UNIVERSITY OF PETROŞANI

HABILITATION THESIS

DOMAIN: MINING, OIL AND GAS

RESEARCHES ON STABILITY AND ECOLOGICAL RECONSTRUCTION OF THE LAND AFFECTED BY MINING

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2016

CONTENT

„Der Bergbau ist nicht alles - aber alles ist nichts ohne den Bergbau”

(Mining is not everything - but everything is nothing without mining)

Prof. Dr. H. Gerhardt, Freiberg 2000

ACKNOWLEDGMENTS

The Habilitation Thesis submitted to your attention to is the result of a continuous process of learning, documentation, training and research in the fields of mining engineering and environmental engineering. I chose this topic because it addresses two areas that overlap, the slope stabilization techniques and the ecological reconstruction of degraded lands are giving to mining activity a dimension that contributes to increasing the acceptability and sustainability. As expressed by Professor Gerhardt in 2000, mining is not everything, but everything is nothing without mining. Even though mining industry generates a significant impact on the environment in general and on the land in particular, this paperwork demonstrates that this impact is reversible, often the areas affected by mining can gain a greater ecological value than before mining operations.

Elaborating this thesis would not have been possible without the support of my mentors and colleagues from the University and collaborators from the economic field.

First of all, I wish to thank Professor Dumitru Fodor, thanks to which I understood still from high school the importance of the mining sector, by involving me from that period in research activities. As a PhD supervisor, Professor Fodor has succeeded to direct my efforts with maximum competence, so I can perform the necessary steps to completion of my doctoral thesis, being for me both a mentor and a friend. Equally I wish to thank my professors Mircea Georgescu and Ilie Rotunjanu, with whom I developed teaching and research activities, continuously learning from the experience which they shared with me as true mentors. My gratitude turns also to Professor Iosif Andraş, who generously and competently supported me and shared with me from his knowledge from different fields, that otherwise perhaps I would not had. Special thanks to Professor Carsten Drebenstedt, for his support during the research internship from Bergakademie Freiberg, but also for the collaboration opportunities in teaching and research.

Also I thank to all the colleagues I worked with and I assure them that every interaction has enriched my knowledge as a result of the problems we've solved together and for the vision on how to continue the research.

For most of the research I needed primary data, field analysis and samples for laboratory tests, which were obtained with the support of the managers from Oltenia and Jiu Valley mining areas. I assure all professionals with whom I’ve worked and who supported me along time in my research efforts of my deep gratitude.

Last but not least, I wish to thank my family and friends, which often were deprive of my presence at various events, but always understood and encouraged me.

Mai, 2016

SUMMARY

Any academic career involves a wide spectrum of activities, but the most important components are teaching and research, which must be in constant interaction

In terms of teaching, I have contributed on training many generations of students, both in mining and environmental engineering. Interactive lectures, debates at laboratory and seminar classes were the tools of transmitting theoretical and practical knowledge. These methods have proved their effectiveness, given that many of the graduates I have worked with are now performing on labor market and their feed-back is a positive one. I went through all promoting stages by competition, from the academic rank of assistant professor to full professor, the latter being obtained in 2007 (M.Ed.C.T. Order no. 1013).

Regarding the scientific research, since the beginning of my career I was involved in joint projects of the university's research teams. Initially, I worked in the mining field, the research being oriented towards slope stability issues, techniques and technologies for the exploitation of useful minerals deposits and dewatering of aquifer formations. During this stage, in 1998, I completed my doctoral thesis entitled "**Recovery and capitalization of thin lignite layers from Oltenia open cast mining perimeters**", obtaining the title of Doctor in Technical Sciences (M.E.N. Order no. 5182). In the thesis I approached technical issues related to the optimization of coal reserves extraction from thin layers in order to minimize reserves losses and lignite dilution, also dealing with the environmental issues. At this point I began the transition towards the field of environmental engineering, a field in which I progressed following postgraduate and postdoctoral courses performed at prestigious universities in Europe. The new research directions, that have joined those mentioned before, are directed towards environmental impact assessment and restoration of land degraded by industrial activities.

If obtaining the didactic degree of professor validated my teaching activity and my scientific activity has been confirmed by obtaining the title of doctor of technical sciences, I believe that obtaining the title of doctoral advisor, after sustaining my habilitation thesis entitled "**Research on stability and ecological reconstruction of lands affected by mining**", can be regarded as the coronation of my academic career.

The habilitation thesis is structured as a logical summary of main results of research in the fields of mining and environmental engineering, and is divided into three parts, including: a short description of the didactic and scientific activity, researches regarding the environmental impact assessment caused by mining (particularly on land); mining waste deposit's stability assessment; solutions to increase and ensure the stability of waste deposits; assessment of the impact generated by dewatering works and solutions on restoring the groundwater regime; ecological reconstruction of mining waste deposits and former quarries, as well as the career development plan in the future. The results presented in this paper are based on a series of research materialized in scientific papers published in international journals or conferences, as author or co-author.

The first part of the thesis presents a synthesis of didactic and scientific results obtained throughout my academic career, as well as elements of national and international visibility. Also, this part highlights my permanent concerns for documentation and training in teaching and research interest areas.

The second part of the habilitation thesis presents the contributions resulting from scientific research, is divided into four chapters, and consist in a brief presentation of theoretical foundations and the elements of analysis, research and interpretation specific for the addressed theme.
The first chapter is dedicated to identifying and analyzing the effects of mining activities on the environment, particularly on land, at all stages of a mine development (especially for a quarry).

This chapter clarifies the concept of "land" (as defined by scientific literature), explains the functions that give value to the land and describes the main mining activities generating impact on the land in various operating stages. It also provides information on land areas occupied and degraded by mining activities in Romania and the main associated risks. Chapter one is rather an introductory one that aims at problematizing and imposing specific research in order to ensure the stability of the mining works, monitoring of groundwater regime and ecological reconstruction of the affected areas.

The second chapter deals with the issue of mining works stability, especially stability of mining waste deposits, which store impressive volumes of material and whose sliding can endanger not only the natural and/or anthropic environment, but also the lives of people living in their area of influence. During my work as a researcher at the Technical Mining and Geology Department and, later, at the Management, Environmental Engineering and Geology Department, slope stability problem was one of the main lines of research that I've covered. The main contribution in this area concern, in particular, results of stability analyzes, their interpretation and establishing measures to prevent landslides. To have more evaluation opportunities, I have worked to implement unconventional methods of analyzing the technical condition of mining waste deposits (probabilistic methods and based on fuzzy logic), which provides additional information regarding the likelihood of various forms of instability. Starting from these premises, I have developed a specific methodology for assessing the environmental risk in the event of a landslide, developing a matrix on which there are established several categories of environmental vulnerability for different assumptions on the technical condition of analyzed waste deposits. I also conducted comparative analysis between the results for the same conditions (geometry, physical and mechanical characteristics) using different categories and types of stability analysis methods (classical methods, methods based on the theory of finite elements and differences). Another contribution in this area is the development of an Excel application (when the now existing specialized software were in a pioneering phase), which allows a rapid analysis of stability (for circular and polygonal sliding surfaces), application that has proved to be extremely useful both for research work and for teaching seminars.

The third chapter presents the results of research on the changes in groundwater hydrodynamic regime, for phreatic aquifers and captive aquifers (pressurized or unpressurised) as a result of the dewatering work. The analysis presented refers to the hydrogeology of Rosia de Jiu quarry, which operates under the protection of the most advanced dewatering system in Romania. Also, the research described in this chapter are directed towards the possibilities of limiting the negative effects of the dewatering of aquifer formations (lowering hydrostatic level, the occurrence of aridity phenomena inside the depression area, reducing groundwater resources, subsidence phenomena) on environmental and the possibility to use the water (from dewatering work) for different purposes. The main contributions in this area concern the development of a new hydrogeological classification of lignite deposits (used for the classification of the main quarries from Oltenia), studies on the effects of dewatering works on groundwater hydrostatic level variations, the infiltration mechanism of rainfall into mining waste deposits, solutions to reduce the impact on the environment and on restoration of the hydrostatic level in waste deposits.

Chapter four is dedicated to research regarding the necessity of using an integrated approach in ecological restoration activities of the lands affected by mining activities (waste dumps or former quarries). Contributions in this area concern the development of a holistic approach model for the rehabilitation of a mining basin in which several lignite quarries operates, done using MineSight software, during a research internship conducted at Bergakademie Freiberg, model on which I built an app for Rovinari mining basin

Also, in this chapter, is presented a model for the rehabilitation of the remaining hole of lignite quarries, developed for Urdari quarry, model that leads to the ecological reconstruction of adjacent areas, and, following the formation a lake in the remaining hole, accelerates the restoration of the hydrodynamic regime of groundwater. Because of the difficulties encountered in several projects regarding the optimal restoration type of lands affected by mining (determined strictly on the basis of several principles), I developed a methodology for the establishment of the optimal type of ecological reconstruction of degraded lands, which goes through several stages and take into account a series of indicators.

Part III of the habilitation thesis presents the career development plan and sets out the main directions of research that can be addressed in the future doctoral theses. In this part, there are also highlighted the objectives regarding the teaching and mentoring activities, and future dissemination of the research results.

PART 1

SUMMARY OF THE ACADEMIC AND SCIENTIFIC ACHIEVEMENTS

I defended my doctoral thesis entitled "Recovery of thin layers from the surface exploitation perimeters in Oltenia" in 1998, a period in which energy coal mining in Romania seemed to be rising. PhD thesis aimed to establish methods for exploiting thin layers of lignite quarries in Oltenia and optimize the application of these methods depending on the thickness and length of the work front. The justification for this subject was, on the one hand, finding solutions for rational exploitation and relatively full deposit of lignite, on the other hand, reducing the phenomena of dilution and losses generated by the bucket-wheel excavator, which has a limited degree of selectivity. Solutions for extracting highly selective proposed and developed in this thesis lead to its inclusion mining in an expanded concept of sustainable development through the rational exploitation and efficient use of reserves, but also to obtain a cleaner coal and to avoid storing coal in dumps where, after auto-ignition phenomena generate pollution and environmental impact.

Even before the doctoral thesis defense and obtaining the title of Doctor of Science in the field Mining, Oil and Gas, besides teaching and scientific activities in the mining domain, I began a series of documentation and training and conducted two research internships in environmental engineering.

1. Academic activity

I am a member of the academic staff of the University of Petrosani since 1990. I started as an assistant professor in the Department Mining Engineering and Geology. Gradually, according to the conditions and standards in force, I became lecturer (1996), associate professor (2001) and professor (2007). Currently, I am part of the Department of Management, Environmental Engineering and Geology.

In terms of teaching, I began by supporting seminars and laboratories at the disciplines Slope stability, Aquifers dewatering, Opencast mining.

I actively participated in the establishment of specialization Environmental Engineering in Mining, now named Environmental Engineering and Protection in the Industry. With the establishment of specialization in the field of environmental engineering, I worked on the development of new courses specific to this area, such as Recovery and reconstruction of degraded land, Human impact on the environment, Hydrology and hydrogeology, Artificial and natural slope stability. Training in this area began in a student, then continued by conducting internships documentation, training and research conducted in universities prestigious in Europe (BA-TU Freiberg - Internship training in the field of surface mining and environmental protection 1994 - 1995; Internship research ecological restoration land 2001; Politecnico di Torino - Internship documentation in environmental hydrology 1999; Ecole de Mines Nancy - Internship research mining stability in 2000).

Besides these subjects during teaching career I taught courses such as Fundamentals of engineering technology, Environmental and other types of risks, Mining hydrogeology, both for bachelor and master.

Since the beginning of the career of a teacher I had as a priority to build a relationship teacher - student based on a climate of communication and academic collaboration at the highest standards, but at the same time I tried, and mostly we managed to be close and to support all those students who have encountered problems professionally or personally. Over time, I have coordinated numerous papers and diploma projects for bachelor and master, many of which are listed in Note 10 to the committees of support. Some of these works were published together with graduates in different scientific journals.

I believe that the results of teaching activity at the University of Petrosani, are found both in terms of quality of graduates and in terms of books and manuals that support the courses that I teach. Thus, I produced 10 books as sole author or co-author, as follows:

✓ ***Books***

1. Dumitru Fodor, Ion Vulpe, **Maria Lazar –** Technical and technological rehabilitation of the lignite open pits. Publisher INFOMIN. Deva, 2003. ISBN 973-86131-4-0, 270 p.
2. Dumitru Fodor, Maria Lazăr, Emilia Dunca – Monography of departament of Mining Technique and Geology. Publisher INFOMIN. Deva, 2004. ISBN 973-86131-5-9, 176 p.
3. **Maria Lazar**, Ioan Dumitrescu - The human impact on the environment. Publisher Universitas. Petroşani, 2006. ISBN (10) 973-8260-87-6; ISBN (13) 978-973-8260-87-0, 310 p.
4. **Maria Lazar** – Rehabilitation of degraded land. Publisher Universitas. Petroşani, 2010. ISBN 978-973-741-161-7, 393 p.
5. Rotunjanu, I., **Maria Lazar** – Hydrology and mining hydrogeology. Publisher, Petroşani, 2014. ISBN 978-973-741-341-3, 442 p.

✓ ***Manuals***

1. **Maria Lazar** - Ecological Rehabilitation. Publisher Universitas. Petroşani, 2001. ISBN 973 - 8035-48-1, 206 p.
2. **Maria Lazar** - Surface Water Management. Publisher Universitas. Petroşani, 2001 ISBN 973-8035-49-X, 199 p.

✓ ***Laboratory guide/Applications***

1. **Maria Lazar**, Faur Florin - Identification and evaluation of environmental impact. Project guiede. Publisher Universitas. Petroşani, 2011. ISBN 978-973-741-236-2, 96 p.
2. Dumitru Fodor, Ioan Dumitrescu, **Maria Lazar**, Gabriela Dumbravă – Explanatory Dictionary for Science and Technology – Mining. Publisher AGIR, Bucureşti, 2012. ISBN 978-973-720-360-1, 246 p.
3. **Maria Lazar**, Florin Faur – Slope stability and shaping. Calculation examples. Publisher Universitas. Petroşani, 2015. ISBN 978-973-741-453-3, 206 p.

I also am the coordinator of the bachelor study program Engineering and Environmental Protection in Industry and master program Impact assessment and ecological reconstruction of environmental, programs that are conducted in the Faculty of Mining, for whose authorization and accreditation I had a significant contribution.

2. Research activity

Scientific research belongs to the field of mining and environmental engineering, and currently, the main areas addressed include human impact on the environment, stabilization, recovery and ecological restoration of degraded mining.

The result of research conducted throughout the academic career are detailed in the list of works and in the verifying sheet for the fulfillment of the minimum conditions for habilitation and can be summarized as follows:

- 15 scientific publications Thompson ISI - Web of Knowledge, including two in journals with impact factor (total impact factor 1.70);
- 58 scientific papers in journals of international databases (BDI);
- 59 scientific papers presented at international congresses and conferences or published in journals, which were not indexed BDI at the moment of publication;
- 5 international grants, for 2 having the quality of grant director;
- 16 national grants, for 2 having the quality of grant director;
- 26 projects from more research/consulting with economical operators, for 3 having the quality of project manager.

The two international grants that we have obtained through competition (one of them ongoing), as UP grant partner director, fall into the category of grants financed by the European Union and thematic concerns the modernization and greening the mining sector coal in Romania, respectively operating of bucket-wheel excavators under condition of excavation of sterile rocks with high cutting resistance.

National grants which I led as UP grant partner director, were won in partnership in the MENER program and covered topics such as drawing of the structural maps for technological rehabilitation in mining areas using the geographic information system and structural changes of the technical mining solutions to achieve the environmental protection requirements in areas of active mines and quarries.

The habilitation thesis relies on some of the results obtained in research, namely those related to the addressed theme, results which were used in a significant number of papers, published and presented in congresses, conferences, international and national symposia. The representative papers for the issue of the stability and rehabilitation affected of mining lands on which the thesis was based are:

- ✓ **Maria Lazar**, Izabela-Maria Nyari, Florin G. Faur - *Methodology For Assessing The Environmental Risk Due To Mining Waste Dumps Sliding - Case Study Of Jiu Valley.* Carpathian Journal of Earth and Environmental Sciences. Volume 10, 2015 - Number 3, 223-234 pp. Factor de impact: 0,63.
- ✓ **Maria Lazar** - *Using Possibilities Of The Groundwater From Dewatering Works Of Jiu Rosia Open Pit.* 15th International Multidisciplinary Scientific GeoConference SGEM 2015, www.sgem.org, SGEM2015 Conference Proceedings, ISBN 978-619-7105-36-0 / ISSN 1314-2704, June 18-24, 2015, Book3 Vol. 1, 721-728 pp.
- ✓ **Maria Lazăr,** Iosif Andraş - *Quick assessment method for the slope stability factor of waste deposit dams*. Proceedings of the 29th International Symposium on Computer Applications in the Mineral Industries, 2001, pp. 709-710.
- ✓ **Maria Lazar**, Florin Faur, Emilia Dunca, Daniela Ciolea - *Landslides occurred in Bujorascu Valley dump and stability improvement solutions - Environmental Engineering and Management Journal*, ISSN 1582-9596, Vol. 11, Nr.7/2012, 7, pp. 1361-1366. Factor de impact: 1,117.
- ✓ **Maria Lazăr**, Florin G. Faur, Emilia Dunca, Daniela-Ionela Ciolea - *Establishing The Optimal Type Of Ecological Restoration Of Degraded Lands*. Proceeding of the 7th Symposium SESAM 2015, INSEMEX Publishing House, ISSN 1843 – 6226. Vol. 1, 234-243 pp.
- ✓ Ilie Rotunjanu, **Maria Lazar** – *Hydrological classification and evaluation of coal deposits.* Mining Revue, Vol. 20, No. 2/2014. Published by University of Petrosani. ISSN-L 1220-2053/ISSN 2247-8590, pp. 7 -14.
- ✓ **Maria Lazar** – *Reaserch on geotechnical stability of sterile rocks dump Petrila* - International University of Resources. Scientific Report on Resourse Issues 2012, vol. 1, Part.1. Medienzentrum der TU Bergakademie Freiberg, ISSN 2190-555X, pp. 230-240.
- ✓ **Maria Lazar**, Florin Faur – *Cercetări privind posibilităţile de amenajare şi umplere cu apă a golului remanent al carierei Urdari* – Revista Minelor, ISSN 1220-2053, Vol. 18, Nr. 2/2012, pp. 18-23.
- ✓ **Maria Lazar**, Florin Faur - *Research on Rainfall Infiltration Regime into the Waste Dumps Body from Mining Basin Motru* - Proceedings of the International Conference on Environment and BioScience (ICEBS 2011). ISSN: 2010-4618, Egipt 2011, pag. 150 -156.
- ✓ **Maria Lazar** - *Stability Estimation For Waste Dumps From Jiu Valley Using Fuzzy Theory.* Proceeding of the 6th International Conference On Manufacturing Science And Education-MSE 2013- Sibiu-Romania, Ed. Universităţii Lucian Blaga, ISSN 1843-2522, pp. 359-362.

I note that the data used in habilitation thesis also comes from the results of research carried out under research contracts or by specialized experts who are found also in the list of published papers.

3 Visibility and impact of research

There are a number of criteria which shall be assessed the activity of teaching and research, including its assessment by students to whose training contribute, recognizing the value of scientific citing research results and/or the invitation to participate as a member of the scientific committees and/or reviewer of internationally recognized conferences and national scientific committees, participation as a reviewer for supporting doctoral theses etc.

Evaluation by students

According to the legislation, my teaching activity has undergone regular student assessment, who appreciated me, according to the evaluation criteria established as being a very good teacher. Moreover, at the end of each semester, students under request of anonymity, feedback and suggestions regarding course content and teaching methods, and the responses received confirms the results of the evaluations. I mention that many of the suggestions apply relevant on a range of issues that can be improved so that learning becomes more effective.

International and national visibility

In terms of visibility as a member of the academic staff of the University of Petrosani and as a scientist, I would like to mention, above all, cooperation in various fields with experts from international academic world (BA-TU Freiberg / Germany RWTH Aachen / Germany , Politecnico di Torino / Italy Ecole de Mines Nancy / France; Technical University of Crete / Greece national Technical University of Athens / Greece; University of Miskolc / Hungary etc.) and national (Technical University of Cluj-Napoca, Alba Univesiy December 1, 1918 Iulia Gheorghe Asachi Technical University of Iasi, Constantin Brancusi University of Tg. Jiu etc.).

I also want to point out cooperation with research institutes and businesses in the country and abroad, among which the National Institute of Research Development for Mining Security and Protection against Explosions INSEMEX Petrosani, Institute for Scientific Research, Technological Engineering and Design on Lignite Mine (ICSITPML) Craiova; National Research Institute for Metals and Radioactive Resources Bucharest; Poltegor Instytut Instytut Gornictwa / Poland; Oltenia Energy Complex, Hunedoara Energy Complex; Cuprumin Abrud; Wzkumny Ustav Pro Hnede Uhli AS / Czech Republic; Public Power Corporation AE / Greece; Instytut Techniki Gorniczej Komag / Poland; PGE Gornictwo I Konwencjonalna Energetyka SA / Poland; MAN TAKRAF Fördertechnik GmbH / Germany; Lausitzer- und Mitteldeutsche Bergbau-Verwaltungsgesellschaft mbH LMBV / Germany; WEQUA Wirtschaftsentwicklungs- und Qualifizierungsgesellschaft mbH / Germany; Vattenfall Europe AG / Sweden etc.

Citations

- ✓ Citations in ISI journals and publications: 4
- ✓ Citations in BDI journals and publications: 28
- ✓ Included in Marquis Who's Who in 2010

Member of the editorial staff or committees and reviewer of ISI scientific journals and scientific events:

- ✓ Member of the Program Committee of the International Symposium Continuous Surface Mining, Springer Verlag Aachen 2014. Proceedings indexed. Thompson Reuters ISI indexed.
- ✓ Reviewer Continuous Surface Mining International Symposium, Springer Verlag Aachen 2014 and ISI Proceedings indexed Thompson Reuters.

Member of the editorial staff or committees and reviewer of BDI scientific journals and scientific events:

- ✓ Conference Chairs - 2015 6th International Conference on Agriculture and Animal Science (ICAAS 2015). Ulrich's Periodicals Directory, Google Scholar, EBSCO, Engineering & Technology Digital Library, CrossRef and Electronic Journals Digital Library.
- ✓ Member of the program committee of BALKANMINE 2015.
- ✓ Reviewer for the Annals of the University of Petrosani - Mining Engineering- indexed in Ulrich's Periodicals Directory, ISSN 1454 - 9174 - EBSCO Publishing Inc .; Periodicals.ru; Suweco; Scipio, mines indexed magazine reviewer EBSCO Publishing Inc.

Member of the editorial staff or scientific committees for non-indexed national and international scientific journals:

- ✓ International Symposium Advisory Board Member of Continuous Surface Mining, Freiberg 2010.
- ✓ Member of the Scientific Committee of the XIII Balkan Mineral Processing Congress - Bucharest 14-17 June 2009.
- ✓ Chairman organizing committee and reviewer Continuous Surface Mining International Symposium, Petrosani, 2008.
- ✓ Reviewer 6th International Multidisciplinary Scientific Symposium Universitaria SIMPRO 10-11 October 2014, University of Petrosani.
- ✓ Organizing committee member of the National Student Symposium "GEOECOLOGIA".

Managerial experience

- ✓ Environmental Engineering and Geology Department Director 2011
- ✓ Management, Environmental Engineering and Geology department Deputy Director, 2012-2016.
- ✓ Member of the Council of the Faculty of Mines, University of Petrosani 2008 – 2015.

Member of professional associations

- ✓ Membru Ring Deutscher Bergingenieure – German
- ✓ General Association of Engineers in Romania - AGIR
- ✓ Society of Georesources and Environment (SoGeRem) - founding member.
- ✓ Scientific-technical platform ECOMINING - founding member.
- ✓ Jiu Valley Social Institute - founding member.

Among other activities, although they are not considered in the evaluation process to support habilitation thesis, but which I think are important in terms of recognition of academic and scientific prestige, I would like to mention the following:

- ✓ Member of the organizing committee of the Summer School "From Dredging to Deep-Sea Mining" Freiberg, 6 to 10 July 2015; the courses were attended by three students of the University of Petrosani;
- ✓ Member in over 70 committees supporting the scientific reports of the examinations and doctoral internships;
- ✓ Official scientific reviewer in committees for public defense of 12 doctoral theses.

PART II. TECHNICAL DESCRIPTION OF SCIENTIFIC CONTRIBUTIONS

CHAPTER 1

MINING EFFECTS ON THE LAND

1.1 The land and its functions

The land is a finite, fragile and non-renewable resource, that represents, on one hand, the available area for a particular use, and on the other hand, a particular form of presentation of the Earth's surface.

The land holistic concept has been already recognized in the Land Evaluation Framework Programme [B.59], repeated by default in Chapter 10 of the United Nations Conference on Environment and Development 1993, and officially described in FAO 1995, as follows: " *Land is a delineable area of the earth's terrestrial surface, encompassing all attributes of the biosphere immediately above or below this surface including those of the near-surface climate the soil and terrain forms, the surface hydrology (including shallow lakes, rivers, marshes, and swamps), the near-surface sedimentary layers and associated groundwater reserve, the plant and animal populations, the human settlement pattern and physical results of past and present human activity (terracing, water storage or drainage structures, roads, buildings, etc.)*".

According to this definition, land represents a broader concept than soil or surface crust. The variation of soils and/or of landforms is often the main cause of differences between the cartographic units in a particular area, because the studies on the soil represent sometimes the main basis for defining of the land cartographic units. However, the soils compatibility for land use can not be assessed isolated from other aspects of the environment.

"The land", "the land functions", "land assessment", "land quality", " sustainability ", "resistance" etc., are concepts that must be carefully defined, to avoid the confusions and to ensure an effective cooperation between national and international planning institutions dealing with assessing of the changes in land conditions. The most important functions of land are (figure 1.1):

- ✓ productive function - the land is the basis for many systems that sustain life by producing biomass that provides food, feed, fiber, fuel, wood and other biotic materials for human use, either directly or through livestock farming, including aquaculture;
- ✓ connection function - land provides space for transporting people and for wildlife movement between different areas of natural ecosystems;
- ✓ hydrological function – the land regulates the storage and the flow of water resources and influences their quality;
- ✓ biotic function - the land is the basis of terrestrial biodiversity by providing habitat, biological and genetic reserves for plants, animals and microorganisms, both underground and at surface;
- ✓ storage function - the land is a deposit of raw materials and minerals for human use.

Besides the main functions, the land fulfills and other functions, such as:

- ✓ function of waste and pollution control - receiving, filtering, transformation and storage of dangerous chemicals;
- ✓ function of human habitat - land provides the physical basis for human settlements, industrial plants and social activities such as sports and leisure;
- ✓ function of archive and heritage - land stores and protects the cultural and historic evidence of humanity, and is a source of information about the past, such as its previous climatic conditions and uses.

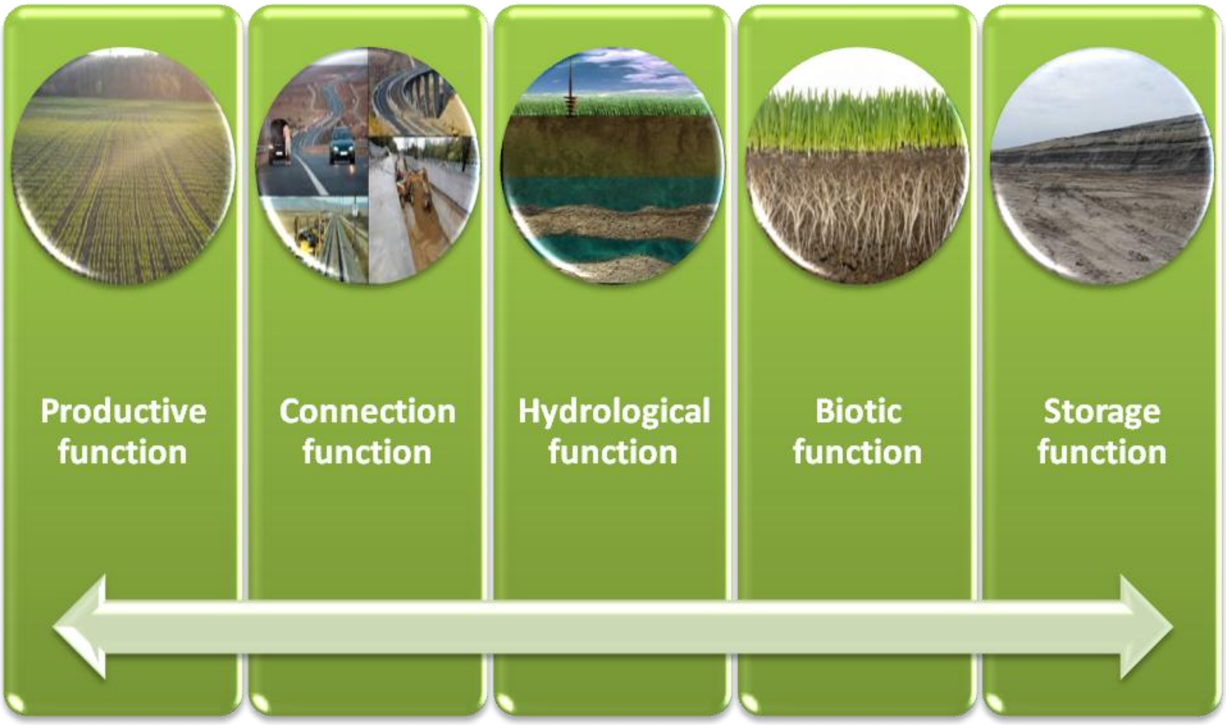


Figure 1.1 The main functions of the land

All these functions are interdependent and any modification of one of them feels on the others.

1.1 Mining impact on the land

The useful mineral substances are the base to any industrial activity and therefore premise for economic growth of any nation. Buildings, cars, boats, aircraft, glass, computers, are just some examples of needed items of everyday life, whose achievement is impossible without the raw materials from mining activities. Worldwide, mining delivers annual about 17 billion tons of raw materials, without taking into account building materials [B.39], needed to meet the needs of society, and the demand for raw materials will increase further in the coming decades as a result of increasing world's population and the rate of growth of the developing countries.

Extractive activity leads always to negative long-term effects on environment. The environmental factor that suffers the most serious degradations as a result of mining exploitation is the land and therefore, the entire ecosystem of the area.

The organizational phase of mining units requires the execution of specific activities (construction of access roads and communication roads with the existing ones, construction of work platforms, construction of buildings and sometimes changing natural drainage), each constituting disturbances, changes and fragmentations in the continuity of environmental elements.

Opening a mineral deposit constitutes an action with a destructive character, which corresponds to fertile soil and vegetation excavation, with possible repercussions on the local habitat and wildlife. This effect is particularly serious in the case of natural environments with a high value.

Extracting useful mineral with explosives causes air pollution by emissions of noise and dust, leading to major damages on vegetation in the surrounding areas. Extraction by mechanical equipment produces a sound pollution due to operation of equipment (noise permanently). Other problems may be caused by the extraction by dredging of alluvial materials, when may occur irreversible physical, chemical and biological deterioration of aquatic habitat, with negative consequences on upstream and downstream areas. Above all, transporting and processing the extracted materials causes noise and dust pollution, affecting vegetation and wildlife in the area. Discharging residual slam from preparation plants into natural water courses of is another activity responsible for the different mutations of the physico-chemical characteristics and of the river habitat.

Mining activities, as a whole, do not fall unrestricted into the context of sustainable development, but the sequence of mining operations, respectively exploration, preparation, exploitation, closure and ecological rehabilitation can be directed so that the environment, economy and local communities can meet net superior quality standards to those existing before the start of mining activity.

The works of opening a deposit, extraction of minerals, transport and storage are destructive actions, with repercussions on local fauna and habitat (figure 1.2). The effects are extremely serious in the case of the natural environment with high value, because are endangered ecosystems containing rare or protected species of flora and fauna. Other major issues are the need of the resident population displacement or deviation of water courses in the case of exploitation of useful minerals in open pits.

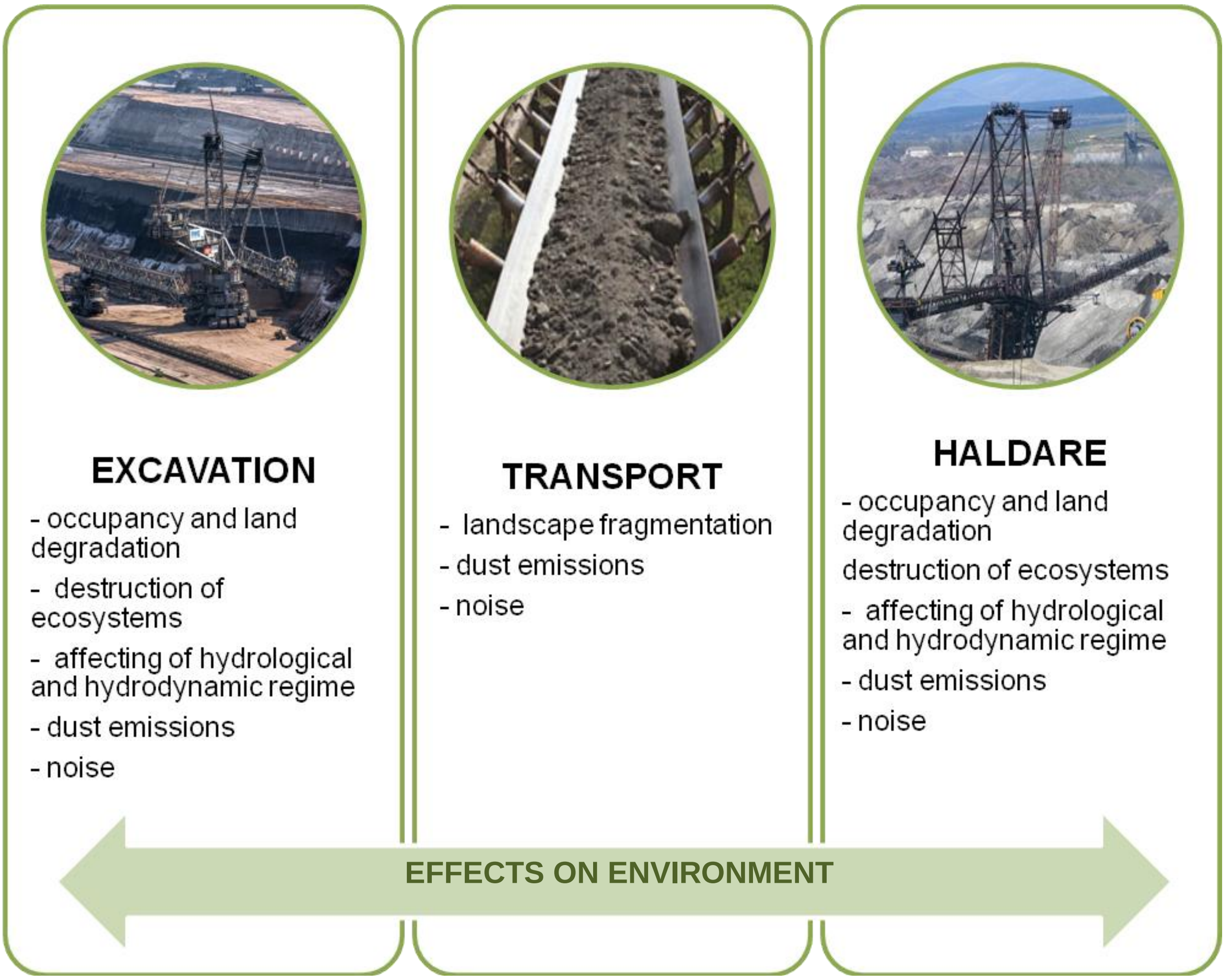


Figure 1.2 Effects of mining on the environment

Extractive activities, regardless of how it is performed, always lead to long term negative effects on the environment, the environmental factor most affected as a result of mining being the land, with all its components.

Table 1.1 presents the main potential impacts generated by mining (surface and underground mining) on the land and its components, and a range of measures that can help to reduce this impact [A.22].

