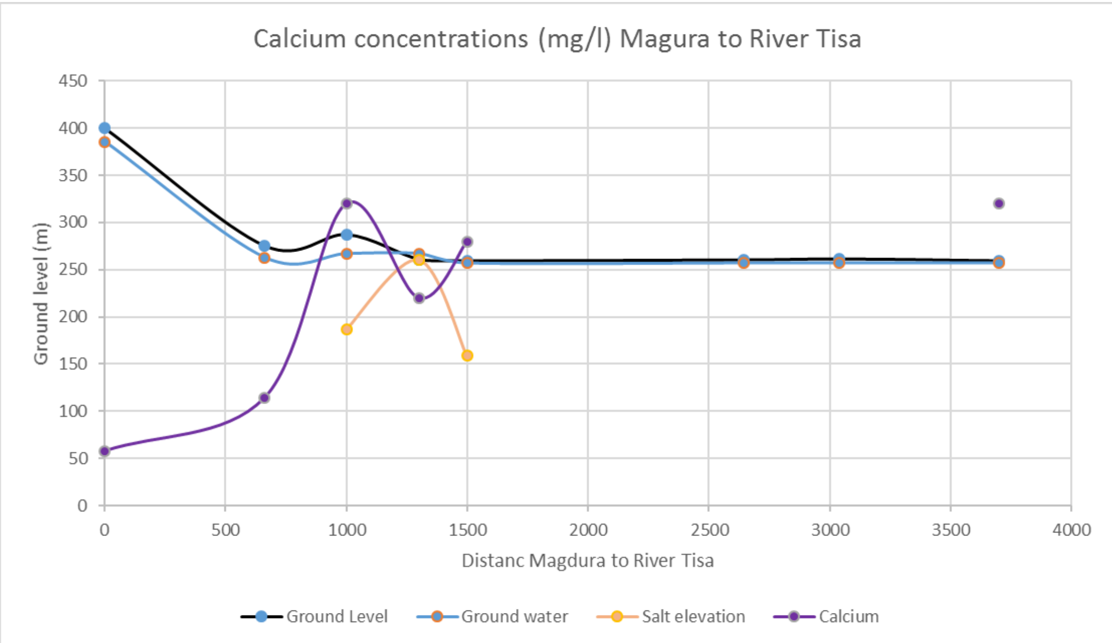


Figure 3.5.6: Profile of spot calcium concentrations from Magura Mountain to the River Tisza

Corr elations were determined for the chemical data (*Figure 3.5.7*), from this we can see that for the under-saturated water electrolytic conductivity is not necessarily a direct analogue for chloride, as it also correlates strongly with sulphate and potassium. From this, it can be seen that electrolytic conductivity cannot be relied upon to assess the chloride concentration of the under-saturated water and that chemical analyses are required for the assessment of groundwater quality.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Conductivity | | | | | | | 1 |
| Chloride | | | | | | 1 | 0,89578963 |
| Potassium | | | | | 1 | 0,881883882 | 0,709643947 |
| Calcium | | | | 1 | -0,231287344 | -0,363661331 | -0,423687527 |
| Sulphate | | | 1 | -0,500387667 | 0,433561752 | -0,645073996 | 0,797959848 |
| Alkalinity | | 1 | 0,074984755 | 0,22513155 | -0,193671876 | -0,134857009 | -0,14165941 |
| Total Hardness | 1 | 0,479356051 | 0,56534943 | 0,261720128 | 0,473844805 | 0,29847403 | 0,270700636 |
| | Total Hardness | Alkalinity | Sulphate | Calcium | Potassium | Chloride | Conductity |

Figure 3.5.7: Correlation chart showing correlations between chemical parameters and electrolytic conductivity.

With respect to the correlations that were determined for the chemical data, it is evident that for the under-saturated water, electrolytic conductivity is not necessarily a direct analogue for chloride, as it also correlates strongly with sulphate and potassium. From this, it can be seen that electrolytic resistivity cannot be relied upon to assess the chloride concentration of the under-saturated water and that chemical analyses are required for the assessment of groundwater quality.

**Sewage**

The municipality is responsible for the disposal of waste water. In the residential areas most of the houses are connected to a sewer. In the west, at the end of the flood barrier, the municipality has a sewage treatment facility. On 18 September 2016 it was observed by the EUCPT that waste water flows into the most recently formed collapse of Mine No 8. This is understood to have been a sewer built in the 1920's by the Czechs. Data on the amount of inflow to the Mine No 8 crater not available. Whilst diverting and updating the sewer system has a lower priority then improving the drinking water supply and electric power supply (interview with deputy director water & sewage municipality Solotvyno on 28-9-2016), it a threat to human health.

## 3.6 Social situation

## Residencies and building constructions

Brief description of the residential history of Solotvyno

According to the 2000 census there are 2,750 residencies in the Municipality of Solotvyno.

The first buildings in the area were constructed in late 1920`s – early 1930`s. Construction activity bloomed in the decades of 1950`s and 1960`s. In 1990, a land distribution programme created a new construction activity in the area as it provided the opportunity to the permanent residents to own the plot where they built their house. The resorts were privatized within the same programme.

The Municipality is the owner of the lakes and the mine area belongs to the Mine Company.

Construction laws/codes

Construction legislation applies in the Ukraine. According to this legislation and the land use plan, a permit is required for all the construction works in the city of Solotvyno.

Since 2015 a construction permit is required, supervised by the relevant Technical Services. A geological survey is also required before the issue of the construction permit.

Nature of the constructions/construction materials

The majority of the buildings in the urban area and the mining area are one or two storey masonry constructions, based on concrete platforms 1 m – 1.20 m without any other foundation system or interpretation.

The concrete platforms are generally not reinforced, or poorly reinforced and the concrete is filled with pebbles instead of gravel (Figures 3.6.1 & 3.6.2).


Figure 3.6.1: Unreinforced concrete platform


Figure 3.6.2: Poorly reinforced concrete platform

The masonry consists of handmade compressed earth blocks, cement blocks and in some cases wood, rock, bricks or adobes, mainly without connecting material, plaster and isolation and without concrete zoning ("chainage") (Figure 3.6.3).
The majority of the plastering mortars, where ever they are applied, consist of compressed earth with straws covered by paint (Figure 3.6.4).


Figure 3.6.3: Masonry of wood, bricks and adobes without "chainage"


Figure 3.6.4: Plaster of compressed earth with straws

The roofs are mostly covered by asbestos slates (Figure 3.6.5) and in some rare cases by metallic roof plates.

Figure 3.6.5: Roof covered by asbestos slates

In very few cases there are some reinforced concrete elements but even then they are not operating as they should since there are very few beams, no ties with the few existing columns and the concrete slabs bear directly on the masonry frames (Figure 3.6.6). The concrete slabs, where and when they exist, are very thin (~10 cm-15 cm) and rarely reinforced.

Figure 3.6.6: Building with mixed material masonry, some concrete elements and thin slabs

Buildings with reinforced concrete framework were not observed in the affected area.

Short history of the damages in the residential area

The first problems appeared in 1953. In 1956 a small abandoned village disappeared due to a huge collapse in the area of Mine No 7. There were no victims and the residents relocated by the Soviet Union Government into other areas in the country. No safety measures were taken for the rest of the area and the other Mines (No 8 and No 9), continued to work as usual.

In 2005 and 2006 cracks and soil settlements were observed in several houses in the nearby residential area and the buildings of the mines. After the collapse of Mine No 8 in 2008 the damages multiplied and became more apparent and severe.

In 2010 the company in control of the mines inspected the affected area and concluded that 133 houses were not fit for use and should be evacuated. Subsequently, the Government decided to implement a relocation programme for the residents of the affected houses. The relocation area is 40 km distant from the affected area with totally different socioeconomic situation (Ethnicities, culture, religion) for the affected residents, so they refuse to move. As a result, the programme was never realized. The cost of the relocation programme is reported to have been 100,000,000 Grivnia.

Present situation of the houses/buildings/constructions

Inspection and observation points are presented in the following map (Figure 3.6.7).

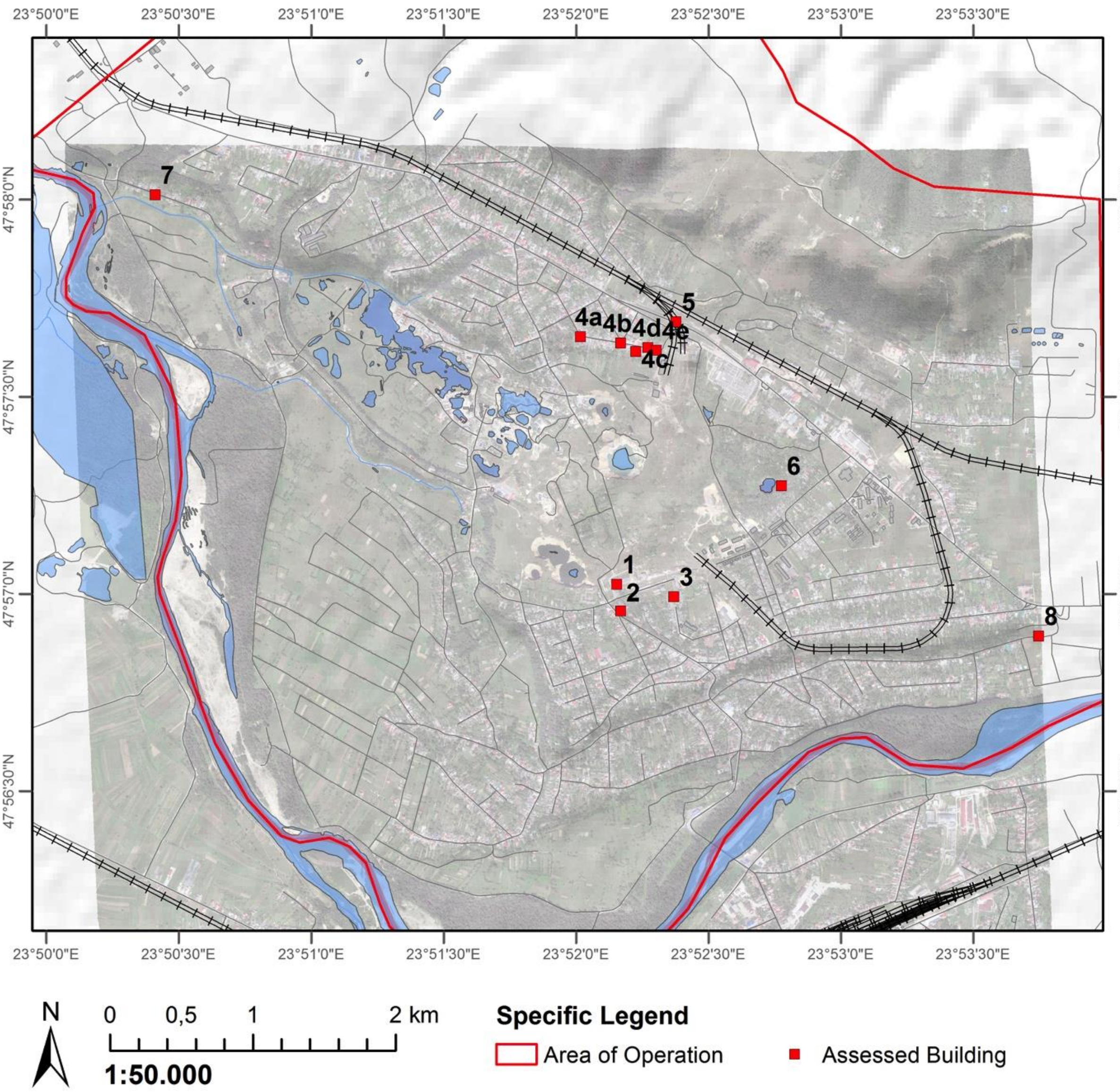


Figure 3.6.7: Inspection and Observation Points

**Point 1:** Mine Administrative building and workers buildings

The Central Mine Administrative building is a 2 storey mixed material masonry construction (rock, bricks, wood, handmade compressed earth blocks) built in two phases (Figures 3.6.8, 3.6.9 and 3.6.10). The second part is not in use.

Figure 3.6.8: Central Mine Administrative building (part in use)

Figure 3.6.9: Central Mine Administrative building. The white part is not in use

Figure 3.6.10: Central Mine Administrative building (east side)

The building presents extended internal crackings on the masonry, on the roof and on the floor along with an intense floor slope (Figures 3.6.11, 3.6.12 and 3.6.13).

It is obvious that the building has never been restored or maintained throughout the years. All the other buildings are partially collapsed and are not in use for several years.

Figure 3.6.11: Through cracking on the masonry infill

Figure 3.6.12: Extended cracking on the masonry

Figure 3.6.13: Extended cracking on the roof

**Point 2:** Apartment building and houses near the Mine entrance
The 2 storey apartment building at the S-SE side of the Mine entrance was built late 1920`s - early 1930`s, has three entrances, a basement and 8 apartments. The building is a masonry (brick) construction with concrete elements based on a hollow poorly reinforced concrete platform (basement) (Figure 3.6.14).

Figure 3.6.14: Outward aspect of the apartment building

The building presents extended internal and external crackings on the masonry, vertical through cracking in the middle of the building, floor slope and deviation from vertical (tilts) (Figures 3.6.15 and 3.6.16). The damages in the concrete elements were obvious on the entrances and the internal staircases which are separated in three parts (Figure 3.6.17).

The basement is based on bare ground and the oxidation of the few existing reinforcement of the roof is obvious.

Figure 3.6.15: Internal masonry crackings

Figure 3.6.16: Vertical through cracking

Figure 3.6.17: One of the three staircases

Extended external masonry crackings were also observed at two houses on the other side of the street (Figure 3.6.18). The houses in the surrounding area present no obvious damages.

Figure 3.6.18: Masonry crackings

**Point 3:** Apartment building

The 2 storey masonry apartment building (built ~1950 – 1955), is located at the South of Mine No 8 and presents no exterior damages. The owner denied the entrance to the inspection team so the inspection was not completed (Figure 3.6.19).


Figure 3.6.19: Outward aspect of the apartment building near M8

**Point 4:** Solena Street
The street is located at the N-NE side of the Mine No7 collapse. There are 50 constructions/houses in Solena Street. Most of the houses were built in the 1970`s and 1980`s. Extended through crackings and splits have been observed on the masonry of the houses. There are also gaps (~5cm) in the junctions between the external walls and the pavements and deviation from vertical (tilts) (Figures 3.6.20, 3.6.21, 3.6.22, 3.6.23 and 3.6.24). One of the two houses at no 48 is partially collapsed (Figure 3.6.25, **Point 4c**). An extensive soil subsidence (~20cm) is present at the entire length of the backyards of the houses in the south side of the street.

Figure 3.6.20: Masonry wall separated from the base

Figure 3.6.21: Masonry wall separated from the roof

Figure 3.6.22: Gap between external wall and pavement

Figure 3.6.23: Extended through crackings

Figure 3.6.24: Extended through crackings

The damages are more severe on the south side of the street although they are also progressing in the north side (Figure 3.6.26).

According to the residents of the street, the first noticeable damages appeared 10 to 12 years ago and are gradually progressing.10% of the houses are recent constructions (2009-2014) and they do not present any obvious damages.

Figure 3.6.25: Partially collapsed house

Figure 3.6.26: Through crackings at a house in the north side of Solena Street

**Point 5:** Highway Bridge
The Highway Bridge is located near to Solena Street (Figure 3.6.27). There is some oxidation of the enforcement on the superstructure along with signs of solifluction on the base of the pillars but no indication of ground movement or any other deterioration on the construction.

The Bridge is considered stable and the slight damages observed are due to age, weather conditions and lack of proper maintenance.

Figure 3.6.27: Highway Bridge

**Point 6:** Houses located on the East side of Black Moor
Two masonry houses built on a hill slope located at the East side of the Black Moor collapse. The collapse occurred 10 years ago and since the houses gradually move towards it. The first house was locked and not inspected. The second house presented extended through crackings and splits due to the downhill landslide (Figures 3.6.28, 3.6.29, 3.6.30 and 3.6.31).

Figure 3.6.28: Outward aspect of the second house on the East side of Black Moor

Figure 3.6.29: Vertical through cracking

Figure 3.6.30: Vertical through cracking

Figure 3.6.31: Vertical through cracking at the back side of the house

**Point 7:** Zarechnaya Street
Zarechnaya Street is located at the N-NW of the Mining area close to Tisza River. Only two houses (no 13) of the street presented some damages.
The first house is wooden, based on a concrete block platform. The second house is a masonry construction based on a hollow concrete platform (basement).
Although there are no damages on the masonry, both houses have extended crackings on the bases (Figures 3.6.32, 3.6.33 and 3.6.34).

Figure 3.6.32: Outward aspect of the two houses on the No 13 of Zarechnaya Street

Figure 3.6.33: Cracking and obvious movement on the base of the wooden house

Figure 3.6.34: Gap between the basement staircase and the external wall

The damages on Zarechnaya Street are estimated as an isolated incident and do not lead to an accurate conclusion.

<u>Further Observations</u>

- The observed damages on the constructions certify a ground movement on the N-NE, SE-S area around the mines.
- Although there are considerable steep inclines in the affected area, only one retaining wall (**Point 8**) was observed in the slope area near Tisza River (residential area) (Figure 3.6.35).


Figure 3.6.35: Retaining wall in the residential area near Tisza River

Recommendations

- The partially collapsed buildings should be demolished.
- The central mine administration building is not fit for use by the employees of the mine company. Demolition of the building and relocation of the employees is recommended.
- Detailed structural vulnerability survey is recommended with scientific monitoring and observation programmes in all the affected area. Taking into account that the Highway Bridge is situated near the Mine No 9 subsidence zone, further monitoring and geometric measurements are necessary.
- Retaining wall systems and retaining walls should be constructed to prevent landslides on the slopes.
- The existing construction legislation should be implemented in order to avoid further problems in the future.
- The community in the affected area has very strong community and religious bonds. Therefore and after the safe area is determined, within the borders of Solotvyno, a socioeconomic analysis is recommended for the relocation of the affected residents.

## Critical infrastructure

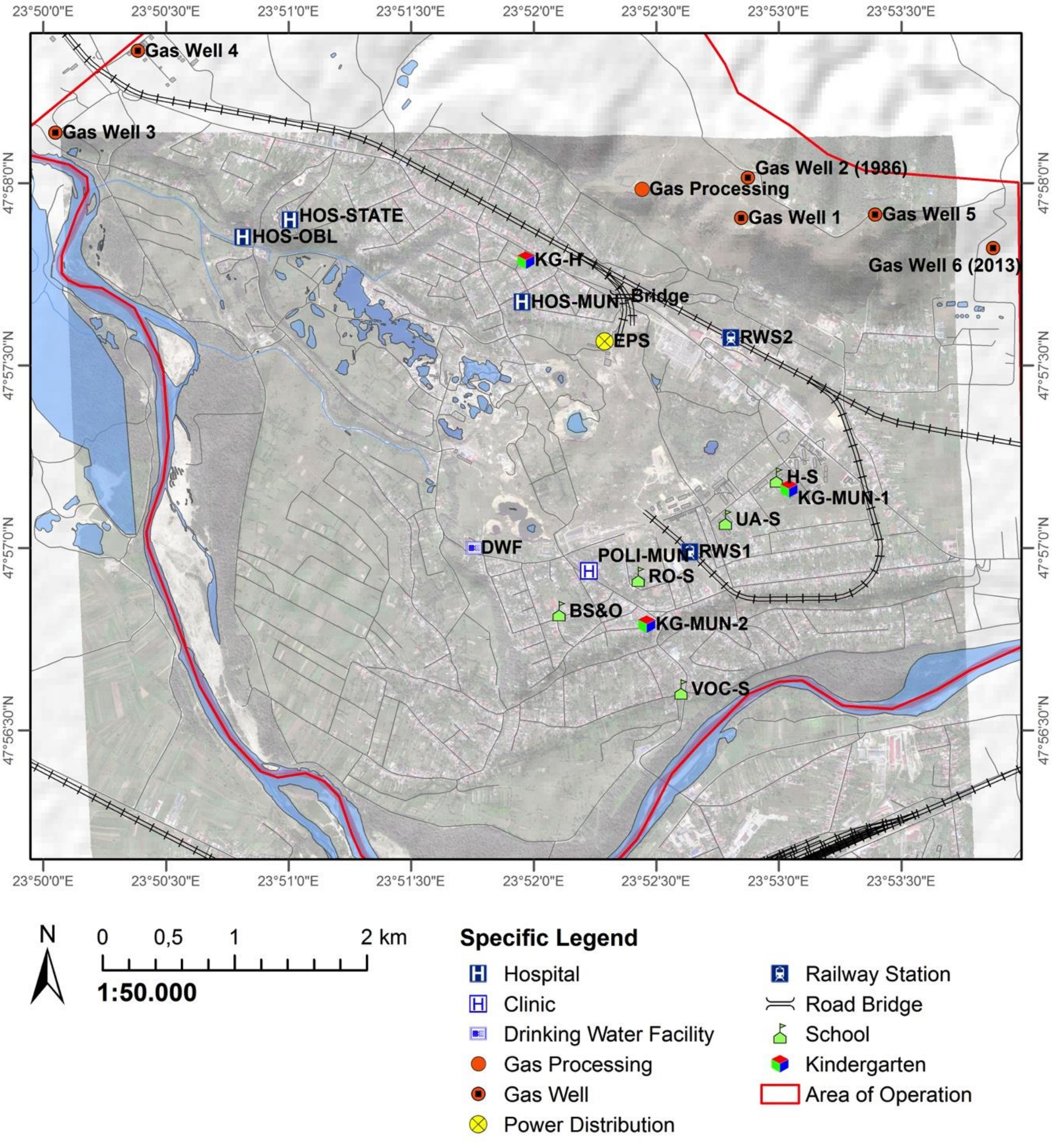


Figure 3.6.36: Locations critical infrastructure

### Railway station


Figure 3.6.37: track to railway station

Solotvyno-2 railway station [RS2] and facilities is situated on the northern edge of the town, just where the ground rises to the Magura Mountain. It serves the railway between Solotvyno main station and Tatsiv. Five times a day a passenger train passes the Solotvyno-2 one of them goes all the way to L'viv. Once or twice a day a cargo train is unloaded and loaded. It heads for Tatsiv. Recently a Romanian company started investing in railway facilities of Solotvyno-2 for transhipment and exporting goods by rail to Romania. The local zone of influence of the cargo goods is about 20 kilometres around these facilities. The next district Rakhiv, is also dependent on the transport of goods by rail on Solotvyno-2 and the railway (interview railway 29-9-2016).

### Electric power substation


Figure 3.6.38: electric power substation

Next to shaft 10 in the northern part of the mining area, the mining company built an electric power substation [EPS] for the mining works. A 110 kV power line enters and leaves the substation. The power line supplies Tatsiv or beyond and leads to the Rakhiv district. In the substation transformer 1 lowers the voltage to 35kV and 6kV. The 35kV feeds another power line to Rakhiv and transformer 2. This transforms 35kV to 6kV. The 6KV feeds the municipality of Solotvyno. Since the mining works stopped the substation feeds 3560 houses and 300 businesses in Solotvyno. The substation subsided between 5 and 10 years ago. Some power lines are visually more tense than others. The local electricity company (REM) has no plans for relocate the station. It is not clear who is the owner of the substation as REM and the mining company are co-owners without a clear division. If the substation trips, this has most effects on Solotvyno. In the district of Rakhiv a second system can provide backup electric power to the district. The same applies to failure of the power line (interview with head and employee REM on 28/29-9-2016).

### Drinking water supply


Figure 3.6.39: pumps on floodplain Tisza

The drinking water is pumped from a well, which is 13 meters deep [DWW] in the floodplain of the Tisza. It is transported to the drinking water facility (reservoirs) [DWF] south of the town. It is located on the edge of the mining area relatively close to the new craters of the collapses of Mine No 8. When the craters formed, the main drinking water pipes supplying the town were broken. This also happened when the Black Moor sinkhole formed. The municipality of Solotvyno is responsible for water supply and built a new sub-surface system further away from the crater. The pipe, which broke when the sinkhole in the Black Moor appeared, was not replaced. Water supply to the households in Solotvyno is restricted to a few hours hours each day. Several years ago the well in the floodplain of the Tisza was sampled and analysed by a Hungarian firm. They confirmed that the water was suitable for drinking but didn't provide the test-report. 80% – 90% of the houses in Solotvyno are connected to the water net. Some houses have private wells for private use. Some houses supplement this with their rainwater. In the town there are also some publicly accessible water wells (interview with deputy director of water & sewage municipality Solotvyno 28-9-2016).

**Primary and secondary schools**

The Solotvyno school system is divided along the ethnic lines. Each ethnic group has its own school for primary and secondary education. The Romanian primary and secondary school has approximately 350 pupils, the Ukrainian school approximately 400 pupils and the Hungarian school approximately 200 pupils.

Apart from the segregated schools there is also a boarding school and orphanage in Solotvyno. This is also for both primary and secondary education. The pupils are orphans, children from impoverished families and children with learning problems (mentally or due to lack of prior education). About 150 pupils live on the premises.

A vocational training centre is located close to the bridge over the Tisza River (interview mayor on 29-9-2016).

**Kindergartens**

The town has three kindergartens. Two are run under the responsibility of the municipality. The largest, with a capacity of 340 children, is situated next to the Hungarian school. 200 children were using it at the time of reporting. At the smaller, municipal kindergarten, are only 50 children. The third kindergarten is run by a Hungarian charity. About 100 children are playing in this kindergarten (interview with mayor on 29-9-2016).

**Hospitals**

Since Solotvyno has a historical reputation in the treatment of allergic diseases it has 3 hospitals. A small general one with local importance and the bigger hospitals. One is run by the state and used to be linked with the underground hospital in Mine No. 9. The regional hospital used to be linked with Mine No. 8. In the southern centre of the town a policlinic is situated (interview mayor on 29-9-2016).

**Gas**

In 1986, while drilling for a salt deposit on the top of the Magura Mountain, a small gas field was found (see geology section) [GW 1]. Since they weren't prepared for hitting gas the well-released gas for more than three months until Siberian engineers closed the well. After that more boreholes were drilled. Two delivered gas to Solotvyno. For that purpose, a gas processing station was built which was fed by the two gas wells. At the time of reporting only one well was producing gas, just enough to provide 5 apartment blocks with gas. The rest of the municipality has no gas. In 2013 a new gas well was drilled. This well was supposed to provide to whole town with gas. At present they are connecting the well with the gas processing station (interview mayor 29-9-2016).

## 3.7 The drainage system

Deep mining for salt started at the end of XVIII century, with the first mine named 'Krisztina' in 1778. This was followed by next newly opened mines, such as the 'Albert' in 1781, 'Kunigunda' in 1789, 'Miklós' in 1799, 'József' and 'Ludvig' in 1804, 'Ferenc'(current is 'Mine No 7') opened in 1809, the 'Mine No 8' opened in 1886 and the last one, 'Mine No 9', started operating in 1975.

The base statement is that there is no mine without water. The volume of water that enters a mine is dependent on the geological/hydrogeological condition and planning, constructing and maintenance of the water management system.  Until the time of reporting six mines of the nine mines were abandoned because of water. These events focus attention on the significance of water in the mining area.

Water management commenced with the beginning of deep mining. The most important action was to arrest/stop surface water from entering the mine (particularly from the area of the slopes of the Magura mountain which feeds water into small creeks and some springs) and shallow groundwater is moving in the alluvium down hydraulic gradient towards the Tisza River. Nevertheless, in flood the Tisza River threatened inundation to the mines, particularly in the case of the old mines, which were established closer to the river and this was why a flood barrier was constructed to the south-west of Solotvyno, together with a drainage system. to collect and guide surface and shallow groundwater away from the mine.

Despite the vital importance of an effective and well maintained and managed water system, during the last 70 years the system was neglected. At the time when Solotvyno was part of Hungary the system was constructed and worked well, as proven by its duration of safe operation of more than one hundred years. The last development of this system was before the WW2 when Solotvyno belonged to Czechoslovakia.

During the Soviet era the management of Mining Enterprise of Solotvyno focused continuously on the volume of the mined salt only, increasing production year by year. In the drive for productivity, blasting operations became an everyday practice through the application of highly effective explosives.

The mine workers regularly attracted the attention of mining management to the importance of leading water away from the mining area, reminding them of the more than one hundred year experience of water management, but there appears to have been no response to this plea.

**Recent situation**

The drainage system is composed of two different constructions: a surface water channel system and a subsurface gallery (water tunnel) system in the alluvium (approx. 30 m below ground surface). It was used to prevent the mining area from water flooding. The track of the drainage system is shown in *Figure 3.7.1*.

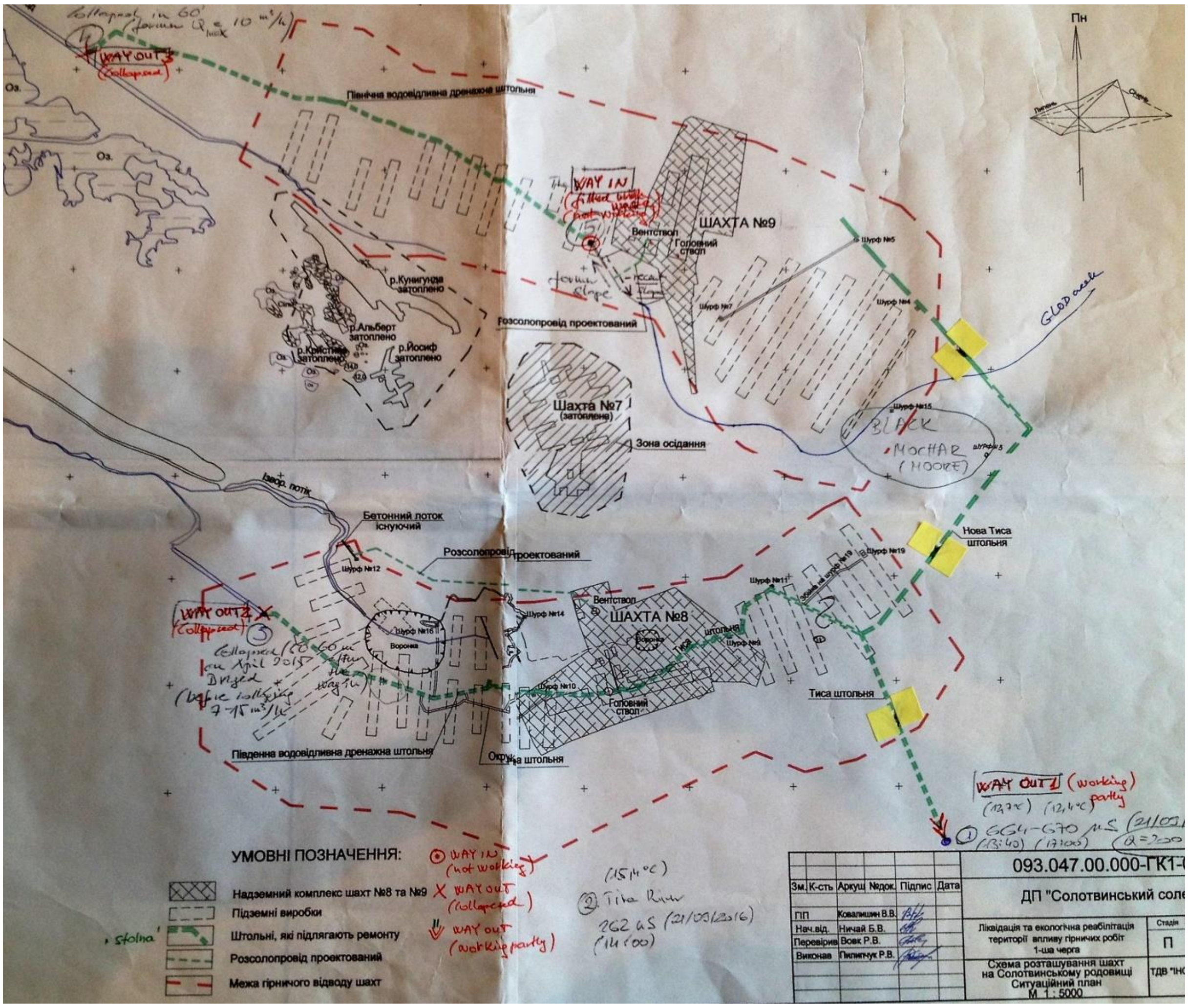


Figure 3.7.1 Map on water drainage system/'water tunnel' (local name is 'stolna') signed by green broken lines

The water drainage system, which is still intact today is assumed to be around 4 km in length. It is separated into two branches/arms which are independent of each other. The N and SE branch/arm (local name is 'Nova Tisza stolna and Tisza stolna') of the system is 2.8 km long and the N branch ('stolna') is 1.1 km long.

Two surface water creeks were present previously (Glod and Isvor). These surface water creeks (channelling systems) have also lost their lost function due to the development of sinkholes. The creeks are fed by the precipitation falling in the Magura Mountain, collecting surface water from precipitation in the Solotvyno mine area. As a consequence, an artificial water channel was developed to direct the water away from the Glod Creek into the starting point of the North 'stolna'(see *Figure 3.7.2* WAY IN point). Due to the subsidence, the channel is not functioning today (found to be dry), as it is leading uphill. Additionally, the intake (WAY IN in Figure 1) of North 'stolna' is filled with communal waste as shown in *Figure 3.7.3*.

Figure 3.7.2 Artificial channel guiding water from the Glod Creek

Figure 3.7.3 The Stolna and the communal waste infill.

Since the Glod Creek is a living watercourse its water may potentially feed the Black Moor as it is located on the E (upstream) side of the mining area.

Conditions of other parts of the North 'stolna' are not known. The WAY OUT 3 of this 'stolna' has been closed since the 1960's. According to the experts of the Mine Enterprise there has been no discharge for many decades, probably since its collapse.

The longer branch/arm of the shallow groundwater drainage system is the E and S 'stolna'. It is 2.8 km long and its condition is not known. This 'stolna' has two outlets. The WAY OUT 2 (lower left corner in Figure 1) collapsed approx. 60 m from the outlet, on April 2015. The operational part of this 'stolna' was found to by dry during the time of the mission. The second way out (named WAY OUT 1) discharges water directly into the Tisza River. The distance from the riverbank is only few tens of meters. The condition of this 'stolna' exit seems relatively good and functional.

The discharge was measured by the mining staff one week before EUCPT visited the site and was stable. The discharge of the WAY OUT 1 was estimated to be approximately $200 m^3$/hour, and the conductivity was 670 µS/cm (21/09/2016).

The spot water discharge measured is considered low, in the context of the permeability of the alluvium and the length of the shallow groundwater drainage system. By very rude calculation the value of discharge should be approximately five times greater. Without monitoring of the 'stolna' system working in the mining area it is not possible to verify this.

It is remarkable that not only the artificial channels designed to lead surface water away and the 'stolna' system for shallow groundwater control were destroyed and collapsed (partly or totally) by ground movement resulting from the collapse crater, but the other line facilities (drinking and wastewater networks, gas pipelines, railroads, electricity network) have been affected. As an example there is wastewater flowing directly into the Mine No 8 subsidence (*Figure 3.7.4*)

Figure 3.7.4

## 3.8 Risk assessment

**Overview**

This chapter describes eight scenarios that are considered possible. The so called Bowtie scenarios schematically presents the mechanisms leading to a major event and the consequences of the event. For each scenario the mechanism leading to the major event is described. So are the consequences, their likelihood and risk. To assess the likelihood and risk, expert elicitation was deployed. in a structured discussion of the EUCPT experts. Estimations and assumptions were made. The same discussion sessions were also used to make the recommendations.

The eight scenarios discussed are:

1. Collapse of Mine No. 8
2. Collapse of Mine No. 7
3. Forming sinkholes
4. Landslide
5. Liquefaction
6. Forming Black Moor sinkhole
7. Collapse of mines 1 to 6
8. High chloride levels in Tisza River

In annex B the scenarios are presented in a readable format. In *Figure 3.8.1* a map is shown in which the different areas of interest are defined.