Table 1.1 Potential impacts of mining on the environment

Environment factor	Open pit	Underground mine	Mitigation measures
Land, soil and subsoil	- Changing morphology as a result of development in depth of open pit and the emergence of rock dumps - Changing land use during mining activities - Damage to adjacent land use, as a result of changing the regime of surface water and groundwater - Acidification of soil in the surrounding areas in case of acid drainage	- Changing land use as a result of construction and infrastructure development - Changing morphology and hydrodynamic regime due subsidence - Damage to land use as a result of land degradation, water and subsoil - Draining waste water from underground affects soil	- Land planning in the mining areas and optimization of the land requirements for various uses - Planning environmental rehabilitation of affected areas and re-use post-mining land
Surface and groundwater	- Dewatering and depression of groundwater aquifers causes lowering of groundwater level on extended surfaces, reducing underground water resources, failures in water providing to human communities and vegetation, subsidence of land surface - Risk of acid drainage and pollution of surface water and groundwater with heavy metals - Increase the solid suspensions in surface waters	- Dewatering and depression of groundwater aquifers causes lowering of groundwater level on extended surfaces, reducing underground water resources, failures in water providing to human communities and vegetation, subsidence of land surface - Emergence breaches which may promote leakage in underground of waste water from surface and groundwater contamination - The pumped waste water from underground and discharged into the natural receptors can lead to phenomena of pollution	- Proper planning of mining activities and dewatering schemes, using three-dimensional models - Establish an appropriate management of water
Ecosystems	- Removal of flora and fauna from the mining perimeters - Damage of surface water and groundwater induce negative effects on aquatic ecosystems - The dust emitted into the atmosphere is deposited on the vegetation of adjacent areas, and slow their development - Noise and vibration affecting animals and birds from the forests in the area of influence - Reduce groundwater resources affects natural plants and crop of the neighborhood	- The extinction of vegetation and fauna of the areas occupied by buildings and infrastructure - Reduce groundwater resources affects natural plants and the crop of the neighborhood - Reduce the capability of fertile soil from areas affected by subsidence phenomena - Discharge of polluted water from underground in natural receptors can generate problems of aquatic ecosystem	- Mining planning must to consider removal from forest circuit of the lower surfaces, and after mining closure to provide for recovery of forestry land; - Planting of adequate compensation forests; - Creating a "bank" of flora in order to preserve species and their subsequent reuse; - Reducing the intensity of noise and vibration, so as to affect to a lesser extent the fauna of adjacent areas

Human factor	- Displacement of localities, for the purposes of preparing, opening and exploitation of useful mineral deposits, cause changes in lifestyle of the population, loss of traditions etc.. - Changes in population dynamics: management and qualified labor force most often is not available in the local population, which requires to select them from other areas. Thus, the population dynamics of the area suffers a major change, resulting in the time the dilution of point of view ethnic, cultural and religious. With the closure of mining activity, the population is decreasing very fast. - Cost of life: communities dependent on agriculture and forestry have in general a lower standard of living. Developing industrial activities generates higher revenue and lead to increased purchasing power of the involved people. As a result, the cost of life increases, which reflect negatively on the population not involved in industrial projects. - Reduction of water resources: As the open pit, and the underground mine involve dewatering of aquifers formation, resulting in lowering of groundwater levels, especially in phreatic groundwater aquifer, resulting in failures in water supplies of local communities. - Impact on health: Health and welfare of the population from mining areas may be affected by air, soil and water pollution, noise and vibration. Population engaged in mining may suffer various professional illnesses such as diseases of the skin, lungs and respiratory. - Infrastructure facilities: Mining activities and associated activities favors the development of infrastructure elements (roads, schools, hospitals, utility corridors, etc.), which improves quality of life in the area. - Creating jobs: Mining and related activities provide employment opportunities for local people, providing training courses for this purpose.

Transforming the impact into degradation depends on several factors, including:

- ✓ characteristics and dimensions of the mining operation;
- ✓ exploitation technologies and methods (extraction with mechanical equipment or using explosives);
- ✓ the natural characteristics of the region (the extreme cases are represented by areas with high natural value, on the one hand, or areas already compromised on the other side).

To establish the interventions needed to reduce the impact of mining activities on soil and subsoil, geotechnical and geomechanical researches that underline the project of exploitation, ecological rehabilitation and open pit related work should be run. Such studies should lead, first of all, to knowledge gathering about the hydrogeological and morphological situation and the rocks resistance characteristics.

Generally, it is important that the exploitation and rehabilitation operations to be carry out following well established project, based on actual knowledge of the environment of the territory where working.

The exploitation and surrounding areas should be studied in details, in terms of flora, fauna and ecosystems, by using work tools such as:

- ✓ census of plant and animal species, with any evidence of rare or unique populations;
- ✓ studies of any "weaknesses" of the community, the adaptability of different species;
- ✓ ecosystem characterization by describing the principal climatic factors (rainfall, temperature, wind, humidity), the soil components in relation to morphology, geology, water cycle;
- ✓ highlighting the relationship between soil, vegetation, fauna and the causes that lead to ecosystem degradation and determining the possibility of autonomous recovery in time.

Using the obtained information, the following measures can be taken:

- ✓ optimization for mining units location, according to the needs of protecting the surface of areas with rare or unique biota;
- ✓ establish mining perimeter dimensions not only in terms of mineral deposit extending, but also in terms of ecosystem endurance capacity;
- ✓ selecting exploitation methods and techniques so as to facilitate operations of improve and ecological rehabilitation of degraded lands (wherever possible, the two activities should to be carried out simultaneously);
- ✓ draft a real rehabilitation project of area (naturalist, agricultural or forestry reclamation);

- ✓ establish protective measures against surface water and groundwater pollution, and measures to protect groundwater resources;
- ✓ establish measures to protect the surrounding areas against dust dispersion and propagation of noises and vibrations;
- ✓ reduce waste production and test them if re-usable.

Recovery and ecological restoration of degraded lands by mining activity is a obvious necessity, requested both by the industry, and by administration and the legislation, but above all by the inhabitants of those areas.

1.3 The impact of the Romanian mining industry on the land areas

Romania's mining sector occupies and degrades large tracts of land, necessary for mining perimeters, mining facilities, access roads, waste dumps, tailings ponds, etc. Depending on the location of the mines, significant land areas were removed from agricultural, forestry or for other uses and were degraded.

2.2.1 Land occupation

✓ *Coal extraction*

Coal mining in Romania occupies significant land areas, especially when it comes to the lignite opencast mines from Oltenia region, land that was removed from economic, natural and / or residential cycle. On the land areas taken into use by mining operators are located pits, waste dumps, tailings ponds, processing plants, facilities, and transport infrastructure. In summary, the coal mining sector occupies about 23500 ha of land, of which 9655.7 ha mining facilities, 2314.7 ha buildings, 7829.5 ha opencast mines. As a result of coal mining activity they were built 137 waste dumps and 6 tailings ponds, which store a total volume of 2000 million m^3 of waste rock and occupies an area of over 3600 ha [A.15], [B.22].

So far, due to the opening and expansion of lignite opencast mines they were displaced 2200 private households, 40 social and cultural buildings, 5 churches and 6 cemeteries. On exhausting reserves of lignite coalfields of Oltenia, it is expected to be affected by mining 56 cities, including 14 in their entirety.

So far, due to the coal mining in Oltenia, from the total 17000 hectares occupied were given back to the agricultural and forestry sector about 2000 ha, and the rest will be rehabilitated and given back to the economical entities in the more or less close future.

✓ *The extraction of ores and non-metallic substances*

The exploitation of mineral deposits and non-metallic substances in Romania occupies an area of over 8200 hectares. Part of this area (about 46%) is for carrying out production activities and the remainder, amounting to 54% is for construction of waste dumps and tailings ponds [B.21], [B.22]. Mining companies dealing with extraction of these types of useful minerals had to administer 577 waste dumps with a volume of rocks contained of about 200 million m^3, occupying a total area of 813 ha, and after processing the extracted ore were built 65 tailings ponds, which occupies an area of about 1350 hectares and stores over 360 million m^3 of waste rocks.

Part of the waste rock deposits released from technological tasks were rehabilitated and given back into the economic or natural cycle, but most are in conservation status, because the ecological rehabilitation works involves very high costs.

1.3.2 Sliding of waste dumps

Mining, regardless of how it is performing (surface or underground) leads to the formation of waste dumps and tailings ponds, which store different volumes of material from several thousand cubic meters up to several hundred million cubic meters. Stability problems that arise from waste dumps comprise phenomena of superficial and deep landslides, discharge phenomena of the embankments and base land and sometimes even plastic disposals and flow phenomena. Such landslides could occur during all phases of existence of these important engineering works, namely during construction, immediately after abandonment, or after a relatively long period from their release from technological tasks.

Since the sliding of a pile may involve a dangerous motion of some important material masses, which leads to damage of both the natural environment and the man-made environment, it is imperative to analyze the technical condition of their regularly and whenever necessary, and identifying the measures to prevent slides and / or to combat the effects of large-scale landslides.

In terms of stability of the waste dumps in Oltenia, it has been compromised in many cases, but landslides that have moved large volumes of sterile, of millions of cubic meters, and affected the natural and man-made environment after 1990. Landslides were recorded at the outside waste rock pile from opencast mine Rosia de Jiu (1995), outside waste rock pile Ştiucani (1992 and 2001), outside waste rock pile Valea Mănăstirii (2000), outside waste rock pile Valea Rogoazelor (2001, 2004 and 2006), outside waste rock pile Valea Negomir (2001) outside waste rock pile Bujorăscu Mic (2007).

Most waste dumps in the Jiu Valley suffered deformations, from superficial erosion to deep landslides, also affecting the base land through discharge phenomena, but the effects on adjacent areas were at much smaller dimensions than the waste dumps of Oltenia.

Many of the waste dumps of the mineral and non-metal substances mines shows risk of sliding, these are being kept under observation, and regarding the tailings ponds, it can be mentioned here the landslide from the tailings pond of the mine Certej - Săcărâmb (1971), slide what resulted in about a hundred victims, and the failure of tailings pond SC Aurul Baia Mare (2000), which led to serious pollution of the river system, affecting several river basins in Romania and Hungary.

1.3.3 Mining subsidence phenomena

Another negative impact of mining activity on the land is the fracturing and subsidence of the land surface with variable amounts that can reach tens of meters, due to underground mining of thick deposits and pressure directing by total collapse of the overburden. The most spectacular phenomena of subsidence is recorded at EM Deva, EM Ghelar, EM Baia de Aries, EM Moldova Noua and in the Jiu Valley, where, because of the mining methods applied in underground, subsidence troughs and huge funnels were created, with volumes of hundreds and even thousands of cubic meters [B.22]. It is interesting to note the phenomenon occurred in saline Ocnele Mari, where, as a result of hydraulically union of 6 wells, it has been formed an underground empty space of a considerable size, with an area of approx. 10 ha and a volume of over 4 million m^3. Because of this underground empty space, the land surface began to collapse, displacing and spilling into valleys and watercourses in the area large quantities of brine, thus creating a major impact on terrestrial and aquatic ecosystems.

From the aforesaid, it follows that mining generates a significant impact on land through occupation and degradation, and the major risk of sliding of the waste dumps and tailings ponds.

Given that land suffer various forms of degradation at national and international level, making it unusable for other purposes, the stabilization, recovery and ecological reconstruction of mining land that is released from its technological use is an effective tool to give mining a chance to become a sustainable activity and a real engine of sustainable economic development of the areas in which it is conducted.

CHAPTER 2

STABILITY OF WASTE DUMPS

The stability problem of waste dumps is more difficult than that of slope work and natural slopes because the instability occurs right from the building phase, as a result of laying down a mixture of rocks in loose form, often with higher humidity than the material found in undisturbed condition. By excavation, the cohesion is destroyed and as a result, physical and mechanical parameters of the mixture are different from those of the rocks "in situ". Examples of phenomena of lack of stability caused by improper works on waste dumps can be:

- ✓ slope instability due to incorrect sizing or nonobservance of the geometrical elements (excessive tilt and height in relation to the physico-mechanical properties of rocks);
- ✓ waste rock pile instability due to the incorrect geometrical configuration or excessive accumulation of waste rock material, resulting in a too high tilt;
- ✓ unstable land on which the pile is built, due to exceeding the loading capacity etc.

Even from the construction phase, waste dumps are an overload of land, which contributes substantially to the degradation both in terms of aesthetics of the landscape and the increasing environmental pollution. Moreover, waste dumps may be, if placed or built incorrectly, a real danger for the area as a result of deformation and slide risks [B.42].

Developing a mine in a region leads to significant changes in morphological appearance, causing stability problems can have serious consequences on the natural and man-made environment in the influence region. When operating a opencast mine, the stability problems are made worse by the presence of residual empty spaces representing negative landforms, occurring after depletion of useful minerals and termination of exploitation works (figure 2.1).

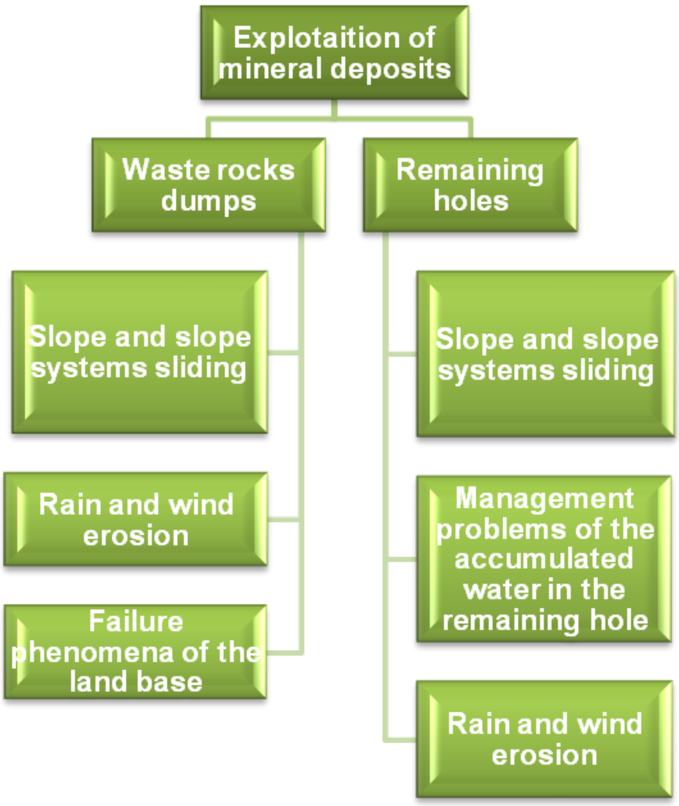


Figure 2.1 Morphological changes and stability problems generated by the operation of an open pit

Ensuring the stability of waste dumps and tailings ponds is one of the most important issues in mining, both in terms of technology and environmental protection, since any slide can have serious consequences. The problems that occur in design of waste dumps and tailings ponds varies by stored material characteristics, site characteristics and way to fill the material, the volume of waste material to be stored, i.e. height and extension. Control of deposits under construction or in conservation, is necessary right from the design phase to provide a series of measures to control periodically the stability of the pile or pond and of the surrounding areas and carrying out geotechnical studies on the rocks in the ground and on rocks and substances that are stored.

Because many waste facilities (piles and ponds) were damaged, leading to disaster of large proportions that affected large territories, it is absolutely necessary to conduct a large number of field and laboratory studies serving on monitoring their technical state [A.1]. In order to protect the natural and man-made environment of the area of influence of the piles, there are necessary field studies that reveal the items shown in figure 2.2:

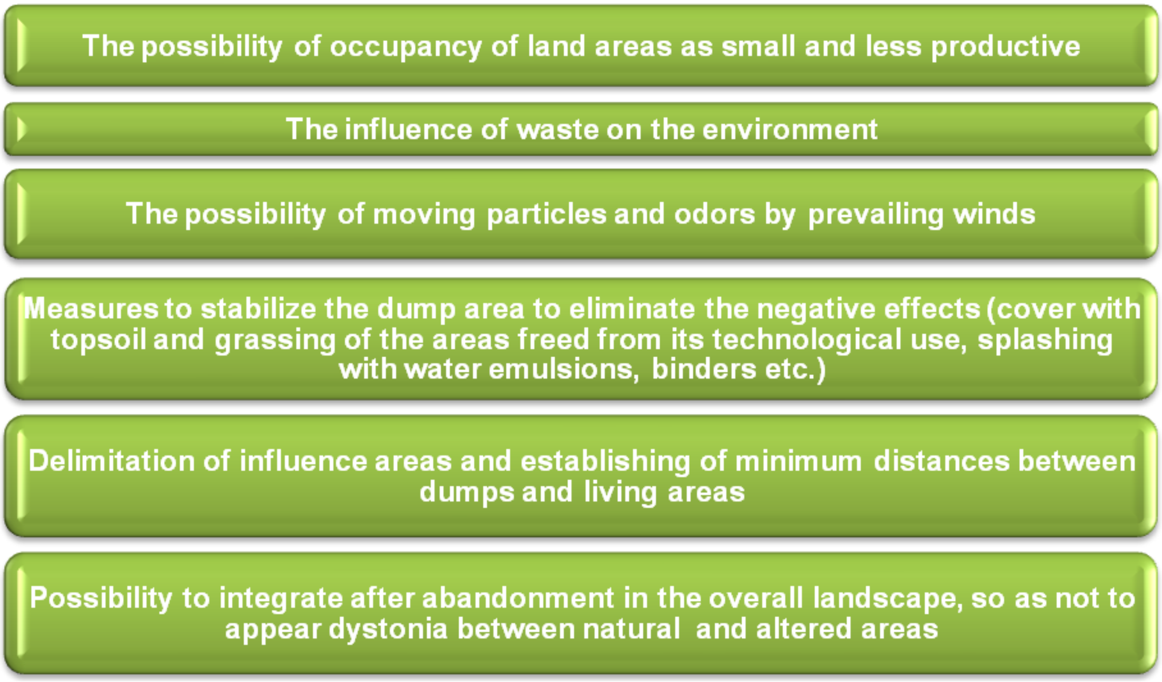


Figure 2.2 Necessary studies for environmental protection

2.1 Principles for assessing the stability of waste dumps and tailings ponds

2.1.1 Analysis methodology

Stability analyzes are based on the assumption that a slope loses its equilibrium conditions when the shear strength on any possible slide surface is exceeded by the resultant shear forces exerted on that surface by the masses of material located above it.

The surface that is most likely to occur sliding is called critical or potential slide surface. Highlighting such surfaces is quite simple when geological conditions permit defining of movement on the basis of obvious stratigraphic or structure discontinuities. When sliding phenomenon occurs in a homogeneous formation and unaffected by discontinuities, any surface within the slope can meet critical slide surface conditions [B.42].

To guarantee the stability conditions of a slope, there must be a force of resistance whose value to offset the active force. The force of resistance includes total cohesion on critical slide surface, the resultant of normal pressure on the sliding surface and friction that it can develop. It is obvious that in analyzing the stability of a slope should take into account the lowest values of shear strength of rocks, in order to obtain a covering quantitative assessment of the stability, but this is detrimental to the economic aspects and for this reason, the stability analysis must take into account the importance of the work, the social danger that it has, the environmental effects etc.

The main objectives of stability analyzes are presented in figure 2.3.

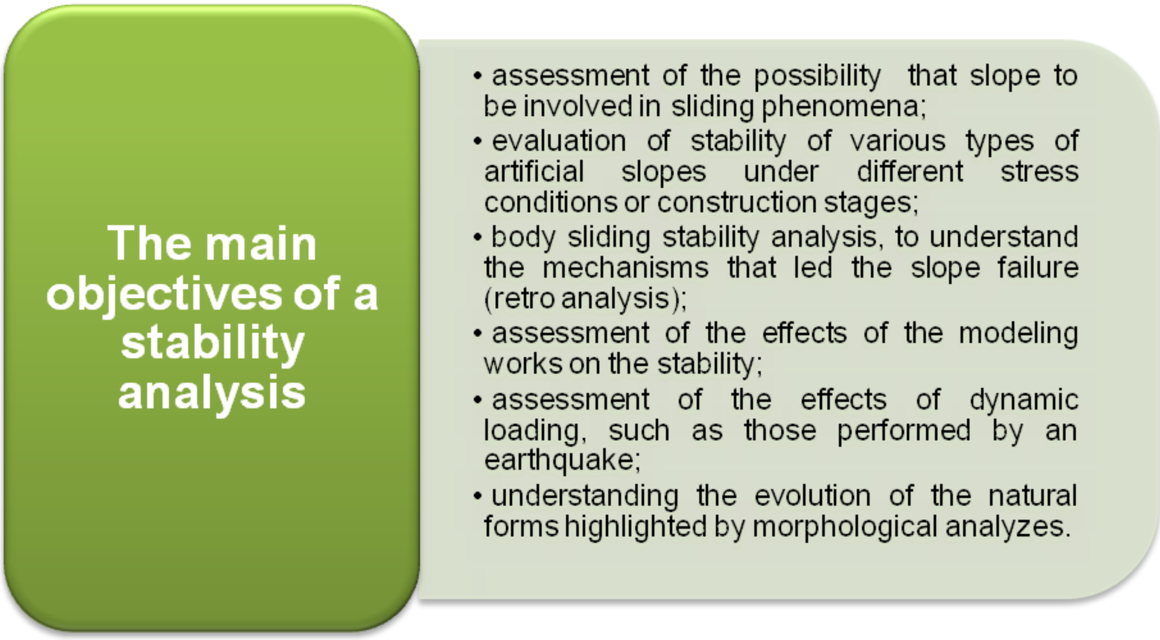


Figure 2.3 Stability analyses objectives

Slope stability analysis methods are grouped into two categories:

- ✓ methods that take into account the limit equilibrium state in a given area of detachment from the massif. In this case, the sliding part is considered rigid, and the interaction between it and the rest of the massif is carried out by means of the forces that occur on the sliding surface. In most cases, it is considered that slopes slid on a cilindrico-circular surface, but it must be taken into account specific cases that relate to pre-existing sliding surfaces, such as areas of weakness.
- ✓ methods not entailing a sliding surface and taking into account the state of efforts and deformations of the massif and its interaction with rocks resistance. Such methods can model the behavior of the massif of rocks and can highlight, if necessary, dangerous areas where plastic failure processes can begin.

The most used method for analyzing slope stability are methods that take into account the limit equilibrium state on a sliding surface and they have a long period of application and verification in practice. Depending on how they consider the sliding mass, these methods can be grouped as follows:

- ✓ methods that considers the sliding mass as a whole (plane sliding surfaces methods, friction circle method, logarithmic spiral method);
- ✓ methods that supports dividing the sliding mass in vertical strips, which allows consideration of various geometries and complex application conditions (Fellenius's methods, Maslov-Berer, Janbu, Bishop, etc.)

Analytical methods based on the limit equilibrium state assume the verification of conditions for the stability of the masses that constitutes a slope, in particular for the equilibrium of forces and moments. Methods based on similar criteria broadly provide modeling of the analyzed slope, defining the state of charge and adopting a breaking criterion. Consequently, these analyzes depend on the type of the adopted model and on the assigned physical-mechanical properties of the materials.

Landslides may occur by different mechanisms and may be characterized by a well defined sliding surface (flat, cilindrico-circular, polygonal or compound) on that can be achieved an analysis by the method of limit equilibrium.

2.1.2 Prior studies to stability analysis

After geological, morphological and geotechnical surveys and after analyzing the stratigraphic, structural and geomorphological local situation, it should be checked the assumptions made and it should be collected other indispensable information that can be obtained only after a suitable series of directly and indirectly type of research that can be associated with an automatic control system of variations of key parameters, such as relative movements of the control points, oscillation of aquifer structures and borehole or watercourses rates.

To the direct research on the land (topography) and in depth (mechanical drilling) and indirect research (geophysical methods) are associated "in situ" research (penetrometer, piezometric, inclinometer and extensometer measurements etc.) and geotechnical laboratory analysis of undisturbed samples taken during mechanical drilling, to define the physical and mechanical parameters that characterize the surrounding rock and slipped material.

Knowing the underground conditions must be based on the final results of research using appropriate means to this end. As an indication, in figure 2.4 is proposing major research facilities for the general knowledge of the underground

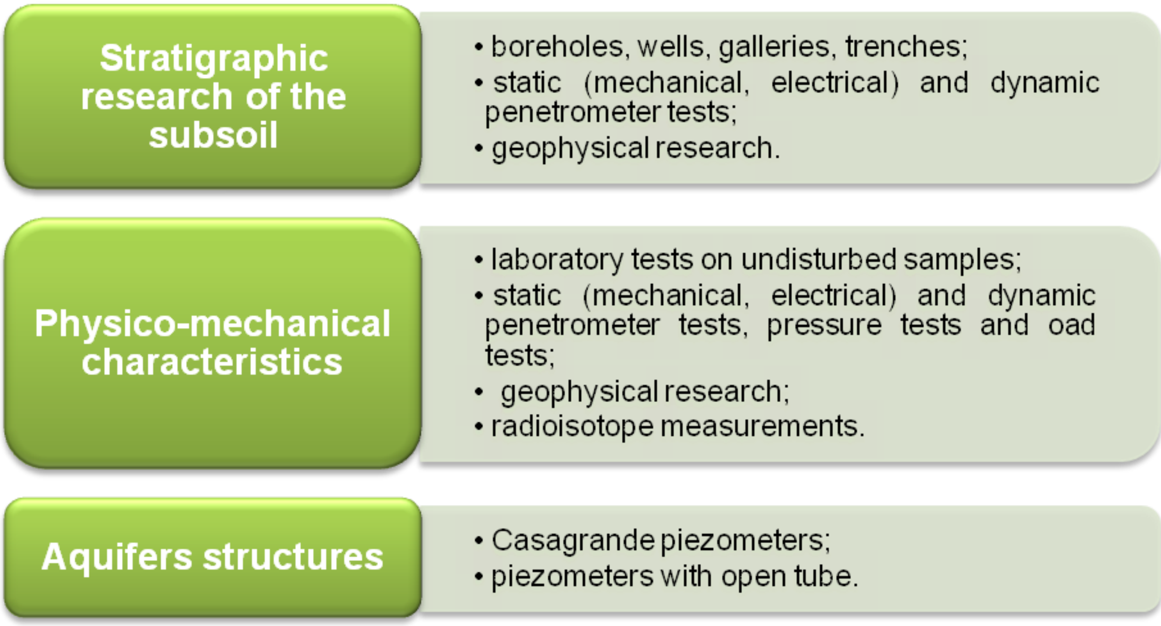


Figure 2.4 Subsoil investigation tools

For the case of slope and hillside sliding it is necessary to know the geometry of the moving mass, the sliding surface position and the relative conditions of the material in motion and of the surrounding area [A.1].

After clear establishing of the geological and geomorphological aspects of the study area and after defining the geometry of the slope and the sliding area, it can be continued with analyzing the data determined "in situ" and in laboratory, in order to reach a geotechnical characterization of the materials involved in the sliding phenomenon. These analyzes are needed to determine kinematics, weight, cohesion, internal friction angle, the effect of groundwater, lithostatic pressures, deformations and the sliding surface of the sliding materials and the surrounding rocks.

These items, correlated in geological terms (qualitative) and rock and soils mechanics (quantitative) permits to define the significant parameters and the way by which occurred the natural equilibrium disturbing, causing the phenomenon of sliding. Must be taken into account that usually the research is conducted after the sliding occurs and that in these circumstances, the resistance values at the onset of sliding can not be determined directly, they are deducted. In general, ulterior verification is required, considering the stability factor equal to unity and thereby determining the average values of resistance along the sliding surface to assess the present and future conditions of stability of slopes.

Quantitative estimation regarding extremely complex natural phenomena, given the causes and ways of occurrence, involving natural materials with extremely varied mechanical behavior in space and time, can not be absolute. Moreover, it is generally recognized the difficulty of reducing complex natural situations to simple models claimed by analytical treatment.

Based on these considerations, the program of "in situ" research and in laboratory can be realized on undisturbed samples, taken during mechanical drilling or on reconstituted samples, for accurate definition of natural conditions and quantitative characterization of the necessary parameters in analytical assessment. Broadly, laboratory samples aim to determine some properties such as grain size, limits and indications of consistency, specific gravity, volumetric density, porosity, natural moisture and degree of saturation, while for the knowledge of mechanical characteristics or hydraulic behavior it can be performed the following tests: monoaxial compression, shear strength in drained and undrained state, deformability, consolidation, permeability.

Choosing the type of samples depends on the characteristics of the analyzed materials and research purposes. "In situ" samples refers to the static and dynamic penetrometry, dilatometry, seismometry, overload, permeability and lead to the definition of the strength, relative density, the internal friction angle, cohesion in undrained state, the coefficient of permeability, the seismic wave velocity, degree of fracturing and alteration, modulus of elasticity etc.

To analyze the slope stability we must consider the following factors:

- ✓ geology, stratigraphy and tectonic in particular;
- ✓ geotechnical characteristics of the rocks;
- ✓ hydrogeology;
- ✓ overloads presence near the slopes;
- ✓ geometric parameters (height and tilt of the slope).

For the artificial slopes, their geometry is determined by the stability reserve that is required depending on the size, extent and duration of their stay in place. If a slope is steep, it is possible to trigger the slides, which can be produced, mainly as follows:

- ✓ sliding on imposed surfaces (most often sliding occurs through rotation, and the surfaces are circular) that affect only the slope or both slope and base land;
- ✓ sliding on pre-existing surfaces, when sliding occurs the most often through translation.

In the first case, the sliding surface is formed in areas where the rock strength is minimal, and in the second case, the reduced strength of the rock is due to the geological structure (contact surface between the layers, sedimentation discontinuities, faults, contact surfaces between the piles and base land etc.).

2.2 Research on dumps stability using classical methods

The classical methods for stability analysis accept a circular sliding surface, and the sliding prism is divided into vertical strips. Slope stability is analyzed assuming limit equilibrium between active and passive forces (figure 2.5), and finally the position of the critical slip surface, to which corresponds the minimum value of the stability factor, is determined.

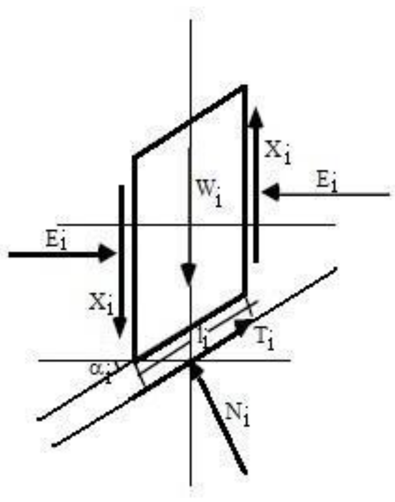


Figure 2.5 Forces acting on a slice

Numerical solution of the stability factor is given after Fellenius [B.17] assuming that the forces which occur at the boundary between tow strips (E_i and X_i) are null, by the expression:

$$F_s = \frac{\sum_1^n c \cdot l_i + \sum_1^n W_i \cdot \cos\alpha_i \cdot tg\varphi}{\sum_1^n W_i \cdot \sin\alpha_i} \tag{2.1}$$

Janbu's simplified method [B.32] takes into account the shearing forces and uses a correction coefficient that depends on the type of rocks. The stability factor is given by the relation:

$$F_s = \frac{\sum_1^n c_i \cdot b_i + \left(\frac{N_i}{\cos\alpha_i - u_i \cdot b_i}\right) tg\varphi_i}{\sum_1^n W_i \cdot tg\alpha_i} \tag{2.2}$$

where N_i is given by:

$$N_i = \frac{\left(W_i - \frac{c_i \cdot l_i \cdot \sin\alpha_i}{F} + \frac{u_i \cdot l_i \cdot tg\varphi \cdot \sin\alpha_i}{F}\right)}{m} \tag{2.3}$$

where:

$$m = \cos\alpha + \frac{\sin\alpha \cdot tg\varphi}{F} \tag{2.4}$$

Bishop's method [B.5, B.6] neglects the shear forces between the strips and considers an arbitrary position for the resultants of the normal forces. This method is particularly recommended for circular slip surfaces. The stability factor is given by the relation:

$$F_s = \frac{\sum_1^n \frac{c_i \cdot b_i + \left(\frac{N_i}{\cos\alpha_i} - u_i \cdot b_i\right) tg\theta_i}{m}}{\sum_1^n W_i \cdot \sin\alpha_i} \tag{2.5}$$

where m is determined by:

$$m = \left(1 + \frac{tg\varphi_i \cdot tg\alpha_i}{F}\right)\cos\alpha_i \tag{2.6}$$

For Janbu and Bishop methods [B.5], [B.6],[B.32], the equations are solved by successive approximations, starting from an initial value for F and iterations until the calculated value coincides with the initial one. Signification of notations in formulas:

W_i – strip's weight;
N_i – normal component of the force of gravity;
T_i – tangential component of the force of gravity;
E_i – horizontal forces transmitted to neighboring strips;
X_i – vertical forces between neighboring strips;
n – number of considered strips;
b_i – strip width;
c_i – rock's cohesion along the strip;
φ_i – angle of internal friction;
α_i – inclination of the strip;

u_i – neutral pressure along the strip; l_i – length of the strip.

Although Fellenius method neglects the forces that occur between the strips, is the simplest method of determining the stability factor. This method leads to reduced values for the stability coefficient and is not recommended for slopes with small inclination and high water pressure. Bishop's method is applicable only for circular sliding surfaces and satisfies the overall conditions for vertical equilibrium of force moments. Janbu's method is based on the balance of forces, is more flexible, and leads to lower values for the stability coefficient than those calculated with Bishop's method [B.1].

2.2.1 Rogoazelor Valley waste dump – Roşiuţa open pit

The rocks dump Rogoazelor Valley is located north of Roşiuta open pit, in the valley of the same name. It was put into service in 1985, access to dump being provided by 67 Tg DN. Jiu - Drobeta Tr Severin. The dump occupies the superior area of the valley, which mostly was covered with forests, which has ensured a high degree of stability. Subsequently, the clearing of forests caused the reduction of the stability of slopes. Morphological, Rogoazelor Valley is a broad valley which collects more creeks (figure 2.6).

From start of rocks storage until the standstill of the activities, occurred more geo-mining negative phenomena, of which mentions the three sliding which set in motion important volumes of rocks, produced in the years 2001, 2004 and 2006 (figure 2.7) [A.10], [A.13].

The dump operated until 2006, when it was affected by a major landslide and the depositing activity was stopped. Between 1985 and 2006, in this dump were stored approx. 51 million m^3, in 6 - 8 steps with a total height of 120 meters and a slope angles between 4 - 8°.

The landslide from 2001 occurred along the main valley, over a length of approx. 1000 m, affecting a surface of 26 hectares. The causes of this landslide are related to the presence of water in the dumps body, being identified as ways of penetration of water into the dump the twinning areas of the dump with natural slopes, springs from the dump foundation and water accumulations in uneven areas after significant rainfall.

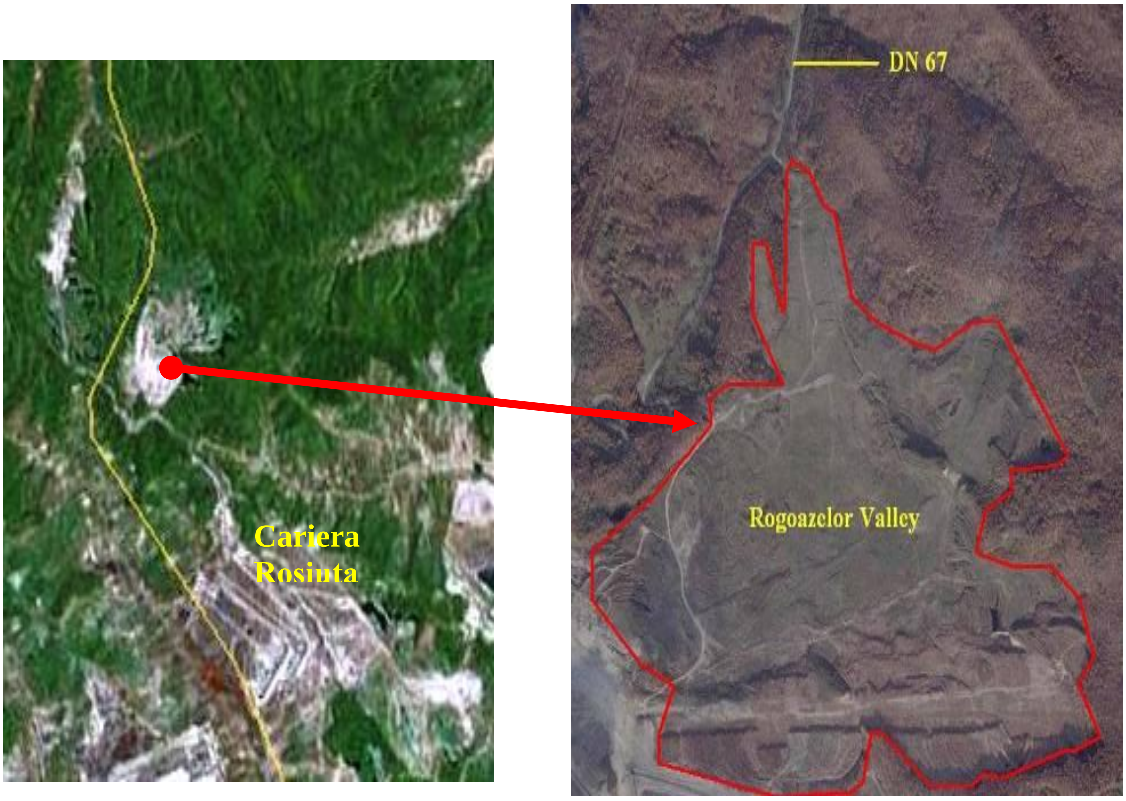


Figure 2.6 Location of Rogoazelor Valley dump

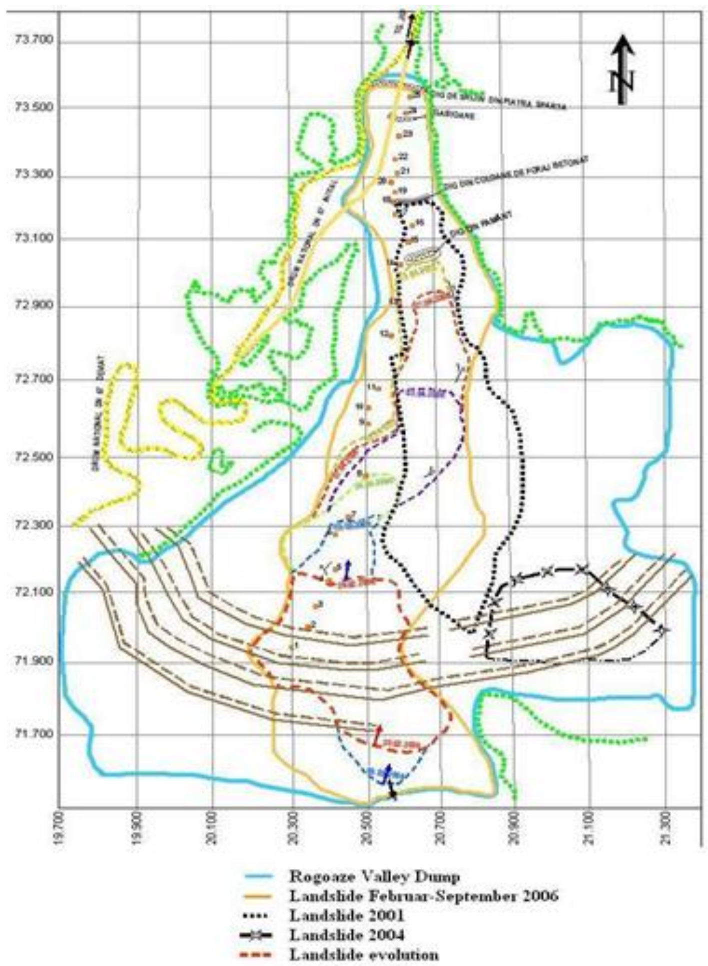


Figure 2.7 Landslides affecting Rogoazelor Valley dump – Roşiuţa open pit

As measures taken to reduce the effect of water on stability, are mentioned: that execution of contour channels for isolating the final surface of the dump from surface water inflow; works for handling and transfer of surface water from upstream areas towards downstream areas of the dump; water drainage works on provisional and final surfaces of the waste dump, and works to lower the piezometric level into the dumps body (horizontal drains and drainage wells); scarifying works to achieve cooperation between the deposited material and the base terrain; leveling and compacting works for the steps, slopes and final surfaces.

After this landslide, in the dump Rogoazelor Valley continued rocks storage, executing in parallel works to improve the conditions of stability. consolidation of the area at the foot of the dump by running a spur of land and a support wall made of cased columns of 508 mm diameter, 17 m long, 3 m represent column stretching from the ground surface; six boreholes will be executed hydro observation to monitor water levels in the dumps body and its evacuation by pumping; systematic leveling of depositions and compliance with designed geometric elements.

The landslide from May 2004 had a less magnitude than in 2001, affecting approx. 9.5 ha from the dump area. The effects of this sliding were eliminated through the leveling and planning with classic machines. Simultaneously, continued works to ensure the dump stability and have been executed since 6 drillings for water level observation. Until the next landslide, deformations that could indicate instability phenomena were not observed (fissures, cracks, subsidence or displacement of drilling).

The landslide from February 2006 occurred under conditions of abundant and long-term rainfall (maximum values 56 mm in 24 h). As a result, occurred a major landslide, affecting an area of 17.6 ha (figure 2.7). Immediately after the landslide, tried to stop its development trough interventions with classic machines, but heavy rainfall did not allow the necessary works, so that the water from rainfall infiltrated into dump, sliding speed reaching some tens of meters per day, in the direction of valley axis. The rocks dump movement continued until April, when it was reactivated and the landslide from September 2001, and at the beginning of May was exceeded the support wall from basis of the dump, and has been destroyed and blocked road DN67.

The landslide was extended to approx. 600 m wide and 2,200 m long, and the area affected reached approximately 75 hectares. Given the volume of involved material, of the difference between break and failure quota, of appearance and position of break surface, it is assumed that the failure surface affected the dumps background too. This large landslide led to the suspension of depositing works in the dump.

2.2.1.1 Characterization of stored material

The structure of rocks from dumps is dependent on the structure of geological formations of the overburden [A.10], [A.13]. The weight of the different geological formation in the overburden is as follows:

- very cohesive rocks (loam and shale) – 10.4%;
- cohesive rocks (clay) – 69.4%;
- less cohesive rocks (clay and dust, clay and sand) – 20.2%.

In most cases it is a non-homogenous mixture of rocks and this heterogeneity can occur either along the steps or in their direction, and the structure of each step. Therefore given the heterogeneity of stored material, plus variations in the granulometry of excavated material or variations in moisture of rocks from the overburden, especially during periods of heavy rainfall, the behavior of the deposited material is totally uncontrollable. There have been identified areas in the dumps body with a high degree of loosen rocks, but also more compact areas, with high compaction factor.

The first areas are prone to uneven compaction and easy infiltration of precipitation water that contributes to changes regarding the states of consistency of rocks, and even worse, the formation of aquifers zones where the manifestation of pore water pressure is possible and even the occurrence of a hydrodynamic pressure.

In areas with better compaction, especially in the presence of clays, the presence of physically bound water was found (absorbed or adsorbed), which does not generate hydrostatic or hydrodynamic pressure, but modifies the strength characteristics of rocks, and sometimes those rocks no longer correspond to tension conditions. Those areas are of plastic failure, and plastic failures are the preceding phases of landslides.

2.2.1.2 Geotechnical and hydrogeological characteristics of the deposited rocks

For the study of geotechnical characteristics of the deposited rocks, three drillings were executed, whose location focused on the directions of landslides [A.21]. Drilling depth was dependent on the execution possibilities, being generally up to 20 m. These depths did not allow sampling the entire height of the dump or to take samples from the foundation. Samples were taken in nozzles and they ware targeted on highlighting the different mixtures of rocks from the dumps structure.

For each drill there were collected 3 to 5 nozzles, to which were added 1-3 disturbed samples. Determination of physical and mechanical characteristics was performed in accordance with the STAS-es in force, using appropriate and metrologically checked equipment for this purpose. Thus, the determined characteristics were: porosity, moisture content, volumetric density and strength characteristics of the material collected in the three drills. Geotechnical research results performed in the laboratory are shown in table. 2.1.

In terms of grain size and even lithologicaly, the mixture of deposited rocks reflects the composition of rocks from the overburden, with a high percentage of particles below 0.05 mm, which shows a structure predominantly pelitic where it was found the presence of physically linked water.

Samples humidity is high, which is explained by high water retention capacity of clayey rocks and through frequent rainfall during the period when the drillings were executed (Nov. - Dec. 2007).

The specific density has a restricted domain of variation, reflecting a fairly high homogeneity of the material terms of structure and even in terms of compaction. Lower values are found for the sandy samples (dusty sands) characterized by low humidity. The porosity of deposited rocks (n) is between 42-48% and indicates a high water storage capacity and the pore index, ε = 0.73 to 0.93, shows moderate compactions.

Table 2.1 Physical and mechanical characteristics of the deposited material

Drill depth	Porosity n	Moisture w	Volumetric density γ_v	Shearing strength	
				Cohesion c	Internal friction angle φ
m	%	%	kN/m^3	kN/m^2	degree
Drill no. 1					
0-3.0	48.37	34.69	18.15	14	16
4.50-5.30	44.79	31.42	18.32	13	17
7.0-8.0	44.65	27.64	18.93	18	18
8.50-11	44.04	26.09	18.98	21	19
11-15.3	42.33	25.05	18.88	31	16
15.3-20	42.27	23.68	19.37	20	17
Drill no. 2					
0-1.30	48.04	26.40	18.85	37	14
1.30-5.3	48.19	32.76	18.06	29	10
5.3-9.0	45.78	29.94	18.83	28	14
9.0-17.7	45.70	27.71	18.55	26	18
17.7-20	44.93	26.14	18.58	20	22
Drill no. 3					
0-5.6	43.14	27.40	19.10	30	22
5.6-9.0	42.90	16.50	17.80	39	19
9.0-16.4	45.38	26.92	18.64	41	21
16.4-21	42.51	25.68	19.00	32	18

Filtration and permeability coefficients determined in the laboratory show that the clayey rocks are poorly permeable and they have a high water retention capacity. Filtration coefficient values for loamy or silty rocks ranges from $2.4 \cdot 10^{-5}$ and $1.045 \cdot 10^{-2}$ cm/s for Rogoazelor Valley dump. For clayey or dusty sands, the determined values were somewhat higher but still low ($kf = 5.4 \cdot 10^{-3}$ cm/s), so the rocks can be classified as poorly permeable rocks, leading to the conclusion that any drainage works using vertical drillings are ineffective, both as flows and as extensions of depression areas.

The physical characteristics of deposited rocks waste and their nature indicate that the identified rocks are prone to liquefaction and thixotropic phenomena.

Shear resistances (plan on plan) of samples taken from drillings have low values and they depend on the lithological nature of the sample and the humidity of the material. Argillaceous rocks cohesion varies between 13 - 41 kN/m^2 and internal friction angle between 10 - 22º. The limits of variation of these characteristics reflect their dependence on rocks consistency, degree of consolidation and the presence of absorbed or adsorbed water in the structure of deposited rocks.

The different values of cohesion and internal friction angle within the same drill and especially the presence of low values for certain intervals demonstrates on the one hand, the structural heterogeneity of the material and, on the other hand, the presence of areas of weakness where the occurrence of tension states can cause irreversible deformation of the deposited rocks. These areas can be defined as areas of plastic failure of clayey rocks under the influence of the materials weight. Avoiding the formation of such areas into the dumps body can only be achieved through a rigorous management of the depositing process, to ensure uniformity and better compaction in order to be consolidated over time. Current measurements of the physical and mechanical characteristics of rocks confirm and supplement the tests carried out previously and determination of permeability provides knowledge on rocks behavior under the presence of gravitational water in their structure.

2.2.1.3 The stability of individual steps

Stability analyzes focused on verifying the stability conditions of dumps individual steps, for the designed and achieved geometry, taking into account the influence of pore water on the stability and the establishment of geometric elements that ensure stability [A.21]. For stability analysis there have been taken into account the following elements:

- nature of the rocks stored in the dumps;
- geotechnical characteristics of the rocks;
- hydrogeological conditions;
- geometric parameters (height and inclination of the slopes).

For stability analyzes of individual steps, it was started from geometry provided by the designer and the geometry achieved in the course of dumping process (table. 2.2).

Table 2.2 Geometric elements of the waste deposits of Rosiuta open pit

Specification	**Height of the step h (m)**	**Slope angle α (degree)**		**Height of the dump H (m)**		**General slope angle α_{gen} (degree)**	
		Designed	Achieved	Designed	Achieved	Designed	Achieved
Rogoazelor Valley dump	15	26	38	140	80	6	4

One of the major problems of stability analysis, especially for waste dumps, is related to the choice of physical and mechanics parameters of the mixture of rocks. In order to obtain results as credible, the values for cohesion and internal friction angle determined in laboratory were statistically processed (table. 2.3) taking into account two sets of values, the minimum and the corresponding M-σ, so that the analysis highlights the stability issues that can arise when the mechanical resistance characteristics of the deposited material are altered (which is very likely, given the presence of water in the dumps body).

Table 2.3 Results of statistical processing

	c	**φ**
Average	26.6	17.4
Max.	41	22
Min.	13	10
Module	20	18
Median	28	18
Standard deviation	8.76	3.20
M-σ	17.84	14.20
M+ σ	35.36	20.60

The stability analyzes were performed using a specialized software in geotechnics (SLOPE produced by GeoStru), and the results are presented in table. 2.4 and in figures 2.8 and 2.9.

Table 2.4 Stability analysis for individual steps

		h (m)	**α (degree)**	**c (kN/m²)**	**φ (degree)**	**Stability factor Fs**		
						Fellenius	**Janbu**	**Bishop**
Designed geometry	Min. values	15	26	13	10	0.83	0.96	0.89
	Values for M-σ	15	26	17	14	1.13	1.32	1.21
Achieved geometry	Min. values	15	38	13	10	0.66	0.78	0.69
	Values for M-σ	15	38	17	14	0.89	1.06	0.94
Stable geometry	Values for M-σ	15	20	17	14	1.14	1.22	1.22

In order to verify the possibility to increase the height of the dump, stability analyzes were performed for the current geometry as well as for the cases when the height of the dump is increased with one or two steps. Taking into account the height and large volume of rocks deposited, there were considered the minimal values of strength characteristics of rocks, also pore water pressure was taken into account, the results are presented in table. 2.5 respectively in figure 2.10.

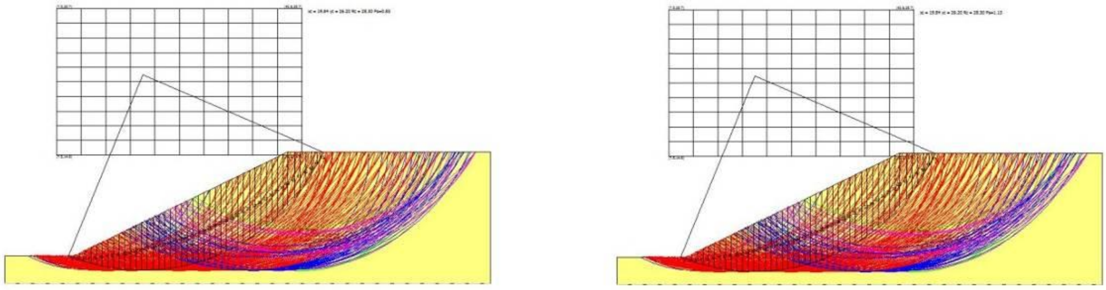


Figure 2.8 Stability analyzes for the designed geometry

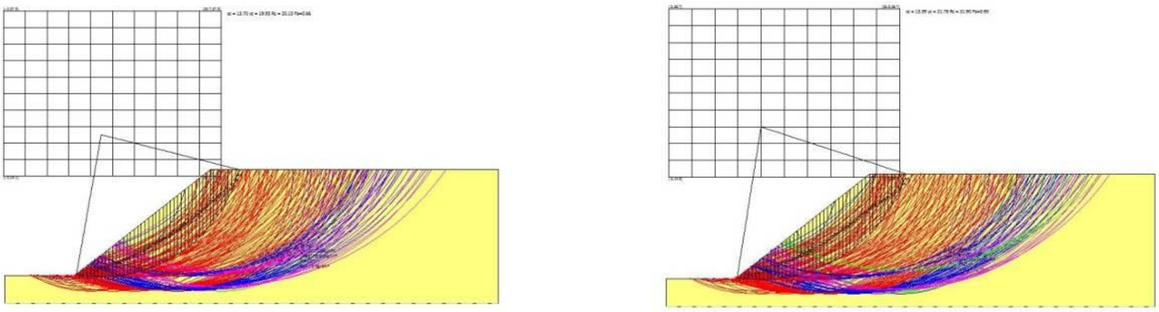
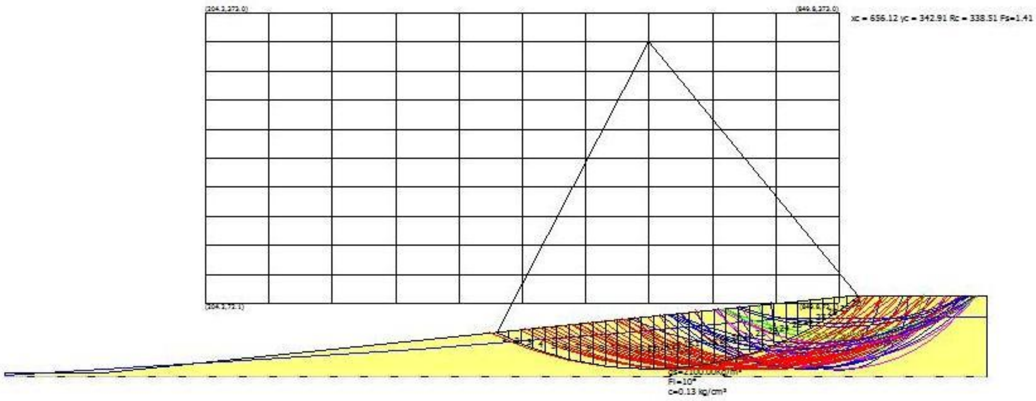


Figure 2.9 Stability analyzes for the achieved geometry

Table 2.5 Stability analyzes results for the entire dump

	h (m)	α (degree)	c (kN/m^2)	φ (degree)	Stability factor Fs		
					Fellenius	**Janbu**	**Bishop**
Present geometry	80	6	13	10	1.41	1.73	1.53
Height increase by 1 step	95	6	13	10	1.39	1.73	1.56
Height increase by 2 steps	110	6	13	10	1.33	1.66	1.49



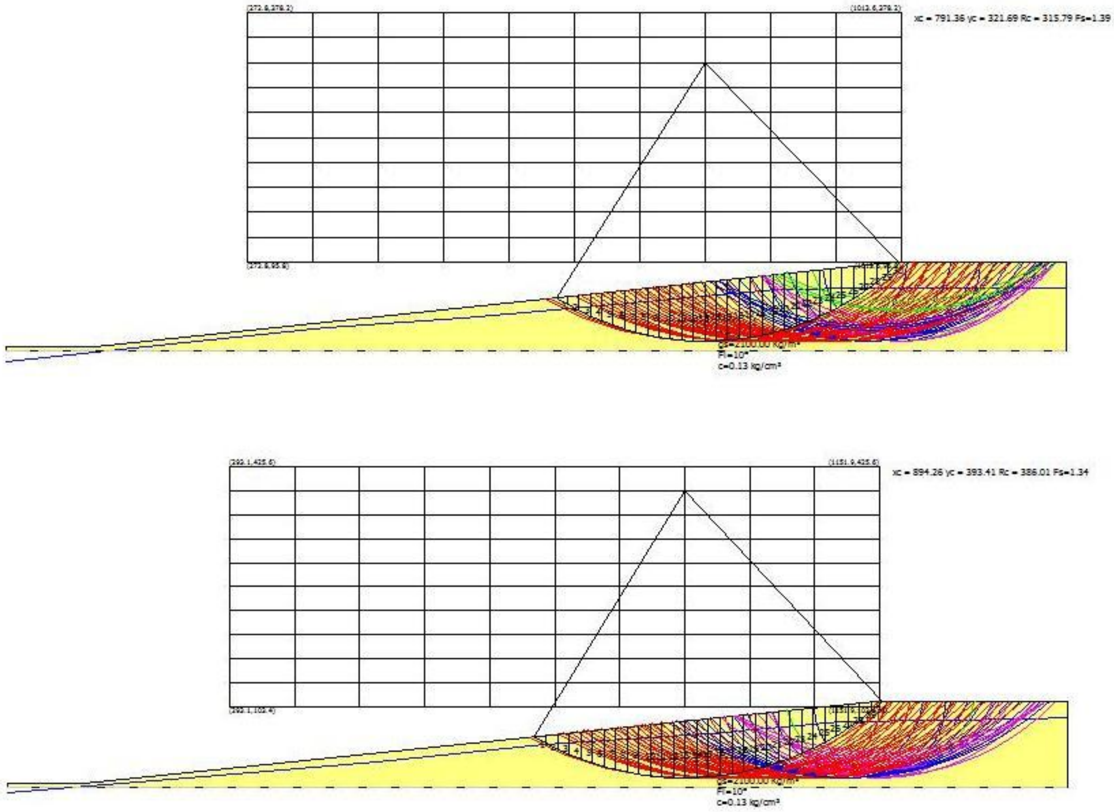


Figure 2.10 Stability analyzes for the increased height of the dump

From the results of the stability analyses performed the following conclusions can be draw:

- ✓ when minimum values of mechanical resistance characteristics of rocks are achieved (which generally occur during periods of heavy rainfall or during periods of snow melt), the individual steps of the dump with the designed geometry become unstable.
- ✓ the achieved geometry of the steps is disadvantageous in terms of stability for minimum values of cohesion and internal friction angle, stability factors having values of around 0.66 to 0.78. The existence of a certain degree of stability of the steps is explained by the fact that such areas have local expansion and strength properties of the rocks can change, depending on the presence of water in the dump.
- ✓ taking into account the natural slope angle of the deposited rocks and the depositing technology is efficient to maintain a slope angle with a higher value. For keeping a slope angle of 35 - 38º and ensuring a reserve of stability of 10 - 15% (sufficient for individual steps, as they last for relatively small periods in one place), the strength characteristics of the mixture of rocks must be maintained at higher values, respectively c = 20 kN/m^2 and φ = 14º. Such values are characteristic for the rocks and they can be kept under specific measures on preventing the ingress of water into the dumps body (compaction, leveling), in conjunction with measures to monitor the water level.
- ✓ geometric elements that provide stability for individual steps of the dump, even at inferior values of physical and mechanical characteristics are h = 15 m, respectively α = 20º.
- ✓ the critical slip surface does not delimit very high volumes of sliding mass, but slips of individual steps can generate static and dynamic efforts that can change the balance of the whole system of steps.
- ✓ after the last landslide produced in 2006 and after leveling works executed, the dump was stabilized. If the height is increased it maintains its stability. What can be seen from stability analyses carried out, it is that a deterioration of the strength characteristics of the rocks may cause a slip of the dump at the top, in which case the sliding surface affects almost the entire height of the dump.

2.2.2 Bujorăscu Valley dump – Rosiuta open pit

Bujorascu Mic waste dump is the third external sterile deposit of Roşiuţa open pit, put into service in 1992 and occupies over 75% of the valley with the same name, generally the top of the valley. The average distance of transport from the open pit to this deposit is 6 km, and the sterile rocks are transported on a circuit of conveyor belts. Bujorăscu Mic Valley is a valley feature hill areas, with the valley side slopes exceeding 10°, and the slope downhill along the valley of 5°. Before starting deposition, the valley was covered with forest, brush and thicket, vegetation that has helped to ensure a relatively good stability. In the initial phase of construction of the deposit the same method was used as the filing and to extend it downstream [A.5], [A13].

The dump is built in areas with rough terrain, along valleys with slopes affected by older or more recent landslides (but with high sliding potential). The material deposited is inhomogeneous in terms of lithology, being a mixture of clays, sandy or silty clays and clayey or silty sands, with a pelite-psamitic structure. The dumps variable structure of the material can not be explored in detail due to the high cost involved by research. The existence of fine grain fractions (Φ <0.05 mm) favors the presence of physically bound water (absorbed and adsorbed) which provides a high humidity of rocks (S = 0.8 to 0.96), with adverse effect on the strength characteristics of the deposited mixture of rocks.

The presence of free water that appears in the structure of the deposited material after rainfall or during spring after snowmelt, can lead to liquefaction phenomena of rocks or rock mixtures (clayey or silty sands). The adverse influence of water is manifested by increasing the volumetric density of rocks, changing their consistency to a critical domain (liquefaction - flow), increased inflow of water and pore water pressure. Pore water pressure reduces the normal stress influencing friction, which has a higher importance in the shearing resistance of earths, being higher than the force of cohesion. Given that the rocks are also coming from Rosiuta open pit, the structure and the physical, mechanical and hydrogeological characteristics are almost identical to Rogoazelor Valley dump (paragraphs 2.2.1.1 and 2.2.1.2).

The stability analysis for Bujorăscu Mic Valley waste dump refers to the landslide which took place in November 2007, the analyzed area being the one affected by the landslide, between the altitudes of +305 and +265. In fact it was done a retro-analysis, which had as objective to determine the variation of the rock resistance characteristics and of the cohesion values and internal friction angle which caused the landslide.

For the stability analysis there were taken into consideration elements and parameters like: the types of rock stored in the analyzed dumps, the geo-technical characteristics of the rocks, the hydro-geological conditions, the geometric parameters (the height and angle of the slopes).

The material that composes the dump Bujorăscu Mic Valley is mostly clay, and the lab analysis determined high values for porosity (n = 42-48%) and extremely low values for the permeability coefficient ($k_f = 4.18 \cdot 10^{-5} – 1.04 \cdot 10^{-2}$ cm/s). Since the material is mellow, a part of the water from precipitations is infiltrated in the deposits body, where, due to the low permeability coefficient, the water stops circulating, the water being absorbed by the clays which have a high storage capacity. The combination between clay and water leads to the reduction of the mechanical resistance characteristics of the clay, and to a higher pressure in the pores, so the water gets a slanted ascendant character.

Therefore, in the stability calculations there were considered the minimum values of the mechanical resistance characteristics, which are highly probable, in the plastic crack areas of the deposit, respectively $c = 0.09$ daN/cm^2 and $\varphi = 9^o$. The volumetric weight of the material from the deposit took into consideration in the stability calculations is $\gamma_v = 18$ kN/m^3. Stability analyzes were performed for different combinations of the values of dump material cohesion and internal friction angle and the results are presented in the table 2.6.

The figures 2.11 and 2.12 present the stability analyzes performed on the longitudinal section of the dump for two of the considered cases. Therefore, there were raised two hypotheses regarding the dump slide transmission mechanism:

- the sliding surface is transmitted progressively on the entire slide area (figure 2.11);
- the sliding surface starts from downstream the detachment surface, and it was transmitted regressively upstream (figure 2.12).

Table 2.6 The results of the stability analysis

Internal friction angle φ [°]	Stability factor Fs		
	c = 4 [kN/m^2]	c = 9 [kN/m^2]	c = 15 [kN/m^2]
3	-	-	0,92
4	-	0.82	1.04
5	-	0.95	1.17
6	0.89	1.07	1.29
7	1.02	1.20	1.42
8	1.14	1.32	1.54
9	1.27	1.45	1.67
10	1.40	1.58	1.80

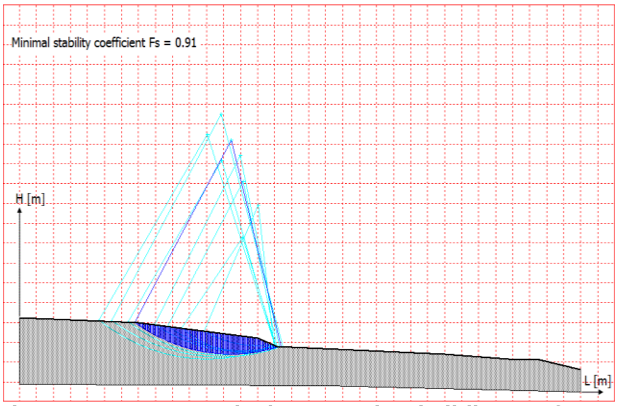


Figure 2.11 Progressively transmitted sliding surface

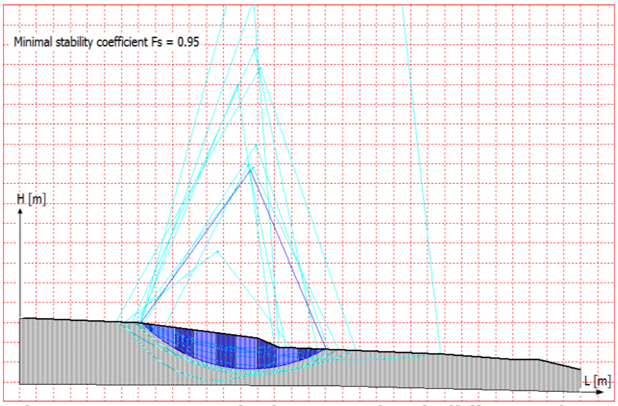


Figure 2.12 Regressively transmitted sliding surface

From the stability analysis, the conclusion is that the sliding hypotheses for the two types of slide transmission are possible in the following conditions:

- ✓ for both hypothesis the sliding was possible by lowering the resistance characteristics of the stored material because of water infiltrations in the deposit's body;
- ✓ the sliding on the surface extended on the entire slide area was possible if the cohesion reached the level c = 0.09 daN/cm^2 and the internal friction angle φ was below the value 4°, case when the stability coefficient s<1, and the dump could slide;
- ✓ the sliding on the surface transmitted regressively upstream was possible if the cohesion reached the level c = 0.09 daN/cm^2 and the internal friction angle φ was below the value 5.5°, case when the stability coefficient s<1, and the dump could slide.

Since it is a low probability for the internal friction angle to get below 4°, the research team considers the second hypothesis more plausible. Furthermore, there were processed statistically the data obtained from the stability analysis, indicating the dependences between the internal friction angle and the stability coefficient for different cohesion values, but also the regression equations which describe these dependences.

For this case, the data from stability analyzes performed were statistically processed, drawing the dependencies between and internal friction angle and coefficient stability for different values of cohesion and regression equations that describe these dependencies.

From the statistic processing of the results of the stability analysis (table 1) there were established the values of the internal friction angle which makes the dump stable, on the variation of the cohesion between 4 – 15 kN/m^2 (figure 2.13) [A.5].

From the graphic we notice that for achieving the equilibrium of the deposit, for the three cohesion values considered, the internal friction angle needs to have the following minimum values:

- ✓ for c = 0.04 daN/cm^2 → φ = 6.86°;
- ✓ for c = 0.09 daN/cm^2 → φ = 5.42°;
- ✓ for c = 0.15 daN/cm^2 → φ = 3.66°.

Likewise for the individual deposit steps, it is needed to avoid the water infiltrations in the deposit bodies (by compacting and leveling the area), towards maintaining the mechanical resistance characteristics at a level which would ensure the stability.

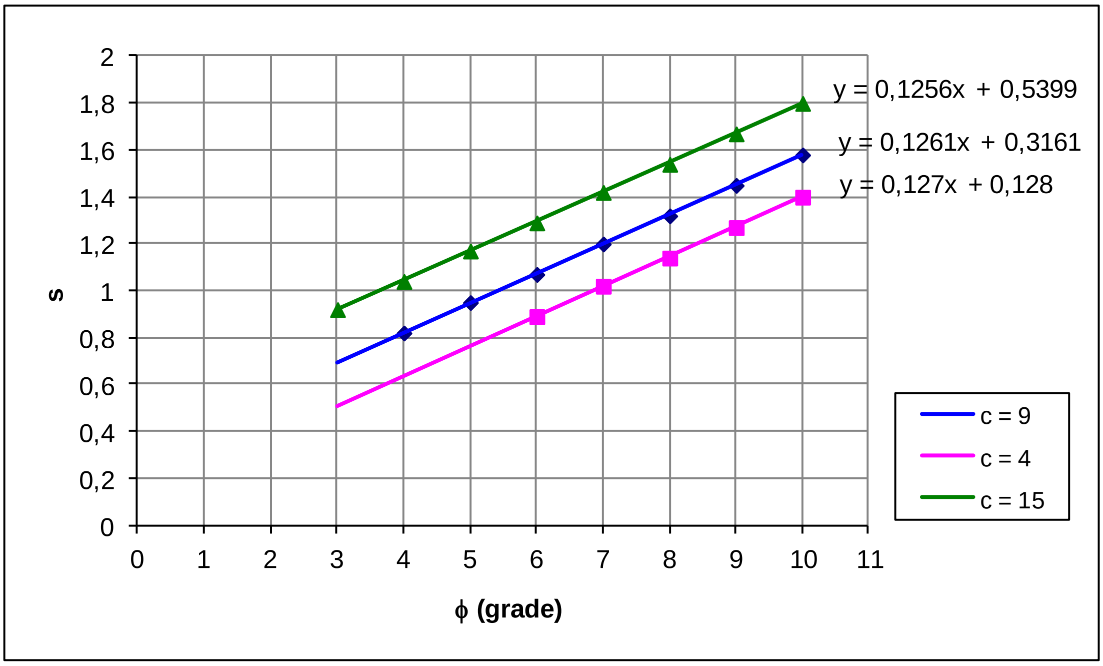


Fig. nr. 2.13 Dependence between the internal friction angle and the stability factor

The pore water pressure in the rocks considerably influences the slopes stability conditions by a deterioration of the mechanical strength characteristics of the deposited rocks. The value of pore water pressure in the rocks is dependent on the hydrostatic level position in the dump.

Reducing the presence of water in the pores of the deposited rocks can be assured only through preventive measures, namely by compacting and leveling the deposited rocks. By compacting the material the volume of pores decreases and an increase of rocks density is achieved, which determines an increase in terrains resistance by increasing friction and the shear resistance.

2.2.3 The interior dump of Olteţu open pit

The interior dump of Olteţu open pit stores a volume of approx. 45 million m^3 and is built in two steps with a height of 15 m each and slope angles of 30 - 40º, the overall inclination is of 5 - 6º. The depositing process advances on tilt, from north to south, on the base level. Construction technology is continuous, using for this purpose a spreader type A2RsB4400x95.

Over time, partial slips occurred along the depositing front and a large slip in 2005, which included almost the entire dump. Based on field observations and geotechnical investigations, the slip of the interior dump of Olteţu open pit has been framed as a progressively transmitted one, extended from the top step to the lower one, continued on the contact plane with the base level.
At the bottom it manifested as a plastic flow, which affected the coal extraction front. The presence of several failure zones in the sliding mass attests that the landslide occurred was a complex one, which initially affected the dumps body and then was transmitted on the contact surface [A.10].

Stability analysis was performed taking into account a longitudinal profile that mapped the sliding direction of the dump (figure 2.14).

Since data on resistance elements manifested on the contact surface between the dump and the base land lacked, it was needed to perform a retro analysis to determine the values of cohesion and internal friction angle after assuming that the slip occurred on the contact surface.

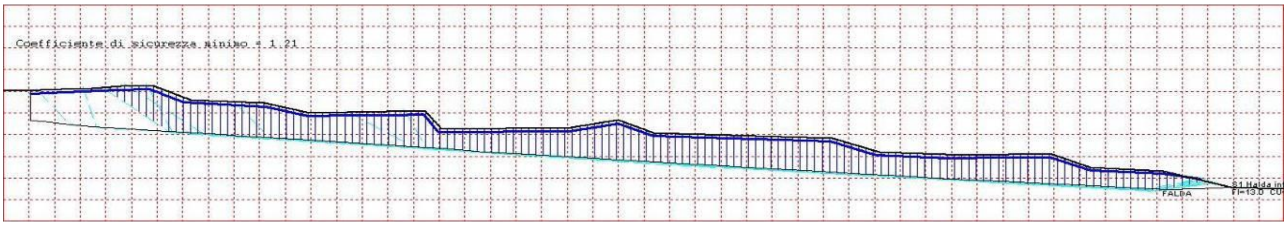


Figure 2.14 Longitudinal profile through the interior dump of Olteţu open pit (after the 2005 slide)

To study the behavior of the slopes under the presence of water in the pores, based on data provided by the mine operator, it was accepted that the water level in the dumps body can rise so as to be at a depth of 2.5 - 3 m to surface.

2.2.3.1 Stability of individual slopes

For stability analysis after circular surfaces, the slopes were generated and analyzed using the specialized software GeoTecB [A.35].

For stability calculations, the values of physico-mechanical properties were taken from ICSITPML Craiova and analyzed, and after processing the raw data their average values were determined. Thus, the following were considered:

- volumetric density: γ_v = 18.7 kN/m^3;
- cohesion: c = 22 kN/m^2;
- internal friction angle: φ = 13º;
- porosity: n = 43.4%.

Stability analysis was performed for two cases concerning the natural conditions of the material from the dump: under total drainage and, following the occurrence of rainfall, the water level in the dump is at a depth of 2.5 - 3 m to the surface.

After running the entry data for all analyzed slopes, there were obtained the values for the stability factor presented in table 2.7.

Table 2.7 Results of the stability analyses for circular sliding surfaces

Slope	Height (m)	Slope angle (degree)	Stability factor Fs					
			Drained conditions			Undrained (H_{NH} = 2.5 m)		
			Fellenius	Janbu	Bishop	Fellenius	Janbu	Bishop
1	12.57	24.17	1.41	1.47	1.48	1.04	1.11	1.12
2	17.16	52.85	0.89	0.98	0.94	0.61	0.69	0.68
3	12.75	19.01	1.57	1.64	1.66	1.16	1.24	1.25
4	12.76	22.37	1.43	1.49	1.56	1.04	1.13	1.17
I	21.75	8.9	2.94	3.07	3.07	1.99	2.15	2.16

After analyzing the stability for individual slopes, based on the results obtained, the following conclusions can be highlighted:

- ✓ for a well drained dump, the stability factor is generally higher than one, even exceeding the value required by the technical prescriptions (1.3). It is considered that this is due to the relatively low heights (around 12 m) and slope angles (19 - 25º);
- ✓ for slope no. 2, the stability factor of below one, even in the absence of water inside the dumps body. This is caused by the high value of the slope inclination (52.85º) at a height of 17.16 m;
- ✓ for the two-steps system examined (I), there is a very high stability factor, as a result of under-sizing of the geometric elements (a general slope angle of about 9º, at a height of 21.75 m;
- ✓ the presence of water in the dumps body, particularly as a result heavy or long term rainfall, reduces the stability reserve by about 27%, which indicates, in some cases, values close to the stability limit.