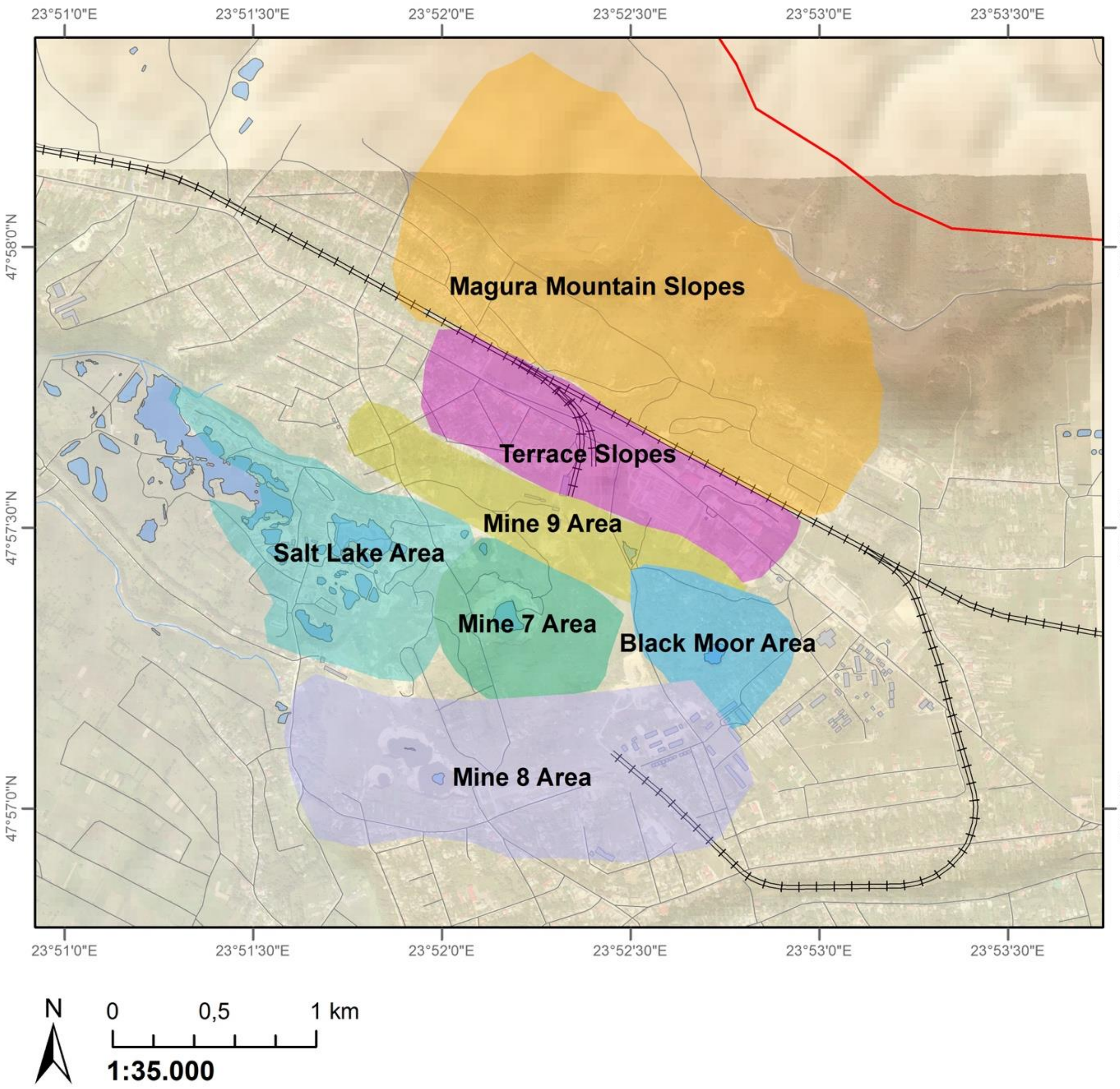


Figure 3.8.1: Area of interest

**Collapse of Mine No 8 (see annex B, figure B.1)**

*Mechanism*

Referring to the back analysis of previous collapses, mining, geological and hydrogeological contexts, scenarios that can lead to another collapses have been described as follows.

The origin of major collapses linked to Mine No 8 is found in the failure of the large underlying chambers from the mining operations and by their filling with the soft materials that cover the salt deposit. The collapse is due to the rupture of pillar between chambers or/and the rupture of chamber roof.

After the period of flooding, mining works can be assumed to be fully flooded with saturated brine. In that case, conditions that trigger to a new collapse are found in the combination of several factors:

Under-saturated inflows of water can lead to an additional dissolution of salt pillars reducing their size (width) and their geomechanical capacity to support the overburden load. Several sources of under-saturated water inflow into the mine have been identified (seasonal water exchange, waste water inflow, hypogene water flow, water entering via fault).

The failure of the chamber roof can be also be induced by additional dissolution, decreasing its thickness and mechanical strength. This can be the consequence of fresh water inflow to the mine (see above for pillar failure) or surface karstification on the surface of the salt dome. The karstification results from two factors: presence of fresh under-saturated water (from subsurface) and hydrological windows that authorize hydraulic connection between fresh water to salt dome. These windows can consist of boreholes, shafts, natural absence of impermeable formation (Pallag formation), faults and overall disturbance of mining works themselves.

*Consequences*

Potential collapse of Mine No 8, which might form an instananeous crater in the ground, size of the collapsed roof of the Mine.

In this case the probability of damaged or collapsed buildings is very high along with pedestrians and passing cars falling down from a hight that would be more than 7 m. Casualties are certain in that case along with economical impact (collapsed buildings).

The hole of the collapse could also trigger a formation of a crater until gadient slope is 35°. On the western end of the area above mine no. 8 the drinking water supply is situated. It delivers drinking water to 80- 90 % of the households in Solotvyno. Destruction of this facility will have a high impact on the people of Solotvyno. Access to drinking water is a necessity in life and therefore it should be restored as soon as possible, probably with high costs

Schools in the surrounding area (Hungarian, Romanian etc.) would also be in danger.

Casualties along with the loss of infrastructures will result to major socioeconomic damages to Solotvyno

*Likelihood (expert elicitation)*

It is probable that the construction of the interior is prone to further collapses due to poor engineering. This is supported by historical data. It is highly probable that the integrity of the mine has further weakened after flooding. The karstification on top of the chambers is contributing to a further weakening of the roof. Precipitation in combination with the local absence of pallag and the presence of many boreholes are seen the contributors to the karstification. Even as the weakening of the interior has stopped when the water was saturated, the roof will further deteriorate. It is a matter of time till a next collapse will occur.

The inflow of wastewater in the crater is a possible source undersaturated water in the mine. The disposal of rubbish, waste is a possible accelerator to dissolution in the mine and karstification.

Another consequence can be a wave of brine entering the ground water flow after a collapse. A 'wave' of saline water will it that case flow to the Tisza River and high concentrations of chloride downstream will occur.

*risk (expert elicitation)*

The estimated risk is high. The consequences are very high (death and injured) and the impact on the local society will be high.

A brine pulse in the ground water is seen as likely. Especially if a large amount of materials falls in the existing crater. The consequence for the river depends on the water flow and level of the Tisza River at that moment. The salination will results in a long period of higher chloride levels.

**Collapse of mine 7 (see annex B, figure B.2)**

*Mechanism*

The mechanism leading to the collapse of mine 7 is similar to mechanism leading to collapse of mine 8.

*Consequences*

The area around the crater of the collapse of mine no. 7 is not in use, because of the proximity to the recreational area it's used by locals as a short cut. Also tourists/ visitors wander around. A flock of sheep and goats and its shepherd use the rough land. If counter measures are made it is feasible to avoid casualties.

Another consequence can be a wave of brine entering the ground water flow after a collapse. A 'wave' of saline water will it that case flow to the Tisza River and high concentrations of chloride downstream will occur

*Likelihood (expert elicitation)*

A further collapse of the southern part of the mine is highly likely. The salt of the roof is directly exposed to rainwater. An (old) underground flow map indicates that the flow is low, but this is not validated. Karstification features are visible and the weakening of the roof is in process. The collapse is a matter of time, but it is based on the available information not predictable.

A brine pulse in the groundwater is seen as likely, especially if a large amount of material falls into the existing crater. The consequence for the river depends on the water flow and level of the Tisza river at that moment. The salination will remain as a plane of higher salination levels.

*Risk (expert elicitation)*

Risk for the direct surrounding is considered low. The risk for the salination of the Tisza river is seen has considerable.

**Forming sinkholes (see annex B, figure B.3)**

*Mechanism*

The sinkhole scenario is focused on the potential for natural sinkhole formation in the area that is underlain by soluble rocks. The causal factors in this scenario have been divided into (i) naturally occurring and (ii) anthropogenic sources of under-saturated water that have the potential to cause dissolution of the salt dome. Karst processes may be more concentrated in areas where the salt is exposed, e.g. breaches of the pallag, or via hydrological windows that have formed through tension cracks in the loess, continuing, or forming as preferential flow paths in the granular river terrace deposits. In these areas sinkholes will develop as suffusion sinkholes, i.e. the gradual ravelling of the granular material into voids formed by dissolution of the salt. In areas that have been used for waste disposal the generation of landfill leachate (the product of water infiltrating waste and dissolving soluble matter as it passes through) may act as an accelerator to the karst processes. As well as potentially contributing to the process of sinkhole formation, faults commonly form openings upon which karst process are initiated, resulting in an alignment of the sinkholes that develop.

The potential natural sources of under-saturated water that have been identified include:

- Precipitation, which may be in direct contact with the salt surface, or infiltrate via the hydrological windows through the superficial deposits;
- Connectivity with under-saturated water in the surface water system (Tisza River), particular as a consequence of back-flooding during periods of flooding;
- Connectivity with recharge of under-saturated water in the sub-surface flows from the Magura Mountain.
- Any groundwater flow entering this mine area via the fault system (hypogene fow) or from up hydraulic gradient (Magura Mountain) is also likely to be under-saturated.

The potential anthropogenic sources of under-saturated water that have been identified include:

- Under-saturated water focusing via anthropogenic openings, e.g. boreholes or mine shafts.
- Zones in which there has been disturbance or removal of the pallag.

- Ground disturbance, in particular the formation of low points in the surface may contribute to the focusing of the flow of under-saturated water.

*Consequences*

Sinkholes might form instananeous holes (craters) in the ground. The size can vary from small, several meters to tens of meters.

In this case the probability of damaged or collapsed buildings is very high along with pedestrians and passing cars falling down from a height that would be more than 7 m. Casualties are certain in that case along with economical impact (collapsed buildings).

The sinkhole could also propagate until a gradient slope of 35° is reached. More sinkholes might also trigger more subsidences in the surrounding area with more building damages/collapses.

On the western end of the area, above Mine no 8 the drinking water supply is situated. It delivers drinking water to 80- 90 % of the households in Solotvyno. Destruction of this facility will have a high impact on the people of Solotvyno. Access to drinking water is a necessity to life and therefore it should be restored as soon as possible, probably with high costs

Casualties along with the loss of infrastructure will result in major socioeconomic damages to Solotvyno.

*Likelihood (expert elicitation)*

The likelihood is considered to be high. The karstification is an ongoing process. The sinkhole that was formed on the 2$^{nd}$ of May 2016 illustrates this. Boreholes are known triggers to karstification because they make direct water inflow in karstification voids possible. Besides this the layer of pallag is sensitive to disturbance. Precipitation is seen as the most likely source of fresh water, although the water in the Black Moor can also have a contribution.

*Risk (expert elicitation)*

The risks around the crater of Mine no. 7 and between it and the Black Moor are considerable to the people who use these areas to make short cuts to the Salt Lakes, the northern part of the town and the market.

The risks around the area of Mine No 8 is considered very high. The likelihood is high and the consequences includes the loss of life.

**Landslide (see annex B, figure B.4)**

*Mechanism*

The landslide scenario is focused on the potential for large scale translational landsliding as a consequence of cavern opening in Mine No 9. Many of the triggering processes described in this scenario are also applicable to the potential for landsliding in slopes associated with the Black Moor area.

The causal factors in this scenario have been divided into mining related, tectonic and karstification processes. In each case it is recognised that mining activity in Mine No 9 has breached the surface of the salt dome. With respect to the mining related causal factors for this scenario it is recognised that further collapse in the mine will generate more void to accommodate deforming materials involved in the potential landsliding process and that this may occur because of any one or more of the following:

- connectivity with the Black Moor would provide a source of under-saturated water with a potential for further consequential destabilisation of the mine workings;
- any groundwater flow entering this mine area via the fault system (hypogene fow) or from up hydraulic gradient (Magura Mountain) is also likely to be under-saturated (consequence, as described above), and
- here is a potential for surface karst to connect with the mine providing a flow path for undersaturated water (consequences as described above).

Processes of karstification provide another means of void generation and therefore accommodation for deforming materials mobilised by landsliding processes. Karstification may result from any of the following:

- connectivity with the surface, e.g. by cavern roof collapse or breaching;
- under-saturated hypogene flow coming into contact with the salt dome, and
- fresh water focusing via anthropogenic openings, e.g. boreholes or mine shafts.

Mine No 9 is situated on the flank of the dome, a focal point for tectonic processes, with the potential to contribute to the potential landsliding processes through:

- neotectonic movement on the faults (a potential trigger for earth movement) and a zone of tension (pull apart faulting is suspected), which provides space accommodation for deforming landslide materials;
- high rates of salt movement on the flank of the dome (a feature that has been described in other salt diapirs), and which has the potential to induce a geomechanical response and loss of stability in the existing mining cavities, and
- there is a potential that ground in the vicinity of Mine No 9 forms part of the resisting force against landsliding and the load exerted by the potential slide mass is now being exerted on the mine system, with a potential for pillar/roof deformation and collapse

*Consequences*

Although the faults in the area are capable of producing earthquakes of small magnitude (max M4), the possibility of landsliding is present due to the susceptibility of the soil (alluvial and clay deposits). Subsidence in plane areas (like Solena Street, S of railroad) can trigger lateral spreads or flows.

In steeper slopes (e.g. Magura Mountain, N of railroad) a prolonged rainfall can also trigger the phenomenon or even a combination with a seismic event which will lead to translational slides.

The lack of proper constructed retaining walls in slopes, will increase the impacts of the event.

In both cases landslides will cause further damages to the houses/buildings/structures such as partial or total collapse and extended through masonry crackings.

Casualties are possible especially in the case of a sudden translational slide. The loss of the houses/buildings/structures will result in major economic loss to the homeless/workless population which along with the possible casualties will cause great social damage due to the extended disruption of the normal everyday life.

The railroad, the main road (with a flyover), the pipeline for drinking water, the pipeline for drinking water and gas are all present in a strip of land with a 100 m width. It is prone to landslide of the Magura Mountain, but also to the effects of a landslide on the terrace. Loss of these functions has a high economic impact. The railroad and road are important for the region. The loss of supply of gas and especially drinking water has a high impact on the people living in Solotvyno.

On the lower slope, south of the railway, an electric power substation is situated. If this substation fails, Solotvyno will face a long term black out. Restoring the electricity temporarily and on the long term will lead to considerable costs.

*Likelihood (expert elicitation)*

The mechanisms leading to triggering the landslides due to mining works in the past are difficult to assess. It is however very likely that karstification is of the flank of the salt dome is in progress. Also it is very likely that the fault is opening due to tectonic movement. Destressing in the top layer is may occur. It is unknown what the speed of movement is.

The slopes South and North have properties that will make them prone to landslide.

On the slopes north of the railroad on the Magura Mountain it is clearly visible that in the past landslides already have occurred. It is known that slopes with a history of landslide are very prone to reactivation. The slopes are waiting for a trigger event. This trigger can be induced by the mechanism in this scenario, but other ‘normal’ triggers can also lead to landslides, for example extreme weather, heavy equipment inducing long wave shocks, etcetera. Therefore, the likelihood is qualified as high.

*Risk (expert elicitation)*

Considering the consequences and the likelihood the scenario of a landslide is considered high.

**Liquefaction (see annex B, figure B.5)**

*Mechanism*

The top layer of the Solotvyno area might be prone to liquefaction (*See Figure 3.8.3*). The layer consists partly of small silt and sand particles. If those particles have the certain size can act as a liquid if triggered. The groundwater levels in the Solotvyno can be high. That in combination of a (small) seismic shock can lead to liquefaction.

*Consequences*

Although the faults in the area have the potential to generate earthquakes of small magnitude (max M4), the possibility of liquefaction is present due to the susceptibility of the soil (alluvial and clay deposits). A prolonged rainfall can also trigger the phenomenon or even a combination of both.

The behavior of the soil as a viscous liquid will cause further damages to the houses/buildings/structures such as sinking, partial or total collapse and extended through masonry cracking (*Figure 3.6.15*).