Considering the above conclusions, it requires a resizing of the steps geometry so as to ensure individual slope stability both in normal conditions and in the event of water saturation.

2.2.3.2. The overall stability of the dump

To determine the causes that generated the sliding of the interior dump of Olteţu open pit was considered the initial geometry. For this situation, there were analyzed two possible hypotheses, namely sliding through the dumps body and sliding on the contact surface between the dump and base land [A.35].

Stability analysis was performed using the specialized software GeoTecB and physico-mechanical properties of the material from the dump considered were those listed above. From the data available from previous studies for similar conditions, for the contact surface between the dump and the base land, the following values were considered:

- cohesion c_c = 6 kN/m^2;
- internal friction angle φ_c = 9º;
- porosity n_c = 43.4%.

Following processing, there were obtained the following values of the stability factor (table 2.8).

Table 2.8 Results of the stability analysis for the dump

Sliding surface	Stability factor Fs					
	Drained conditions			Undrained conditions		
	Fellenius	Janbu	Bishop	Fellenius	Janbu	Bishop
Through the dumps body	2.94	2.89	2.97	1.90	1.88	1.94
On the contact surface	1.89	1.87	1.94	1.17	1.17	1.21

As shown in the table 2.7, the results of the stability analysis seem to rule out both version of dump sliding: following the contact surface between the dump and base land or following a parallel plane to the contact surface which is transmitted through the dumps body.

However, taking account of the findings in the field and experience, presumably the complete sliding of the dump was driven by slipping of slopes at the top of the dump, which generated additional forces, thus resulting the sliding on the contact surface. These events have been triggered as a result of saturation with water of the material from the dump. Also, the water infiltrated through the material down to the contact surface was a contributing factor, leading to a deterioration of the mechanical strength characteristics on this surface.

As a result, it was considered necessary to perform a retro analysis, in order to determine the values of the cohesion and internal friction angle at the time of sliding. To this fact contributed that, as already mentioned, the stability analysis was performed considering approximate values for these characteristics. The results obtained are shown in table. 2.9.

Table 2.9 Results of the stability retro analysis on the contact surface

Cohesion, c, (kN/m^2)	Internal friction angle, φ (degree)	Stability factor Fs					
		Drained conditions			Undrained conditions		
		Fellenius	Janbu	Bishop	Fellenius	Janbu	Bishop
4	8	1.66	1.65	1.69	1.01	1.02	1.04
2	8	1.62	1.61	1.65	0.98	0.99	1.01
0	8	1.58	1.58	1.61	0.94	0.96	0.98

From the results obtained after carrying out the retro analysis, it appears that water infiltration on the contact surface between the dump and base land leads to a reduction of cohesion, which in these conditions is between 0 and 4 kN/m^2 and the angle of internal friction angle reaches 8º. For this reason, proper drainage measures are needed for the dump, and if its extended, execution of technical works to ensure a better twinning between the deposited material and base land.

2.2.3.3 Resizing the geometric elements of the dump

Given the negative geo-mining phenomena occurred in the interior dump of Olteţu open pit, and the fact that to their occurrence contributed both the geometry of individual steps and the presence of water in the material and on the contact surface between the dump and base land, the need to determine the geometric elements of individual steps to ensure their stability in all conditions arises.

Because the values of geometric elements of the steps are different in most sections, to determine these elements for ensuring the stability it was used the procedure of E. Hoek [B.28] which has proved its worth in many cases stability analysis. The assumption underlying this process is that the dumps slope sliding occurs after a circular surface. Starting from the influencing factors on the stability factor, Hoek builds a graph, in X, Y coordinates (figure 2.15), based on relations 2.7.

$$X = \alpha - 1{,}2\ \varphi; \qquad Y = \gamma\ H / c \qquad (2.7)$$

When considering the influence of water on slope stability reserve, function X of Hoek's chart is determined by the relationship:

$$X = \alpha - \varphi\ (1{,}2 - 0{,}5\ H_{NH}/H) \qquad (2.8)$$

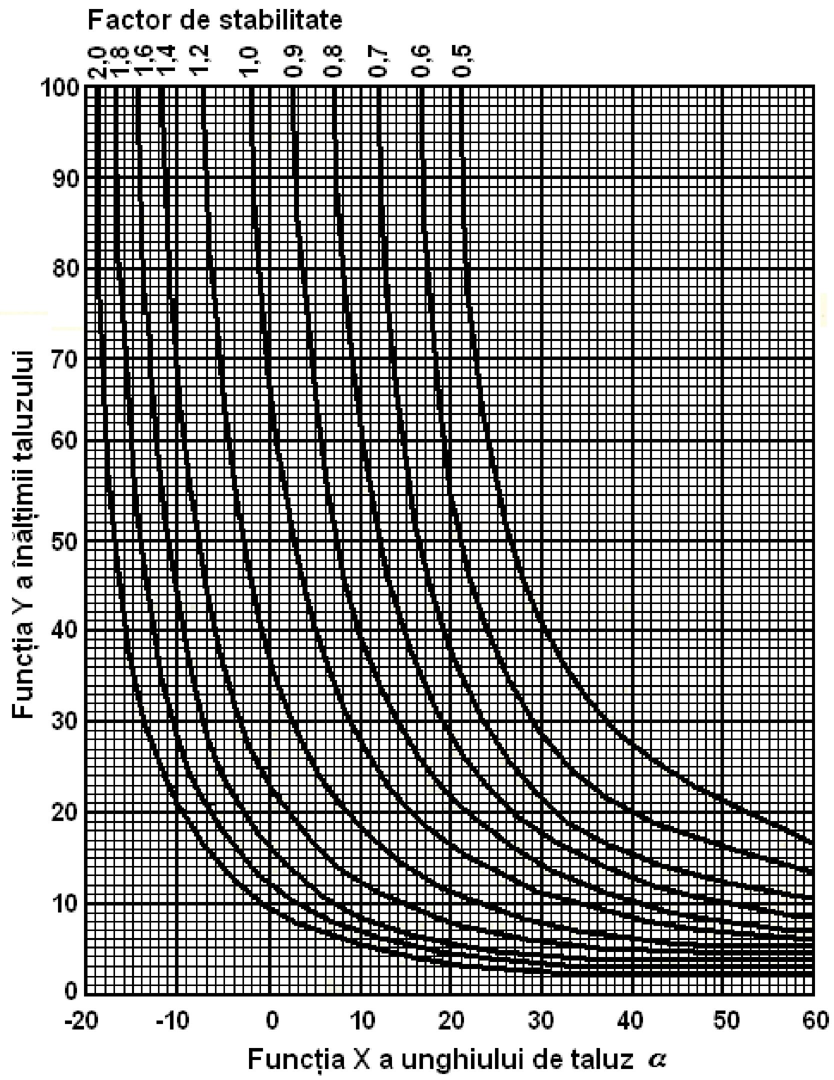


Figure 2.15 Graph for determining the geometric elements based on the stability factor (after E. Hoek)

Starting from the value set for the stability factor of the slopes of the dump (Fs = 1.3), resizing aimed at determining the slope angle for this stability factor for a height of the individual step of 15 m. The results are presented table 2.10.

Table 2.10 Resizing results

H (m)	Slope angle α, degree	
	Drained coditions	Undrained conditons
15	25	15

The results of the resizing of the geometric elements of individual steps were verified using the software GeoTecB, the values obtained are presented in Table. 2.11.

Table 2.11 Verifying the resizing results

Stability factor Fs					
Drained conditions			Undrained conditions		
Fellenius	Janbu	Bishop	Fellenius	Janbu	Bishop
1.27	1.32	1.34	1.15	1.28	1.30

Among the causes triggering the sliding of the interior dump of Olteţu open pit, can be mentioned: advancing the construction of the dump on its tilt without executing twinning steps and drains to collect and divert of water on the dumps foundation, altering the characteristics of strength and liquefaction of the deposited material in the contact area, infiltration of rainfall into the dumps body, and others.

Measures taken to stabilize the dump: resizing the geometric elements of the dump and execution of twinning steps in each extraction entrance (depositing strip), the execution drains filled with ballast on the foundation of the dump in the front direction and partial leveling and compacting of the dump.

2.2.4 *Arsului Valley dump – EM Vulcan*

The dump Arsului Valley was created for storage of sterile rocks resulting from underground coal exploitation EM Vulcan. The location of the heap is in the valley of the Arsului creek and is formed by transport with trucks and dump with bulldozers of the sterile rocks. The inclination of eastern and western slopes of the valley in cross section is between 7 and 18°. The inclination of the valley bottom in the dump area is about 5°. In hydrographical terms, the dump area is affected by the Arsului creek and by the torrents that forms on the slopes during periods with heavy rainfall or melting snow. After deposition of the sterile rocks in the valley, the creek bed was deviated and formed a lake downstream, due to land sinking due to underground mining activity, with natural drainage possibilities (figure 2.16). The presence of the lake is an unfavorable factor in terms of stability, whereas the water saturated the rocks at the base of the dump and modifies their physico-mechanical properties. In addition, it can lead to the formation of hydrostatic pressure that alters the balance of active and passive forces in the dump. During periods with heavy rainfall are present erosion and accumulation of water in the southern part of the dump. The rocks from the dump consist of rocks that occur in the productive horizon, i.e. clay, marl, sandstone, argillaceous sandstone and carbonaceous shale with different degree of granulometry and alteration. The granulometric composition of the stored material is very different; the granules having sizes from millimeters to tens of centimeters. [A.7].

Fig. nr. 2.16 Halda Valea Arsului

The dump has an uneven geometry and consists of three steps, which in this study were numbered from 1 to 3 from upstream to downstream. The berm between the slopes 1 and 2 has a length of about 180 m, and an inclination of 2.9°, the berm between the slopes 2 and 3 has a length of about 57 m and an inclination of 3° to slope 2 and lower berm has a length of about 65 m and is almost horizontal. The slopes height is variable and dependent on the land surface altitude and on the amount of deposited material and ranges from 5 m at the bottom and top of the dump and 7 – 10 m in the middle. Slope angles have values between 11° – 37°, higher values being found in particular in cases of the eastern and western slopes. The dump has a length of about 420 m and a width of about 210 m at the top, and narrows to 80 m in the lower area.

The sterile rocks from the dump Arsului Valley are a heterogeneous material in terms of grain size and lithology. In terms of particle size predominates gravel (Φ = 2 – 20 mm) and sand (Φ = 0.05 - 2 mm). The field observations on lithology of the sterile rocks show a mixture of rocks from productive horizon, consisting of clay, marl, sandstone and shale coal. The bulk density (γ_a) varies widely due to the mineralogic-petrographical heterogeneity of the sterile rocks and due to the different humidity. The stability analysis was considered the maximum values of the volumetric weight, which correspond to the worst situation. Shear strength characteristics are influenced by mineralogic-petrographic composition of the sterile rocks and by their humidity. Technical conditions of the dump and the limits of variation of mechanical characteristics lead to adopting the average values of cohesion and internal friction angle for the stability analysis.

2.2.4.1 Circular sliding surfaces

Stability analysis aimed four sections drawn in the areas where the slope geometry is less favorable: the longitudinal section (L_{1-1}) and three cross-sections (T_{1-1}, T_{2-2} and T_{3-3}). The geometry of the slope in the analyzed sections is presented in table 2.12 [A.7].

Table 2.12 Geometry of slopes

Section	Slope	Height H, m	Slope angle φ, grade
L_{1-1}	1	5	15
	2	6.4	13.2
	3	7.8	10
T_{1-1}	East	9.1	13
T_{2-2}	West	5.6	23
	East	10	30
T_{3-3}	West	6.8	37
	East	9.2	35

To determine the physical and mechanical characteristics of the stored material, samples were taken from the dump and the base land (represented by topsoil), and from the clay layer on which the topsoil is deposited over. The values determined in the laboratory were added to the existing database for Arsului Valley dump.

The values of the strength properties for sterile rocks and topsoil considered in stability analyzes are the result of statistical processing of the values obtained in the time (table 2.13). Thus, we determined the mean (M), standard deviation (σ), the corresponding values M ± σ and were set four calculation alternatives of the stability factor.

Table 2.13 The values of the mechanical characteristics

Material	Variant I		Variant II		Variant III		Variant IV	
	c, kN/m^2	φ grade	c, kN/m^2	φ grade	c, kN/m^2	φ grade	c, kN/m^2	φ grade
Topsoil	32	23.1	32	17.2	11	23.1	11	17.2
Sterile rocks	38	25.8	38	12.7	12	25.8	12	12.7

For bulk density were taken in account the maximum values, respectively γ_v = 18.05 kN/m^3 for the deposited sterile rocks and γ_v = 17.88 kN/m^3 for the topsoil. The geo-mechanical characteristics of the clay layer on which is deposited topsoil are following: bulk density γ_v = 18.06 kN/m^3, cohesion c = 58 kN/m^2 and the angle of internal friction φ = 16.49°.

Stability analysis was performed for three hypotheses concerning possible sliding of the dump:

- circular sliding surfaces sent both through the dump, and through base land;

- polygonal sliding surfaces, transmitted on the contact plane between topsoil and clay;
- circular sliding surfaces for the entire steps system.

The stability analysis was carried out for normal natural moisture, taking account of the pore water pressure and of the seismic acceleration coefficient for the studied area (a = 0.1g, according to Seismic Design Code P100 [B.57]).

As a result of running the input data for each considered case, the obtained values of the stability factors shown in tables 2.14 – 2.17 for circular sliding surfaces, for circular failure sliding surface, and in figures 2.18 – 2.20 the critical failure surfaces for the representative sections.

Table 2.14 Cross section T_{1-1}

Slope	Variant	Stability factor, Fs		
		Fellenius	Janbu	Bishop
Eastern	I	2.74	2.92	2.79
	II	2.42	2.55	2.50
H = 9.1 m	III	2.11	2.28	2.25
α = 13°	IV	1.49	1.58	1.50

Table 2.15 Cross section T_{2-2}

Slope	Variant	Stability factor, Fs		
		Fellenius	Janbu	Bishop
Western	I	3.66	4.15	3.94
	II	3.00	3.20	3.03
H = 5.6 m	III	2.32	2.58	2.52
α = 23°	IV	1.46	1.60	1.54
Eastern	I	2.25	2.60	2.47
	II	1.85	2.04	1.91
H = 10 m	III	1.75	1.88	1.81
α = 30°	IV	1.06	1.19	1.15

Table 2.16 Cross section T_{3-3}

Slope	Variant	Stability factor, Fs		
		Fellenius	Janbu	Bishop
Western	I	2.23	2.61	2.42
	II	1.77	1.99	1.82
H = 6.8 m	III	1.40	1.48	1.41
α = 37°	IV	0.90	1.01	0.97
Eastern	I	2.45	2.71	2.60
	II	2.07	2.22	2.07
H = 9.2 m	III	1.55	1.63	1.56
α = 35°	IV	1.03	1.10	1.04

Table 2.17 Longitudinal section L_{1-1}

Slope	Variant	Stability factor, Fs		
		Fellenius	Janbu	Bishop
1	I	3.24	3.92	3.51
	II	2.93	3.31	2.98
H = 5 m	III	1.93	2.32	2.23
α = 15°	IV	1.43	1.61	1.53
2	I	2.84	3.38	3.09
	II	2.36	2.59	2.41
H = 6.4 m	III	2.44	2.62	2.52
α = 13.2°	IV	1.44	1.59	1.51
3	I	2.73	3.00	2.82
	II	2.57	2.77	2.62
H = 7.8 m	III	2.46	2.70	2.56
α = 10°	IV	1.58	1.69	1.61

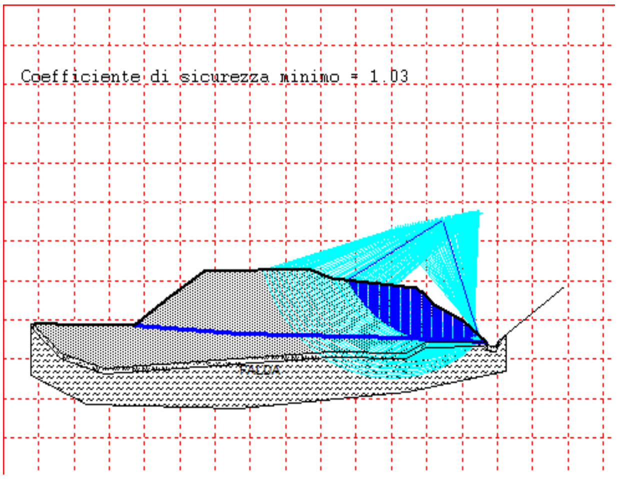


Figure 2.17 Section $T_{3\text{-}3}$, western slope – var. IV

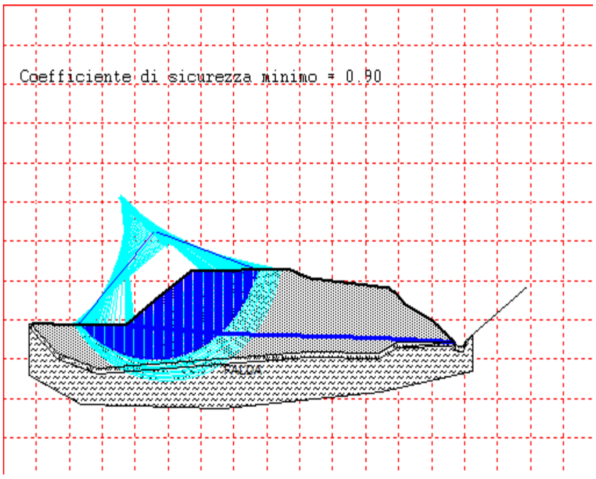


Figure 2.18 Section $T_{3\text{-}3}$, eastern slope – var. IV

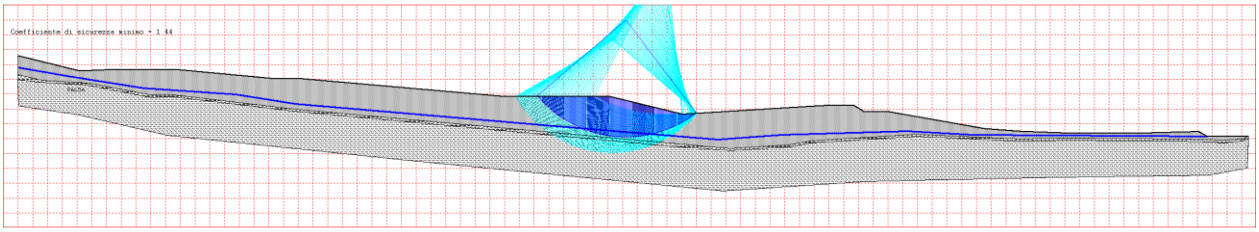


Figure 2.19 Section $L_{1\text{-}1}$, step 2 – variant IV

Analyzing the results of stability tests in the cases of the circular failure surfaces can be found the following:

- ✓ For the longitudinal section $L_{1\text{-}1}$ (H between 5 – 7.8 m and α between 10 –15°) and cross section $T_{1\text{-}1}$ (H = 9.1 m and α = 13°), the stability factor show a sufficient stability reserve in all analyzed cases, with values greater than 1.3 as is recommended by the literature [B.56], [B.62];
- ✓ For the cross section $T_{2\text{-}2}$ was analyzed the stability for the western and eastern slopes, and the following results were obtained:
  - The western slope (H = 5.6 m and α = 23°) is stable in all analyzed cases, the values of the stability coefficient result higher as 1.3 for all used analysis methods;
  - The eastern slope (H = 10 m and α = 30°) is stable for the sets of values corresponding variants I, II and III, and is at the limit of stability for the values corresponding variant IV (Fs = 1.06 after Fellenius, Fs = 1.19 after Janbu and Fs = 1.15 after Bishop);
- ✓ For the cross section $T_{3\text{-}3}$ was analyzed the stability for the western and eastern slopes, and the following results were obtained:
  - The western slope (H = 6.8 m and α = 37°) is stable for the sets of values corresponding variants I, II and III, and unstable for the values corresponding variant IV after Fellenius (Fs = 0.90) and after Bishop (Fs = 0.97) and at the limit of stability after Janbu (Fs = 1.01);
  - The eastern slope (H = 9.2 m and α = 35°) s stable for the sets of values corresponding variants I, II and III, and is at the limit of stability for the values corresponding variant IV (Fs = 1.03 after Fellenius, Fs = 1.10 after Janbu and Fs = 1.04 after Bishop);
- ✓ The steps system analyzed in the longitudinal section is stable for all considered variants;
- ✓ The critical failure surface is transmitted through the ground base of the dump in the case of high values of cohesion and angle of internal friction of the sterile rocks and topsoil, and only trough the body dump in the case of low values of these parameters. It also notes that any failure slip will be a deep failure, involving large volumes of waste material.

It is noted that the slopes that are unstable or is at the limit of stability are inclinations higher as 30°. A possible failure of the eastern slope leads to blocking of the riverbed, causing more problems related to water regime and management. A failure of the western slope would lead to blocking of the access road and, under certain conditions, can affect the electrical network pillars.

2.2.4.2 Polygonal failure surfaces

To analyze the stability over the polygonal failure surfaces are taken into account the sections L_{1-1}, T_{1-1} and T_{2-2}, where the dump ground has inclinations that could favor the slide. Were analyzed three variants for the transmission of the failure surface: trough the sterile rocks, trough the topsoil and on contact surface between topsoil and the clay layer.

The obtained results are shown in the table 2.18. The results are presented only for the values of the geo-mechanical characteristics of variant IV (the worst in terms of stability), since even in these conditions the value of the stability coefficient exceeds 1.3. For all analyzed sections, the critical failure surface is transmitted through the sterile rocks from dump.

Table 2.18 Stability analysis results at polygonal surfaces

Section	Inclination of the dump ground, β_{max} (grade)	Stability factor, Fs		
		Fellenius	Janbu	Bishop
L_{1-1}	5.53	1.52	1.78	1.56
T_{1-1}	15	1.71	1.79	1.73
T_{2-2}	24.9	1.76	1.85	1.82

In these cases, the failure probability is almost zero, because the stability coefficients have values above 1.3 and in the calculations was used the worst value of the rock strength characteristics. It was also taken into account the rate of seismicity of the area.

2.2.4.3 Resizing and design of the geometric elements of the dump

Given the stability analysis results and the consequences of a possible landslide, it is necessary to resize the geometric elements of the dump, so to have a minimum 30% stability reserve, even under the most unfavorable geotechnical conditions. To establish the geometric elements of the dump under slope stability conditions, can be used different graphic-analytical methods as E. Hoek [B.28] which proved its viability in many cases, including for the many dumps in the Jiu Valley (figure 2.15).

The obtained results of calculations are presented in table 2.19.

Table 2.19 Resizing of the geometric elements

H, [m]	φ, [grads] for Fs =	
	1.3	1.5
5	56	47
10	41.5	35
15	34	29
20	30.5	26
25	28	24
30	26.5	22

The resizing calculations lead to the conclusion that in order to provide a sufficient stability supply, also in the presence of water in the pores and/or in the case of a seismic event, the height of each step should be kept to 10 m in terms of an slope angle of the maximum 30º.

For a total dump height of 30 m, the general slope angle is recommended to be 22^{o}. Therefore, it is proposed to construct the dump in three steps by providing a protective berms of 5 m by Arsului Valley side [A.7].

The stability studies show that the Arsului Valley dump is generally stable, and for the sets of values of geomechanical characteristics I, II and III the stability reserve is adequate, exceeding the reference value of 30%. The failure probability exists only for the set of values corresponding variant IV, for the eastern and western slopes in areas described by sections T_{2-2} and T_{3-3}, where the slope are steep.

Based on the literature, on the field studies and not least on our research experience, we recommend the following measures to ensure stability of the dump.

- ✓ Reducing of the negative influence of water on the strength characteristics of the rocks. It requires works that does not allow water infiltrations infiltrate inside the dump bodies or to their base from various sources like rainfall, snowmelt, streams and water accumulation. Thus, it is recommended a permanent leveling of the berms, providing a terrain inclination for water drainage from the existing dump and the drainage of the lake downstream of the dump by depositing of the sterile rocks in the lake.
- ✓ Compliance of the designed geometry and technology of the dump. It is necessary the construction of steps with a height of 10 m and a slope angle of 30^o for every step. The general slope angle should not exceed the value of 22^o.
- ✓ Permanent leveling and compaction of the dumping zones under lateral expansion of the dump. It is recommended that further expansion of the dump toward south and east in order to drainage of the existing lake.
- ✓ Monitoring of the land base and dump deformations.
- ✓ Ensuring of the final geometry for the definitive slopes for the forestation and grassing works, being known that vegetation are a factor of stability and consolidation of the dumps, trough the land reinforcement effect of the roots and trough the effect of preventing the growth of cracks [B.42]. This eliminates the quickly infiltration of rainfall into the dump body and formation of potential sliding surfaces.

2.2.5 Petrila mine waste dump

The sterile rocks dump Petrila was built for storage of materials resulting from the cutting processes in the underground mine Petrila and from the washing of hard coal in the processing plant Petrila. Since 2002, the processing plant Petrila was closed, and the dump stored only sterile rocks from underground works.

The dump is located on an old plateau with an area of approximately 86 ha. In terms of hydrography, the area is between Rusalin, Fântâni and Devil's streams in the north and Maleia in the south, and is affected by some accumulation of water in the spring with relatively small flows. It should be noted the presence of four lakes, whose surface is dependent on the season and on the presence and intensity of rainfall in the area (figure 2.20).

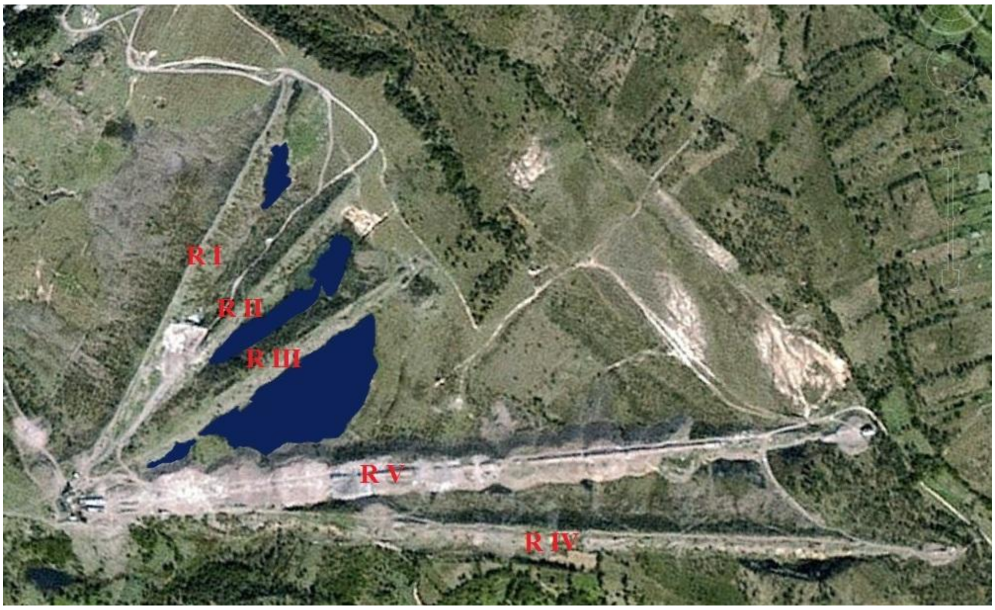


Figure 2.20 Location of Petrila dump

It is possible, that the presence of the two lakes in the northern part of the R V, to have a negative influence on stability, since they are formed even at the base of the dump, and any infiltration can cause a worsening of physical and mechanical characteristics of the stored material.

The slopes height ranges between 16.5 and 19.4 m, with angles between 20 and 50°, the most common values ranging between 30 - 33°.

Based on field observations, the following aspects may be highlighted [A.28], [B.46]:

- ✓ no major adverse geotechnical phenomena, such as active landslides or discharge of slopes and base terrain, are observed;
- ✓ however, it was found, the presence of gullies of different sizes, on the southern and northern slopes, formed by the action of runoff water;
- ✓ at the base of the dump, wetlands are formed, especially on the southern side, whose presence in the area may have adverse effects on stability due to water infiltration and deterioration of material strength characteristics.

2.2.5.1 Determination of physico-mechanical properties of the sterile rocks and topsoil

By studying the physical and mechanical parameters of sterile rocks and base terrain of the dump, their behavior in various situations of stress can be determined. If geotechnical properties of rocks are well known and accurately determined, the interpretation of deformation processes that may be encountered in practice is easier. The proper determination and use of these properties also facilitates the option for specific design solution to ensure the dumps stability and effective management processes. For this purpose, during the field research two samples of dump material and one of topsoil were taken and analyzed in the laboratory, obtaining the results shown in table 2.20 [B.46].

Table 2.20 Physico-mechanical properties of the dump material and topsoil

Sample name	Humidity W (%)	Saturation degree	Shear strength τ_f			Cohesion c (kN/m^2)	Angle of internal friction φ (°)
			σ_1= 100 kN/m^2	σ_2= 200 kN/m^2	σ_3= 300 kN/m^2		
Dump material	13.95	0.58	0.72	0.97	1.27	40	16
	19.564	0.83	0.55	0.88	1.36	14	20
	23.98	1.02	0.41	0.66	0.97	18	15
Topsoil	21.89	0.75	0.72	1.05	1.58	30	23
	25.87	0.90	0.55	1.05	1.52	12	20
	27.72	0.96	0.50	0.72	0.98	21	18
Dump material/	13.95/ 21.89	0.58/0.75	0.41	0.97	1.44	5	24
	19.56/ 25.87	0.83/0.9	0.69	0.98	1.27	31	16
	23.98/ 27.72	1.02/0.96	0.50	0.69	1.25	29	12

Technical condition of the dump and the limits of variation of mechanical characteristics of the sterile rocks lead to the conclusion that mean values for cohesion and internal friction angle can be adopted for stability calculations.

2.2.5.1 Stability analysis and results interpretation

Because the base terrain of the dump looks like a plateau with gradients under 10°, and the underground exploitation favored the formation of the subsidence areas, oriented W-E, it is estimated that instability phenomena may occur only on the slope area and will be limited in size.

Analysis of stability of the dump belonging to EM Petrila was performed using the specialized software Geo-Tec B, for one longitudinal section (L1 - L1) and four cross sections (T1 - T1, T2 - T2, T3 - T3 and T4 - T4), chosen so as to define the sensitive areas in terms of stability, respectively areas where the slope foot comes in contact with the two lakes in the northern areas and the areas with maximum height and slope angle.

To eliminate the high variation of geotechnical properties, for the stability analysis were selected the mean values of physico-mechanical properties and geotechnical indexes. The values of geotechnical properties used in the analysis of stability for the two cases, natural and saturation humidity of the sterile rocks from dump are presented in table 2.21.

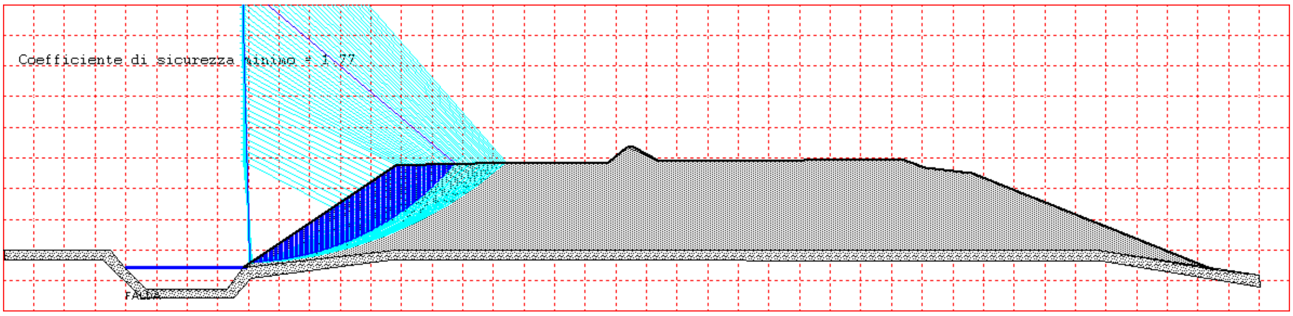
Table 2.21 Geotechnical properties used in the stability analysis

Rock typ	Natural humidity			Saturation humidity		
	Volumetric weight γ_{nat}, (kN/m^3)	Cohesion c, (kN/m^2)	Internal friction angle φ (°)	Volumetric weight γ_{nat}, (kN/m^3)	Cohesion c, (kN/m^2)	Internal friction angle φ (°)
Dump material	17.80	40	16	19.30	18	15
Topsoil	18.10	30	23	19.30	21	18
Dump material/Topsoil	-	29	24	-	5	24

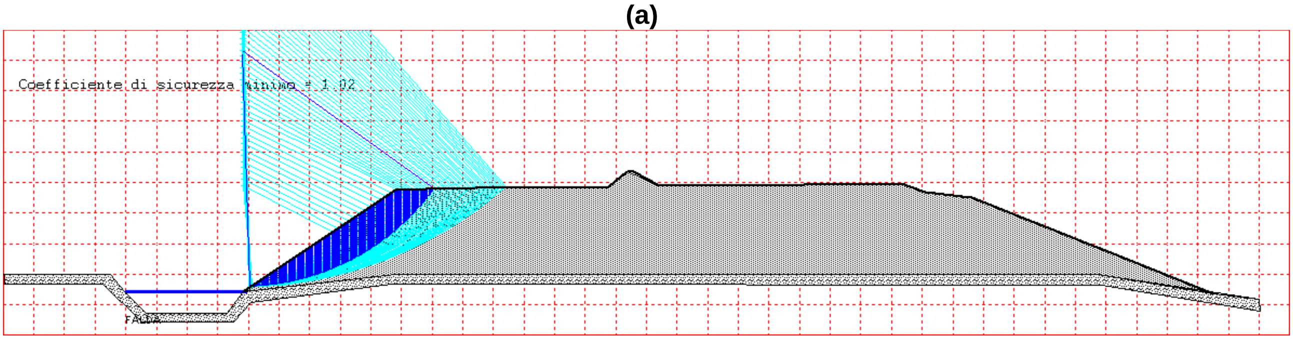
Taking into account the geometric configuration of the dump and the land form, the stability analysis was performed considering that the failure surfaces are circular [2]. In order to determine the slopes stability reserve, the dump's geometry was reproduced using the mentioned software, and then the stability factor was calculated for each slope. In each case, 52 sliding surfaces have been drawn that can be transmitted through the dump's body, determining the most probable failure surface and the corresponding factor of stability. The results of the stability analysis are presented in table 2.22, and how it was performed is exemplified in figure 2.21 for the cross section T_1 - T_1. Note that stability analysis did not take into account the pore water pressure, because the material is granular and has a high permeability, with the possibility of a rapid gravitational drainage of water from the dump's body. In order to analyze the dump behavior in case of rain, were determined and calculated physical and mechanical parameters of the sterile rocks from the dump for different humidity conditions. [A.28].

Table 2.22 Stability factor for circular failure surfaces

Section	Slope	H (m)	α (°)	Natural humidity			Saturation humidity		
				Fellenius	Janbu	Bishop	Fellenius	Janbu	Bishop
$T_1 – T_1$	northern	16.50	33.46	1.77	1.83	1.79	1.02	1.06	1.05
$T_2 – T_2$	northern	16.41	30.33	2.28	2.39	2.30	1.38	1.42	1.40
$T_3 – T_3$	northern	19.40	25.15	1.69	1.75	1.81	1.10	1.15	1.20
$T_3 – T_3$	southern	15.10	50.05	1.36	1.55	1.38	0.78	0.85	0.82
$T_4 – T_4$	northern	25.08	33.10	1.29	1.34	1.33	0.82	0.86	0.86
$T_4 – T_4$	southern	16.94	30.72	1.61	1.69	1.69	1.00	1.05	1.08



(a)



(b)

Figure 2.21 Cross section T1 – T1, northern slope, natural (a) and saturation humidity (b)

The results from stability analysis lead to the following conclusions:

- ✓ stability analysis was performed for slopes with heights between 15.1 m and 25.08 m and slope angles ranging between 25.15 and 50.05°;
- ✓ the cross sections were performed as follows:
  - the cross section T1 –T1 at the contact area with the first lake,
  - the cross section T2 –T2, at the contact area with the second lake,
  - the cross section T3 –T3 in an area with a steep southern slope (approximately 50°),
  - the cross section T4 –T4 in an area of maximum height (25.08 m), and a slope angle of 33.1°.
- ✓ in case of sterile rocks with natural humidity, the values obtained for the stability factor is higher than one, even higher than 1.3 (recommended value by the technical prescriptions concerning the dumps design, construction and conservation);
- ✓ in case of sterile rocks with saturation humidity, only the northern slope of the cross section T2 - T2 has a reserve of stability over 1.3, for the other slopes, the stability factor indicating a limit of equilibrium or instability;
- ✓ stability limit occurs in the northern slope of the cross section T1 - T1 (s = 1.02 after Fellenius), northern slope of cross section T3 - T3 (s = 1.10 after Fellenius) and the southern slope of cross section T4 - T4 (s = 1.00 after Fellenius);
- ✓ slopes to become unstable in case of rocks with saturation humidity are the southern slope in cross section T3 - T3 (s = 0.78 after Fellenius - sliding is determined by the steep slope) and slope of the northern cross section T4 - T4 (s = 0.82 after Fellenius), which has the highest slope height (25 m) at an inclination of 33°;
- ✓ analyzing the shapes and positions of the critical failure surface (figure 2.21), as a result of the high humidity of the dump material, it is observed that the critical failure surface is closer to the slope, has a smaller length and generates a smaller sliding body.

To ensure the dump stability the following measures are recommend:

- ✓ Respecting the condition $\alpha < \alpha_o$, respectively the slope angle of the dump (α) to be smaller than the natural slope angle of the stored rocks (α_o).
- ✓ Correlation between slope angle (α) and slope height (h).
- ✓ Reduce the negative influence of water on the rock strength characteristics through works of leveling and providing drainage slopes. It also requires works for the collection and management of runoff water outside the dump.
- ✓ Draining of the wetlands from the base of the southern slope, so providing conditions for sterile rocks storage through lateral extending of the dump.
- ✓ Elimination of existing gullies on the northern and southern slopes by filling them with material.
- ✓ Respecting the projected geometry and construction technology. If the rocks are drained is necessary to ensure a maximum slope angle of 35o (the natural slope angle of the sterile rocks from dump α_o = 35 - 38°) but for undrained rocks the angle of slope must be reduced to approx. 20° for slope heights of 25 m.
- ✓ To eliminate the difficulties in operating the funicular (it was shown that, due to lack of leveling works, the funicular cages travels through landfill material) is recommended the lateral expansion of the dump. This solution can lead to avoidance of water accumulation in the valley between the two branches R V and R IV, which would have negative influence on stability. This ensures the creation of a superior platform with the necessary width for storage and leveling of dump material.
- ✓ Permanent leveling and compacting of deposition areas with bulldozers.
- ✓ Proper fitting of the platforms from angular and return stations, by leveling the material deposited in these areas.
- ✓ Provide uniform slopes to drain the water from the dump and adjacent areas.

Given the current technical condition of the dump and stability analysis results, it is estimated that the dump is currently stable without major problems. Any stability problems may occur through improper modification of the dump geometry or amplification of the unfavorable factors. By adapting the proposed measures set and by respecting the designed geometry is considered that activity can continue safely and instability phenomena will not occur.

2.2.6 Excel application for stability analysis after circular sliding surfaces

Between 1995 and 1996, when the specialized software in geotechnical problems were in there pioneering phase worldwide and inaccessible on the Romanian market, we worked on an Excel application that enabled stability analyzes much faster and with highly reliable results, confirmed by their practical verification.

The application was built using Excel program for creating geometric patterns based on mathematical algorithms. In the first stage, the slopes model is generated based on its geometric elements (figure 2.22).

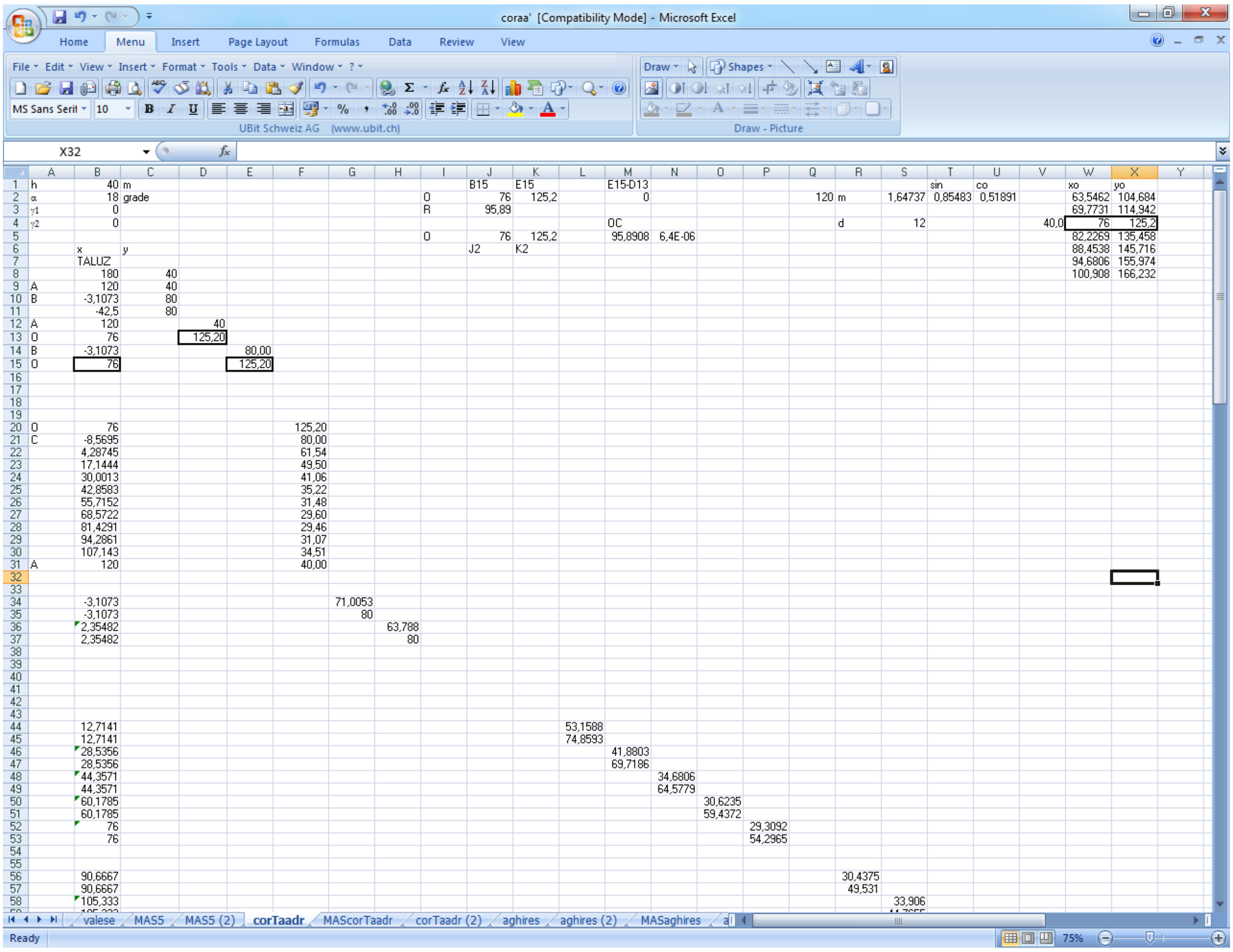


Figure 2.22 Data input and generation of the model

Determination of the critical sliding surface and its center, as well as the sliding surface radius was carried out using the Janbu procedure, by entering the corresponding mathematical relations into the spreadsheet. After drawing the sliding surface, the division of the sliding prism into vertical slices was programmed, taking into account the points where the slope is changing its inclination and where the slices belong to the passive or active prisms.

The geometry of the slope, the position of the critical sliding surface and the slices elements are taken directly from the spreadsheet, and on their basis a table containing this data is generated, as well as the graphical representation of the slope section (figure 2.23).

Using circular references, the necessary data are imported into another spreadsheet, where the values of physical and mechanical properties of the rocks constituting the slope are introduced, and the stability analysis is performed using the Fellenius method (Swedish method) and Maslov-Berer method (horizontal forces method).

The calculation is done automatically, both for determining the resistance forces and sliding forces, and for determining the stability factor for each of the two methods used (figure 2.24).

Once built, the model can be used for any configuration of natural and artificial slopes and rocks of any kind, simply by changing the geometric elements (height and slope angle) in the first spreadsheet and geotechnical parameters of rocks in the second spreadsheet.

The application was adapted for stability analysis under the action of hydrostatic pressure of pore water or for submerged slopes.

Also, with the aid of this application, functional dependencies have been established between the parameters that influence the stability of a slope, extremely useful for assessing stability and for designing and redesigning the slope's geometry.

The application has been used for a long time both for solving stability problems raised in research (especially for stability analysis of the Jiu Valley and Oltenia waste dumps) and for training students in the seminar activities.

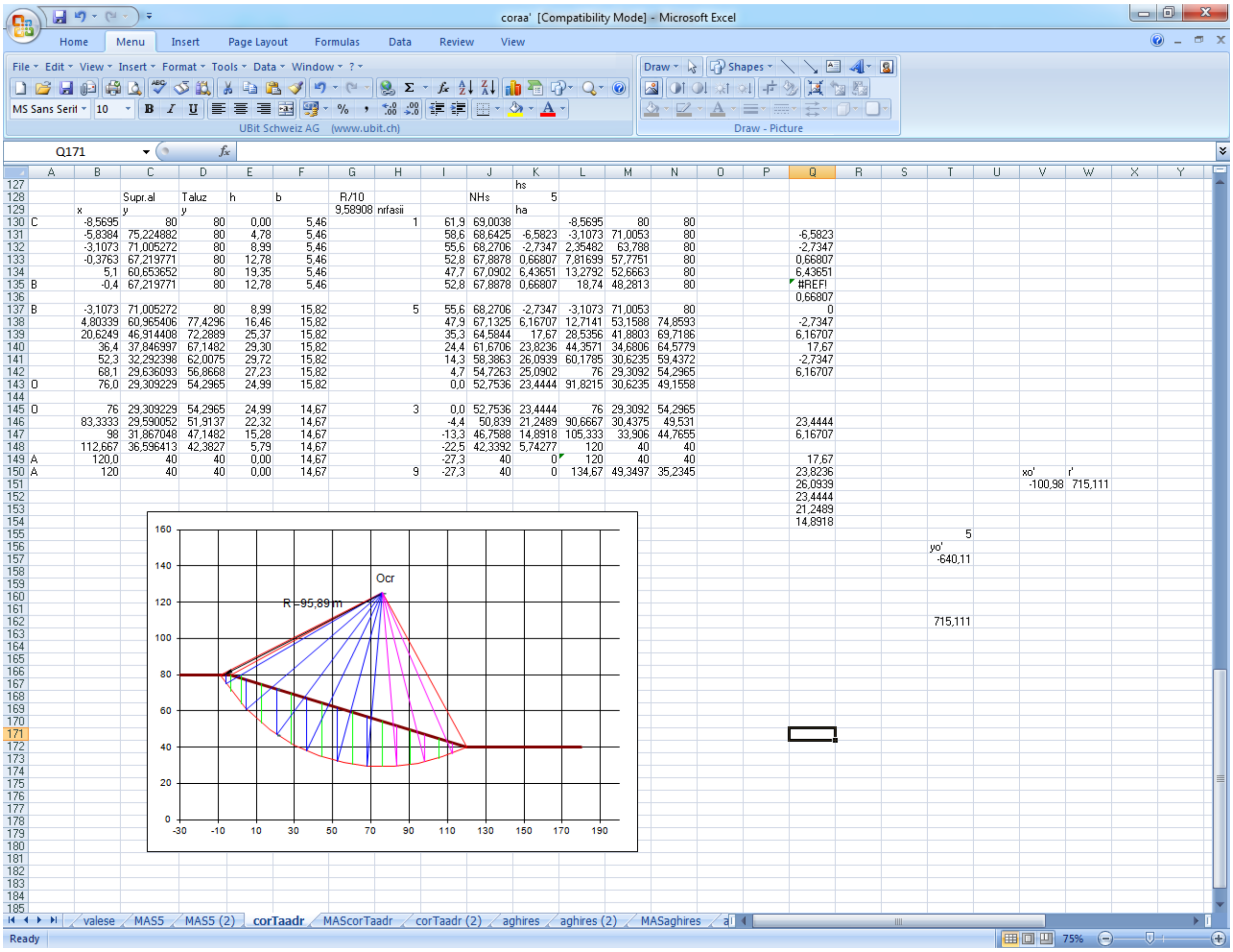
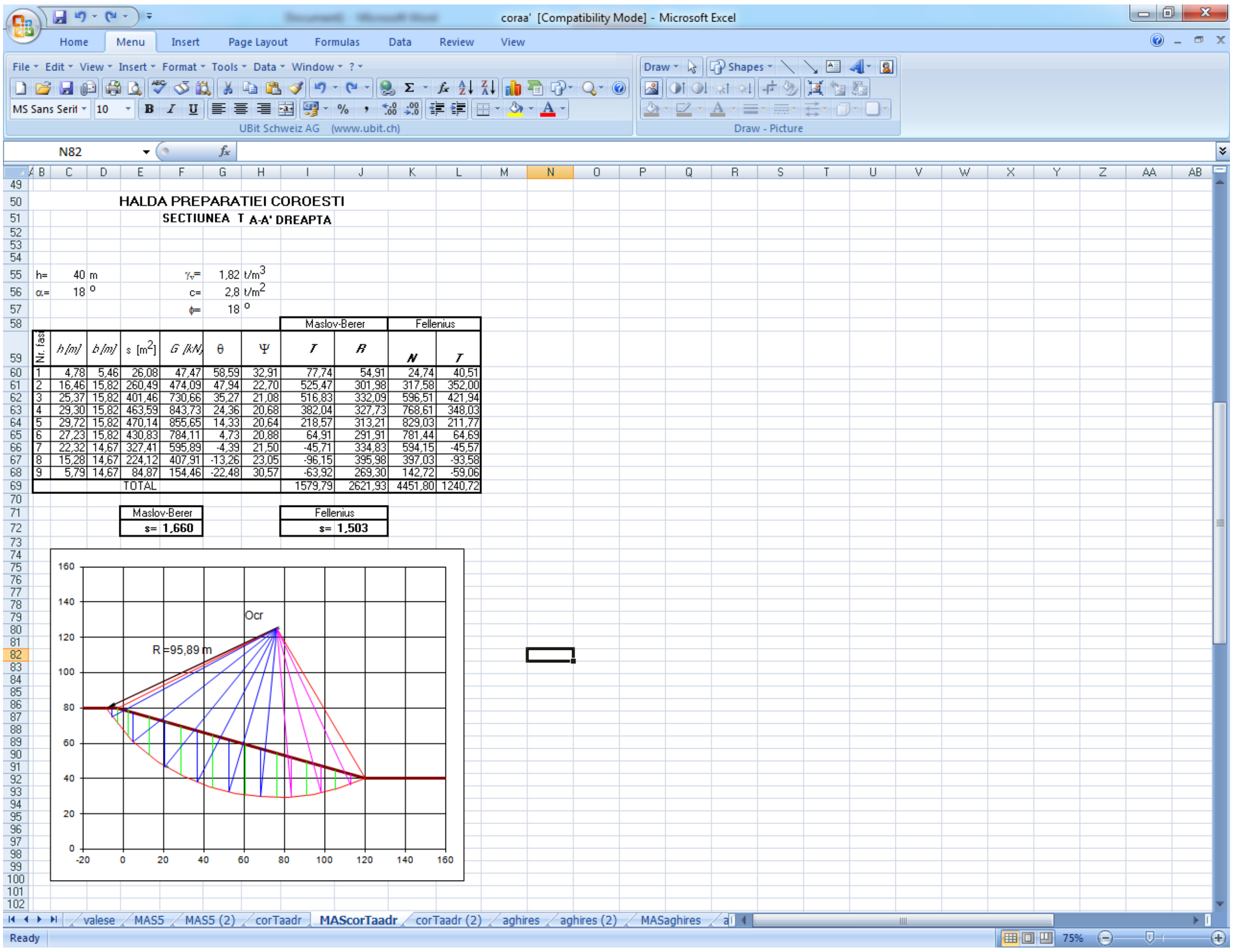


Figure 2.23 Determining the critical sliding surface and dividing into slices



Nr. fasii	h [m]	b [m]	s [m²]	G [kN]	θ	Ψ	T (Maslov-Berer)	R (Maslov-Berer)	N (Fellenius)	T (Fellenius)
1	4,78	5,46	26,08	47,47	58,59	32,91	77,74	54,91	24,74	40,51
2	16,46	15,82	260,49	474,09	47,94	22,70	525,47	301,98	317,58	352,00
3	25,37	15,82	401,46	730,66	35,27	21,08	516,83	332,09	596,51	421,94
4	29,30	15,82	463,59	843,73	24,36	20,68	382,04	327,73	768,61	348,03
5	29,72	15,82	470,14	855,65	14,33	20,64	218,57	313,21	829,03	211,77
6	27,23	15,82	430,83	784,11	4,73	20,88	64,91	291,91	781,44	64,69
7	22,32	14,67	327,41	595,89	-4,39	21,50	-45,71	334,83	594,15	-45,57
8	15,28	14,67	224,12	407,91	-13,26	23,05	-96,15	395,98	397,03	-93,58
9	5,79	14,67	84,87	154,46	-22,48	30,57	-63,92	269,30	142,72	-59,06
TOTAL							1579,79	2621,93	4451,80	1240,72

Figure 2.24 Calculation of the stability factor

Having provided a quick instrument for slope stability assessment and large number of data regarding the slope geometry and rock characteristics of the dumps, we then worked on designing a nomogram with which the stability factor can be determined quickly during the construction of dumps [A.4]. This method of evaluation is based on statistical analysis of data obtained from laboratory analyzes of rocks and results obtained from a large number of tests performed on Jiu Valley dumps with the previously submitted application.

In assessing the stability of a slope, its geometry and the rock's physical and mechanical characteristics are strongly interconnected. Accordingly, methods and procedures for assessing stability used in designing, construction and monitoring of dumps are based on imposing one of the geometric elements (height or slope angle), given a certain stability reserve, and the other geometric element is derived as a function of the imposed variable. In this case, it is necessary to correlate the value of the stability factor with the variance in height and slope angle.

Based on the graphs presented in figure 2.25, it has been demonstrated that this dependence has the following form:

$$F_s = s_0 \cdot h^{a_h} \cdot \alpha^{a_\alpha} \cdot c^{a_c} \cdot \varphi^{a_\varphi} \quad (2.9)$$

where: Fs – stability factor;

h – slope height, m;

α – slope angle, degrees;

c – cohesion, kN/m²;

φ – internal friction angle, degrees;

s_o, a_h, a_α, a_c, a_φ – statistically determined coefficients.

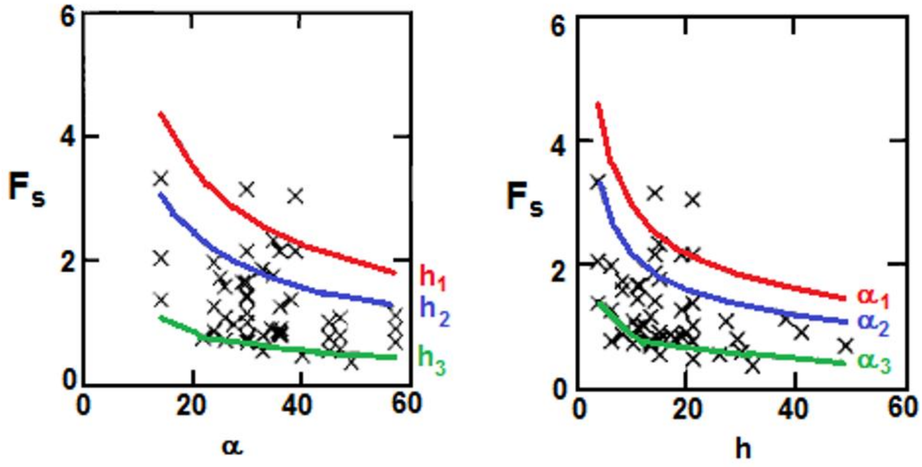


Figure 2.25 Stability factor depending on height and slope angle variance

The value of the stability factor Fs can be calculated using relation 2.9, in which the values for the slope geometric elements are inserted, along with physical and mechanical characteristics of rocks and the values for the statistically determined parameters, or it can be estimated using the nomogram from figure 2.26.

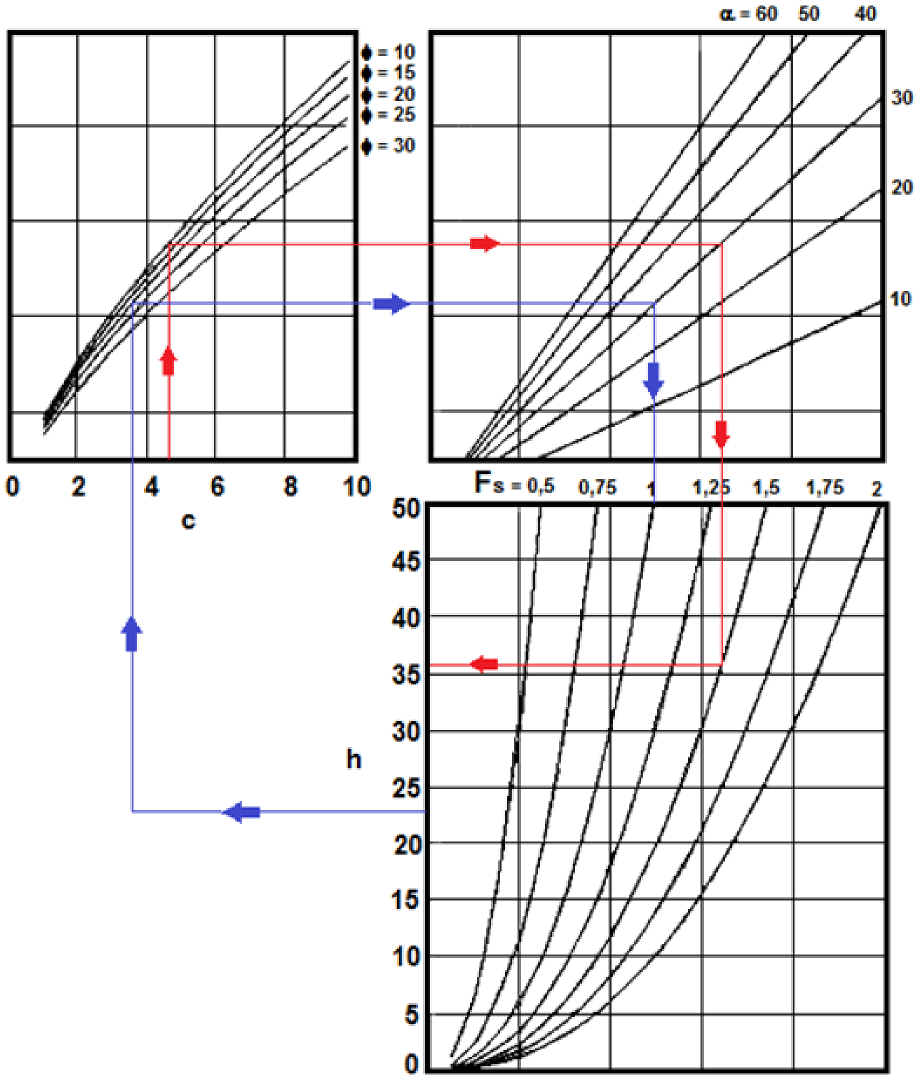


Figure 2.26 Nomogram for determining the stability elements

The nomogram can be used for rapid determination of height and/or slope angle for an imposed value of the stability factor, knowing the resistance characteristics of the rocks and imposing the technical criteria for one of the other geometric elements.

In the figure are shown methods for determining the slope height and stability factor. Thus, for a cohesion value of 4.3 kN/m^2, an internal friction angle of 9^o and a slope angle of 30^o, given the conditions of an imposed stability factor Fs = 1.5, a height of 36 m is determined (the red trace). In determining the stability factor, for a slope with a height of 23 m, a slope angle of 30^o, cohesion of 3.8 kN/m^2 and internal friction angle of 15^o, a value of Fs = 1 is obtained for the stability factor (the blue trace).

For each set of physical and mechanical characteristics, a graph can be built from which the geometric elements of the slope can be determined for an imposed stability factor value (or the stability factor in definite conditions for the slope's geometry) (figure 2.27).

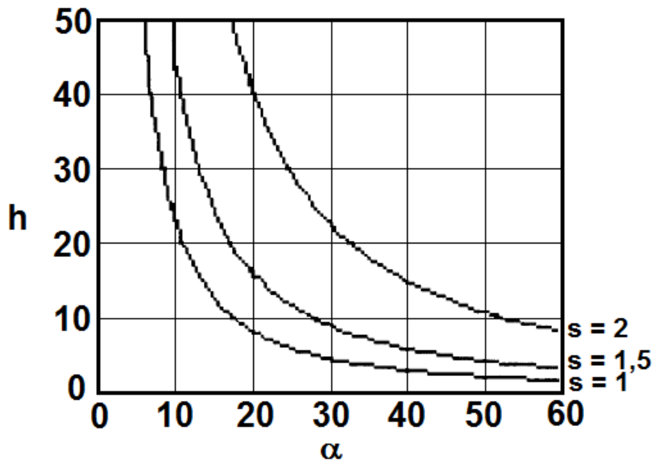


Figure 2.27 Determining the stability factor for a set of values

Thus, using the statistical correlation between the stability factor and geometric elements of the slope along with the physical and mechanical characteristics of the rocks, the quick estimation of the dump's stability is possible even during its construction. The charts presented can be drawn to the average values of physical and mechanical characteristics, and can be used for estimating the stability factor of dumps made of rocks with similar properties.

2.2.7 Research on stability of base terrain of the waste dumps in Jiu Valley

As a result of exploitation of hard coal in mines located in the Jiu Valley results significant amounts of waste rocks, derived from opening and preparation operations, but also from coal preparation processes. The waste rocks are deposited in dumps of various sizes, placed on level ground or on slopes. Although dumps building projects envisaged topsoil stripping (for reasons of stability, increasing the carrying capacity of the base land, and for reasons of environmental protection), in most cases the dumps were formed without fulfilling this requirement, the direct foundation of the dumps being the topsoil.

Field observations have shown that in addition to superficial or deep sliding phenomena of slopes, the base land is affected by discharge phenomena, which indicates that the carrying capacity is exceeded, especially during periods with precipitations. The purpose of this paper is to determine the carrying capacity of the base land of active dumps that stores important volumes of rocks and identify measures to be taken in order to avoid discharge phenomena and damage adjacent areas or underground mining works.

Currently, there are 49 waste dumps in Jiu Valley that stores a volume of about 37 million m3, occupying an area of over 250 ha [B.21]. Due to a lower activity in underground coal mining, most of these dumps were closed, being in different phases of rehabilitation and/or preservation. Among the active dumps, those that store large volumes of rocks are owned by mining units Lupeni, Uricani and Lonea and the dump owned by Coroeşti Coal Preparation (table 2.23)

Table 2.23 Characteristics of the waste dumps with volumes over 400000 m³

Waste dump	Mining unit	Surface, m²	Volume, m³
Branch 3	E.M. Lupeni	62700	1360108
New Funicular	E.M. Uricani	27000	547329
Branch 2	E.P.C.V.J.	112000	2573889
Lonea 1	E.M. Lonea	23000	426119

To achieve the goal, we started from the study of the existing documentation and direct observations in the field, new samples collected at the scene were analyzed in the laboratory, and the results were compared with those of existing stability studies and statistically processed. The carrying capacity of the base land was determined based on current regulations [B.58] and analyzed according to the pressure exerted by each dump in part, at natural humidity and saturation of the deposited rocks.

2.2.7.1 Negative geominig phenomena in the dumps field

Most dumps in Jiu Valley suffered deformations, from erosion to deep landslides, affecting also the base land by discharge phenomena.

- *Branch 3 – M.E. Lupeni*

The dump Branch 3 is located between Boncii and Renghii hills, being a dump located on slopes. It is one of the dumps where geotechnical work necessary for setting the foundation, topsoil removal, scarification of base land or construction of twinning steps were not performed. Failure to carry out these works, plus the almost total absence of work necessary for capturing and routing the surface and even underground waters (springs), makes possible to appearance of instability phenomena such as landslides, discharge and erosion.

The main types of deformations present on the dump Branch 3 are represented by compaction, erosion, land slides and discharge of the base land [B.46].

Compactions are normal, of stabilization, due to compaction of the dumped material under its own weight and due to circulation of heavy equipments, and also occur as a result of the dumping technology which does not provide a very high degree of compaction of the mixture of rocks. They have generally a favorable action on the stability reserve by reducing the slope angle and the height of the dump, but also by increasing the compaction and cementing the dumped material, with positive effects on shearing strength of rocks.

In addition to normal compaction inside the dump’s body, there are present some phenomena of subsidence with ground breaking (in steps) of the base land. The presence of these phenomena are due to underground mining activity, respectively the work fronts of Barbateni mine, and they appear downstream of the southwestern slope of the dump [B.46].

Erosion occurred as a result of mechanical action of surface water from rainfall and the lack of catchments and routing works, which led to the formation of gullies of different sizes, depending on the intensity of the runoff and the degree of compaction of the dumped material.

The dump quite frequently is affected by landslides on the slopes, occurring both in the dump, as well as through the base land, due to the tilt surface of contact, the presence of topsoil in the foundation and water infiltrations that wets the rocks and reduce their strength characteristics. The sliding surfaces are, regularly, of the progressive type and cylindrical-shaped.

Besides these slides of the heap, there must be mentioned some breakage and slippage of the slopes in the surrounding areas. It was considered that these were caused by underground mining activities.

Discharge of rocks occurred in the base land, at the boundary of the slope sliding area in the southwest part of the dump, and they occurred due to transmission of the slipping through the direct foundation (topsoil) by pushing rocks from the bottom of the dump [B.46].

In the area of the angular station, no significant instability phenomena were observed, outside rocks settling slips occurring where the limit height of the formation cone and the slope angle are exceeded. Not even in this area there were not executed works for foundation improving and the expanding of the dump towards the lake formed in the area of the hydraulic manifold causes a very weak interaction between the deposited rocks and direct foundation. For this reason, there is a risk of plastic flow phenomena occurring on the base land [B.4], [B.20], formation of dynamic shocks by sliding a larger amount of material in the lake, which may affect the stability of hydraulic manifold and uncontrolled discharge of water from the lake.

- *New Funicular – M. E. Uricani*

The dump consists of three main bodies. Following field observations and mapping the area it was found that the three dump bodies, although their geometry is not uniform, are stable and there are no special deformation phenomena.

It can be seen, however, some geomining phenomena specific for waste dumps such as compaction of the dumped material, erosion and discharge of slopes and base land [B.46].

Erosion occurs as a result of training the dumped material by runoffs, the dump being affected by such events on the side slopes.

Discharge of slopes and/or base land are the result of the transition of rocks in a plastic failure state, after which occurs a shift of argillaceous rocks from the dump and the base land under the influence of the dumped rocks weight. Such phenomena were observed more rarely in the case of ME Uricani dump.

- *The dump of Coroeşti Processing Plant*

The dump has a relatively uniform geometry, due to technological works and geomorphology of the area in which it is located.

In terms of geometry, the waste dump is characterized by high values of the height and slope angle (often exceeding 30 m height and the slope angles are between 30 - 43º. Due to geometric elements, land's morphology and by worsening the physical and mechanical characteristics of the deposited rock and the rocks from the direct foundation (represented topsoil), rainfall and the existence of lakes from which water seeps under the dump, the eastern slope was affected for a number of slides that have expanded and covered the road in the area [B.46].

Rainfall represents the main supply source of groundwater and existing streams on the two branches of the dump. Due to slow infiltration of water, wetting of the base rocks and deposited rocks in the lower part of the dump occurs, thus decrease their strength characteristics. If the precipitations are in the form of heavy rains, they have a destructive action by causing erosion [B.4], [B.20]. These phenomena are located mainly in shallow formation areas of the dump [B.46].

- *Lonea 1 – M. E. Lonea*

The old dump of Lonea mine is affected by phenomena of ruptures, curls, thrusts and plastic slides of the slope and plastic failure phenomena of the base land, particularly in the north-east. At the base of the new dump there were identified a number of water reservoirs, which are located along the abandoned conveyor route on a NW - SE direction, over a distance of 30 - 50 m. The status of tensions in the area is explained by the absence of an appropriate geometry, improper geometrical parameters of slopes (19 - 20 m height and inclination of 30° - 50º) and the presence of water seepage at the contact between the dump and the base land.

In case of slow melting snow, water seeps to the bottom of the dump, and some drain to the surface and trains a portion of the dumped material.

2.2.7.2 Physical and mechanical properties of deposited materials and of base land

Physical and mechanical characteristics (bulk density, cohesion and angle of internal friction) of earths are qualitative indices that respond to solicitations or the stresses that occur in the dumps and base land. Based on these values the size of the geometric elements of the dump and steps are determined.

Resistance characteristics are used in both the design and analysis of stability, but also in determining the carrying capacity of the base land. For this reason it is necessary to determine them rigorously, as the uncertainty on their values are transferred to the calculations. Strength characteristics of the material from the dumps and base land were determined in the earths mechanics laboratory of the University of Petrosani [B.46].

Since the values of these features vary within very wide limits, for the calculations were considered the statistical determined values (table 2.24).

Tab. nr. 2.24 Calculation values of the physical and mechanical characteristics

Rock type	Natural humidity			Saturation humidity		
	Volumetric weight γ_{nat}, (kN/m^3)	Cohesion, c, (kPa)	Angel of internal friction φ (grade)	Volumetric weight γ_{sat}, (kN/m^3)	Cohesion, c, (kPa)	Angel of internal friction φ (grade)
Branch 3 – ME Lupeni						
Waste material	18.7	31.38	27	19.4	25.49	23
Topsoil (dump's direct foundation)	18.0	33.34	26	19.2	24.51	21
New Funicular - ME Uricani						
Waste material	18.1	35.30	32	19.2	28.43	24
Topsoil (dump's direct foundation)	16.3	29.42	19	17.2	27.45	9
Coroeşti Processing Plant						
Waste material	17.2	27.45	26	19.1	14.71	12
Topsoil (dump's direct foundation)	18.2	34.32	20	18.2	19.61	14
Lonea 1 - ME Lonea						
Waste material	18.1	17.65	20	19.2	13.72	15
Topsoil (dump's direct foundation)	18.9	19.61	21	19.1	14.71	16

It is mentioned that laboratory measurements were made on both samples with the natural and saturation humidity.

2.2.7.3 Determination of the carrying capacity of the base land

According to Normative for designing structures of direct foundation NP 112-04, 2005 [B.58], in the calculation of the carrying capacity of the base land the following condition must be satisfy:

$$P_{ef} \leq P_{cr} \qquad (2.10)$$

were: P_{ef} – calculation value of the vertical action or the vertical component of total shares applied on the foundation base;
P_{cr} – calculation value of the carrying capacity.

The critical pressure what can be supported from the land was calculated on the basis of the national standards [B.58], using the equation:

$$P_{cr} = \gamma^* \cdot B' \cdot N_y \cdot \lambda_\gamma + q \cdot N_q \cdot \lambda_q + c^* \cdot N_c \cdot \lambda_c \quad \text{kPa} \qquad (2.11)$$

where: γ* - volumetric weight of the rock layers under the dump, kN/m3;
B' – reduced width of the dump base, m;
q – calculated overload acting on the side at level of the dump foundation, kPa;
c* - cohesion of the rocks layer under dump base, kPa;
N_y, N_q, N_c – dimensionless coefficients of the bearing capacity that depend on the angle of internal friction φ* of the rock layers under the dump;
λ_γ, λ_q, λ_c – shape coefficients of the dump base, depending on the reduced width and reduced length of the dump base.

On the basis of the geometrical and geotechnical characteristics and taking into account that overload q is null (because the dump is built directly on the land) have considered the following calculation values for the two cases: natural humidity of the rocks (table 2.25) and for water saturated rocks (table 2.26) [A.31]. It should be noted that the calculations were made taking into account the average size of the waste dumps, and their actual pressure was accepted as a distributed load.

Table 2.25 Calculation elements and results – natural humidity

Waste dump	γ* kN/m^3	B' m	N_y	λ_γ	c* kPa	N_c	λ_c	P_{cr} kPa	P_{ef} kPa
Branch 3 – ME Lupeni	18.0	95	4.5	1.07	24.51	22	0.93	7589.94	622.62
New Funicular - ME Uricani	16.3	50	1.8	1.13	27.45	14	0.88	1654.84	1651.11
Coroeşti Processing Plant	18.2	150	1.9	1.11	19.61	14.2	0.89	4754.30	702.71
Lonea 1 - ME Lonea	18.9	48	2.0	1.16	14.71	16	0.84	1700.35	1785.36

Tab. nr. 2.26 Calculation elements and results – saturated rocks

Waste dump	γ* kN/m^3	B' m	N_y	λ_γ	c* kPa	N_c	λ_c	P_{cr} kPa	P_{ef} kPa
Branch 3 – ME Lupeni	19.2	95	2.1	1.07	24.51	15.5	0.93	3910.05	645.93
New Funicular - ME Uricani	17.2	50	0.2	1.13	27.45	7.8	0.88	390.38	1751.45
Coroeşti Processing Plant	18.2	150	0.7	1.11	19.61	10.2	0.89	1855.11	780.34
Lonea 1 - ME Lonea	19.1	48	0.9	1.16	14.71	11.9	0.84	848.74	1893.86

Analyzing the two tables it can be seen that:

- ✓ Under natural humidity of the rocks deposited in the dump and the base land
  - the specific effective pressure generated by the dumps Branch 3 - ME Lupeni and Coroeşti Processing Plant do not exceed the critical pressure, with a covering stability factor;
  - the specific effective pressure generated by the dump New Funicular - ME Uricani is almost equal to the critical pressure;
  - the specific effective pressure generated by Lonea 1 dump is slightly above the critical pressure.
- ✓ Under saturation humidity of the rocks deposited in the dump and the base land
  - the specific effective pressure generated by the dumps Branch 3 - ME Lupeni and Coroeşti Processing Plant remains below the critical pressure;
  - the specific effective pressure generated by the dumps New Funicular - ME Uricani and Lonea 1 exceed by far the critical pressure value.