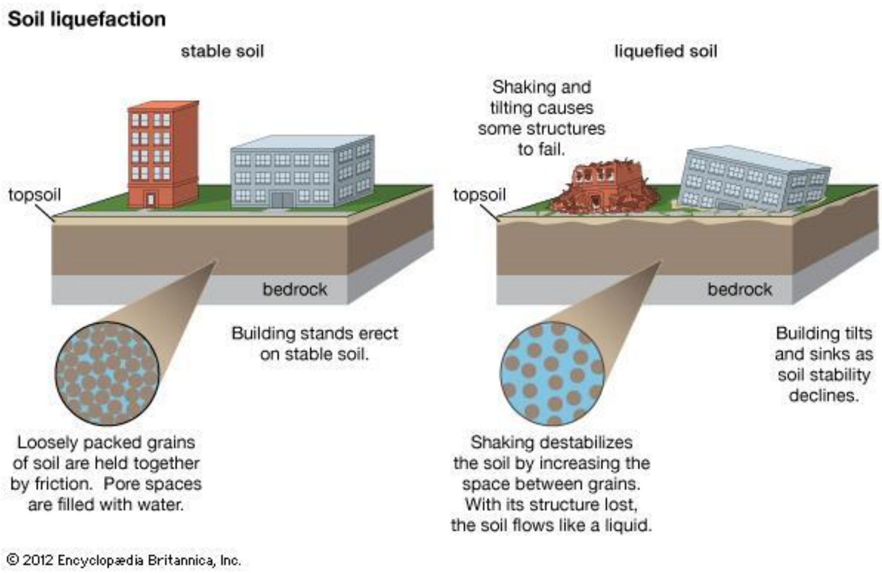


Figure 3.8.3: The qualities of stable so soil compared with those of liquefied soil

The loss of the houses/buildings/structures possible lead to casualties and will also possible result to major economic loss to the homeless/workless population which along with the possible casualties will cause great social damage due to the extended disruption of the normal everyday life. Liquefaction will certainly cause great damages to the major infrastructure of the area (*See Figure 3.8.4*)

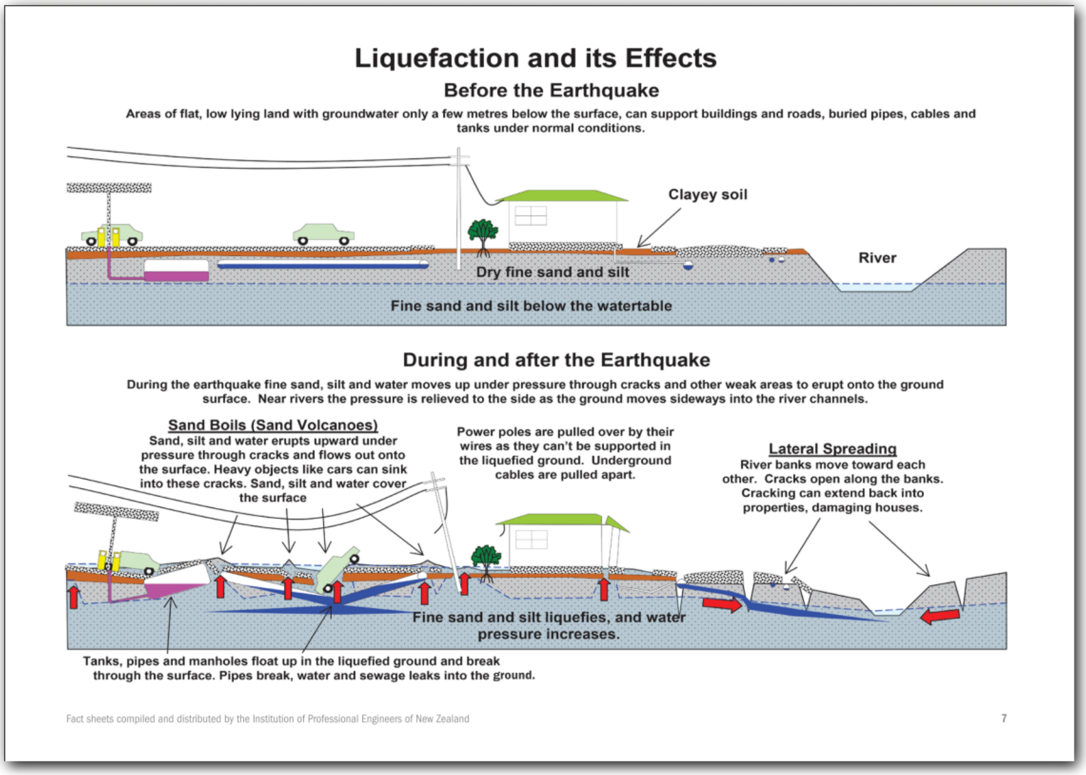


Figure 3.8.4: Liquefaction and its effects

Liquefaction could lead to considerable damage to infrastructure including water and gas pipelines. The flyover of the road could be damaged. The railway and road might subside. The economic loss would be considerable for the region and high for Solotvyno.

Damage to the electric power substation will lead to a long term black out in Solotvyno and short term black out in the Rakiv region.

*Likelihood (expert elicitation)*

The potential for a earthquakes and where they occur is indicated on the seismic risk map Which shows for this region a medium risk to a low magnitude earthquake. Since there is a large g portion of water in the cracked layers and surface of the salt dome, an earthquake with low magnitude cay have relatively large consequences. It is, however, not possible to assess the likelihood with the available information, knowledge and expertise.

*Risk (expert elicitation)*

The risk is not assessed.

**Forming Black Moor sink hole (see annex B, figure B.6)**

*Mechanism*

There is a risk of (further) collapse to the Black Moor. As described above, the Black Moor collapsed twice in the recent past. For a collapse to occur, a cavern has to exist underground, however the Black Moor is not situated above of a mine cavern, according to mining plans. Potentially there is a connectedness by karst caverns between the Black Moor and one of the Mines No 8 / No 9 enabling fast water flow and high dissolution rates. A cavern may also form or further increase by freshwater entering the subsurface through boreholes channeling water to the salt dome. When a certain size is reached the cavern will become unstable and prone to collapse. Water temperature measurements indicate that there might be an active inflow of groundwater.

*Consequences*

A new sinkhole might trigger new or further development of the existing Black Moor sinkhole. The event will most definitely lead to a total collapse of the houses built at the slope of Black Moor with an increased probability of human casualties.

The possibility of damages to the three apartment buildings at the top of the hill should be examined as well.

The loss of the houses/buildings/structures will result in major economic loss to the homeless/workless population which along with the casualties will cause great social damage due to the extended disruption of the normal everyday life.

*Likelihood (expert elicitation)*

The likelihood is considered high, as the process is ongoing. There are also many boreholes which contribute to the likelihood of karstification on the flank of the salt dome. The erratic behaviour of the water level of the Black Moor suggests that channels to Mine no 8 and/ or 9 and even Mine no 7 are likely. The likelihood of the forming of a new void that will lead to further subsidence is therefore high.

*Risk (expert elicitation)*

The risk is considered high.

**Collapse of mines 1 to 6 (see annex B, figure B.7)**

*Mechanism*

This scenario is focused on the potential for further collapse within the historic abandoned mines (Mine No 1 – 6) in the area of salt lakes. The causes of collapse may be due to (i) dissolution of the roof or pillars of the mines, (ii) unsaturated water inundation of the walls of the lakes breaking through to the workings, or (iii) the anthropogenically induced flow pathways for unsaturated water. The triggering processes, which have been described in other scenarios comprise:

- Subsurface water flow or precipitation generation of under-saturated water in the mine void, leading to dissolution of the roof or pillars and consequential collapse;
- Dissolutional activity at the sides of the lakes by the upper, under-saturated water in the water column of the lakes (at least in part due to precipitation); subsurface inflows of under-saturated water from up hydraulic gradient (Magura Mountain), or under-saturated water flows from the Tisza River as backwash during periods of flooding;

- Abandoned boreholes and shafts that have not been capped may form pathways for under-saturated water flow,
- Natural and anthropogenic hydrological windows through the pallag or via tension cracks associated with the abandoned mines could also form flow paths for under-saturated water.

*Consequences*

The Salt Lakes form a recreational area with several hotels and facilities for day recreation. In the high season it supposed to accommodate 3000 tourists. A sudden event like a collapse will lead to loss of lives. The damage and economic loss will be high.

*Likelihood (expert elicitation)*

The likelihood is considered low, mainly because of the stability of the situation. It has to be pointed out that the assumed stability is an assumption.

*Risk (expert elicitation)*

unknown

**High chloride levels in Tisza river (see annex B, figure B.8)**

*Mechanism*

Freshwater, which may lead to salt dissolution, can have several origins. Relevant sources identified are: 1) Precipitation in the Solotvyno Mining area, 2) shallow subsurface water flow from the Magura Mountain, and 3) hyporheic flow (i.e. Tisza River water which enters the alluvium at one point in time/space, and returns to the Tisza River at another point in time/space). Additionally to the presence of freshwater in Solotvyno Mine area, so called "hydrological windows" have to be present in order to allow a contact with the salt dome. The conceptual model suggests that the surface of the salt dome is generally protected by a layer of Pallag. Different causes may lead to a disturbance of this layer, which are: 1) presence of boreholes, 2) old mining shafts, 3) the mine collapses and sinkholes, or simply 4) the natural absence of Pallag. Additionally, 4) geomechanical forces above the mine chambers (roofs) may lead to the "stretching" (partial absence) of Pallag. If freshwater flow through such hydrological windows reaches the top of the salt dome, dissolution is enabled. The process of dissolution may be enhanced by the presence of leachate by waste disposal.

At high river stages of the Tisza River, i.e. during flood events (or due to seasonal changes), pressure gradients in the alluvium of the Solotvyno mine area are affected. This is especially true for the floodplain of the Tisza River, possibly leading to a mobilization of saline water present in the alluvium (hyporheic flow). Especially after an extended dry period (several years), the mobilization of (hyper-) saline water might lead to a peak in salt load in the Tisza River prior to a flooding event.

Strong flooding events may also lead to a failure of the protection barrier, which was constructed S of Lake 18. In the case of a barrier failure, the recreational area is prone to flooding, leading to a fast mobilization of saline surface waters from the lakes to the Tisza

River. However, in the case of such an event, large quantities of fresh water are present in the river, leading to strong dilution of salt water.

After the period of active mining in Solotvyno, the average annual concentrations in chloride are reduced by a factor of 5, now equaling the concentrations measured at a station (probably upstream) of Solotvyno. A distinction has thus to be made between instantaneous peak concentrations (also taking seasonality into account) and overall long term Chloride concentrations in the river water.

*Consequences*

Both scenarios could possibly damage the flora and fauna downstream, however the impact depends on the concentration and time. A long term contamination would further impact downstream drinking water supply wells, the salinization of agricultural grounds and could have an irreversible impact on flora and fauna.

*Likelihood (expert elicitation)*

Some of the processes leading to higher chloride levels in the Tisza River can be seen as a normal inflow of salt due to dissolution of the salt dome. However, the disturbance by the mining activities has increased the karstification and dissolution of the surface of the dome. The natural weathering is accelerated. It is expected that the base concentration will rise slightly but it is also possible that an equilibrium has been reached.

The mobilisation of hyper saline water after a period of relatively dry weather followed by long intense rainfall is a credible and even more likely changes in weather patterns. It is therefore likely that this event will occur.

The likelihood of a major flooding of the Tisza river is 1 in 30 years. This can possibly be an event that will lead to process of mobilisation of hyper saline water. In that case the chloride concentration in the river will rise prior to the flood.

A high chloride concentration due to flooding of the Salt Lakes is not likely, because of the high volumes of water. The load of chloride will, however, be considerable.

*Risk (expert elicitation)*

The situation around the Solotvyno salt dome is already contributing to an effect in the Tisza River.

The risk of an event resulting in a higher concentration of chloride is likely. The chloride concentration elevation can in such a case contribute that threshold values downstream are exceeded.

# 4 Conclusions

## Main Conclusions

1. Man-made activities in combination with natural processes have resulted in an overall decay of the mine and surrounding area. This is still ongoing without it being actively managed
2. The overall area is extremely complex in terms of hydrogeological systems and the geological structure, including terrain elevation, karstification and (sub)surface water flows. Therefore more investigations and assessments are required to get a more credible understanding.
3. The consequences of outdated mining technologies and practises along with uncontrolled and unmanaged mining processes taking place over a number of years have resulted in the general situation and state of emergency. However, the possibility of an effective and environmentally sustainable use of salt resources may be viable.
4. Poorly managed development and land use is contributing to the complexity of the issues and overall situation.
5. Through the risk assessment process, key areas of uncertainty and vulnerabilities were identified and the EUCPT was able to provide a number of recommendations to reduce and address the uncertainties and put in place the next steps and potential further actions/programmes.
6. The requirement for a suitable and viable monitoring system was acknowledged and the recommendations are contained under the coordination of the *pillar* "protecting the environment" of the EU Strategy for the Danube Region (EUSDR).
7. Although the EUCPT has not identified a significant level of salt contribution from the assessed area into the Tisza River, since the ending of mining operations in 2010, further investigation and regular monitoring is required.
8. The tipping of domestic and industrial waste is evident within the mine and surrounding areas (a notable increase has been observed since the scoping mission) and is considered a potential risk for health and environment.
9. The EUCPT was unable to make any conclusive observations on the follow up of the immediate recommendations from the scoping mission. However, Ukrainian Stakeholders (at all levels) expressed a positive encouragement and anticipation for the final advisory mission "Risk Assessment" report to act as a platform to move and address the immediate recommendations and potential future actions to address the situation at the Solotvyno mine and surrounding areas.
10. The EUCPT has developed and captured both a digital archive of legacy data and activated both the Emergency and Risk/Recovery modes of Copernicus Satellite mapping capability, including radar data.

The overall conclusion is that the vulnerability of the population in the hazardous area is high. There are significant uncertainties arising from the mining area, in terms of collapses (craters), sinkholes and potential landslides, which could either, have a direct impact on human life or an impact on buildings, houses and other constructions (infrastructure), as well as consequential effects on society and the economy. An additional finding is that the wide spread propagation of domestic and industrial waste is a potential hazard to health and the environment.

## 5 Recommendations

The recommendations hereafter are clustered, where appropriate, in order to provide granularity. The EUCPT advises to use the momentum of the cooperation that has been developed at all levels (State, Regional, District, Local and Scientific), to discuss the implementation of the recommendations and the follow up in terms of specific actions and projects.

The following recommendations are considered in the short, medium and long-term context, broadly approximating to 0-2, 2-5 and 5-10 -year time scales

1. ***Implement a long-term monitoring system including:***
    - Monitoring to establish a "benchmark" for the monitoring parameters;
    - Ground movement and ground levels, including landslides delivered to a common platform;
    - Groundwater quality parameters and groundwater levels;
    - Whilst monitoring data is already available, there is a requirement for continuous monitoring of the Tisza River water quality parameters and discharge rates, as well as water levels up and downstream of Solotvyno;
    - Salt and freshwater lake water quality parameters and levels;
    - Establishment of a flood plain monitoring network, connected to the alluvium quality and elevation (some use of existing wells);
    - A network of monitoring wells and springs between Solotvyno and the Magura Mountain;
    - A programme for drinking water quality monitoring (public- and private- wells and springs);
    - The sewage drainage system is important for the hydrology in the mining area, and the health of the population, but the system is damaged. Therefore, monitoring and further actions are needed (please see recommendation 8).
    - Consideration of monitoring vulnerable critical infrastructure and housing

2. ***Undertake proactive, coordinated, short and medium term mitigation planning in conjunction with the monitoring and vulnerability programmes.***

3. ***Work in proactive collaboration with the EUSDR (short to long term) by:***
    - Establish a regular exchange of data and information;
    - Exploration of funding opportunities for the recommended monitoring system;

4. ***Conduct a detailed geological, hydrogeological, lithological and geomechanical model, including: (short term and ongoing)***
    - Further hazard footprint mapping;
    - The further developing of hydrogeological understanding, including seasonality and karst processes
    - Further investigation of the linkage between Black Moor and the mining area and establishment of a monitoring network, including water level and quality, such as catchment vs precipitation
    - Implementation of a programme to develop the expertise for using ground radar interferometry to monitor ground motion
    - Modelling dissolution rates and time to collapse
    - Further assessment of data archived at the Mining Museum
    - Establish the degree of connectivity between the gas field and the mining area

- Use the model to contribute to the delivery of recommendations 1, 2, 5, 6, 7 & 8.

5. ***Revise the land use plan as a land use management plan (medium to long term), to include:***
    - A robust application of building codes and the implementation of the construction laws
    - Survey on mitigation by civil engineering programmes
    - Contingency planning for restoring critical infrastructure and business continuity planning
    - Demolish old and unsafe mining infrastructure above surface and capping of old boreholes and shafts (risk assessment).
    - Retaining wall systems
    - Relocation of the inhabitants near Black Moor (hazard zone).
    - Structural database
    - Exclusion zones

6. **Consider an environmentally sustainable *Economic Development Plan (medium to long term), including*;**
    - The exploration of the Solotvyno mine and surrounding area
    - The leisure (lake) area
    - The effective use of salt resources (brine and rocksalt) for health purposes (hospital: speleotherapy)
    - Consider industrial heritage to conserve old mining industrial archaeology

7. ***Community safety (short term action, but ongoing)***
    - Improve public awareness campaign on the hazards and risks in the mining area and surroundings
    - Involve local population in further risk assessments, related to the decision making process
    - Continue educational programmes
    - Detailed structural vulnerability survey

8. ***Develop, implement and maintain a robust Waste Management Plan (medium to long term), including:***
    - Domestic and commercial waste
    - Sewage system
    - Hydrocarbon underground storage (former soviet military base)

## More information

For more detailed information, please see the complete Risk Assessment Report which goes into depth regarding technical information, conclusions and recommendations.

## 6 Next steps

The documents, files, maps etc. are handed over to the authorities in Solotvyno. The State, District, Regional and local authorities will consider the way forward, on the basis of the recommendations, provided by EUCPT.

**ANNEXES**

# Annex A Response to recommendations of the scoping mission

| No | EU experts recommendations | Responsible bodies | Status of implementation |
|---|---|---|---|
| 1. | Ukrainian authorities to expand the territory of the protection zone | DSNS Ukraine, Zakarpattya regional state administration, local bodies, state enterprise "VD Solerudlikvidatsiya" | DSNS Ukraine at a meeting on 09.02.2016 on the preparation and organization of the EU Advisory Mission visit the Environment Ministry proposed to consider the possibility to determine the territory Solotvyno salt mine as a zone of ecological emergency.<br>Zakarpattia Regional State Administration proposed SE "VD Solerudlikvidatsiya" to study the possibility of increasing of the protection zone, to conduct weekly full-scale measurements and photographs of failure sizes, in the event of further violations of the buildings and infrastructure to carry out their accounting and fixation.<br><br>SE "VD Solerudlikvidatsiya" decided to conduct monthly visual inspection with respective acts of the technical condition of buildings and structures of enterprises. In case of an emergency (self-destructive or otherwise), the immediate measures should be taken to limit people access to these objects and to notify DSNS Ukraine Tyachiv district. |
| 2. | The people living within the danger zone should be resettled | Zakarpattya regional state administration | Zakarpattya regional state administration instructed Tyachiv district administration to take immediate steps to adopt the common ownership of territorial communities of cities, towns and villages in the area of object "Building on the territory of village council Tereblya of Tyachiv district |

| | | | |
|---|---|---|---|
| | | | the residential complex, social facilities and engineering and transport infrastructure for the relocation of residents village Solotvyno with predictable deformation zones of the earth's surface", followed by its operation as intended;<br>Tyachiv district administration jointly with Solotvynska local council were instructed to consider the issue in the short term relocation of residents living within the danger zone. |
| 3. | Local, regional and state course of action and response plans and in case of an emergency, must be urgently reviewed, amended, agreed, used and tested. It also includes the dissemination of information on public safety | DSNS Ukraine, Zakarpattya regional state administration, local bodies | DSNS Ukraine instructed management of DSNS Ukraine in the Transcarpathian region:<br>6. - Together with local authorities and local governments to clarify and agree response plans for possible emergencies and measures to protect people living in the impact zone of influence of SE "Solotvyno saltmine";<br>7. - To develop in cooperation with local governments sights for people to explain the dangers of living in the zone of influence of salt mine and recommendations for village residents Solotvyno for action in the event of a threat of hazards;<br>8. - to participate in the organization on early learning period the "Safety Day", civil defense lessons with detailed explanation of rules of conduct in the territory of areas of dangerous karsts.<br>9.<br>Transcarpathian Regional Administration has recommended management of DSNS Ukraine in the Transcarpathian region to review, update and coordinate the existing system of response, develop response plans of emergencies in the territory of influence SE "Solotvyno salt mine". Extract from response |

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|---|---|---|---|
| | | | plan on emergency situations on the territory of influence SE "Solotvyno salt mine" should be brought to Solotvynska local council. In addition, management of DSNS Ukraine in the Transcarpathian region together with Tiachiv district administration, Solotvyno local council and Training Center of Civil Protection and Life Safety in Transcarpathian region for a month must hold a fire-preventive testing in Solotvyno village on the treatment in terms of the threat of karst failures. |
| 4. | To carry out weekly local observation on an object as the first step to the monitoring | state enterprise "VD Solerudlikvidatsiya" | The first meeting of the Technical Committee of SE «VD Solerudlikvidacia», was conducted at 8th of September 2016, where were agreed:<br>- to provide weekly a natural measuring of the sizes of downfalls and karstic vortexes, measuring of water level and its photographing on the territory of the influence of mining SE «VD Solotvinskiy solerudnik» with the registration of the information note;<br>- to provide monthly visual inspection of the technical condition of the buildings and constructions of the enterprise with the completion of receipt.<br>In case of appearance of emergency (self-distruction or others), immediately to take measures to limited access of people to this objects and notify the State Emergency Service of Ukraine in Tiachiv region. |
| 5. | Ukrainian involved experts should coordinate and agree common foundation for further cooperation with the Consultative mission of EU | Minagropolicy | It was prepared a common position of the scientific sector of the working group in matters of ecological reabilitation of the territory of influence of mining of SE «VD Solotvinskiy solerudnik» conserning the program of the scientific works in the frame of the cooperation of expert mission EU, |

| | | | |
|---|---|---|---|
| | | | which is set out in the information note dated 18.08.2016,. National Academy of sciences and Ukrainian scientific – research center of salt industry are recommended to provide a participation of the research assistants, members of work groups in matters of ecological reabilitation of the territory of influence of mining SE «VD Solotvinskiy solerudnik» in the work of the Consultative mission of EU. |

*Informative:*
*Zakarpattya regional state administration adopted an Order of 07.09.2016 N 428 «About the recommendation of the review mission of the civil protection of EU», by which SE «PD Solerudlikvidacia», Tiachiv district administration and Solotvyno local Council, management of the State Emergency Service of Ukraine in Zakarpattya region, Department of foreign economic relations, investments and cross-border cooperation of the regional government administration were identified appropriate tasks.*

*Conserning debts of SE «PD Solerudlikvidacia» to the LLC «Girhimprom»*
*Outstanding debt for works of production of the feasibility study to the liquidation and ecological reabilitation of the territory of influence of mining of SE «VD Solotvinskiy solerudnik», executed by LLC «Girhimprom» in 2012, appeared as a result of uncoordinated title on the execution of deep-drilling works for building by Ministry of economical development and trade, and, for conditions of throwing money by Minagropolicy in 2013 for this purposes, didn't allow an enterprice to fulfill commitments to the executives of works.*
*From 2014, by an Order of an Economic Court of Zakarpattya region of 20.11.2014 N 907/928/14 about unquestionable money cancellation to the benefit of LLC "Girhimprom», funds of SE «PD Solerudlikvidacia» were confiscated, what created difficulties in the work of entreprice.*

*Minagropolicy included in budget request for 2017-2019 to the Ministry of finance, as a part of a limit amounts of financing for 2017, costs for the cover of the outstanding debts for the production of the feasibility study in total 1925,8 000 grn.*
*In addition, in letter of 31.08.2016 № 37-32-2-10/13874 Ministry has asked the Finance Ministry to allocate additional funds in the second half of 2016 for the budget program 2801160 "Liquidation and environmental impact of mining the territory of the State Enterprise "Solotvyno salt mine" of Tyachiv district, Transcarpathian region " in sum of $ 9,029.4 thousand. UAH, including 1925.8 thousand. UAH to pay the above mentioned debt.*