The results obtained by calculation are confirmed by the reality in the field, the most serious situation being observed at Lonea 1dump, where deformation phenomena of the base land occurs frequently; especially in periods of excess moisture. The main cause of these phenomena is the fact that the dumps were built without removing the topsoil, and the ratio between the stored volume of rocks and the occupied area is unfavorable.

2.3 Stability analysis using the finite elements method

The problems regarding the analysis of natural and artificial slope stability using the finite elements method are related to its complexity and insufficient data on the properties of the studied terrain. If such analyses are approached and performed correctly, the obtained results are close to reality, providing high reliability results. The finite elements method is based on the following principles:

- ✓ Equilibrium – between external forces and internal efforts;
- ✓ Kinematic – deformations and displacements;
- ✓ Constitutive relations – material behavior.

Many calculation programs based on numerical analysis use the technique of shear strength reduction to determine the stability factor. The method has a series of advantages, including the possibility of estimating the strains and deformations within the solid or manifested upon the sustaining elements.

The reduction technique of shear strength is used systematically to determine an effort reduction factor (safety factor) which determines the slope's instability. The most commonly used approach is the Mohr - Coulomb failure model. Low shear resistance, considering a material with Mohr - Coulomb behavior, is described by the equation:

$$\frac{\tau}{F} = \frac{c'}{F} + \frac{\sigma \cdot tg\varphi'}{F} \tag{2.12}$$

where F is the reduction factor. The equation can be written as:

$$\frac{\tau}{F} = c^* + \sigma \cdot tg\varphi^* \tag{2.13}$$

where,

$$c^* = \frac{c'}{F} \qquad iar \qquad \varphi^* = arctg\left(\frac{tg\varphi'}{F}\right) \tag{2.14}$$

are considered shear strength parameters for the Mohr - Coulomb model.

It is known that failure of earth structures (natural and artificial slopes) is similar to a shearing process at natural scale, in which the knowledge and evaluation of resistance and shear efforts have a vital role. By using calculation programs, the duration of performing analyzes is greatly reduces, and the results obtained are of high fidelity.

In most cases, the waste dumps from the Oltenia open pits consist of several steps, so it is necessary to check the stability for both the individual slopes and the whole step system. To this end, until the emergence of specialized software, classical stability analysis methods were used, which necessitated a large amount of calculations and could sometimes lead to errors caused by measurements on modeled topographic profiles(cut outs). By using the calculation programs, the execution time for these analyzes is greatly reduced, and the obtained results show a higher degree of reliability [A.25], [A.33].

The stability analysis was performed using three specialized softwares for geotechnic, namely PLAXIS, DC - Boschung and FIDES - Gleitkreis, with which the stability factor for individual steps and step systems from Oltenia dumps was determined.

The PLAXIS program, version 7.2, a product of PLAXIS B.V. in the Netherlands, performs a numerical calculation using the finite elements method. After entering the geometric model of the slope, using the automated network generator, the meshing takes place. PLAXIS uses triangular elements and can utilize elements with 6 and 15 knots. To obtain the most precise results, it is recommended to use elements with 15 knots. Mohr – Coulomb's theory, described previously, is assumed analyzing slopes engineered in soft rocks.

After the input of the physico-mechanical is calculating the own weight, and then the stability analysis is performed, using the Phi/C Reduction option, based on Fellenius method. The calculation results (displacements, grid deformation, stresses and tensions, stability factor values) are shown as graphical representations (figures 2.28 and 2.29) [A.33].

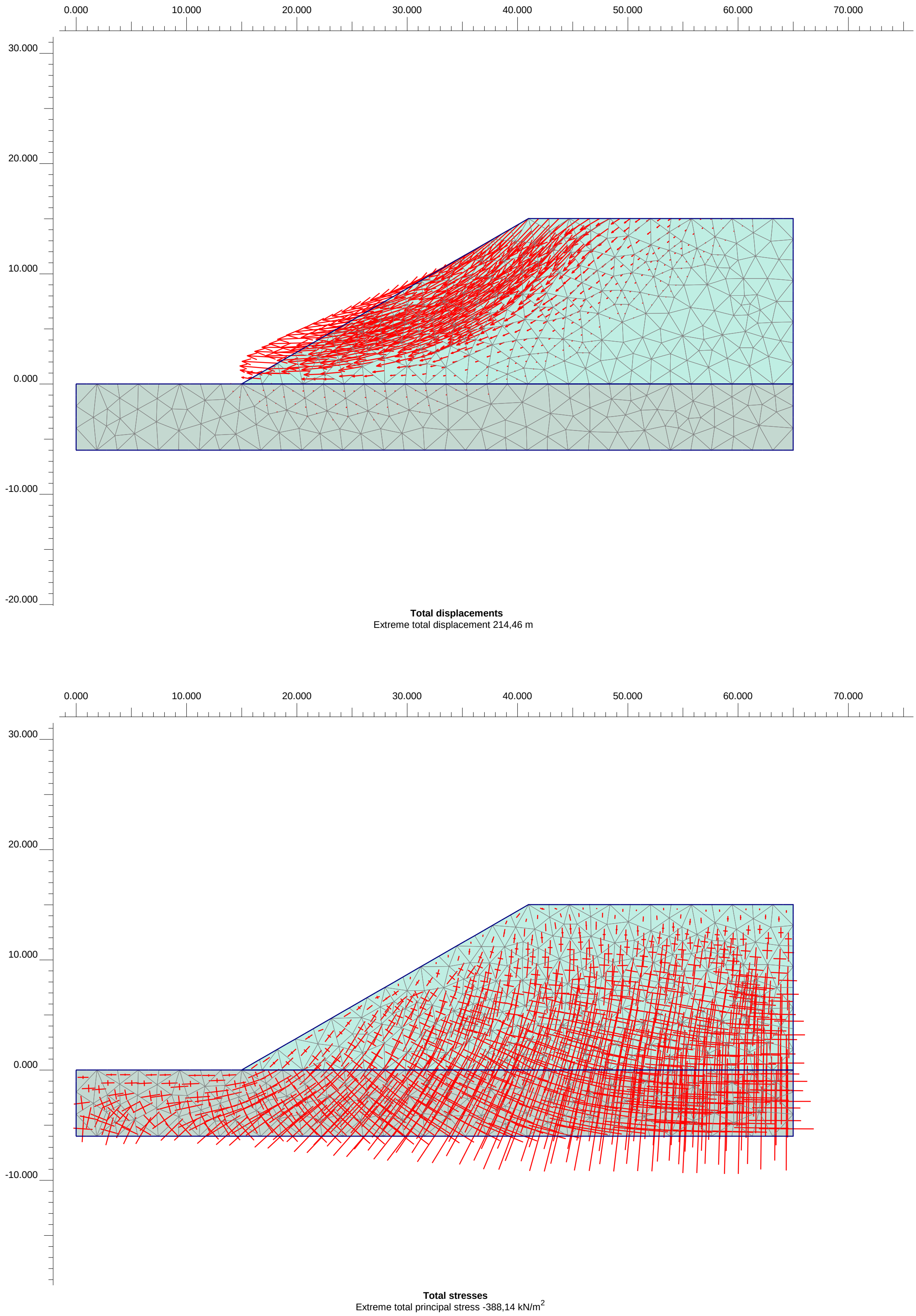
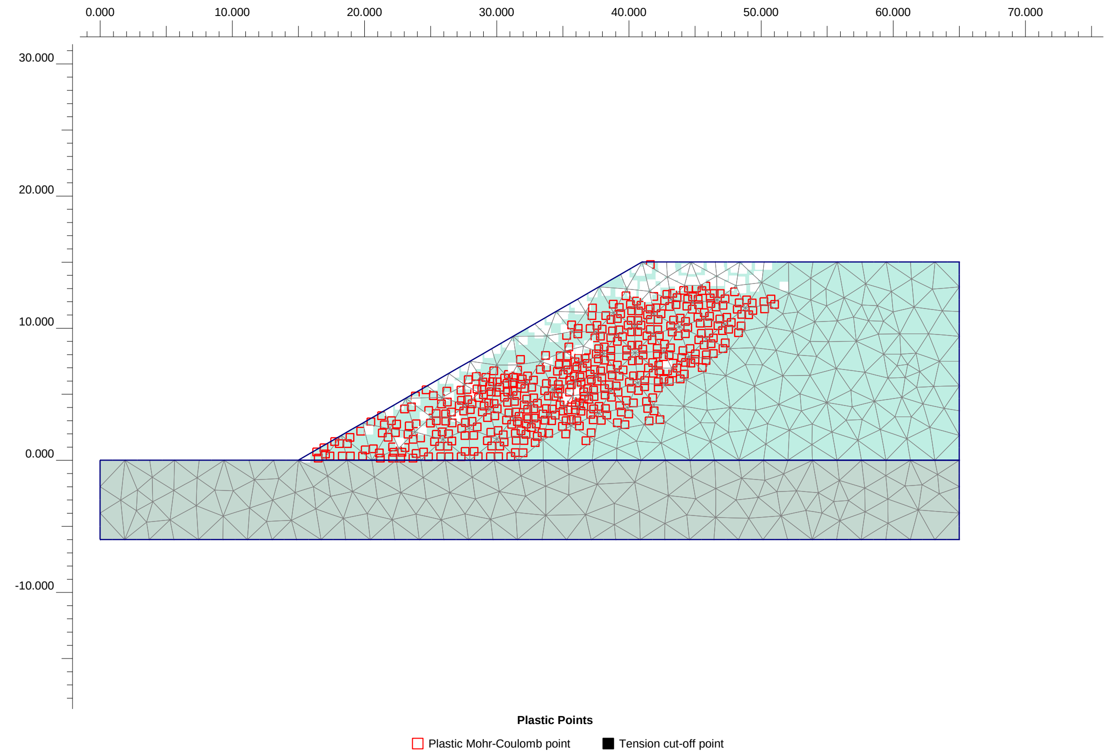


Figure 2.28 Displacements and stresses in the slope



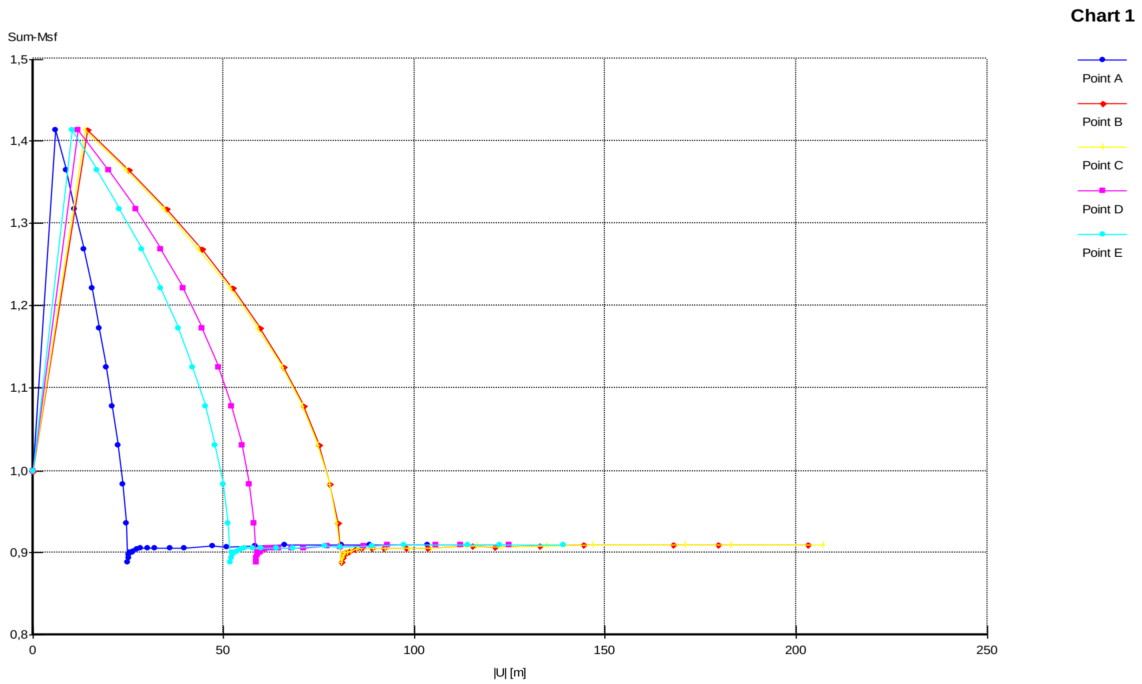


Figure 2.29 Plasticity conditions and stability factor

DC–Boschung and FIDES–Gleitkreis programs are products of the FIDES DV–PARTNER company from Munich and are based on the Krey - Bishop theory. It is accepted for the stability analysis a circular shaped sliding surface. The cross section of the sliding body is divided into slices and the stability factor is determined based on the calculation of torque relative to the center of the sliding surface. Both programs perform several iterations, to determine the minimum for the stability factor. The working principle is shown in figure 2.30.

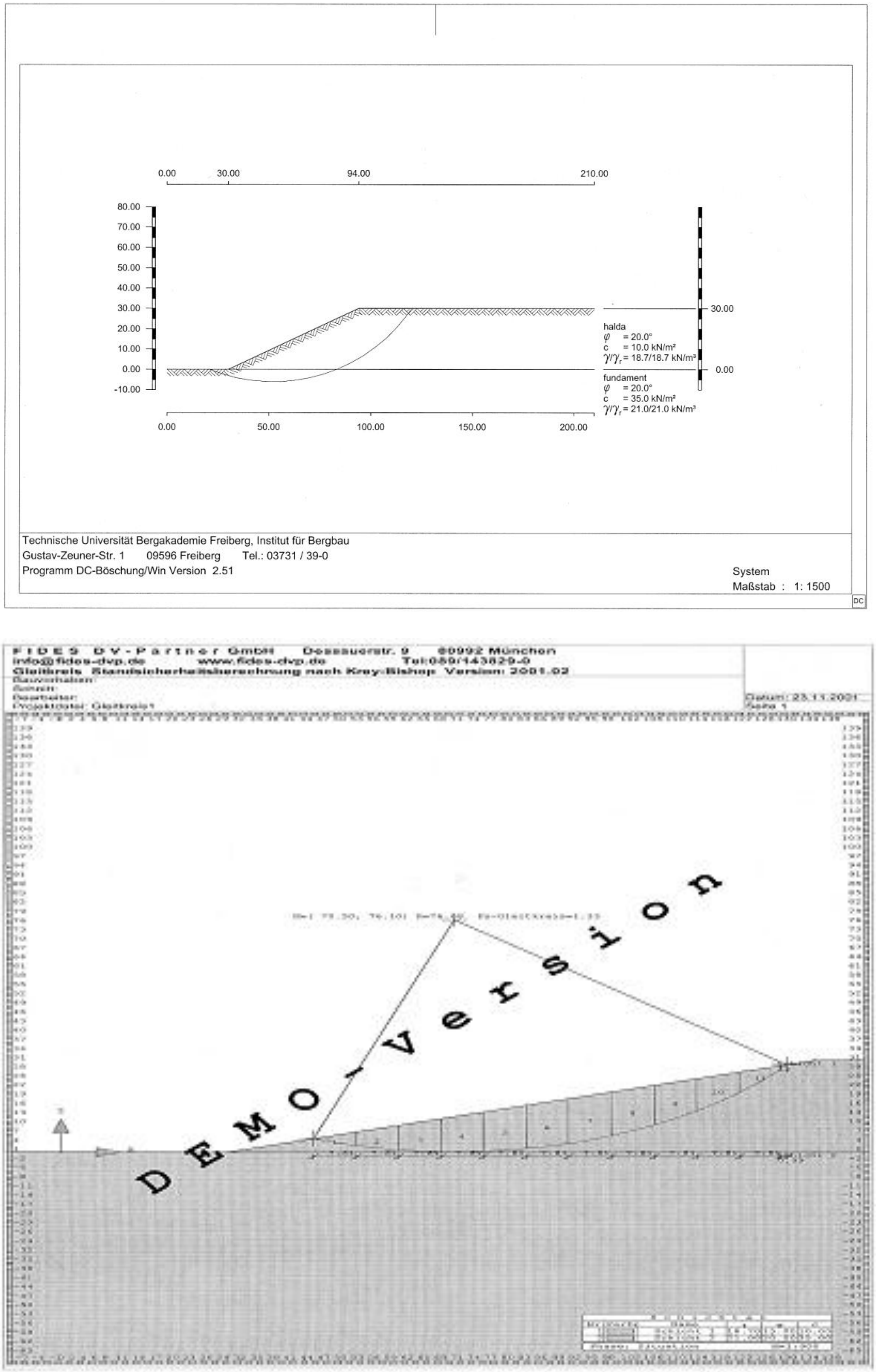


Figure 2.30 Stability analysis with DC – Boschung and FIDES - Gleitkreis

Given the geometrical characteristics of the waste dumps built in Oltenia, more values were considered for the height of the individual steps and their slope angles. Regarding the whole dump, a total working height of 102 m was used, for Pinoasa dump, and a variable general slope angle between 8 - 14º. The physical and mechanical characteristics of the waste dump material are shown in the table 2.27, and the stability calculations use average values thereof.

Table 2.27 Physical and mechanical characteristics of the waste material

Rock type	Apparent specific weight [kN/m^3]	Cohesion [kN/m^2]	Internal friction angle [degrees]
Clays	18.0 - 20.5	40 - 70	23 - 27
Mixture of clay, marl and dust	19.3 - 21.4	30 - 49	22
Mixture of clay, sand and dust	18.8 - 20.5	37	26
Mixture of sand and clay	16.3 - 19.4	2 - 6	26 - 29

Following the stability analysis with the programs described above, we obtained the results in table 2.28 were obtained for the considered cases.

Table 2.28 Stability factor values

Height , H (m)	Slope angle, φ (grade)	Stability factor, Fs		
		PLAXIS	FIDES-Gleitkreis	DC-Böschung
102	8	2.093	2.17	2.42
	10	1.646	1.77	1.90
	12	1.423	1.50	1.56
	14	1.390	1.29	1.34
30	16	1.450	1.33	1.66
	18	1.171	1.18	1.49
	20	1.066	1.08	1.36
	25	0.877	0.87	1.09
20	18	1.293	1.25	1.52
	20	1.196	1.17	1.25
	25	0.994	0.98	1.21
15	20	1.279	1.26	1.53
	25	1.059	1.02	1.29
	30	0.888	0.91	1.23

An interesting fact is that, although the last two programs used are based on similar principles, the results are quite different. Instead, it is obvious that the results obtained by PLAXIS, the program using the finite elements method, are close to those obtained by FIDES - Gleitkreis, leading to higher reliability.

It can be seen in table 2.28 that the slope angle values for which a stability reserve of approx. 1.3 is ensured for each step are relatively small (16º for a height of 30 m, 18º for a height of 20 m, and 20º for a height of 15 m), which leads to a general slope inclination for a waste dump with total height of 102 of 8.5º. This configuration provides quite a high stability reserve for the general slope (s = 2), a justified value bearing in mind the long time span it needs to stay in place. Under these conditions, for a waste dump with 5 steps, each 20 m high, a width of 93 m is recommended for each intermediate berm (figure nr. 2.31) [A.33].

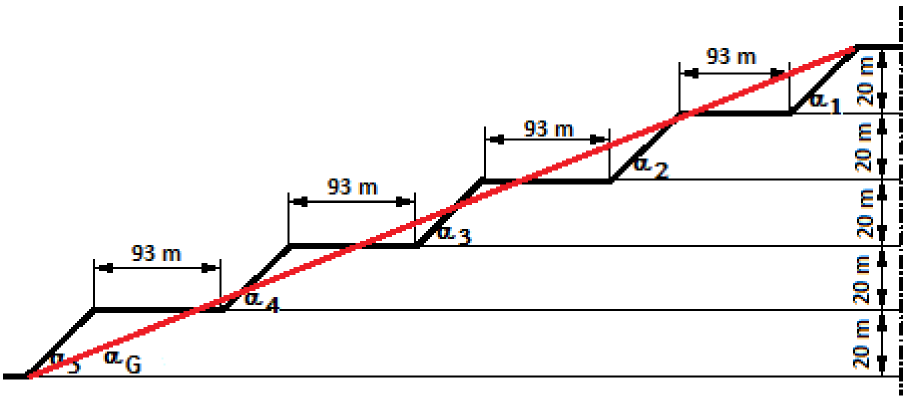


Figure 2.31 Geometry of the steps system

The necessary geometry of the steps system and individual slopes can be obtained by execution of leveling and reshaping works. Achieving this geometry ensures the conditions required for the reintroduction the dumps in agricultural and forestry circuit, without any supplementary arrangement works.

2.4 Probabilistic methods of stability analysis

On checking the stability of a slope, it is considered to be in equilibrium, when the ratio of passive forces (R) and active forces (S) is equal to 1 (R / S = 1). The ratio R / S is called coefficient of stability (Fs). To take account of possible errors introduced into the calculations, for the trust grade and conformity to norms, the reference factor of stability should be higher than 1, usually equal to 1, 3.

In deterministic stability analyses, mainly four sources of errors may occur:

- ✓ natural ones, caused by the heterogeneity of the material: geotechnical research are punctual and allow only a partial knowledge of the variations of the mechanical characteristics of the terrain;
- ✓ reduced accuracy in performing geotechnical research in situ or in the laboratory;
- ✓ approximation of the empirical correlations available in literature for indirect assessment of the terrain parameters;
- ✓ simplifications introduced by the terrain model which is used.

In a deterministic approach, the effects of the errors introduced are covered by imposing a stability coefficient value greater than 1.

A probabilistic analysis, which allows the examination of errors with instruments of probability theory, allow the approach of the sources of uncertainty in a more rigorous and rational manner. Probabilistic analysis uses instead of the concept of stability rate the concept of stability limit (LS), defined as the difference between the passive forces and active forces (LS = R - S).

Because the rigorous application of this definition does not allow the use of some calculation methods, such as classical methods, the limit of stability is redefined with the relationship:

$$LS = \frac{R}{S} - 1 = F_s - 1 \qquad (2.15)$$

On equilibrium, stability limit LS is zero (S = R), and values greater than zero indicates stable slopes and values less than zero unstable slopes.

The sources of uncertainty lead to generate a range of possible values of stability limit LS, distributed according to a law of probability density (as an example, Gauss distribution). It is defined as probability of failure (p_r) the probability that the value of LS to be less than 0 (equilibrium condition).

The confidence index is related to the probability of failure through the relationship:

$$I = 1 - p_r \qquad (2.16)$$

2.4.1 The Rosemblueth Method

The Rosemblueth method [B.40], [B.41] applied to check the stability of a slopes in soft rocks, allows to obtain the most probably value of the stability limit LS (LS_m average) and of an indication of its dispersion (standard deviation S_{LS}). In this case the parameters c and φ may be used as casual variables, assuming that they have a symmetric Gaussian distribution.

The procedure is as follows:.

- ✓ with the data determined in situ or in the laboratory, we calculated the average value of c and φ (c_m and φ_m) and the corresponding standard deviations (s_c and φ_s);
- ✓ using a method of equilibrium limit, the appropriate stability limit is calculated for the following combinations of parameters:

$$\begin{aligned}
&(c = c_m + s_c;\ \varphi = \varphi_m + s_\varphi) \rightarrow LS1\\
&(c = c_m + s_c;\ \varphi = \varphi_m - s_\varphi) \rightarrow LS2\\
&(c = c_m - sc;\ \varphi = \varphi_m + s_\varphi) \rightarrow LS3\\
&(c = c_m - s_c;\ \varphi = \varphi_m - s_\varphi) \rightarrow LS4
\end{aligned} \qquad (2.17)$$

- ✓ then the average LS_m is calculated with the relationship:

$$LS_m = \left(LS_1 + LS_2 + LS_3 + LS_4\right)/4 \qquad (2.18)$$

and standard deviation with the relationship:

$$S_{LS} = 0{,}5 \cdot \sqrt{\left(LS_1^2 + LS_2^2 + LS_3^2 + LS_4^2\right)} \qquad (2.19)$$

The goal of an analysis carried out on probabilistic grounds is the identifying of the probability of breaking (p_r) examined slope. Monte Carlo and Rosenblueth methods allow obtaining proper assessment of the average LS_m and standard deviation S_{LS} of stability limit [B.40], [B.41]. These parameters allow to obtain directly the value of LS associated with a certain probability of sliding (the characteristic value of LS) with the relationship:

$$LS_k = LS_m \cdot \left(1 + \chi \cdot K_{LS}\right) \qquad (2.20)$$

where: LS_k - characteristic value of stability limits;

LS_m - average of stability limit;

K_{LS} - coefficient of variation LS, defined as the ratio between the standard deviation and average values of LS;;

X - parameter dependent of adopted law of probability distribution and of failure probability.

By the failure probability means the probability that the "real" value of LS to be lower than a given value. For example, the statement that a value of LS has a failure probability of 10% means there is a 10% probability that the "real" value of the stability limit is lower.

The parameter χ depends solely on the chosen law of probability density [B.40], [B.41]. In the case of a Gaussian distribution, the values of χ can be obtained directly from the table 2.29 [B.7] or from the graph presented in figure 2.32.

Table 2.29 Determining of the parameter χ

Failure probability (%)	χ	Failure probability (%)	χ
1	-2.326	60	0.253
5	-1.645	70	0.524
10	-1.282	80	0.842
20	-0.842	90	1.282
30	-0.524	95	1.645
40	-0.253	99	2.326
50	0	-	-

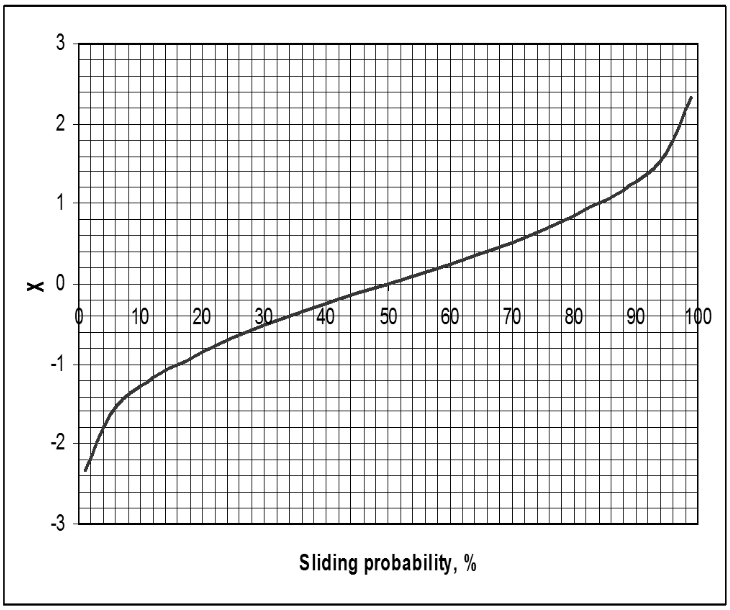


Figure 2.32 The graphical representation of the failure probability as a function of the parameter χ

It remains to define what probability of failure could be considered acceptable and for what value of pr the slope can be defined as stable. In principle, this value should be linked to the importance of the case and to knowledge grade of the characteristics of the land. After Priest and Brown [B.38], the acceptable failure probability could be considered as a first approximation at 1% in situations where the slide does not imply grave material and human damages and by 0,3% in the contrary case. So, if the breaking probability is lower than these values, the slope can be considered stable and otherwise unstable.

2.4.2 Qualitative analysis of slope stability using the fuzzy sets method

Fuzzy logic tools allow rigorous treatment of problems of qualitative assessment, from a series of data with a high grade of approximation. Among the many possible applications is the evaluation on the grade of stability of a slope. Fuzzy theory started with the concept of fuzziness and its expression in the form of fuzzy sets was introduced by Zadeh [B.52].

Fuzzy sets theory can be used to solve of different problems in many areas [B.53], including in the applied geotechnical field. Sakurai and Shimizu [B.47] proposed using fuzzy theory for qualitative assessment of slope stability on the basis of the fuzzified factor of safety (Fs), defined as a trapezoidal membership function. Fuzzy logic tools allow rigorous treatment of problems of qualitative assessment, from a series of data with a high grade of approximation. The method provides three important stages:

- ✓ Definition of the membership functions of the two parameters of rocks resistance, i.e. cohesion and the angle of internal friction. The membership function is the basic tool of fuzzy logic and indicates the grade of membership of a series of data at a particular system. In this case, is the membership grade of the parameters of the shearing resistance c, and internal angle of friction, φ to the proper values of the considered terrain. Those values of c and φ belonging certainly to the terrain will be considered as having the membership grade equal to 1. The values of c, φ certainly not belonging to the terrain have a membership grade 0. The intermediate values have intermediary membership grades.
- ✓ Generation of membership function of the coefficient of stability. Mixing pairings values c, φ available and using a determinist method of calculation (Fellenius, Bishop, Janbu etc.) one obtain the corresponding safety coefficient (one for each pair of values). The sliding surface will be established through a preliminary examination with a pair of average values for c and φ. With the determined values of Fs we build the membership function of the stability coefficient.
- ✓ Qualitative estimation of slope stability. Based on the membership function of the coefficient of stability with the value Fs = 1 (equilibrium condition) is possible to obtain a qualitative

information on the grade of stability of analyzed slope, using the scheme proposed by Sakurai and Shimizu (figure 2.33).

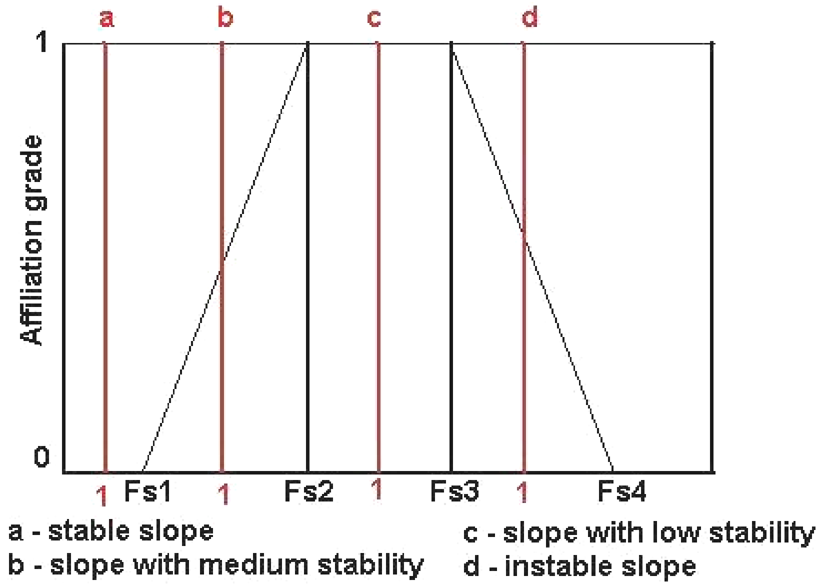


Figure 2.33 Estimation scheme of stability grade

The usefulness of the fuzzy method applied in analysis of slope stability lies in its ability to provide qualitative information on the grade of slope stability through a rigorous process. The method does not replace quantitative methods, determinist and probabilistic, but can represent a prologue, able to give the projecting, before achievement of the geotechnical research and their interpretation, an image on any slope consolidation works.

2.4.3. Estimation of failure probability of the open pit Roşiuţa dumps

In all three of sterile dumps of Roşiuţa open pit, sliding phenomena of a smaller or larger scale occurred along time, both as regards individual slopes and the benches system. As mentioned, the large-scale landslides occurred mainly in Rogoazelor Valley dump, but there were such phenomena in the other two dumps of Rosiuta open pit, respectively Bujorăscu Valley and Ştiucani Valley. In the following one deals with the question of assessing the grade of stability and sliding risk of sterile dumps, using the probabilistic methods. [A.10], [A.13].

For statistical analysis of the geotechnical characteristics of the rocks in the dumps structure, in addition to data from three drillings executed in the dumps Rogoazelor Valley and Valley Bujorăscu (table. 2.1), were processed in the laboratory samples taken from other three drillings executed in the dump Ştiucani Valley, for which were determined the necessary characteristics for the stability analysis, all used values are presented in table 2.30.

Table 2.30 Physical and mechanical characteristics of the material sampled from boreholes

Proved interval	Volumetric weight γ_v	Shear strength		Proved interval	Volumetric weight γ_v	Shear strength	
		Cohesion c	Internal friction angle φ			Cohesion c	Internal friction angle φ
m	kN/m^3	kN/m^2	grade	m	kN/m^3	kN/m^2	grade
0	1	2	3	4	5	6	7
Drilling 1				*Drilling 4*			
0-3	18.15	14	16	0-1.8	19.23	31	12
4.5-5.3	18.32	13	17	1.8-4.7	18.28	23	16
7-8	18.93	18	18	4.7-6	18.70	9	6
8.5-11	18.98	21	19	6-9.3	18.12	14	22
11-15.3	18.88	31	16	9.3-17.2	17.36	48	13
15.3-20	19.37	20	17	17.2-20	18.99	21	20

Drilling 2				***Drilling 5***			
0-1.3	18.85	37	14	0-3.3	17.46	19	14
1.3-5.3	18.06	29	10	3.3-4.4	18.80	10	12
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**
5.3-9	18.83	28	14	4.4-8.3	19.04	20	23
9-17.7	18.55	26	18	8.3-9.3	18.51	31	19
17.7-20	18.58	20	22	9.3-15	17.70	36	16
Drilling 3				***Drilling 6***			
0-5.6	19.10	30	22	0-2.5	19.51	19	17
5.6-9	17.80	39	19	2.5-4.5	17.93	19	4
9-16.4	18.64	41	21	7.3-9.1	18.48	52	25
16.4-21	19.0	32	18	9.1-11.2	19.30	51	12
				11.2-14	18.56	09	11

2.4.3.1 Estimation of the stability grade with the fuzzy method

Geometry modeling and analysis of the stability grade of dumps were made using specialized software issues geotechnical GeoTecB, the method used for calculating the stability factor is the method of Fellenius.

To this purpose, the physical and mechanical characteristics of the rocks were subjected to a statistical processing, which have determined to the minimum and maximum values, average M and standard deviation σ. It was awarded the affiliation grade 1 for the values between M - σ and M + σ, and the affiliation grade zero for minimum and maximum values, thereby achieving four pairs of values. [A.34].

The results obtained for slopes with height of 15 meters and inclination of 30^{o} (these are the most common geometry of the three dumps slopes) are presented in table 2.31, and their interpretation may follow in figure 2.34.

Table 2.31 The results of statistical processing of the obtained data

Value	**Cohesion c, kN/m^{2}c**	**Angle of internal friction φ, grade**	**Stability factor F_s**
Min.	9	4	0.48
M - σ	14	11.4	0.97
M + σ	38	21	2.25
Max.	52	25	2.93

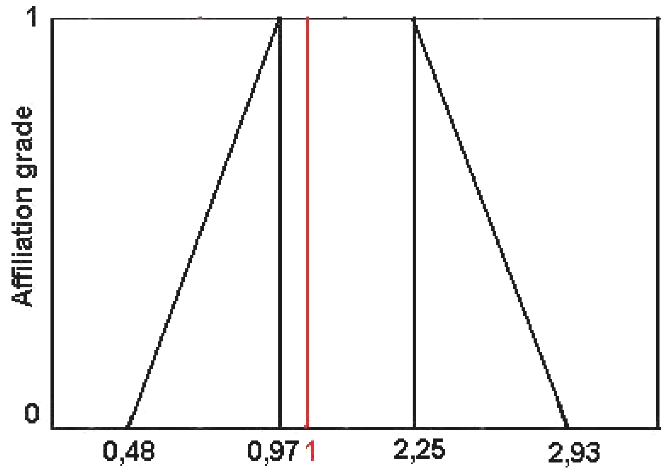


Figure 2.34 Qualitative estimation of dumps stability

According to these results, the dump slopes with considered geometry, consisting of waste rocks from Roşiuţa open pit mine, exposes a low grade of stability and can fail under the action of some external factors, such as, e.g., rainfall.

2.4.3.2 Estimating of failure probability

For this purpose, the Rosemblueth method has been used, to assess the failing probability of slopes, taking into account the mechanical characteristics of the rocks for the same pairs of values used previously and determining first the limit of stability (table 2.32).