## Annex B Bowtie model

Figure B.1: Scenario collapse of mine No 8

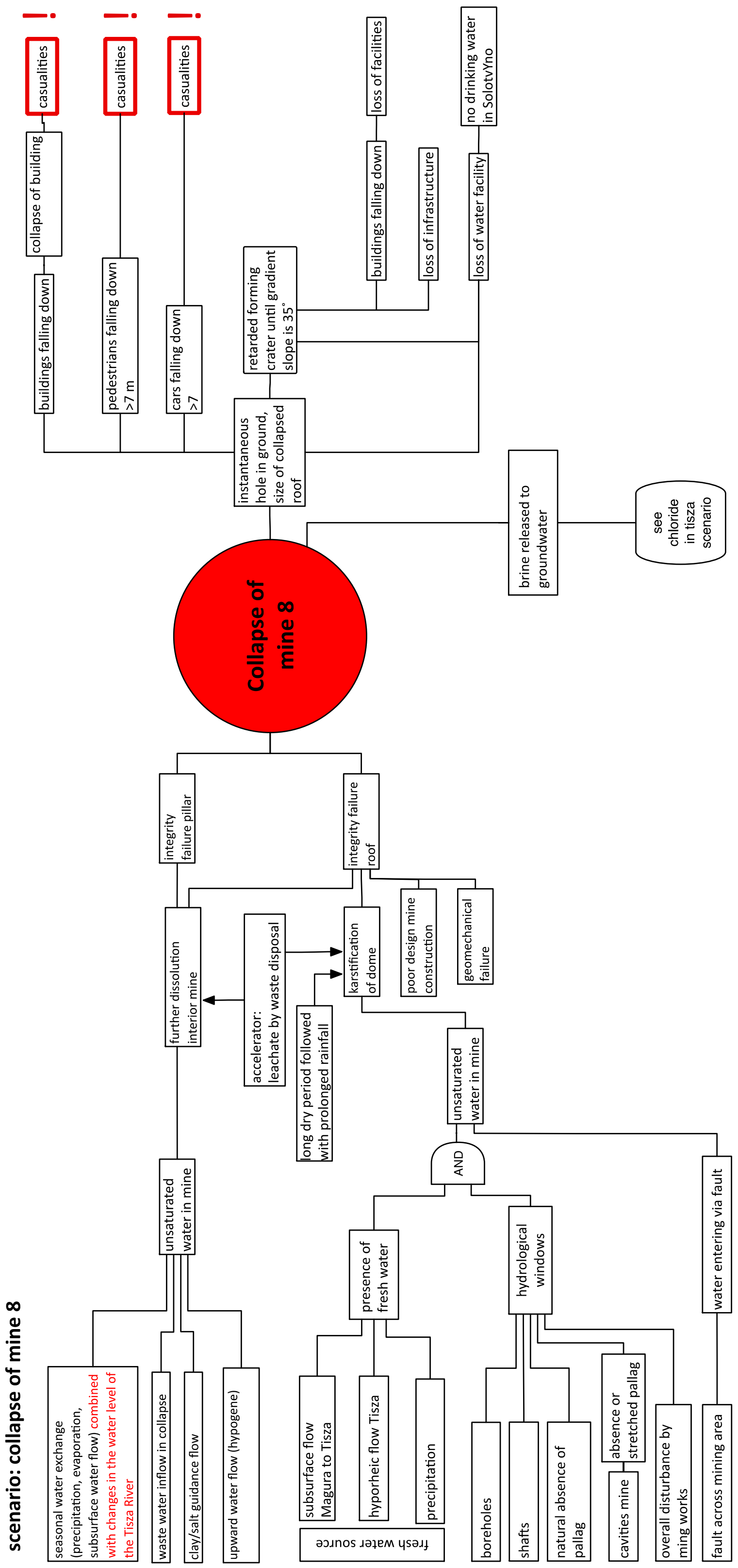


Figure B.2: Scenario collapse of mine No 7

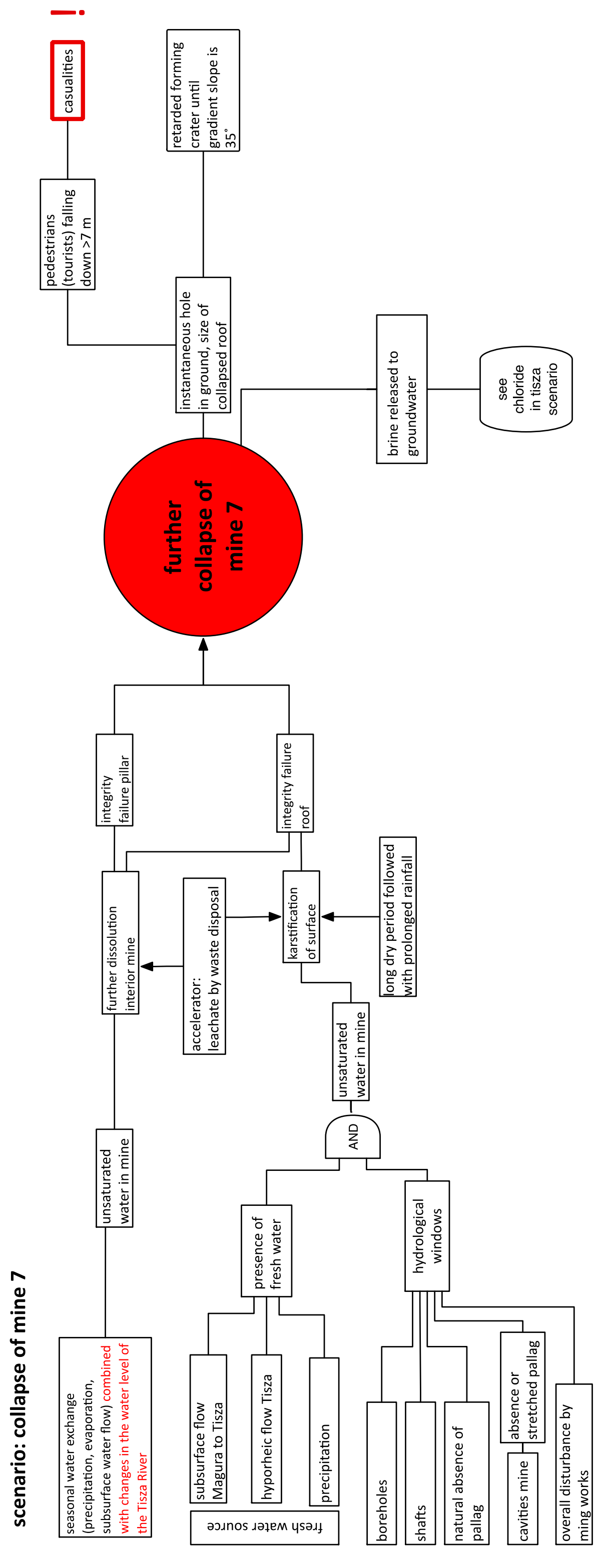


Figure B.3: Scenario forming of sinkholes

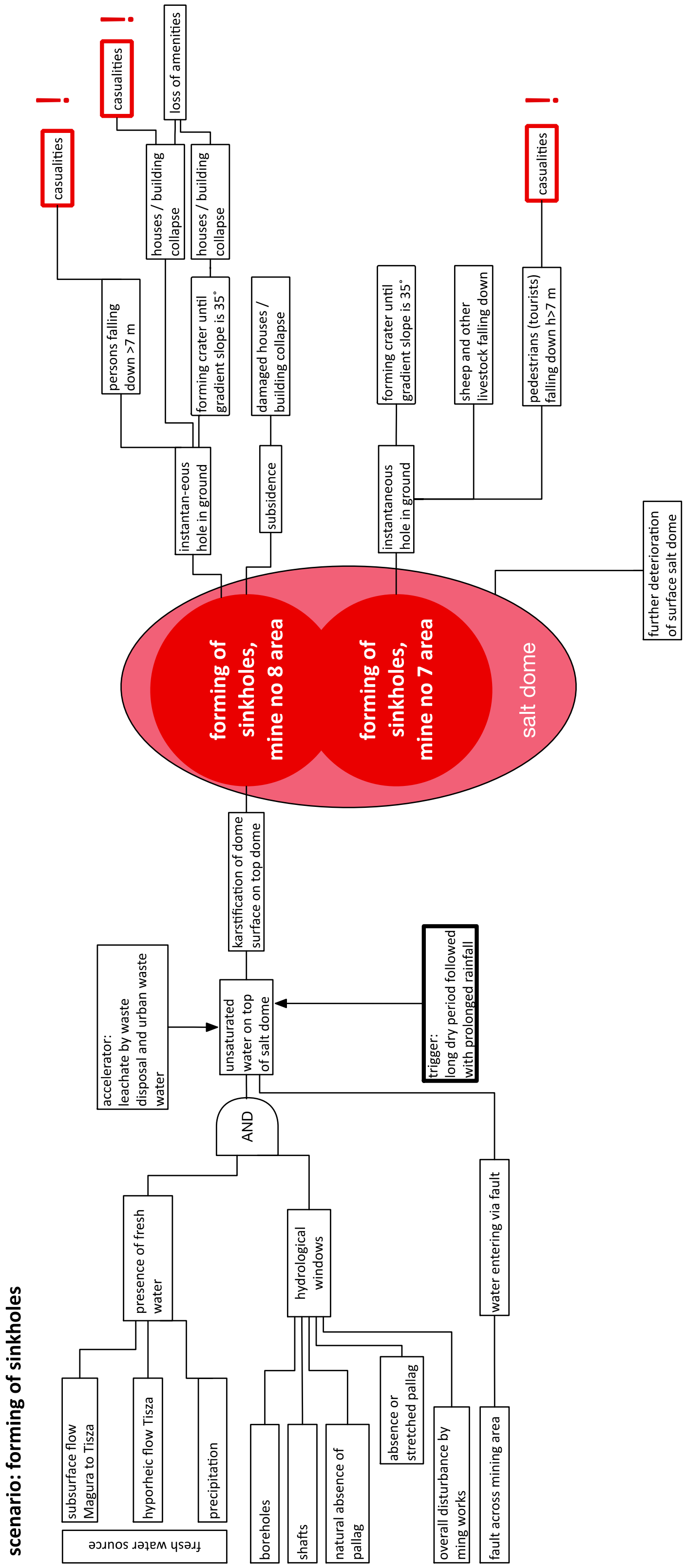


Figure B.4: Scenario landslide

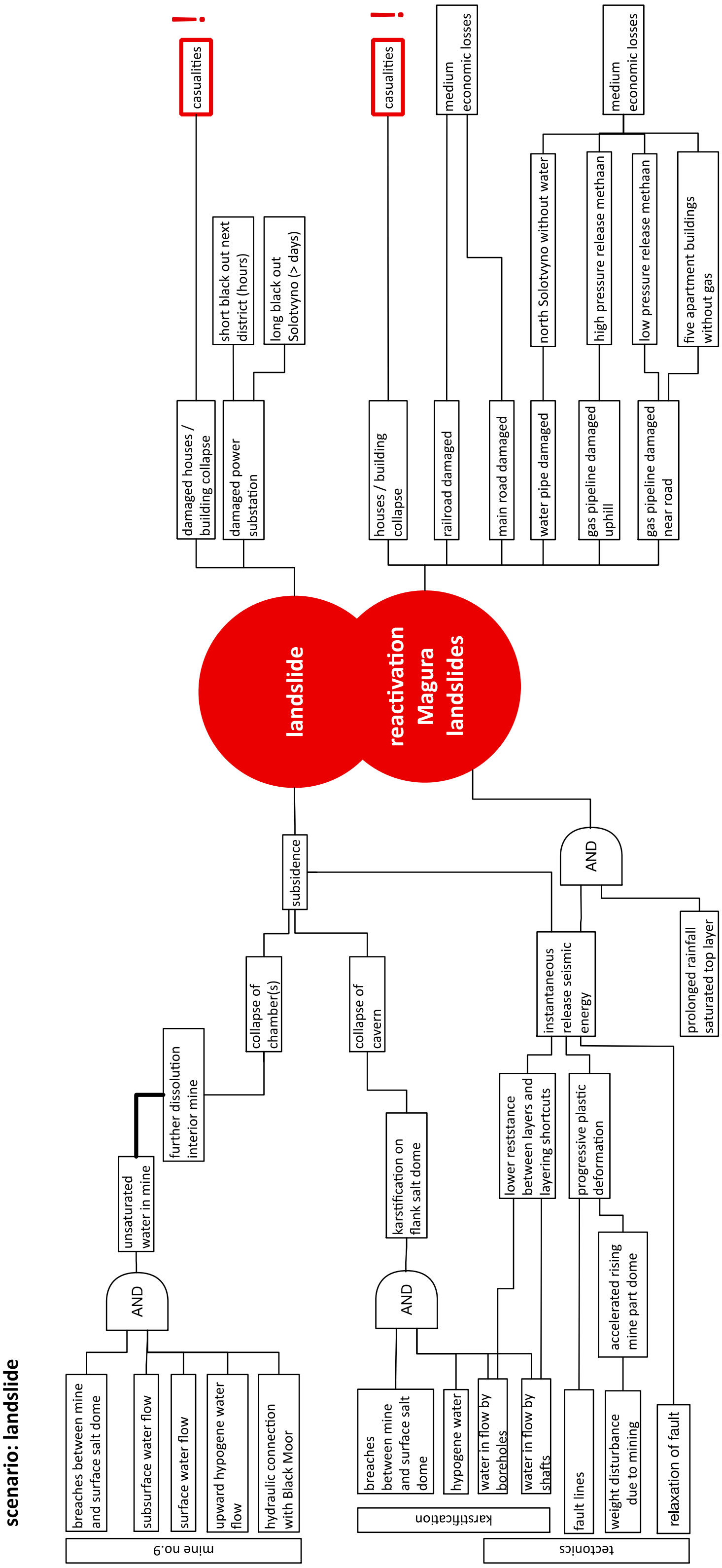


Figure B.5: Scenario liquefaction

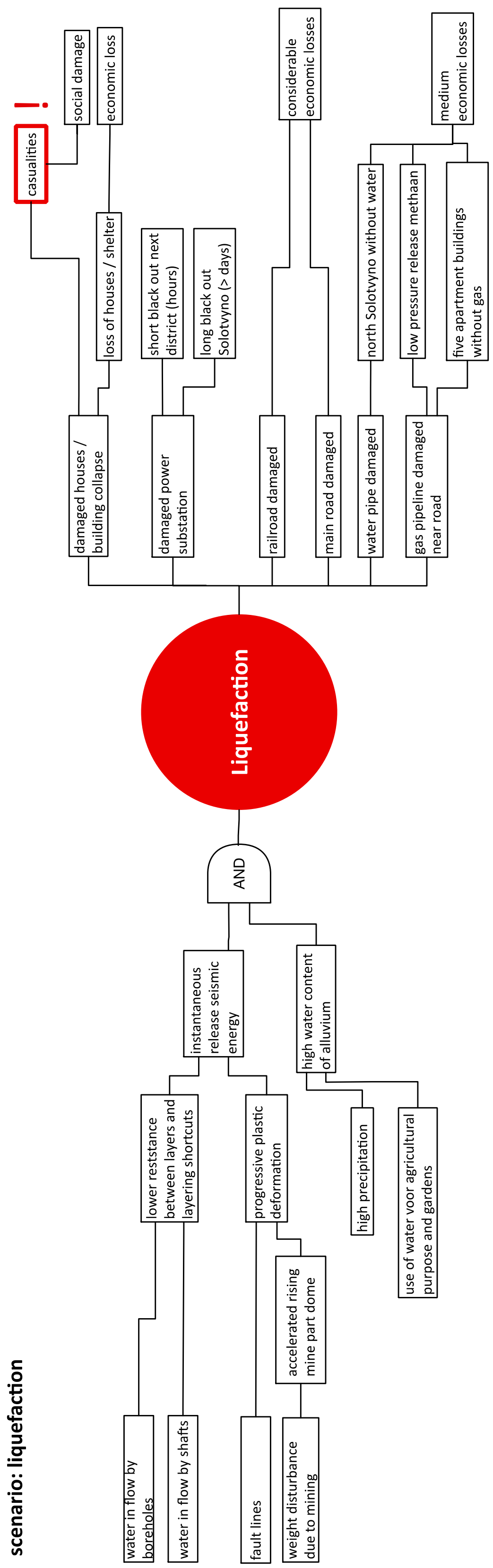


Figure B.6: Scenario forming of Black Moor

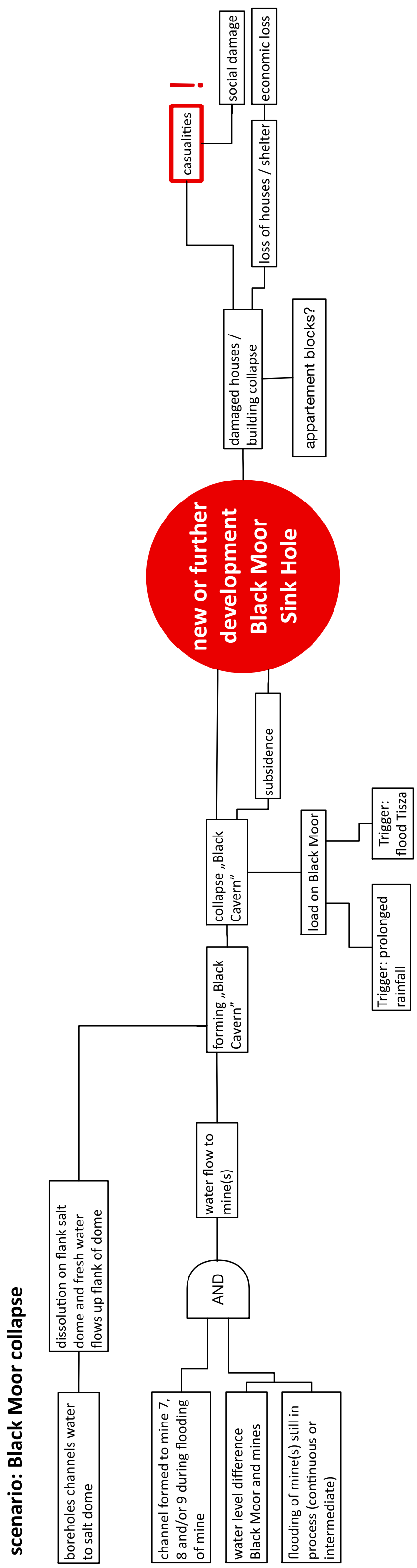


Figure B.7: Scenario collapse of mines No 1 to 6

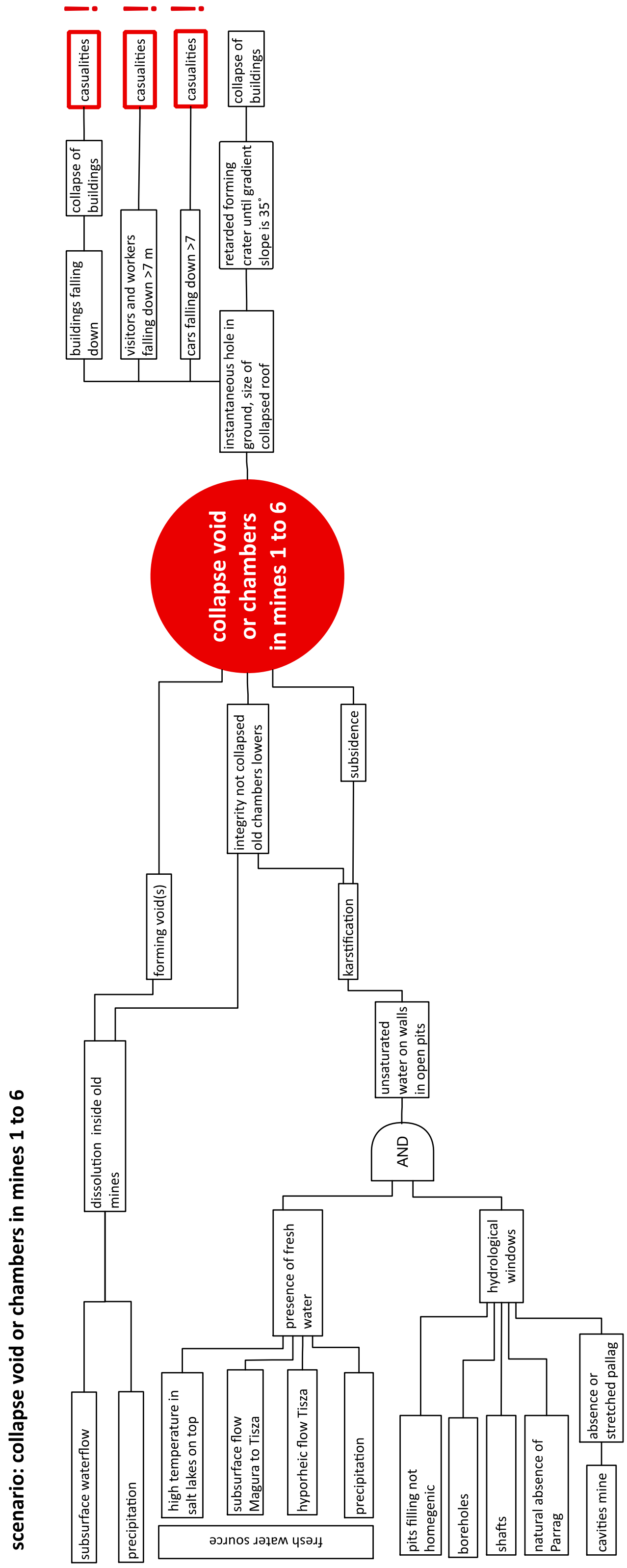
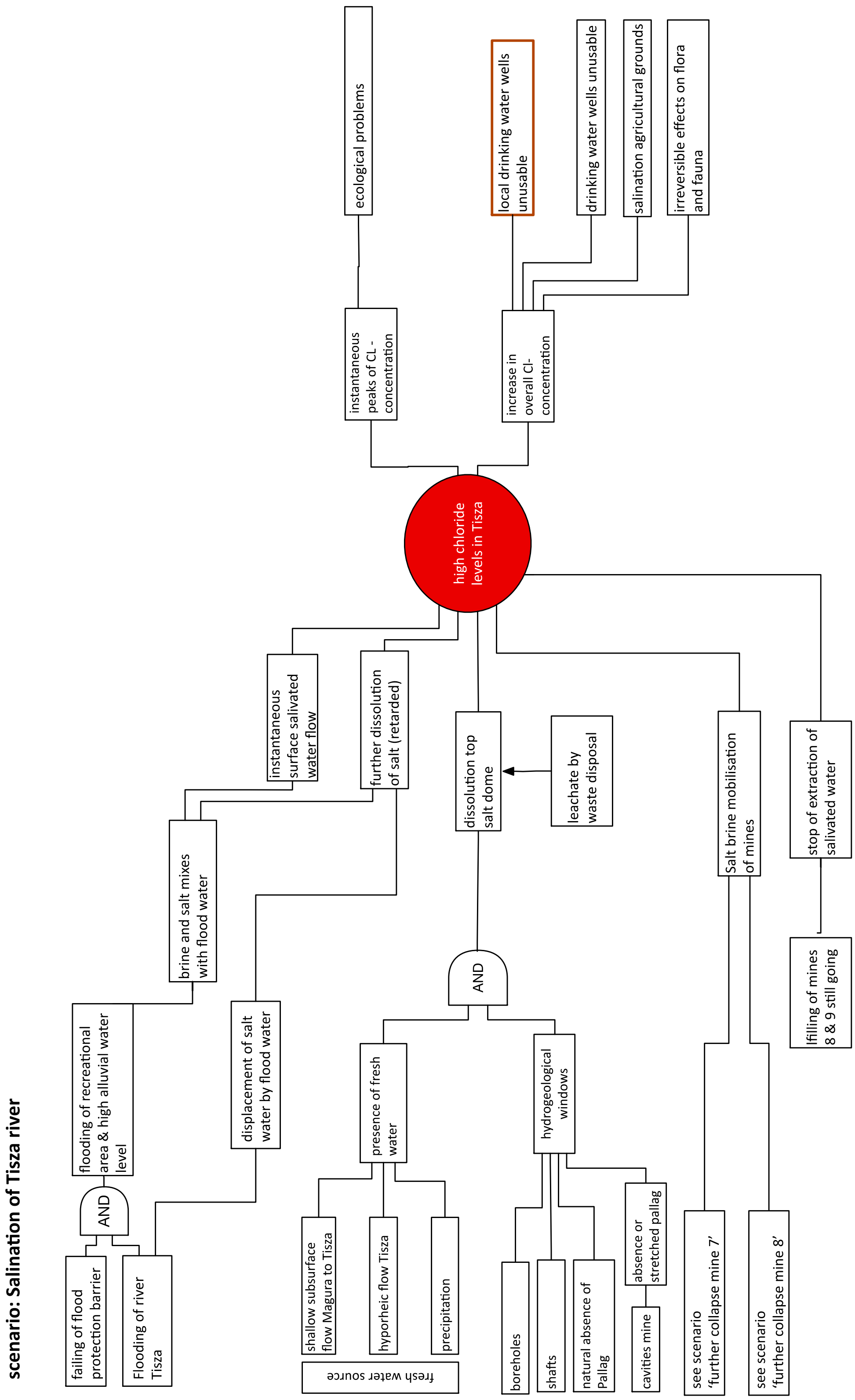


Figure B.8: Scenario chloride in Tisza River



## Annex C Glossary of terms

**Alluvium:** gravel, sand, silt laid down by the river and composed of a layer of approximately 10 to 30 m in thickness

**Bedrock:** Pre-Quaternary (older) geological deposits.

**BowTie:** A diagram that visualises the risk you are dealing with in just one, easy to understand picture.

**Collapse:** Involves mainly vertical downwards ground movement of the surface of the Earth due to different processes of rock or soil weathering reaching a point where the rock structure cannot bear its own load.

**Consequences**: the negative effects of a disaster expressed in terms of human impacts, economic and environmental impacts, and political/social impacts. (ISO 31010).

**Dam:** a barrier that impounds ground or surface water.

**Deep groundwater:** groundwater in the bedrock

**Economic and environmental impacts**: the sum of the costs of cure or healthcare, cost of immediate or longer-term emergency measures, costs of restoration of buildings, public transport systems and infrastructure, property, cultural heritage, etc., costs of environmental restoration and other environmental costs (or environmental damage), costs of disruption of economic activity, value of insurance pay-outs, indirect costs on the economy, indirect social costs, and other direct and indirect costs, as relevant.

**Exposure**: People, property, systems, or other elements present in hazard zones that are thereby subject to potential losses. (UNISDR, 2009)

**Floodplain:** the area of the River Terrace deposits that is prone to flooding by the modern course of the Tisza River.

**Hazard**: a dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage. Comment: [...] In technical settings, hazards are described quantitatively by the likely frequency of occurrence of different intensities for different areas, as determined from historical data or scientific analysis. (UNISDR, 2009)

**Hazard assessments**: a determination of the probability of occurrence of a certain hazard of certain intensity.

**Hazard map**: a map that portrays levels of probability of a hazard occurring across a geographical area. Such maps can focus on one hazard only or include several types of hazards (multi-hazard map).

**Human impacts**: the quantitative measurement of the following factors: number of deaths, number of severely injured or ill people, and number of permanently displaced people.

**Hypogene:** Upwelling

**Inversion (geological):** the reversal of compressional or extensional tectonics, whereby, for instance, basins may be uplifted.

**Multi-hazard assessments:** determination of the likelihood of occurrence of different hazards either occurring at the same time or shortly following each other, because they are dependent from one another or because they are caused by the same triggering event or hazard, or merely threatening the same elements at risk (vulnerable/ exposed elements) without chronological coincidence.

**Multi-hazard map:** a map that portrays levels of probability of several hazards occurring across a geographical area.

**Multi-risk assessments**: determination of the total risk from several hazards either occurring at the same time or shortly following each other, because they are dependent from one another or because they are caused by the same triggering event or hazard; or merely threatening the same elements at risk (vulnerable/ exposed elements) without chronological coincidence.

**Pallag (Pallah):** local name for the clay/salt layer acting as an impermeable layer between the salt dome and the overlying alluvium

**Political/social impacts**: a a semi-quantitative rating scale that may include categories such as public outrage and anxiety21, encroachment of the territory, infringement of the international position, violation of the democratic system, and social psychological impact22, impact on public order and safety, political implications, psychological implications, and damage to cultural assets23, and other factors considered important which cannot be measured in single units, such as certain environmental damage.

**Resilience**: The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions. (UNISDR, 2009)

**Risk**: a combination of the consequences of an event (hazard) and the associated likelihood/probability of its occurrence. (ISO 31010)

**Risk assessment**: the overall process of risk identification, risk analysis, and risk evaluation. (ISO 31010)

**Risk identification**: the process of finding, recognizing and describing risks. (ISO 31010)

**Risk analysis**: the process to comprehend the nature of risk and to determine the level of risk. (ISO 31010)

**Risk evaluation**: the process of comparing the results of risk analysis with risk criteria to determine whether the risk and/or its magnitude is acceptable or tolerable. (ISO 31010)

**Risk criteria**: the terms of reference against which the significance of a risk is evaluated. (ISO 31010)

**Risk map**: a map that portrays levels of risk across a geographical area. Such maps can focus on one risk only or include different types of risks.

**Risk scenario**: a representation of one single-risk or multi-risk situation leading to significant impacts, selected for the purpose of assessing in more detail a particular type of risk for which it is representative, or constitutes an informative example or illustration.

**Salination**: the process of increasing the salt content of water or a soil body.

**Salt lakes:** Land locked bodies of water with a concentration of salt that exceeds that of other inland lakes. Here this term is also used to define the geographical area that is underlain by the older mine workings (including lake Kunigunda) on the north-western part of salt dome.

**Sedimentary**: comprising accumulations of particles of rock or organic matter

**Shallow groundwater:** groundwater in the superficial deposits.

**Sinkhole**: Closed depression of basin, cylindrical or funnel shaped form that has formed due as a consequence of the natural dissolution of soluble rock.

**Superficial geology**: Quaternary and recent geological deposits.

**Vulnerability**: The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard. (UNISDR, 2009). In probabilistic/quantitative risk assessments the term vulnerability expresses the part or percentage of Exposure that is likely to be lost due to a certain hazard.

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**Cartography**

## Annex E Historic overview on the mining situation at Solotvyno

To the W of Mines No 7 /8 /9, more than six old mines are reported in the literature (e.g. Bányászati és Kohászati Lapok, Ukranian Journal of Mines). In ancient times most information about mining techniques was gathered during the exploitation phase i.e. adapting as conditions varied. Often, water was encountered underground, which, in many cases led to flooding and consequential abandonment of the mines. Knowing that the underground mining work was risky, more detailed geological and hydrogeological investigations were undertaken in the vicinity of Mine Nos 7, 8, 9. This includes the drilling of boreholes.

The geological condition of most of the salt dome remained unknown. From experience it was understood that the upper horizons were water saturated with under-saturated water and salt became drier with depth. To protect the mines 11 km of water drainage was constructed (3.7). This ensured that Mine No. 7 could be reliably operated as from 1809 to 1956, the mine No. 8 from 1886 to 2008.