Table 2.32 Assessment of the failure probability

Value	Cohesion c, kN/m^2	Angle of internal friction φ, grade	Stability factor F_s	Stability limit LS
Min.	9	4	0.48	-0.52
M - σ	14	11.4	0.97	-0.03
M + σ	38	21	2.25	1.25
Max.	52	25	2.93	1.93
LSm	0.6575			
SmS	1.178845			
VLs	1.79292			
χ	-0.55775			

Based on the above relationships were calculated elements necessary to determine the failure probability of the dump slopes. As it can be seen in the table 2.32, for the value calculated by χ = -0557, it results the sliding probability of 30%, which indicates a serious risk of dumps sliding, given the size and the large volumes of the stored waste material.

Probabilistic methods to estimate the slope stability do not replace the deterministic methods, but may offer a first assessment of the grade of stability, depending on the slope's geometry and on the mechanical and physical properties that characterizes the mixture of rocks from waste rock dumps. Regardless of methods used, in the case of external waste rock dumps of the Roşiuţa open pit mine it is obvious that the occurrence of slide phenomena is possible, which requires measures to be taken in the design of the geometry of dump's benches. [A.34].

2.5 Methodology for assessing the environmental risk due to mining waste dumps sliding - case study of Jiu Valley

Waste dumps stability problem is particularly important because sliding phenomena can endanger the natural and anthropogenic components of the environment situated in the influence area. Also, waste dumps sliding involve works and additional costs to restore the geometry and/or may result in damage to equipments or even can endanger the personnel working with these equipments. In the particular case of mining areas where the number of waste dumps is high and they are located either in areas with high naturalistic value or close to infrastructures, industrial buildings, households etc., is important to know the technical condition of the dumps and the risks faced by the adjacent areas in case of a landslide.

The Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 regarding the management of waste from extractive industries and amending Directive 2004/35/EC requires „*long-term geotechnical stability of any dams or waste dumps rising above the pre-existing ground level as well as the physical stability to prevent pollution or contamination of soil, air, surface water or groundwater on short and long term, and to minimize, as much as possible, damages on landscape*" [B.64]. Taking into account these aspects, the aim of this paper is to establish a risk assessment methodology to which the environment is subjected (both natural and anthropogenic components) in circumstances of waste dumps sliding.

Starting from the assessment of the technical conditions of active dumps from Jiu Valley, a matrix defining the vulnerability of natural and anthropogenic components of the environment in the adjacent areas in the event of sliding phenomena was developed. This matrix was modeled based on the classification of waste dumps according to the sliding hazard degree. Using several sets of values resulted from statistical processing of the physical and mechanical characteristics of the deposited material, stability studies were performed in order to determine the probability of waste dumps sliding. In the end an environmental risk scale was determined. This risk scale depends on the slopes sliding probability and the value of the natural and anthropogenic components of the environment that may be affected by sliding. Based on the results, measures to stabilize recover and rehabilitate the waste dumps can be taken in order to ensure the physical stability both during construction and after completion of depositing works for their immediate reintegration in natural cycles.

2.5.1 Overview of current situation of waste dumps from Jiu Valley

In Jiu Valley mining basin there are now 9 still active dumps; the others are in different ecological rehabilitation stages or were abandoned. The 9 active waste dumps occupies an area of 50.75 ha and they store an amount of 6.46 million m^3 (table 2.33) [A.29].

Table 2.33 Active waste dumps from Jiu Valley

Waste dump	Mining Unit	Dump surface [m^2]	Designed capacity [m^3]	Used capacity [m^3]
Lonea 1	EM Lonea	23.000	4.000.000	426.119
Jieţ	EM Lonea	10.400	90.500	65.122
Branch R-V Petrila	EM Petrila	195.900	3.755.454	336.231
Maleia AS no. 2-3	EM Livezeni	23.000	380.000	318.758
Livezeni preparation	EM Livezeni	36.000	144.000	468.115
Arsului Valley	EM Vulcan	17.500	1.200.000	367.918
Branch 2 J.V.C.P.E.	E.C.P.V.J.	112.000	2.000.000	2.573.889
Branch 3 Lupeni	EM Lupeni	62.700	2.000.000	1.360.108
New Funicular	EM Uricani	27.000	700.000	547.329

Natural and anthropogenic environmental components located near active waste dumps are numerous, so the environmental risk in case of loss of stability may be major. However, the risk severity depends on the nature of the impact on the receiver and on the probability to occur the impact.

2.5.2 Field researches

In order to evaluate the technical conditions and behavior of the waste dumps visual observations and geotechnical mappings were made. The waste dumps still active from Jiu Valley are located in valleys or on slopes, and in the adjacent areas there are natural and anthropogenic components of the environment that may be affected by their sliding.

Following field research, there were identified the natural and anthropogenic components of the environment located in areas adjacent to the waste dumps (table 2.34) [A.8].

Table 2.34 Objectives in the waste dumps influence area and technical conditions of the dumps

Waste dump	Natural and anthropogenic components/technical conditions
Lonea 1	Households and School no. 3 at approx. 200 m, scattered (restricted) movement of people, East Jiu River, land with poor vegetation/affected by landslides, discharge of material and erosion.
Jieţ	Households, communication routes with limited traffic and scattered (restricted) movement of people, lake located S-W of the dump, river Jieţ, deciduous forests, farmland/relatively stable, some erosion.
Branch R-V Petrila	Households and DN7A road at approx. 500 m, communication routes with limited traffic and scattered (restricted) movement of people, the lake from the northern side belonging to Pro Fishermen Association, Ştiurţ Lake from the southern side, land with poor vegetation (grazing), brushes, especially birch, willow and acacia/superficial landslides and erosion.
Maleia AS no. 2-3	Households, DN7A road, woodworking hall belonging to SC ALPINE SRL, communication routes with intense traffic and intense movement of people, Maleia creek, deciduous forests/superficial landslides and erosion.
Livezeni preparation	Households, communication routes with limited traffic and scattered (restricted) movement of people, East Jiu River, land with poor vegetation (deciduous)/relatively stable, some erosion.

Arsului Valley	Coastal tunnel, individual households, communication routes with limited traffic and scattered movement of people, Arsului Valley creek, the lake formed due to sinking land, land with thick vegetation, deciduous forests/relatively stable, some erosion.
Branch 2 J.V.C.P.E.	Scattered movement of people, mine premises at approx. 1 km from the waste dump, Vulcan residential area at approx. 1.5 km, several individual households, West Jiu River, Priboi creek, two water reservoirs, land with thick vegetation, deciduous forests/affected by landslides and erosion.
Branch 3 Lupeni	Scattered movement of people, Lupeni residential area and mine premises at approx. 1.5 km, West Jiu River, Ferejele and Boncii creeks, water reservoirs (lakes and ponds), land with thick vegetation, mixed forests of predominantly deciduous species and less coniferous species/affected by landslides, discharge of material and erosion.
New Funicular Uricani	Scattered movement of people, West Jiu River at approx. 100 m, water reservoir (lake), springs, land with thick vegetation, mixed forests (deciduous and coniferous species)/ affected by material compaction, erosion and discharge of material.

Also there were observed the geometry and technical conditions of the waste dumps, their behavior under the influence of external factors and the presence of signs indicating a decrease of the resistance of the deposited rocks (erosion, water reservoirs, etc.), the results of the investigations are shown in figure 2.35 [A.8].

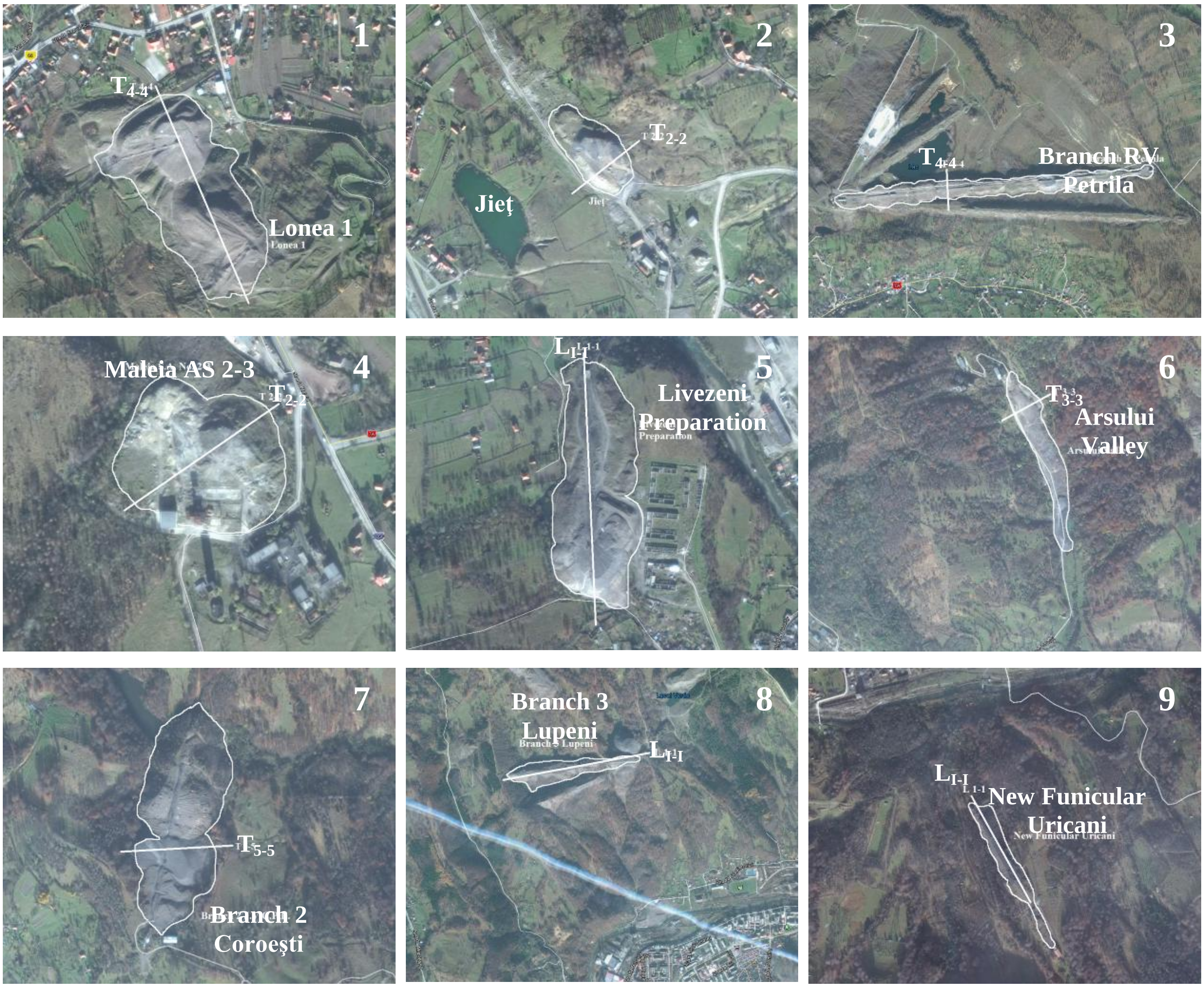


Figure 2.35 The active waste dumps and the natural and anthropogenic components located in their influence area

It can be observed that the components of the natural environment and those built up near active waste dumps are numerous and important. (natural ecosystems, industrial infrastructures and buildings, administrative buildings, households etc.). This underlines the need to ensure the stability of the waste dumps in order to eliminate the possibility of sliding phenomena to occur that may lead to their damage or destruction.

2.5.3 Developing the environmental vulnerability matrix for waste dumps slides

The vulnerability level is determined mostly by the physical exposure of natural or anthropogenic components of the environment, due to their location in areas where there is likelihood of various destructive phenomena to occur [B.26], including landslides or waste dumps slides.

In the literature there is a classification of waste dumps depending on the type of buildings and infrastructures situated in the influence area and their stability degree [B.62].

By adding to this classification the type of ecosystems present in the influence area, a matrix was developed. This matrix establishes the level of vulnerability of the natural and anthropogenic components of the environment in relation with the stability degree of the waste dumps (table 2.35).

Table 2.35 Matrix for determination of the environmental vulnerability (adapted after MLSP, 1997)

Technical conditions of the waste dumps / **Natural and anthropogenic components of the environment located in the influence area**	**Waste dumps with dangerous movements, active sliding, involving important volumes of material**	**Waste dumps with active superficial sliding that can go in to dangerous movements**	**Stable waste dumps, no active movements, can go in to sliding due to triggering factors**	**Stabilized waste dumps, for which sliding phenomena are not likely**
Anthropogenic components Households and social constructions *Natural components* Forested areas, waterways and/or backwaters, land with high value	V = 5	V = 4	V = 4	V = 3
Anthropogenic components Industrial constructions and installations, communication routes with heavy traffic, waterways *Natural components* Arable areas, forested areas, waterways, productive land	V = 4	V = 4	V = 3	V = 3
Anthropogenic components Communication routes with limited traffic or scattered movement of people *Natural components* Wooded grasslands with varying degrees of consistency, limited water resources, land with low value	V = 3	V = 3	V = 3	V = 2
Anthropogenic components Areas without constructions or communication routes, sporadic people access *Natural components* Unproductive vacant lots, grasslands with shrubs	V = 3	V = 3	V = 2	V = 1

The matrix of table 2.35 propose 5 five types of environment vulnerability [A.8], as follows:

- V = 1 – very low vulnerability (stable waste dumps, natural components of low value, absence of anthropogenic components);
- V = 2 – low vulnerability (stable waste dumps or affected by controlled movements, natural or anthropogenic components of relatively low importance and/or value);
- V = 3 – medium vulnerability (stable waste dumps or affected by controlled movements – natural and/or anthropogenic components of high or very high value; waste dumps with active or uncontrolled movements - natural or anthropogenic components of relatively low importance and/or value);
- V = 4 – high vulnerability (waste dumps with active or uncontrolled movements - natural and/or anthropogenic components of high or very high value; waste dumps affected by controlled movements - natural and/or anthropogenic components of very high value);
- V = 5 – very high vulnerability (waste dumps with active movements - natural and/or anthropogenic components of very high value).

Based on the objectives identified in the adjacent areas of the waste dumps (table 2.34) and the categories of vulnerability based on the matrix presented in table 2.35, it was established the natural and anthropogenic environmental vulnerability for each waste dump in the study area (table 2.36).

Table 2.36 Establishing the vulnerability in case of dumps sliding

Waste dump	Anthropogenic environment	Natural environment	V
Lonea 1	3	3	3
Jieţ	2	3	3
Branch R-V Petrila	3	4	4
Maleia AS no. 2-3	3	3	3
Livezeni preparation	2	2	2
Arsului Valley	2	3	3
Branch 2 J.V.C.P.E.	3	4	4
Branch 3 Lupeni	3	4	4
New Funicular	3	4	4

Considering that the anthropogenic and natural components that characterize the adjacent areas of waste dumps differ from one to another, the vulnerability class of highest values was considered.

As a result, given the natural and anthropogenic components existing in the area of influence of the waste dumps, in most cases they fall within the medium (Lonea 1, Jieţ, Maleia AS no 2-3, Arsului Valley) and high vulnerability classes (Branch R-V Petrila, Branch 2 Coroeşti, Branch 3 Lupeni, New Funicular Uricani).

2.5.4 Determination of the stability factor using classical methods

The geometry of slopes was taken from previous studies based on the latest available (surveying) topographic documentation [A.29].

For the stability analyses there were considered cross or longitudinal sections (one for each waste dump), in the less advantageous areas, respectively where the geometry is most unfavorable, or there is convergence between the direction of extension of the dump and the direction of slope inclination (figure 2.35).

These sections have been established taking into account, generally, the heights and/or slope angles with the highest values. Between 1993 and 2010 the team from the Mining Engineering Research Center of Faculty of Mining Petrosani conducted 11 stability studies over the waste dumps from Jiu Valley [A.29]. The samples collected from the waste dumps (216 samples) were analyzed in the Earth Mechanics Laboratory in order to determine their physical and geotechnical characteristics. These data were completed with recent data determined by the authors in 2014 on 27 samples (three for each waste dump).

The values of the geotechnical parameters used in stability analysis presented in this paper resulted from statistical processing of all raw data from previous studies and from 2014. Thus, it was obtained a relevant database (total 243 values were processed for each of the physical and mechanical characteristics), which contains values of geotechnical properties of the sterile material that characterizes the waste dumps on their entire height (table 2.37).

Table 2.37 Results of statistical processing (n = 243)

Specification	γ_v [kN/m^3]	n [%]	c [kN/m^2]	φ [°]
Minimum	13.60	23.90	4.00	6.00
Maximum	21.00	53.00	90.00	33.00
Average	17.68	35.08	27.81	19.75
σ	0.16	5.36	0.15	6.69
Average-σ	17.52	29.72	27.66	13.06
Average+σ	17.84	40.44	27.96	26.44

Stability calculations were performed for normal conditions of natural moisture, without taking into account the pore water pressure, considering that the base land morphology, the waste dump's geometry, the nature and granulometry of the deposited material facilitates drainage of groundwater.

As a result of running the input data for each of the cross or longitudinal sections considered, there were obtained the values of the stability coefficients for slides through waste dump body, for circular sliding surfaces as determined by Fellenius method.

For the first 2 sets of values in most of the cases the stability factor is below 1, meaning that the natural equilibrium is lost and the examined slope will slide. The stability coefficient is higher than 1 for the other two sets of values, exceeding in almost all cases the value of the safety factor (Fs = 1.3), as presented in table 2.38.

Table 2.38 Results obtained for cylindrical-circular sliding surfaces

Waste dump	Cross (T) and longitudinal (L) sections	H, [m]	α, [°]	Stability coefficient - Fellenius			
				Min	Average - σ	Average + σ	Max
Lonea 1	T_{4-4}	21.00	15.89	0.43	1.13	2.56	4.15
Jieţ	T_{2-2} western slope	11.22	36.41	0.42	1.06	2.65	4.51
Branch R-V Petrila	T_{4-4} northern slope	25.08	33.1	0.32	0.76	1.82	2.65
Maleia AS no. 2-3	T_{2-2} western slope	8.40	29.78	0.42	0.98	2.22	3.26
Livezeni preparation	L_{I-I} southern slope	20.10	26.58	0.38	0.93	2.21	3.29
Arsului Valley	T_{3-3} western slope	6.80	37.00	0.61	1.52	3.67	4.61
Branch 2 J.V.C.P.E.	T_{5-5} western slope	39.32	33.55	0.27	0.64	1.27	1.77
Branch 3 Lupeni	L_{I-I}	53.62	36.35	0.22	0.52	1.21	1.86
New Funicular	L_{I-I}	54.15	47.73	0.22	0.52	1.22	1.74

2.5.5 Determining the sliding probability - Rosemblueth method

The results obtained by deterministic methods offer a value at a given moment for the stability coefficient, depending on the set of values used for the geotechnical characteristics of the deposited material [A.8].

The Rosemblueth method was used in order to determine the probability of slope failure for different geometry and stress conditions. Thus, the values of χ were determined according to the methodology presented in paragraph 2.4.1. The results can be viewed in table. 2.39.

Table 2.39 Determining the probability of slopes sliding

Waste dump	LS_1	LS_2	LS_3	LS_4	LS_m	S_{LS}	K_{LS}	χ	Pr, %
Lonea 1	-0.57	0.13	1.57	3.15	1.068	1.782	1.669	-0.599	28
Jieţ	-0.58	0.06	1.65	3.51	1.160	1.961	1.691	-0.592	28

Branch R-V Petrila	-0.68	-0.24	0.82	1.65	0.388	0.989	2.553	-0.392	35
Maleia AS no. 2-3	-0.58	-0.02	1.22	2.26	0.72	1.535	2.132	-0.469	31
Livezeni preparation	-0.62	-0.07	1.21	2.29	0.703	1.332	1.896	-0.527	30
Arsului Valley	-0.39	0.52	2.67	3.61	1.603	2.268	1.416	-0.706	24
Branch 2 J.V.C.P.E.	-0.73	-0.36	0.27	0.77	-0.013	0.576	-46.101	0.022	50
Branch 3 Lupeni	-0.78	-0.48	0.21	0.86	-0.048	0.637	-13.408	0.075	51
New Funicular Uricani	-0.78	-0.48	0.22	0.74	-0.075	0.599	-7.986	0.125	53

The correlation between the sliding probability and stability factor was established on the basis of the obtained data and its graphic representation is shown in figure 2.36.

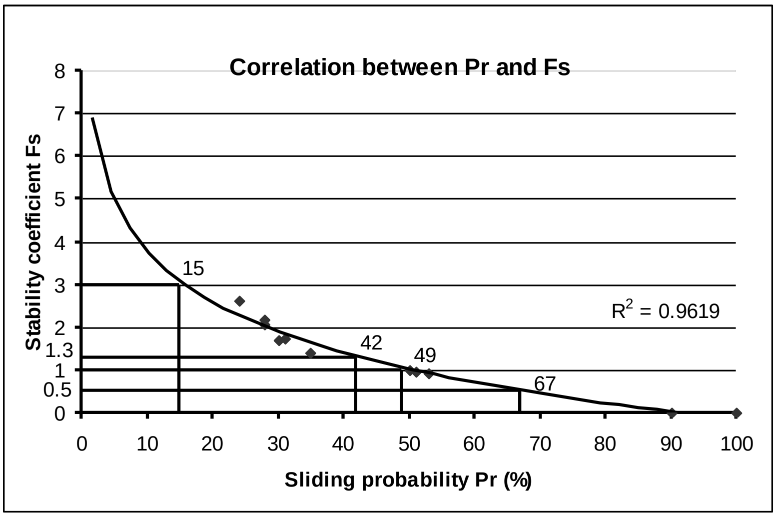


Figure 2.36 Correlation between the sliding probability (Pr) and the stability coefficient (Fs)

Based on this graph, taking into account the recommendations on adopting different values for the stability factor [B.42] and those presented in previous studies concerning the delimitation of sliding probability intervals [B.25], [B.63], [B.33], the following scale has been developed:

- ✓ P = 1 (Pr = 0÷15% for Fs > 3) → very low sliding probability;
- ✓ P = 2 (Pr = 16÷42% for Fs = 1.3÷3) → low sliding probability (Lonea 1, Jieţ, Branch R-V Petrila, Maleia AS no 2-3, Livezeni preparation, Arsului Valley);
- ✓ P = 3 (Pr = 43÷49% for Fs = 1÷1.3) → medium sliding probability;
- ✓ P = 4 (Pr = 50÷67% for Fs = 0.5÷1) → high sliding probability (Branch 2 - Coroeşti, Branch 3 - Lupeni, New Funicular Uricani);
- ✓ P = 5 (Pr = 68÷100% for Fs < 0.5) → very high sliding probability.

It must be underlined that according to mentioned studies, the sliding probability intervals can be variable depending on the specifics of each case study.

2.5.6 Assessing the environmental risk for active waste dumps from Jiu Valley

The risk may be defined as the product between the probability of occurrence of a potential hazard (in this case sliding of waste dumps) and the vulnerability of the natural and anthropogenic environment that may be affected According to the simplified equation of risk, in case of slopes sliding, the next formula may be applied [B.49]:

$$R = P \cdot V \qquad (2.21)$$

where:

R – the environmental risk due to sliding;

P – sliding probability;

V – vulnerability of natural and anthropogenic environment in the event of a slide.

Based on previous studies and literature in the field [B.14], [B.16] the following scale of environmental risk associated to waste dumps sliding was established: [A.8]:

R=1 → minimum risk – insignificant damage to the natural and anthropogenic environment, reversible effects on very short term;
R = 2÷7 → low risk – minor damage to the natural and anthropogenic environment, reversible consequences on relatively short term;
R = 8÷13 → medium risk – partial destruction of habitats and associated biota, endangerment of anthropogenic environment, consequences on medium term;
R = 14÷19 → high risk – destruction of habitats and associated biota on significant surfaces, real threat to anthropogenic environment, reversible consequences eventually on long term;
R = 19÷25 → extreme risk – total destruction of the natural and anthropogenic environment, irreversible consequences.

Knowing the environmental vulnerability and the failure probability, using the formula 2.21 was determined the average environmental risk in the circumstances of sliding of the waste dumps in the Jiu Valley, and the results are presented in table 2.40.

Table 2.40 Establishing the environmental risk of slopes sliding

Waste dump	Environment vulnerability V	Slope failure probability P	Environmental risk R
Lonea 1	3	2	6
Jieţ	3	2	6
Branch R-V Petrila	4	2	8
Maleia AS no. 2-3	3	2	6
Livezeni preparation	2	2	4
Valea Arsului	3	2	6
Branch 2 J.V.C.P.E.	4	4	16
Branch 3 Lupeni	4	4	16
New Funicular Uricani	4	4	16

Conclusions resulting from the analysis of the table 2.42 are:

- ✓three of the nine active dumps fall into the high risk category (branch 2 - Coroeşti, branch 3 - Lupeni, New Funicular);
- ✓one of the nine active dumps fall into the medium risk category (branch V - Petrila);
- ✓the other five fall into the low risk category (Lonea 1, Jieţ, Maleia AS no. 2-3, Livezeni preparation and Arsului Valley).

Given that all these waste dumps are under construction, they must be constantly monitored in terms of stability, as the geometry changes (increasing height and/or angle of slope) and maintaining a geometry that ensures a sufficient stability reserve. Regarding the three dumps with high environmental risk it is appropriate to conduct stability studies according to legal provisions [B.56], [B.62], from which to result the necessary measures to prevent the sliding phenomena.

CHAPTER 3

RESEARCH ON HYDROLOGICAL REGIME IN AREAS AFFECTED BY MINING

The presence of aquifer formations in the geological structure of coal deposits create problems in their exploitation, both for underground mining, but especially for open pit mining, thru the risk of flooding of mining works and extraction fronts, the likelihood of outbreaks of fine or clayey saturated sand or by worsening operating conditions due to the risk of instability of mining works or by reducing the efficiency of installations and technological equipments. [A.2].

To remedy these problems, drainage works are necessary, with the purposes of drainage and discharge the waters from mining areas.

If for underground mining drainage operations are limited to the drainage and discharge of waters from the areas of influence of working fronts or opening and preparation works, for open pit mining the problem is more complex, since groundwater must be drained and discarded both from the whole complex of rocks located in the overburden as well as from adjacent areas, where, due to large level differences that forms by exploitation, a large influx of water is created, that can be removed either by drainage works placed on the outline that intercepts hydrodynamic currents or by screening (waterproofing) the aquifer formations from the adjacent area.

If the water influx is reduced (in the case of mining perimeters with simple or medium hydrogeological conditions), tackling groundwater can be done by passive drainage, namely by water management and discharge measures. Large influxes of water require active drainage, done by drainage works along with water management works.

The choice of methods, technologies and drainage works is based on knowledge of the hydrogeological conditions, the application field of the various methods and drainage technologies and design bases, in order to establish the volume of drainage works and their placement schemes.

3.1 Factors defining the hydrogeological conditions

Hydrogeological conditions characteristic for a deposit may be defined by a number of factors and parameters which influence the behavior of rocks in the presence of water. Based on the hydrogeological data, that must be known since the exploration phase of the deposit, the whole mining process is designed and the exploitation opportunity is appreciated, given that the existence of hard and very hard hydrogeological conditions may lead to the impossibility of exploitation of some deposits.

Among the factors that define the hydrogeology of a deposit are mentioned: geological and hydrogeological structure of the deposit, the characteristics of aquifers and aquifer rocks, the character of groundwater, flow regime, the possibilities for water supply and disposal from aquifer structures, rocks hydraulic conductivity, presence of waterproof formations below and above the deposit, tectonic conditions of the deposit, to which adds the exploitation system and the possibilities of application of various drainage techniques and technologies. [A.2].

For example, if the deposit is horizontal or with reduced inclination, for its drainage it is necessary to close the drainage area through a drainage outline or a shielding outline at the level of aquifer formations, achieved by waterproofing the rocks. For the inclined deposits, drainage is favored by placing the drainage works on successive lines, depending on the advancement of operation on the inclination.

Number aquifer formations, water supply possibilities and rocks hydraulic conductivity particularly influence the drainage activity. Thus, a deposit with multiple aquifers horizons, even with limited development, is harder to be drained than a deposit with a single large aquifer horizon.

The presence of significant dynamic resources requires additional drainage works, which needs to cumulate a higher flow rate then the dynamic resources flow.

For low permeability aquifers, the time required for drainage is much longer than in the case of aquifer horizons with high hydraulic conductivity and the duration and drainage costs increases, even if the influx of water drained and discharged is lower. The presence and thickness of waterproof formations with screening role on the top and below the deposit or coal layers can decrease the volume of drainage works, and for underground mines, where the opening of mining works at the base is reduced, the necessity of drainage may even be eliminated. This is not possible for open pit mining as regardless of their thickness, for the top formations drainage must be complete (they represent the overburden), and for the bed formations the reduction of the piezometric pressure is mandatory down to levels that do not jeopardize the protective screen from the bottom of the quarry. For open pits with a large opening to the base, depressurization of aquifer formations from below is mandatory. For example, at the base of Roşia de Jiu and Peşteana Nord open pits, from Rovinari mining basin, there is a artesian horizon with the piezometric level at an elevation of 145-170 m, which by drainage works must be reduced to an elevation of 45-50 m col.H2O, corresponding to the bottom elevation of the last exploitable coal layer (layer V).

Because all of these factors influence the volume and technical effectiveness of drainage works, which in turn influences the exploitability of a deposit, to assess the conditions under which the exploitation is to be performed, their quantification is necessary in order to asses the hydrogeological conditions and for fitting the deposit in a classification that reflects the operating difficulties in hydrogeological terms.

In the literature there are several classifications that are based on one or more criteria, but without taking into account the simultaneous action of several hydrogeological factors and characteristics.

3.2 Hydrological classification of the coal deposits

3.2.1 Existing classifications

Among the existing classifications are mentioned those taking into account the degree of flooding of the deposits, defined by the position of the deposit to the local erosion base, the presence or absence near the deposit of surface aquifer sources, lithological composition of rocks within the deposit, rocks hydraulic conductivity, tectonic conditions of the deposit. From this point of view, most of the classification groups the deposits according to the hydrogeological degree of complexity as follows:

- ✓ deposits with simple hydrogeological conditions that do not require drainage works, only water management works;
- ✓ deposits with moderate hydrogeological conditions that require some drainage works executed in parallel with the opening, preparation and exploitation works;
- ✓ deposits with complicated or hard hydrogeological conditions (assuming the existence of hydrodynamic links between aquifers or between them and surface water sources) that requires preliminary drainage works to create safe conditions for opening, preparation and exploitation works;
- ✓ deposits with very complicated or very hard hydrogeological conditions (assuming an intensive supply of the aquifers due to the geological and tectonic structure of the deposit and the existence of waters under pressure that can cause significant influxes and even eruptions), which requires intensive drainage both before and during exploitation, aiming the drainage of the aquifer horizons from the overburden of the deposit and the depressurization of those below the deposit thru systematic drainage measures.

Since the size of the flow of water in a mine or quarry is not an index of comparison, because it depends on the expansion of mining works, is recommended the use of water influx coefficient (k_a), which is the ratio between the amount of water discharged (V_w) and extracted production (P) in the same period (the volume of water pumped per tone of useful minerals).

Depending on the water influx coefficient, coal deposits are classified into:

- ✓ weakly flooded, where $k_a < 3$ m^3/t;
- ✓ with average flooding, where $k_a = 3 - 8$ m^3/t;
- ✓ with large flood, where $k_a = 8 - 20$ m^3/t;
- ✓ with very large flooding or heavily flooded, where ka > 20 m^3/t.

Under this classification, beside the water influx coefficient ka it must be taken into account the economic importance of the deposits. Based on the size of the water influx coefficient, surrounding rocks character and manifestation of negative geo-mining phenomena it was developed a classification that applies to deposits of lignite in Romania, presented in table 3.1.

Table 3.1 Classification of deposits taking into account the water influx coefficient and surrounding rocks type

Class	**Hydrogeological conditions**	**Position of the deposit to the local erosion base**	**Water influx coefficient k_a (m^3/t)**	**Characteristics of the surrounding rocks and manifestation of negative geo-mining phenomena**
I	Simple	Above and bellow the local erosion base	< 3	Hydrophilic clayey and loamy rocks stable without water influx due to free drainage. Hydrogeological conditions do not lead to slope stability or mining issues.
II	Medium	Above and bellow the local erosion base	3 - 8	Above the local erosion base lenses of aquifer sands are occurring, confined in impermeable rocks without the possibility of water supply. In the bed of the open pits captive aquifers with free level occur, which can cause the swelling of clayey rocks. There are required some measures of drainage of aquifer formations.
III	Hard	Bellow the local erosion base	8 - 20	On top of the deposit there are thick aquifer sands (10-15 m) or complexes of rocks with complicated structure and water influxes. In the bed of the open pits there are captive horizons with ascending waters, causing hydrostatic pressure. To ensure the stability of mining works and to prevent large water infiltrations drainage works are required.
IV	Very hard	Bellow the local erosion base	> 20	On top and in the bed of the open pits aquifer complexes with under pressure waters appear, which causes high hydrostatic pressures, stationed in argillaceous rocks with inflation trends on contour or slip trends on the contour of extraction steps. Measures are needed to reduce the pressure and systematic drainage measures to ensure slope stability, and systems with adequate flow rates to discharge waters in all phases of work.

Since in the exploitation of coal deposits in Romania, the biggest problems in terms of hydrogeological and drainage were raised by the lignite deposits from Oltenia, based on practical results and experience in the field, a classification of deposits depending on operating conditions was proposed, shown in table 3.2.

The disadvantages of the two classifications are multiple, namely [A.30]:

- ✓ first classification only considers the water influx coefficient, the characteristics of the surrounding rocks and the manifestation of negative geo- mining phenomena, which is insufficient compared to the factors that define the hydrogeological and drainage conditions. There may be hard and very hard hydrogeological conditions in the case of low influxes, as a result of a reduced hydraulic conductivity of the rocks or due to their instability in the presence of high piezometric pressure or in the absence of protective screens etc.
- ✓ the second classification based on operating conditions, the influence factors considered are numerous, but difficult to quantify in the exploration and exploitation design stages, which leads to subjectivism and sometimes nonconformities with the field situation.

Table 3.2 Classification of deposits based on exploitation conditions

Expl. type	Influence factors		MU	Exploitation conditions			
				Easy	Medium	Hard	Very hard
UNDERGROUND MINING	Stratigraphic	Layers inclination	degree	0 - 3	3 - 5	5 – 10	> 10
		Intercalations share	%	0	10 - 20	20 - 30	> 30
		Fracturing degree	fractures/m^2	0	3	3	> 3
		Thickness of the screen on top	m	> 6	6 - 4	4 - 1	< 1
		Thickness of the screen in the bed	m	> 10	10 - 5	5 - 2	< 2
	Tectonic	Mining pressure	tf/m^2	10 - 20	20 - 25	25 - 35	> 35
		Exploitation depth	m	20 - 40	40 - 60	60 - 90	> 90
		Lignite resistance	daN/cm^2	> 70	40 - 70	25 - 40	< 20
		Surrounding rocks resistance	daN/cm^2	> 70	30 - 70	10 - 30	< 10
		Intercalations resistance	daN/cm^2	> 20	20 - 10	10 - 6	< 6
		Tectonic fragmentation degree	accidents/ha				> 3
	Hydrogeological	Water influx	m^3/t	< 1	1 – 2.5	2.5 - 4	4
		Piezometric pressure	m H_2O	0 - 10	10 - 30	30 – 60	> 60
	Technological	Height of the working front	m	2 - 3	1 – 2.5 3 – 3.5	1.2 – 1.5 3.5 - 4	< 1.3 > 4
		Length of the working front	m	< 50	50 - 80	65 - 80	> 80
		Distance from the exploited area	m	> 50	50 - 20	20 - 10	< 10
		Distance from the aquifer area	m	> 30	30 - 10	10 - 2	< 2
OPEN PIT MINING	Stratigraphic	Layers inclination	degree	0 - 3	3 - 5	5 - 7	> 7
		Share of exploitable layers	%	0	0 - 10	10 - 20	> 20
		Share of unexploitable layers	%	0	0 - 5	5 - 7	> 7
		Consistence index of sterile rocks		< 0.7	0.7 – 0.9	0.9 - 1	> 1
	Tectonic	Terrain morphology (relative to the average elevation of the perimeter)	m	20	20 - 35	35 – 60	> 60
		Exploitation depth	m	20 - 40	40 - 70	70 - 100	> 100
		Tectonic fragmentation degree	accidents/ha	2	2 - 4	4 - 7	> 7
		Share of argillaceous rocks in the overburden	%	20	20 - 50	50 - 70	> 70
	Hydrogeological	Water influx	m^3/t	< 3	3 - 5	5 - 7	> 7
		Number of aquifer horizons		2	2 - 4	4 - 6	> 6
	Technological	Overburden ratio	m^3/t	< 3	3 - 5	5 - 7	> 7
		Medium transport distance of the sterile to the dump	km	< 1	1 - 2	2 - 4	> 4
		Open pit's surface	ha	30	30 - 100	100-190	>190

It is therefore necessary to develop a classification able to quantify, on the one hand, the hydrogeological factors, and on the other, the exploitation conditions in the presence of groundwater.