Inflows of karst water were between 0.2 and 90 l/minute, with temperatures in the range 14 - 15$^{o}$C. Water was characterized by very high mineralization. Consequently, and because of the depth of groundwater circulation, under-saturated water was largely precluded, thereby protecting the mine. In the upper parts of the salt, where there is connection with the fresh water (under-saturated water) aggressive conditions prevail. Penetration of this water to greater depth causes dissolution of the salt, which threatened the stability of the operational area. In practice it was found that, even after flooding and termination of work in the area of flooded mines, the water rapidly reached saturation within a few years and the process of salt dissolution stopped enabling work to be progressed.

The understanding of these important factors about the interaction of water and salt facilitated salt extraction even in the damaged upper part of the salt body. From the technical perspective of a mining engineer, Solotvyno mine workings were able to operate to achieve effective salt extraction even under difficult hydrogeological conditions.

Figure: Shaft 8 (Mine No 8)

Figure: Crater of Mine No 7 during water sampling by the Ukrainian Mountain Rescue Team. The hole in front of the boat is the old mining shaft No 7.

In 1946 the two Mines No7 and No 8 produced 233,000 tonnes. In 1947, in order to increase production, a new system of mining was introduced. In caverns of 65 meters in height boreholes of 50 cm diameter were bored and the use of explosive technology was introduced in conjunction with hoppers to transport the salt. The hoppers were driven by electric locomotives. However, the drainage system was not given due attention. As a result of this shortcoming the main shaft in Mine No 7 collapsed in 1950. Salt production was maintained until 1953 via the shaft of Mine No 8. The tunnel to Mine No 7 was blocked with a concrete wall, in order to protect Mine No 8 from the flood water that was building in Mine No 7.

The disturbed surface conditions and the reduced salt production at Mine No 7, lead to its liquidation. Closing procedure of Mine No 7 was conducted by pumping water into the lower level (second horizon), where additionally jumpers were set between the Mines No 7 and No 8 and the termination of the maintenance of the bilge system. As the salt production in Mine No 8 was only enough for the next 12 years, a new mine was planned (Mine No 9), which was operating between 1975 and 2008.

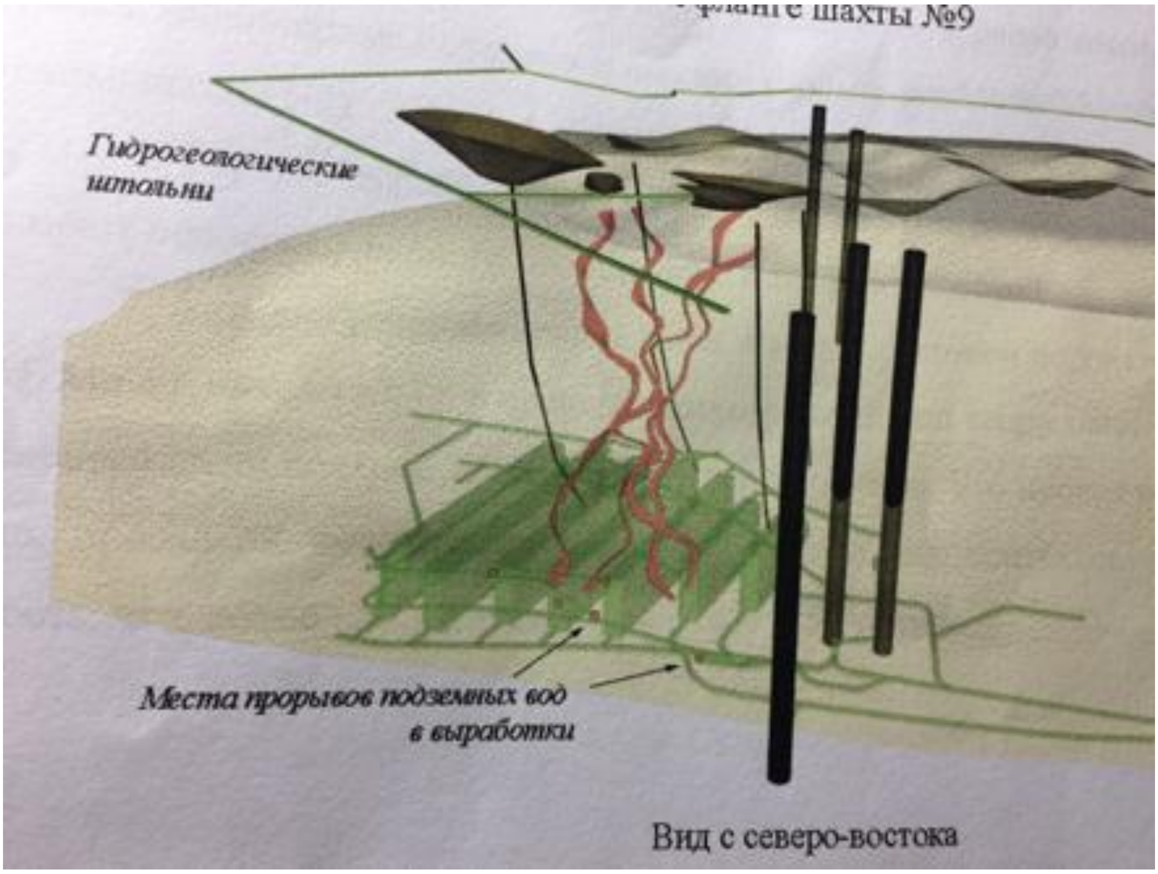
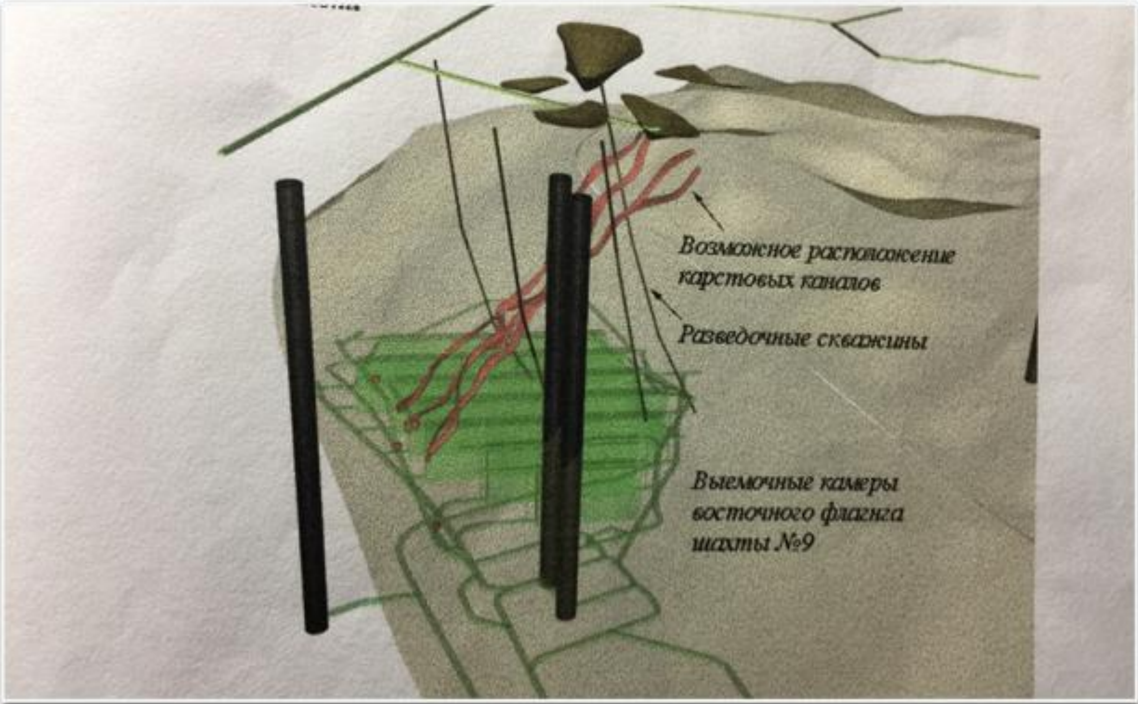



Figure: View from NE on mining works, ventilation and main shaft of Mine No 9. Red bands indicate possible pathways for under-saturated water from the surface into the mine chambers. (Resource: Mine archive of Solotvyno). The green pipes on the top of the Figure show the old drainage system.




Mine No 9. W view on Mine No 9. Possible karst conduits (red), mine chambers (green) and, exploration wells (thin brown lines above chambers). The vertical pipes represent the Skip Shaft (local name Shaft 10), and the mine and weather shafts. (Resource: Mine archive of Solotvyno).

Figure: Skip Shaft of Mine No 9

Any future commercial development of Solotvyno rock salt depends on understanding the historic events of Mines No, 7, 8 and 9.

1) Mine shafts are located in the central part of the salt. These shafts provided the understanding of the development of the structural-lithological elements in the upper salt dome (depth up to 430m; see also references of Khrushchov and Bosevska). The most difficult to understand was the geological conditions at the skip shaft (Mine No 9) at the northern flank of the salt dome. Additionally, drilling and explosive technologies destroyed the salt structures by enforcing geomechanical tension with additional resulting from the Magura Mountain (N of Mine No 9).
2) The flanks of the salt dome were destroyed by mining activities at Mine No 9. This was associated with water inflow into Mine No 9, which progressively increased until the mine was abandoned in 2010.
3) A comparison of the development of Mine Nos 7, 8, and 9 leads to the conclusion that there were fundamental errors during the planning of Mine No 9. The negative effect of both, drilling and explosive technologies are the following:

- the formation of geomechanical deformation of the upper salt dome;
- the connection between mine chambers with the adjacent saturated bed rock,
- an increase in permeability inside and above the salt dome enhancing the water flow.

Salt deposits and mineralized brines could be the main source of natural resources to sustain the social and economic situation of Solotvyno. For this, the following are suggested:

- careful analysis of the historic data of the mine workings to ensure safe development of the area;
- the definition of the zones affected by previous mining activities and which influenced the geological and ecological condition;
- establish a monitoring network to underpin a model of the new understanding of the geomechanical and hydrogeological situation,
- the development and use of new technologies for further regulation of salt dissolution processes for managing the drainage.
- A number of geophysical techniques (Contrucci et al., 2011) could be applied to an investigation of the condition of the abandoned mines and associated karst processes at Solotvyno, in particular the following might be considered:
    - Electromagnetic techniques (see relevant references by Shekhunova and Yakovlev)
    - Seismic techniques (including passive seismic)
    - Electrical resistivity tomography (http://link.springer.com/article/10.1007/s12665-016-5404-0 )

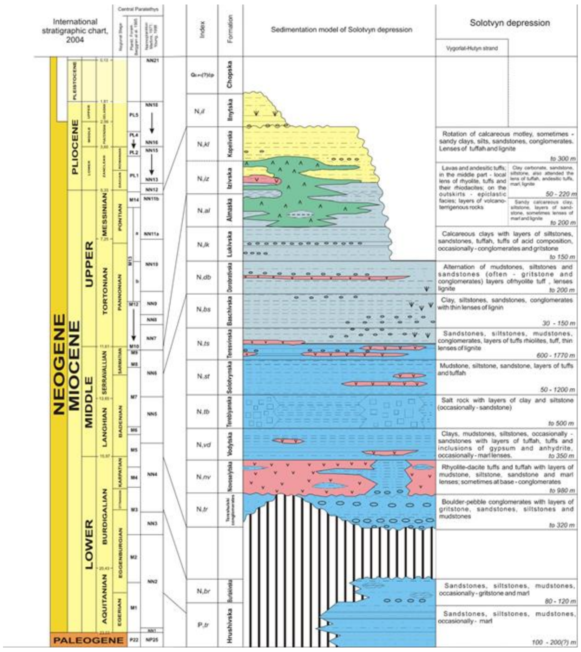
## Annex F Presentation Prof Khrushchov

# Structural and lithological modelling of the Solotvyno salt dome

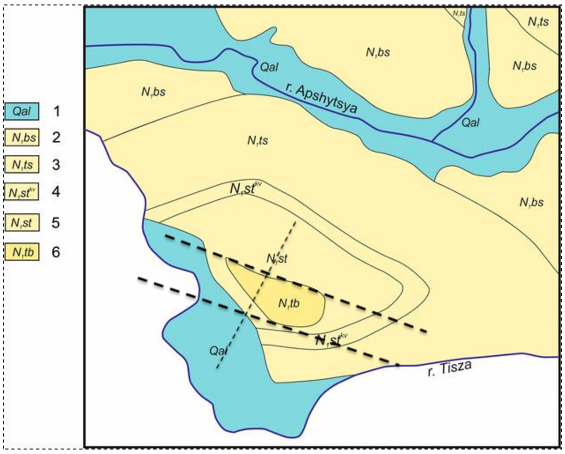
Krushchov, D.P., Yakovlev, Y. and Bosevsca, L.

## Structure

- Part 1 will be a general introduction to the geology
- Part 2 will be a more focused look at the general structure and degradation of the salt



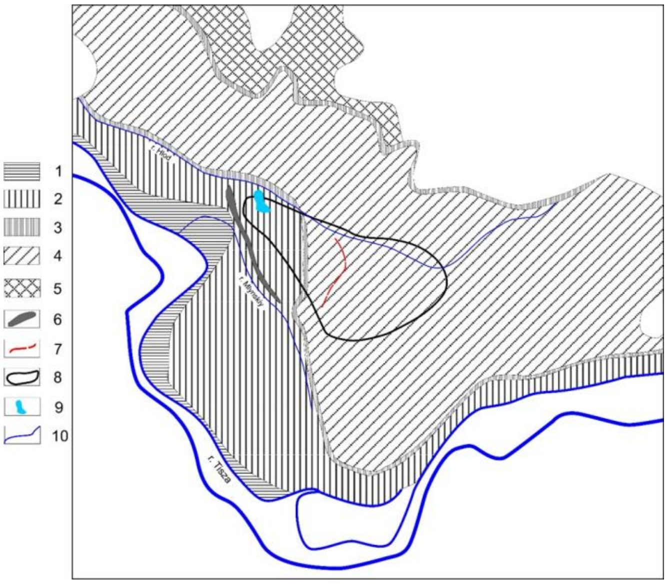

# Stratigraphical setting




# Geology

Geology map of the Solotvyno district annotated with suspected fault alignments.

Legend: 1 – Quaternary, alluvium;
2 – Miocene, Baskhivska suite suite Alternating: clay, sandstone, siltstone and conglomerate;
3 Miocene, Teresvynska suite Alternating: clay, siltstone, sandstone, and tuff;
4 Miocene, Solotvynska suite, Kovachskyi level of tuff;
5 Miocene, Solotvynska suite Alternating: clay, sandstone and siltstone;
6 Miocene, Tereblynska suite Alternating: rock salt with clays.




## Pliocene and Quaternary

1 – Floodplain of Tisza river;
2 Terrace 1
3 edge of terraces;
4 Terrace 2;
5 Terrace 3;
6 Flood barrier;
7 Old quarry wall;
8 salt dome;
9 salt lakes;
10 rivers, streams.
11 Ref. (Elizarov A.F., ..)

# Part 2: Aims

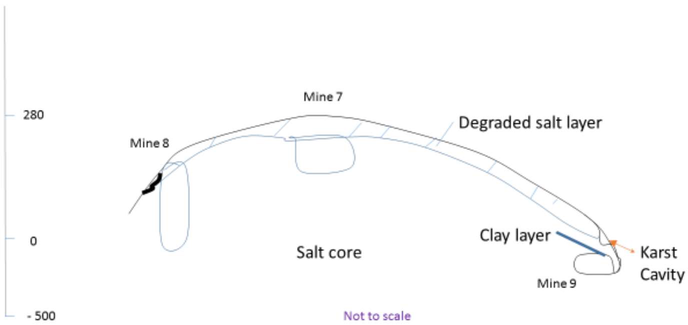
- Introduce the DSLM
- Show how the lithological modelling can be used as the basis for subsequent geomechanical, hydrogeological and hydrochemical modelling
- The model is primarily based on the natural situation. It is recognised that the situation has subsequently been influenced by the mining technology and in particular the use of explosives

# Introduction to the model

- the object comprises three structural functional blocks (subordinate models and sub models), namely:
- salt massif
- overburden cover
- The surrounding sedimentary cover and marginal flanks of the salt core.

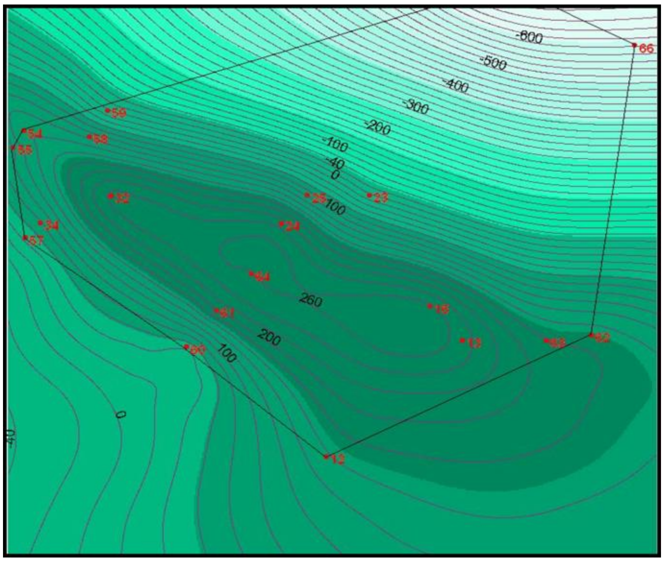
## 1. Salt core

- Composed of rock salt with subordinate beds of salt clays (argillites) and salt sandstones
- Covered with a layer of degraded rock salt
- A number of DSLM visualisations or DSLM derivations have been presented



# External structure of the salt core

- As a whole the relief of the salt core reflects the results of the impact of natural processes, including:
- - The natural protraction and absence of the cover (polag),
- - Juxtaposition of different salt rock lithologies with different functional properties (vulnerable to dissolution), and
- - The presence of salinized non-salt rocks



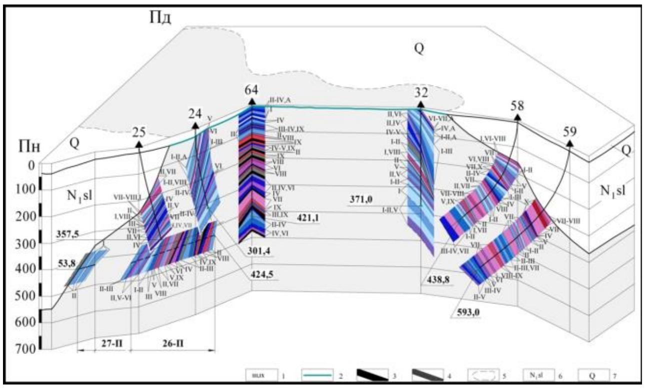
# Internal salt core composition

The model is derived from traditional lithological examination of rock types and the designation of each with pertinent characteristics.

The data was derived from boreholes and mine samples.

Developed using ArcView

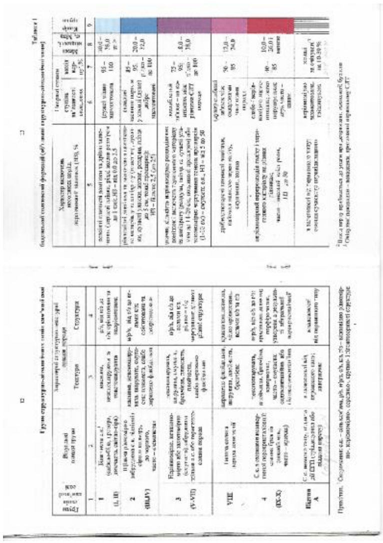
L Bosevsca and N Danishurka



# Summary of the classification Russian and English

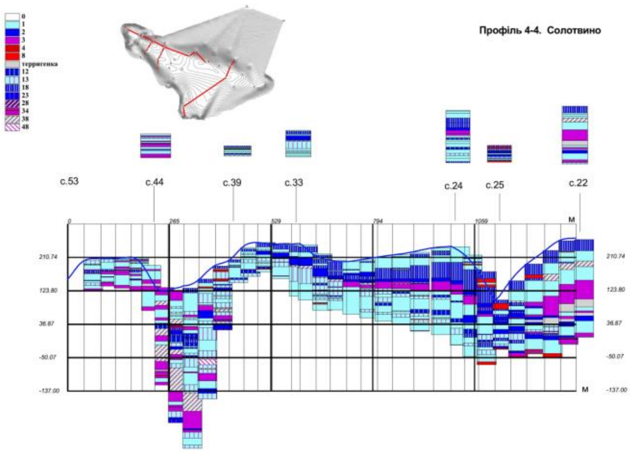
Geomechanical properties (L Bosevsca and N Dmishkurisa)

| Lithological type | Unconfined compressive strength Mpa |
|---|---|
| I, II | 30-38+ |
| III, IV | 20-32 |
| V, VI | 18-38 |
| VII, VIII | 12-24 |
| IX, X | <10-20 |
| Degraded (weathered salt) | Strength reduction of 10-30% |



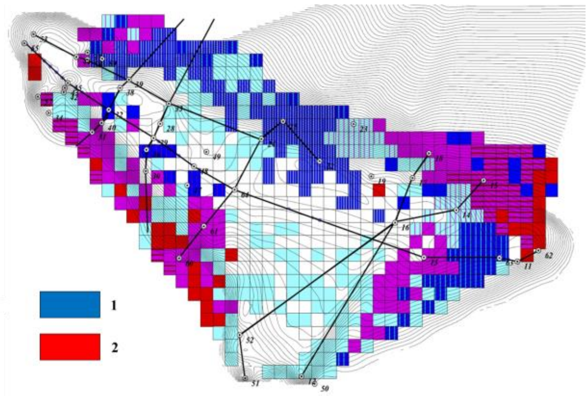
# Generalised profile (NW-SE)

Blue colour denotes favourable physico-mechanical properties and salt types; red colours represent unfavourable physico-mechanical properties

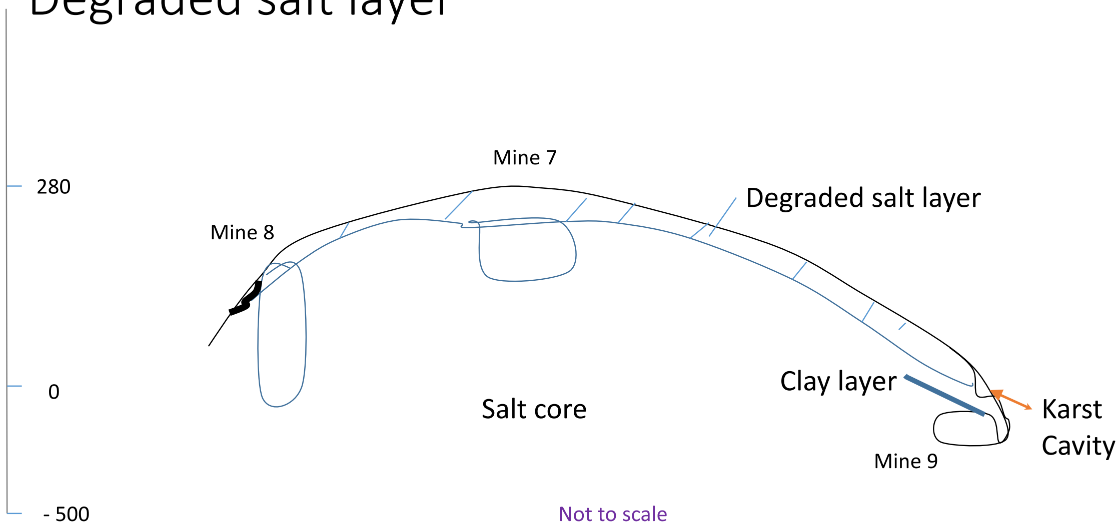



# Horizontal slice of Solotvyno salt massif at +50 m

- Both the section and the slice show the volume and digital position of rock salt types simultaneously reflecting the main geo-mechanical properties (unconfined compressive strength).
- Note the low strength designation in the vicinity of shaft 9
- This image also demonstrates how the model can be used to identify economically favourable zones of salt



# Degraded salt layer




# The layer of degraded salt

- This has not been mapped
- Characterised by fracturing, fissuring, high porosity (slightly cemented) and often brine saturated (wet)
- The strength is at least 30% lower than the salt core, tending to zero in borehole cores
- Local observations suggest that the layer covers the surface and margins of the salt dome
- The permeability of this layer is very high
- The thickness of this layer extends from several metres up 200 m
- Geophysical techniques could be used to map this layer

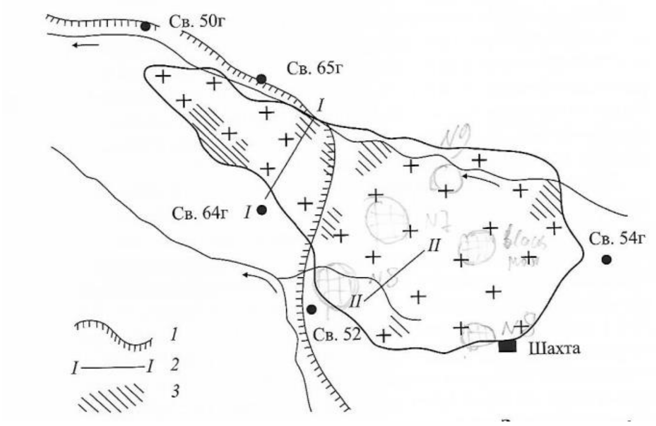
# 2. Overburden cover

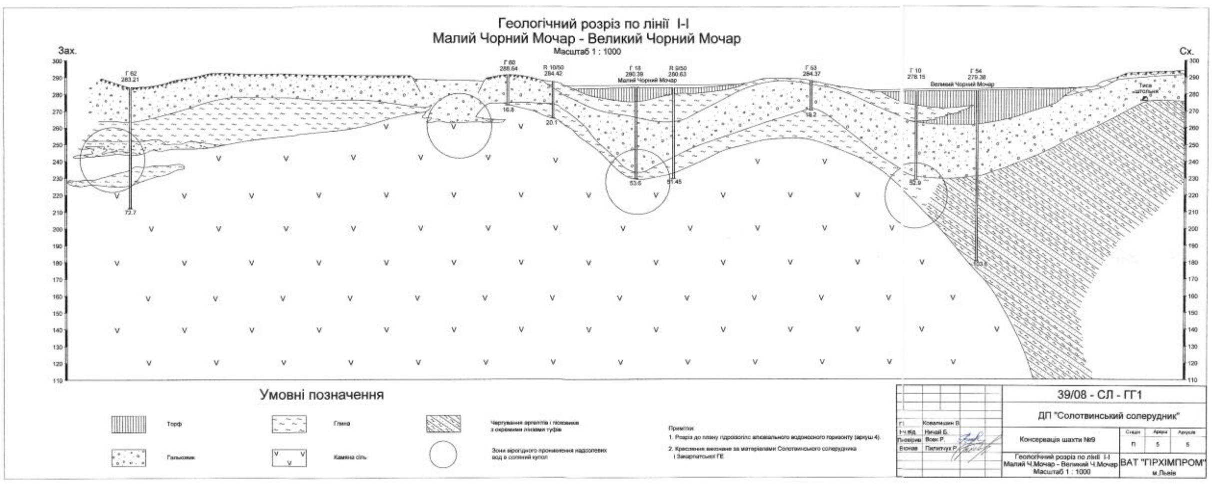
Pallag: predominantly waterproof horizon. Initially it formed a complete cover to the salt dome with restricted areas of pallag absence (of natural and technogenic genesis)

The area devoid of pallag has significantly increased due to:

- Initial windows
- New technogenic hydrological windows
- Collapse features

Current mapping of the pallag spread is sufficient to define the zone of salt core “protectability”

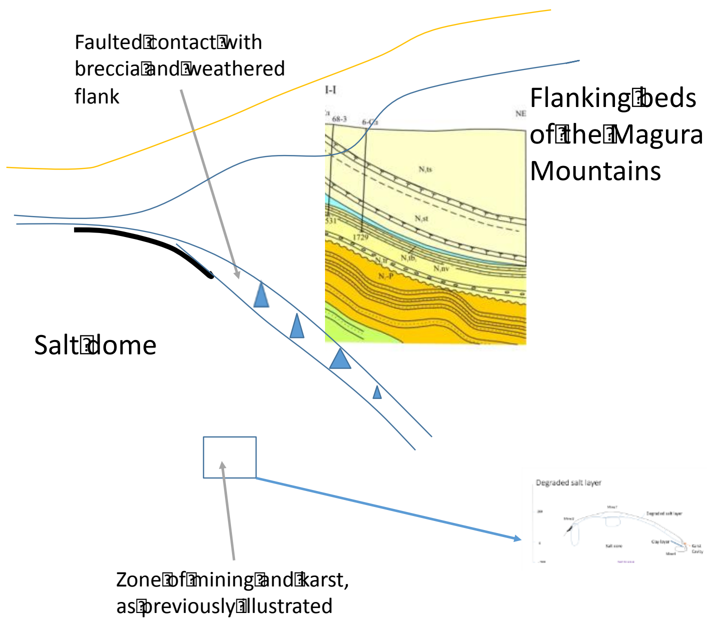


# 3. Surrounding sedimentary series marginal to the surface of the salt core

- Certain of the rocks are characterised by a high degree of fissuring and comprise fractured aquifers
- Water flow at the salt/ aquifer interface results in the formation of marginal karst
- In contrast with the impermeable pallag the marginal breccias are highly permeable and may form water saturated zones
- Marginal karst cavities are usually filled with friable materials and may contain significant volumes of water
- The karst cavities could be predicted from borehole logs by estimation of infiltration properties and water saturation of sedimentary beds in contact with the salt core
- The active tectonic faults can also provide flow paths for ascending water which may also be a factor of marginal karst development

Potential for hydraulic continuity with the Head in the Madura Mountains



# Causes of core deterioration (desalination)

**Technogenic invasion into the salt core media**

**Disturbance of external protective systems**

- Disruption to Pollag and to the layer of stable saturated brine
- Layer of stable saturated brines

→

**Disturbance of internal, natural structure and lithology**

- Technological opening by workings of specific rocks may form connecting channels with aquifers and the degraded salt layer:
- Fissured salt clays
- Specific lithological types of rock salt (fissured, porous, friable)
- Absence of preventative technical measure

# Consequence of technological invasion

- Catastrophic deep karst development in the area of shafts 7, 8 and 9 etc.
- The main resulting processes:
- 1. Flooding of shafts 8, 9
- 2. Intensification of connections feeding sources (a. overburden aquifers; b. surrounding sedimentary series, marginal breccias and karst zones, c.ancient karst funnels (Black Moor and others)
- 3. Development of other resulting hazardous phenomena: earth surface subsidence, landslides etc.
- 4. Subsequent deformation of salt core protective systems

# Long term scenarios of subsequent salt core deformation

**Phase of active karstification**

- Managing mechanism/ karst form
- Related dynamic geomechanical processes – sinkhole development, surface collapses.
- Main hydrogeological mechanism – phase of shaft flooding

Duration several years

**Phase of quasi-stabilization**

- Cause: stabilization of underground water exchange between salt core reworked space overburden and surrounding sedimentary series (due to shafts final flooding)
- General geomechanical affect: gradual weakening of salt core leading to deformation and reduced pillar stability
- This phase comprises two stages: 1. Initial shafts removed space stability increase due to reduced overburden load on working construction elements, closing of fissures by salt crystallization etc. The result: mitigation of all deformation processes. Duration several years. 2. permanent gradual reduction of shaft space and stability 3 The stage of permanent gradual reduction of reworked space stability caused by a number of mechanical and physical processes

# Physical chemical phenomena of rock salt wetting

- Diffusion resulting in salination and strength reduction over several years
- Regular pillar deformation is related to the plastic properties of the rock salt leading to slow chamber volume reduction over 100s of years
- Low movement of undersaturated brines in the upper parts of flooded shaft workings causing dissolution of critical parts of the pillars and collapse development
- Plastic deformation of a number of pillars having been undercut during flooding results in sporadic collapses over months to years
- Local karst development in the location of ancient karst funnels (as Black Moor) and the marginal breccia

# Conclusion

- Currently only the DSLM of the salt core of the object has been developed and presented
- Future modifications of the DSLM of the Solotvyno salt deposit are required, including:
  - Overburden
  - Surrounding facies marginal to the core
- The proposed DSLM of all of the blocks of the objects have to be a key basement for the comprehensive ecological mining geological model, comprising hydrogeological, geomechanical, engineering geological, which also have to be developed as the basis for DSLM
- The defining specialised geological and geophysical works are necessary for the elaboration of the future development of the DSLM
- Specialised geological and geophysical techniques are required to achieve the following:
  - Defining the relief of the salt core surface and marginal parts
  - Mapping of the pallag layer
  - Mapping of the degraded rock salt layer
  - Revealing zones of brecciated marginal salt and karst cavities
- The geophysical requirements are:
  - 3D seismic combined with detailed modification (ore)
  - Micro-gravimetric survey
  - Electric profiling (method of measuring natural electric fields)
  - Magnetometry
  - Etc

# Acknowledgements

Thanks to Vanessa Banks for help with the preparation and to all of the EUCPT team for their collaboration and useful discussions

## Annex G Radar data Solotvyno

**The following emergency requests for radar data for Solotvyno, Ukraine was sent to Copernicus:**

Radar data can be used to determine subsidence of the earth´s surface. It is used to detect vertical ground movement in the range of millimeters. Radar data is freely available from different sources. However, processing requires considerable expertise and time, and therefore costs.

Ground movement in the area of Solotvyno is complex (i.e. both upward movement of the underlying salt diaper and consequential collapse as well as karst sinkhole formation and regional subsidence). To ascertain the rate of sinkhole formation in the area of the abandoned mine workings, where the ground is considered too unstable for detailed ground work, the use of this radar data is considered to be essential from the expert´s perspective. Additionally, in order to establish a timeline for sinkhole formation it is important to obtain historic records. This data will contribute to a risk assessment and zoning of subsidence rates; areas of accelerated ground movement are likely to be indicators of areas prone to collapse, particularly in the areas of urban development where there is critical infrastructure.

Such radar data was and is currently applied to the Beresniki case (salt mine collapse in Russia). It is was initiated for landslide monitoring in Italy. Applied at Solotvyno (coordinates previously supplied to ERCC) this data will form a baseline for subsequent monitoring and an ongoing risk assessment.

To determine the rate of change in subsidence, a long time series is required. The data sets (from which the most recent data are prioritized) are:

1) Sentinel-1A starting 2014
2) Radarset-2 starting 2012
3) ERS 1/2 and Envisat between 1994 - 2010

**The results arrived on 04th of October and the following is a very rapid overview of what the data shows:**

- Preliminary results (demo) by Copernicus by the European Union and ESA
- Scene: Envisat-ASAR by ESA 2003-2010
- Spatial (horizontal) resolution: 20m
- Estimated vertical resolution is 1mm or better
- Dots show integrated subsidence values (in mm/a) over the whole time frame (2003-2010). However **changes** in subsidence **rates** (acceleration and deceleration) can be determined by analyzing the data more carefully: For each data point several radar data measurements at different times are available (see Solotvyno_import_points.xlsx). This is especially important when looking at more recent data after 2010 (i.e. after the abandonment of the Mine No 8 and Mine No 9).
- The dots show vertical ground movement between -27 (red) and 0 mm/a (green), respectively. The blue dots show an increase in height between 0 and +0.25 mm/a.

- The Solotvyno mining area above the mine caverns (shaded in orange) was subsiding between 2003 and 2010 (red dots). However blue dots in the "Lake area" NW of the mining area indicate a rise in altitude.
- The zone of subsidence extends further south of the chambers of Mine No 8, north of the chambers of Mine No 9 as well as to the east of Black Moor into the residential areas (yellow dots).
- Especially south-west of the collapses of Mine No 8 (red dots) confirm the high risk in this area.
- The area around Solena St. (N of mining area) is indicated to be in the area of high subsidence with more than -10 mm/a, which correlates with field data by EUCPT (orange/red dots).
- Yellow dots in the area of deforestation in the Magura Mountains interpreted as soil erosion.
- Landslides, sinkholes, and collapses are indicated independently (see legend).