3.2.2 Complex hydrogeological classification of coal deposits

Starting from this need, based on experience in the field, on existing information, drainage activity results in conditions specific to the lignite deposit from Oltenia and the experience of 20 years, together with a research team from the Department of Mining Engineering and Geology processed and synthesized available data which led to the classification shown in table 3.3 [A.30].

According to this classification, coal deposits can be classified in terms of hydrogeological conditions into four classes, namely:

- ✓ Class I - simple hydrogeological conditions that do not require drainage works, only water management works;
- ✓ Class II – medium hydrogeological conditions that require drainage works and water management works;
- ✓ Class III – hard hydrogeological conditions, due to the presence of aquifer formations on top and in the bed of the deposit, which requires drainage works for the aquifer formations from the top of the deposit and depressurization works for the aquifer formations in the bed of the deposit in the presence of screens with reduced thickness;
- ✓ Class IV – very hard hydrogeological conditions, where aquifer formations contain water under pressure, the hydraulic conductivity of rocks is reduced and the geo-mining conditions are unfavorable in the absence or existence of screens with reduced thickness and the presence of tectonic dislocations.

Table 3.3 Complex hydrogeological classification of deposits

Class		I	II	III	IV
Hydrogeological conditions		Simple	Medium	Hard	Very hard
Position of the deposit to the local erosion base		Above and bellow the local erosion base	Above and bellow the local erosion base	Bellow the local erosion base	Bellow the local erosion base
Number of aquifer horizons		1– 2	2– 4	4– 6	> 6
Thickness of the aquifer strata (horizons) M (m)		0 – 10 (< 20)	10 – 20 (20 – 40)	15 – 25 (40 – 60)	> 25 (> 60)
Piezometric pressure H (m)		0 – 10	10 – 30	30 – 80	> 80
Permeability of rocks k_f (m/day)		> 10	1,0 – 10	0,5 – 2,0	0,1 – 1,0
Water influx coefficient k_a (m^3/t)		< 3	3 – 5	5 – 10	> 10
Character of groundwater		With open level	Easily ascending	Ascending	Ascending and artesian
Thickness of the protective screen (m)	on top	> 6	4 – 6	2 – 4	< 2
	in the bed	> 10	5 – 10	3 – 5	< 3
Type of aquifer horizon		Phreatic or captive with open level	With open level and captive	Captive	Captive
Characteristics of aquifer rocks		Sand and gravel or coarse sands	Medium sands	Fine or dusty sands	Dusty or clayey sands

The values of the hydrogeological parameters chosen to define the corresponding conditions for each class reflects in part the difficulty degree of drainage works, whereas in reality, the

hydrogeological characteristics of the aquifer formations may have different values within the same aquifer or from an exploitation block to another. From this results that in terms of parameter values, the same deposit can be classified into several classes, according to the presented classification.
For practical use of this classification, the shear in which the analyzed parameters affect the drainage of lignite deposits must be appreciated both qualitative and quantitative. Practical experience has shown that many problems, in which regards drainage of deposits, occurs when there are pressurized water aquifers within the exploitation perimeter, in conditions of a large influx of groundwater and in the absence of protective screens located on top and in the bed of exploitable strata. From this point of view, a lignite deposit must be placed in the class corresponding to the most unfavorable value of these parameters.

A second criterion for integration of coal deposits according to the presented classification is that a deposit belongs to a class indicated by the values of the majority of the considered hydrogeological parameters.

Compared to the situation of lignite deposits from Oltenia, the exploitability of coal layers is closely related to the hydrogeological conditions. The area in which the deposit is located forms a large hydrogeological basin, in which there are a number of horizons and aquifer complexes whose hydrogeological characteristics are dependent on their vertical position, lithological characteristics of aquifers, variations in particle size of the rocks and the thickness of sand layers. Due to the geological structure of the region, the hydrogeological conditions vary from one mining perimeter to another, with difficulty degrees from easy to very hard.

Of the probated aquifers, the one located in the bed of lignite layer IV is noticed, characterized by regional expansion, high thickness and flow rates and piezometric pressures that sometimes exceed 100 m col. H2O, which imprints an artesian character in exploitation areas of the layers V and VI. Other aquifers, located at higher elevations, generally have a limited extent, lower flow rates and pressures and higher filtering coefficients.

The aquifers horizons are grouped into two categories: aquifers with regional expansion, located in Dacian, beneath layer VII of coal, supplied in marginal areas of the region, without drainage possibilities and aquifer horizons in Romanian and inferior Pleistocene, which have supply and drainage areas both in marginal areas of the hydrogeological basin and in the internal valleys that cross the region.

The strongest aquifers are in the first category, especially the aquifer formed in the bed of the layer IV of coal, considered the main artesian horizon.
In terms of lithological constitution, aquifer horizons are very different, variations of rocks are found frequently even for the same horizon, from one exploitation perimeter to another, or even within the same perimeter.

If in the phreatic aquifer horizon coarse sand or sand mixed with gravel specific to alluvial terraces is found, in the other aquifer horizons there can be found sands ranging from the medium to fine, dusty or clayey, that have a low water transfer rate and are characterized by very low filtering coefficients. The existence of pressurized water makes them very dangerous in terms of possible blowouts or rupture of the protective screen.

The filtering coefficients vary within very wide limits, from 2.5 to 53.7 m/day for the alluvial deposits and from 0.2 to 0.3 m/day in the complex of the layer V of coal.

The synthesis of hydrogeological parameters for exploitation perimeters from Oltenia showing hydrogeological problems is presented in table 3.4. From this table it is seen that in the case of Roşia de Jiu and Peşteana Nord perimeters the most unfavorable exploitation conditions, in hydrogeological terms, are meet.

For overall hydrogeological characterization of the two perimeters and the integration into the proposed classification, were analyzed hydrogeological parameters defining aquifer formations and were considered the most unfavorable from the point of view of drainage and exploitation conditions. The analysis results are shown in tables 3.5 and 3.6 [A.30].

According to the integration criteria of lignite deposits in the proposed classification, the two mining perimeters are situated in class IV, with very hard hydrogeological conditions, although some upper aquifer horizons might be situated into class II or III, with medium or hard conditions. Hard or very hard conditions in the lower horizons, and especially the large inflows of water into the lower exploitation steps, is explained by the large bumps that are created during exploitation and drainage of the deposit and the expansion of areas affected by depressions created during drainage, which may include new areas with hydrodynamic links, as a result of the geological structure and tectonics of the deposits.

Since the exploitability of deposits is influenced by hydrogeological conditions, it requires their knowledge, as well as the factors that influence them.

Determination of the hydrogeological conditions of a deposit is based on exploration works, continued with hydrogeological research works, which seek to establish: the expansion of aquifer formations and horizons, supply and drainage possibilities, their position in the productive complex, determination of hydrogeological characteristics of aquifer formations, the influence over the exploitation conditions and others.

Table 3.4 Hydrogeological parameters of lignite exploitation perimeters from Oltenia

Open pit	Aquifer horizons	HYDROGEOLOGICAL PARAMETERS							
		Groundwater character	Filtering coefficient (m/zi)	Coefficient of transfer capacity k_c (%)	Piezometric pressure H (m col. H_2O)	Water influx coeff. k_a (m^3/t)	Specific flow q (m^3/zi)	Screen thickness h (m)	Tectonic fragmentation degree (accidents/ha)
ROŞIA DE JIU	Phreatic horizon	Open level	10 - 15	0.2 – 0.3	-	12.63 – 16.32	30 – 150	-	absent
	Complex VI	Ascending	0.1 – 1.0	0.05 – 0.1	10 - 30		10 - 80	0 – 4.0	absent
	Complex V – VI	Ascending	0.3 – 2.3	0.1 – 0.15	70 - 100		8 - 60	1.0 – 5.0	absent
	Bed V and artesian	Artesian	0.356 – 3.0	0.05 – 0.13	70 - 200		20 - 100	5.0 – 20.0	absent
PINOASA	Phreatic horizon	Open level	1.0 – 5.0	0.2 – 0.3	-	3.7	1 – 5	-	reduced
	Complex VI - X	Ascending	0.1 – 1.0	0.05 – 0.1	-		1 – 15	5.0 – 7.0	reduced
	Complex V – VI	Ascending I	0.009 – 3.17	0.1	3.7 – 28.6		5 – 15	2.0 – 8.0	reduced
	Bed V and artesian	Artesian	0.172 – 18.86	0.15	14.7 – 170.8		5 - 20	5.0 – 20.0	reduced
ROVINARI EST	Phreatic horizon	Open level	3.0 – 8.0	0.2 – 0.3	-	4.9 – 5.41	5 – 15	-	moderate
	Complex V – VIII	Open level	0.3 – 1.0	0.05 – 0.1	-		5 – 10	1.0 – 4.0	moderate
	Bed V and artesian	Artesian	1.0 – 3.0	0.15	50 - 150		10 – 50	10.0 – 20.0	moderate
PEŞTEANA NORD	Phreatic horizon	Open level	15.0 – 20.0	0.2 – 0.3	-	12.87	30 – 200	-	reduced
	Complex V – VI	Ascending	0.3 – 1.0	0.05 – 0.1	50 – 80		5 – 50	0 – 10.0	reduced
	Bed V and artesian	Artesian	1.0 – 3.0	0.15	70 – 150		10 - 70	5.0 – 15.0	reduced
JILŢ SUD	Phreatic horizon	Open level lens-shaped	3.0 – 8.0	0.2 – 0.25	-	1.7	5 – 15	-	reduced
	Complex VI - XII	Captive	0.1 – 0.8	0.05 – 0.1	5 – 15		3 – 5	0 – 5.0	reduced
	Culcuş VI	Under pressure	0.2 – 1.0	0.05 – 0.1	20 - 40		5 - 10	0 – 10.0	reduced
LUPOAIA	Phreatic horizon	Open level	4.0 – 6.0	0.2 – 0.23	-	0.7	-	-	absent
	Complex V – VIII	Open level lens-shaped	0.1 – 0.5	0.05 – 0.1	-		3 – 5	0 – 5.0	absent
	Bed of layer V	Ascending lens-shaped	0.2 – 1.0	0.05 – 0.1	0 – 5		2 – 5	0 – 10.0	absent
OLTEŢ	Top of layer II	Open level lens-shaped	0.02 – 0.7	0.1 – 0.11	0 - 20	0.8	0.54 – 2.10	2.0 – 15.0	absent
	Bed of layer. I	Open level	0.1 – 1.42	0.1 – 0.11	20 - 100		2.29 – 7.58	0 – 10.0	absent

Table 3.5 Hydrogeological characterization and classification of Roşia de Jiu mining perimeter

Hydrogeological parameters	Limit values in the mining perimeter	Class	Characterization of hydrogeological conditions
Filtering coefficient, kf (m/day)	0.3	IV	Very hard
Piezometric pressure, H (m)	200	IV	Very hard
Water influx coefficient, ka (m3/t)	16.32	IV	Very hard
Thickness of protective screen, h (m)	5	III	Hard
Character of groundwater	Ascending and artesian	IV	Very hard

Table 3.6 Hydrogeological characterization and classification of Peşteana

Hydrogeological parameters	Limit values in the mining perimeter	Class	Characterization of hydrogeological conditions
Filtering coefficient, kf (m/day)	0.3	IV	Very hard
Piezometric pressure, H (m)	150	IV	Very hard
Water influx coefficient, ka (m3/t)	12.87	IV	Very hard
Thickness of protective screen. h (m)	5	III	Hard
Character of groundwater	Accessional and artesian	IV	Very hard

Since the hydrogeological evaluation of the deposits and the techniques and technologies of drainage, as well as drainage expenses depend on the hydrogeological conditions of the deposit, a proper classification based on objective criteria is a necessity.

Because the existing classifications do not take into account several criteria or the cumulative action of factors influencing the hydrogeological conditions of the deposit and conditions drainage activities, a new classification is proposed. This classification quantifies the hydrogeological and exploitation conditions, based on several factors and parameters that characterize the deposit.

It is estimated that based on this classification a better classification of coal deposits in terms of hydrogeological conditions can be made, and therefore, the evaluation of exploitation conditions and costs of extraction will be a much more rigorous one.

3.3 Influence of dewatering works from Rosia de Jiu open pit on the environment and possibilities to reduce their impact

In terms of drainage conditions, Oltenia lignite deposit falls in the group of deposits with difficult hydrogeological conditions, because of the following characteristics:

- lignite layers are found in sedimentary formations, aquiferous sands and gravel holding a significant share;
- in the exploitation perimeters sometimes there are 3 - 4 aquifers;
- hydrogeological characteristics of the aquifer rocks have significant variations, even within the same exploitation perimeter;
- aquifers thickness is variable (between 5 and 25 m);
- piezometric pressures of the groundwater are between 10 and 60 m H_2O column.

The main objectives of drainage works in lignite open pits are:

- the drainage of aquifers located in the roof of coal layers V;
- takeover of groundwater influx from the outside perimeter of open pits;
- loosening of the artesian horizon located in the floor of coal layer IV;
- the enhancement of the stability of opening trenches slopes, of working stages, of waste dumps, and of open pits margins;
- preventing the suffusion and sliding slopes phenomena;
- preventing open pit flooding by the eruption of artesian water from the floor of layer IV.

3.3.1 Hydrogeological conditions of Rosia de Jiu open pit

Roşia de Jiu open pit is one of the most important open pits in Oltenia, both in terms of large lignite reserves as well as of production capacity. It is located near the town of Rovinari in the floodplain of the Jiu river. Near the open pit there are several localities: Fărcăşeşti, Roşia de Jiu, Moi and Vladuleşti (figure 3.1) [A.30].

Figure 3.1 Location of Roşia de Jiu open pit

The technological flux and the technical equipment of the Roşia de Jiu open pit at the beginning of rehabilitation program are shown in figure 3.2.

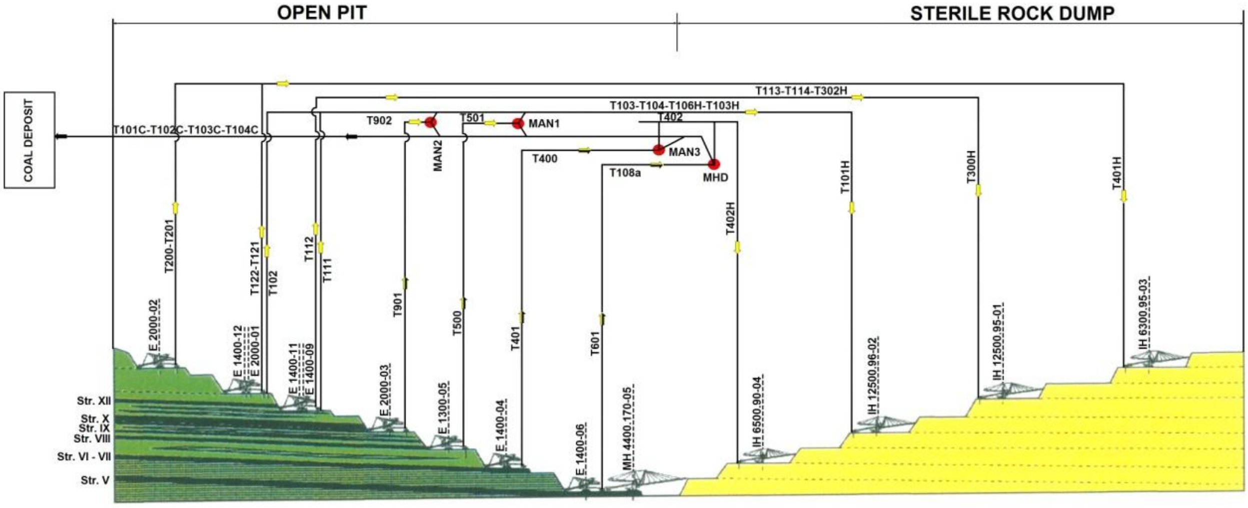


Figure 3.2 Technological flux of Roşia de Jiu open pit

Lignite and sterile rock are extracted directly with various types of rotor excavators and the excavated material is transported on conveyor belts to the coal storage or to the waste dump.

In Roşia de Jiu open pit perimeter, the deposit consists of several layers of lignite, separated by rock formations from Pontian, Dacian, Romanian and Quaternary, represented by clay, sand and gravel. Exploitable lignite layers are stationed in Romanian and Dacian and the most important aquifer, consisting of sand, is hosted in Dacian and Romanian (figure 3.3). Roşia de Jiu open pit is characterized by very difficult hydrogeological conditions (table 3.5). In the open pit, eight lignite layers are being exploited, separated by sterile insertions, which mainly contain the several aquifers:

- The phreatic aquifer, developed in the alluvial deposits from the Jiu overflow meadow;
- The aquifer from the carbonaceous complex, irregularly shaped;
- The aquifer between the lignite layers IX and X, with a nearly continuous expansion

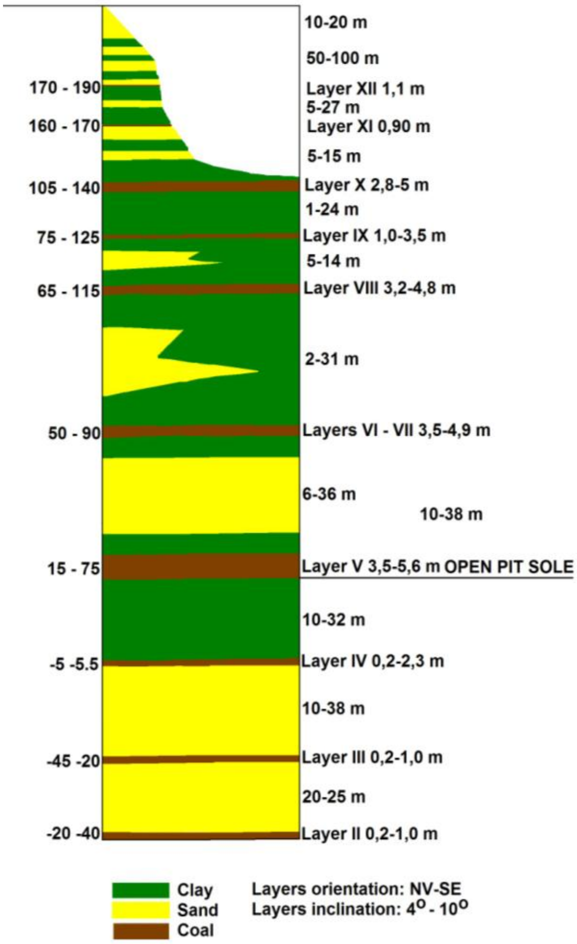


Figure 3.3 The Roşia de Jiu stratigraphic column

throughout the area;

- The aquifer between the lignite layers VIII and IX, with a thickness of 4.95 to 12.25 m;
- The aquifer between the lignite layers VI, VII and VIII, with a total thickness ranging from 1.95 to 11.5 m and ascending water level;
- The aquifer between the lignite layers V and VI, with an average thickness of 19 m and ascending or artesian water character;
- The aquifer between the lignite layers IV and V, with a thickness of 1.0 to 18.1 m;
- The artesian aquifer mainly located in the floor of lignite layer IV.

The presence of these aquifers requires hydrogeological investigation works in order to determine the hydrogeological parameters, to design the technical solutions for drainage and for the complex of hydrotechnic and hydrological works required to operate the lignite layers under maximum security conditions.

After the drainage works had been executed in the open pit, there were extracted large volumes of groundwater annually, which was conducted outside the open pit and discharged into the Jiu river. Depending on the suspensions contained in the discharged water, the mining unit paid monthly penalties, sometimes significant, to the Romanian Water Company. Also, the drainage of aquiferous formations generates a series of negative effects on the environment, mainly by diminishing groundwater resources, lowering hydrostatic level and changing the groundwater regime [A.36].

3.3.2 Hydrotechnical and dewatering works in Roşia de Jiu open pit

Before starting the opening of the mining fields, there were carried out research on aquifers, establishing the hydrogeological parameters of the exploited mining perimeters, technical solutions for drainage and the complex of hydrotechnic and hydrological works allowing the exploitation of lignite layers in maximum security conditions [A.36].

The following hydraulic works for the protection of Roşia de Jiu open pit, have been executed:

- ✓ Jiu riverbed correction in the open pit and waste dump area on a length of 5800 m, by a canal route as an extension of the existing channel downstream of Rovinari accumulation;
- ✓ regularization of Roşia stream over a length of 1770 m upstream of the confluence with the Jiu river;
- ✓ Valea Pârâului channel with a length of 4400 m;
- ✓ collector channels in the Furduieşti - Fărcăşeşti area, with outlet in Valea Pârâului and Roşia stream;
- ✓ protection screen from bentonite and cement for stopping the infiltration from groundwater with a total length of 7600 m and depth between 12 and 20 m.

In the year 2014, in the Roşia de Jiu open pit eight drillings were working being served by 16 submersible pumps (two for each drill), the location of pump stations and water discharge points being shown in figure 3.4 [A.8].

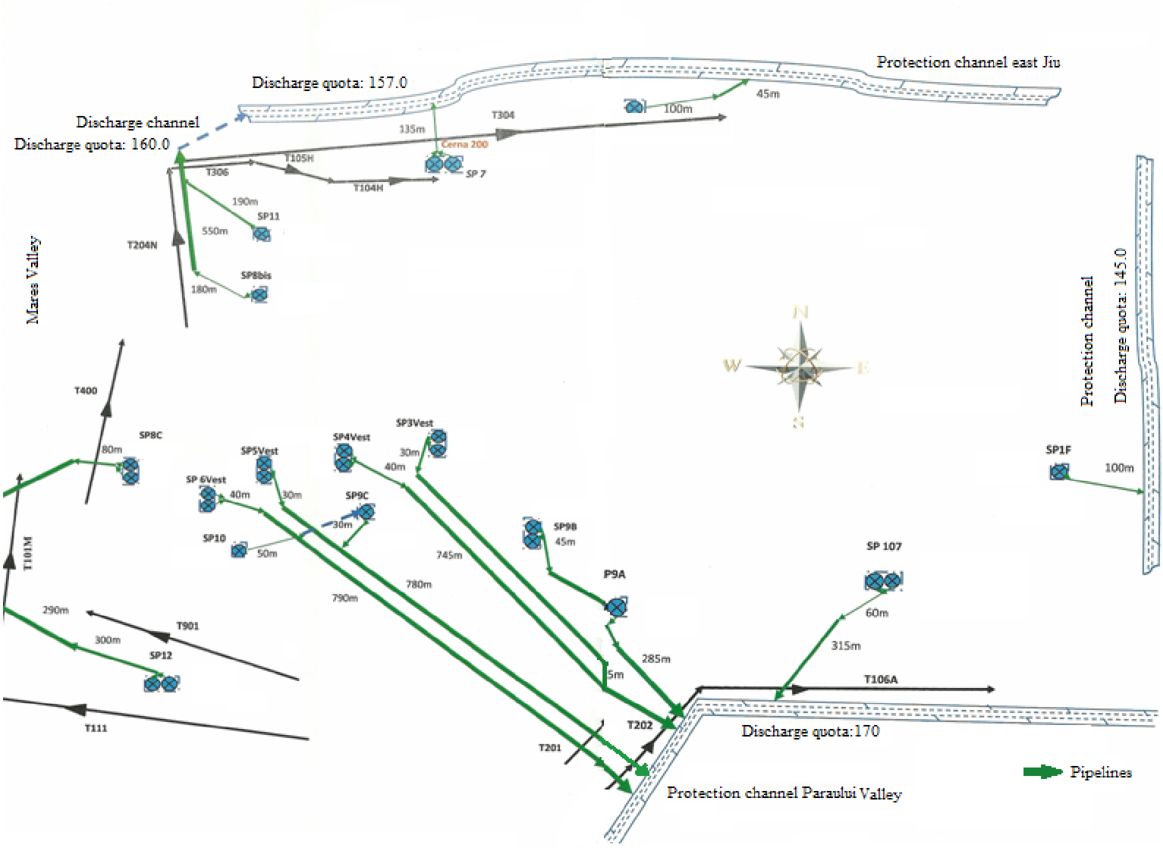


Figure 3.4 Plan for pump stations and groundwater discharge points

As a result of drainage and of reducing the pressure of the artesian aquifer using drillings with free discharge, in 2014, a water volume of 14.5 million m^3 has been drained (through the 8 active drillings), so that, for every ton of coal mined, a volume of 4.89 m^3 of groundwater has been drained and evacuated.

3.3.3 Determining the area of influence of dewatering works

As a result of drainage and water discharge from the aquiferous formations, hydrostatic or piezometric level is reduced, the maximum reduction being produced around the drainage works. Groundwater level lowering effect is felt not only in the mining field perimeter, but also in its surroundings. The distance that the phenomenon (reducing groundwater level) extends to is called the influence radius of drainage and has different values depending on the hydrogeological characteristics of the aquiferous rocks and on the type of drainage used.

3.3.3.1 Phreatic aquifer horizon

The phreatic aquifer horizon around Rovinari Basin area consists of alternating sand and gravel, with a continuous development throughout the entire surface. The water level is free and in some places trapped. The thickness of this aquifer is between 6.5 to 21 m, the average being 13.25 m. The average initial hydrostatic level was 147.53 m [A.36]. The main hydrogeological properties of aquiferous rocks from this horizon have the following values:

- Filtering coefficient k_f = 17.02 m/day;
- Water releasing coefficient k_c = 22%;
- Specific flow rate q_{sp} = 2.7 m^3/h and m.

In order to estimate the expansion of the influence area of drainage works executed in the aquifer horizons, two hypotheses are considered [A.2]:

- the open pit is working as a drainage trench and a specific calculation relation will be applied to this type of work;
- the open pit works like a large pit and Forchheimmer relations will be applied.

If the first hypothesis, the relationship of calculation used the following form:

$$R_t = \sqrt{\frac{3 \cdot H \cdot k_f \cdot T}{k_c}}, \text{ m} \tag{3.1}$$

where: H - hydrostatic level height, m;
k_f - filtering coefficient, m / day;
T - drainage duration, days;
k_c - water releasing coefficient.

Taking into account the values of the hydrogeological characteristics of the aquifer horizon (presented above) and considering the drainage period to 2 or 3 years, the influence radius of drainage will be approx. 1500, respectively 1835 m.

In the case of the second hypotheses there must be taken into account, in addition to the values of the hydrogeological characteristics of the rocks, the size of the open pit. Depending on the dimensions of the open pit and the relation between them, the radius of the reduced drilling is first determined using the relationship:

$$r_o = \eta \cdot \frac{L + l}{4}, \text{ m} \tag{3.2}$$

where: η - coefficient that depends on the ratio l / L;
L – open pit length, m;
l – open pit width, m.

The influence radius of large well can be calculated from the relationship of Sichardt, namely:

$$R = 10 \cdot S\sqrt{k_f}, \text{ m} \tag{3.3}$$

where S represents the achieved elevation of H.L., which on the open pit outline, is equal to the thickness of the aquifer. Finally, we can calculate the expansion of the influence area by summing the two radii:

$$R_o = r_o + R, \text{ m} \tag{3.4}$$

Taking into account the dimensions of Roşia de Jiu open pit (L = 2500 m and l = 1250 m) there were calculated the value of η = 1.174 and the influence radius for the second hypothesis R_0 = 1100 + 825 = 1925 m. Based on the two calculation hypothesis, the area of influence of the phreatic horizon drainage extends over approx. 1835 - 1925 m.

The relations used for calculating the influence radius do not reflect all the factors influencing the enlargement of the depression area around the open pit and the field observations led to the conclusion that the drainage effects are felt over a much greater distance, therefore the influence radius was determined, using also the elevation of H.L: in the slopes area (S = H - h_0) and the average hydraulic gradient (I_{med} = 0.003 - 0.006) [B.15].

$$R_t = \frac{H - h_o}{I_{med}}, \text{ m} \tag{3.5}$$

Considering the height of the dynamic level in the open pit h_0 = 0, it follows that the influence radius of the phreatic aquifer drainage (R_t) is between 2210 - 4420 m, which corresponds to the actual situation on the ground, with consistent reductions in the hydrostatic level on a range of 3 - 4 km. The fact that the hydrostatic level was brought down is demonstrated by decreasing the water level in wells or even by complete drying (the localities of Moi, Fărcăşeşti, Rovinari).

The effects of the phreatic aquifer drainage, in the adjacent areas, are manifested by reducing the static resources, mitigation that can be evaluated using the following relationship:

$$W_{st} = 0{,}33 \cdot P \cdot R \cdot \Sigma M_{imed} \cdot K_{cmed}\,, \quad m^3 \tag{3.6}$$

where: P – the perimeter of the open pit, approx. 7500 m;

R – drainage influence radius, R = 825 m;

Σm_{imed} - summed horizons average thickness from the roof of coal layer VII, equal to 47.8 m;

K_{cmed} – water discharge coefficient for the mentioned horizons, equal to 0.12.

Applying the 3.6 relation, there is obtained the value used to diminish the static resources from the phreatic aquifer or $W_{st}^{freatic}$ = 11.712 mil. m^3.

3.3.3.2 The aquifer situated between the coal complex (layers V-VII)

The aquifer from the coal layers complex V-VII consists of a mixture of sand, gravel and dust, with an average thickness of approx. 20 m. The initial piezometric level was located at the 158.2 m. The average value of the filtering coefficient is 1.17 m/day, the average flow of groundwater q = 0.201 l/s and m, and k_c = 9.75%.

Given that the drainage drillings were placed linearly, and the aquifer is considered to be continuous in the mining perimeter and with an uniform movement of the groundwater, in order to determine the pressure of the remaining water H_x at different distances from the drillings line, S.F. Averianov relations were used [B1]. By interpolation, the influence radius of the drainage can be determined.

To calculate the residual pressure the following equation were used:

$$H_x = H_0 - [S\,(1 - \frac{x}{R})\,\alpha\,\beta], \quad m \tag{3.7}$$

where: H_0 - aquifer thickness, m;

S - maximum difference from the initial and final elevation of H.L., m;

x - calculation distance of remaining pressure, m;

R - influence radius of an individual drill, m;

α - parameter which is calculated by the relationship:

$$\alpha = \frac{1}{1 + \frac{2\sigma}{R} A} \tag{3.8}$$

A - parameter which is determined graphically, as shown in figure 3.5, depending on the ratio σ / R;

2σ = 100 m - distance between drillings;

r = 0.4 m - radius of the drillings;

β - parameter equal to 1 for perfect drillings.

The influence radius of drainage drillings is determined by the relation 3.3, taking into account that the maximum elevation is calculated as the difference between the initial value of the piezometric level (158.2 m) and the top of coal layer V elevation (45 m), obtaining S = 113.2 m and a value for the influence radius R = 1224.44 m. From the graph shown in figure 3.5, A = 1.2 is determined and then α can be calculate calculated (α = 0.91) [A.36].

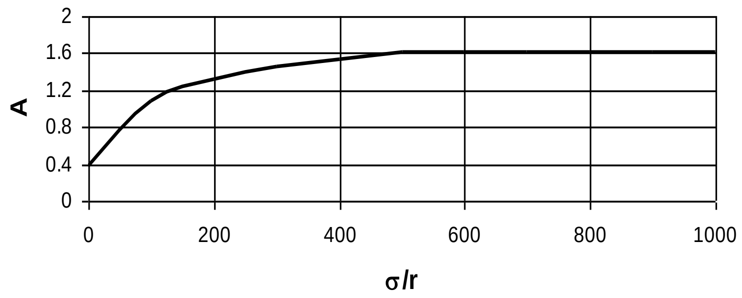


Figure 3.5 Graphical determination of A parameter

Using 3.7 relation, the residual pressure H_x was determined at different distances from the line of drilling and plot depression curves were drawn, thus establishing the influence radius of the drainage of the aquifer from layers complex V - VII. The graph in figure 3.6 shows the dependence from the residual piezometric pressure and the influence radius of the line of drillings conducted in the aquifer from layers complex V - VII, on which one can determine the distance the effects of drainage are felt. Thus, a piezometric pressure equal to the initial one(158.2 m H_2O column), will get the maximum influence radius of drilling line.

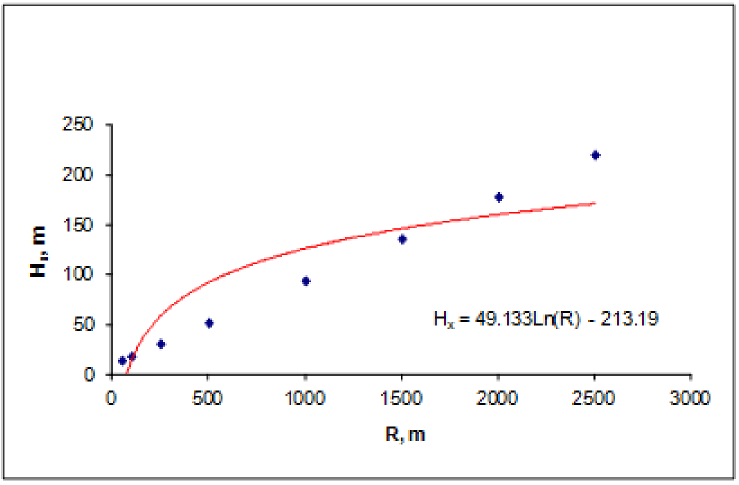


Figure 3.6 Determination of the influence radius for the aquifer from layers complex V-VII

From the graph above, the expression of the influence radius of the drainage of the aquifer from layers complex V - VII has the following form:

$$R = e^{\frac{H_x + 213,9}{49,133}}, \quad m \tag{3.9}$$

The expansion of the influence area of the drainage of aquiferous formations from the layers of coal complex is determined using 3.9 relation, Rt = 1945.59 m.

It should be noted that, because Averianov relation does not consider the average slope of the depression curve, the dependence between the residual piezometric pressure and the drainage influence radius is a rather linear one. Therefore, in order to obtain the characteristic of the depression curves, the points determined by calculation were approximated by a logarithmic regression.

The results show that, even in this case, the drainage works effect extends over a relatively great distance. Although reducing the groundwater levels in this aquifer does not directly affect environmental factors (surface water, flora and fauna), there is the possibility of compactions within the depression cone around the open pit, already highlighted especially in Rogojelu power plant area.

Also, extending the depression area in the adjacent open pit perimeters up to a distance of approx. 1950 m, leads to a reduction of groundwater resources. Assessing these resources using the relation 3.6 (for P = 7500 m, M_{med} = 19.1 m and K_{cmed} = 9.75%), $W_{st}^{complex}$ = 8.987 mil. m^3 can be obtained.

This volume of water drained from the aquifer from the complex of V to VII coal layers and from the open pit adjacent area is also enhanced by the dynamic resources that fuel that horizon, the loss of groundwater resources being, therefore, much higher.

3.3.3.3 Artesian aquifer situated in the bed of coal layer IV

This aquifer is composed primarily from sands and has an average thickness of 77 m. The average initial value of the piezometric level stood at 159.66 m, currently this being lowered in the opening area of layer V to the value of 65 m. This means that from the beginning of the detensioning of the artesian aquifer the value for S = 94.66 m was obtained. The artesian aquifer is characterized by k_f = 3.47 m / day, k_c = 9% and q = 0.449 l / s and m [A.36].

Using the higher shaft method in the case of drilling systems working in artesian and taking into account the dimensions of the drillings close outline (1300 - 675), by applying relations 3.2, 3.3 and 3.4, there was calculated the influence radius of the drainage R_t = 582 + 2345 = 2927 m.

It should be noted that the depresurization of this aquifer, which has practically inexhaustible water resources, affects the environmental components only in terms of the discharge of water from these works in natural receivers, which has a favorable effect on water quality.

The question that arises is linked to diminishing groundwater resources. Based on the same reasoning as in previous cases, the volume of water drained from the adjacent open pit can be obtained, taking into account the thickness of the active area of drilling 20 m ($W_{st}^{artezian}$ = 5.502 mil. m^3).

From the above mentioned and from the analysis carried out for the three aquifers, the results show that the influence area of the drainage works varies from one aquifer to another, depending on the hydrogeological characteristics of the consisting rocks, the geometric characteristics and the hydrodynamic parameters of the horizon.

The absence of hydro observation drillings in the vicinity of Roşia de Jiu open pit did not permit the theoretical estimates to be verified or corrected by practical data.

3.3.4 Dewatering works effects in the adjacent areas of Roşia de Jiu open pit

Most of the alleged activities for the lignite exploitation in open pit influence more or less the groundwater regime. This causes two types of impact on groundwater quality and quantity.

Among the modalities of expressing the quantitative impact the following can be stated:

- The drainage of phreatic aquifer, both inside and outside the open pit perimeter;
- The destruction of aquiferous formations from the excavated perimeters;
- The reduction or even disappearance of underground water resources, leading to drying up wells and reducing water abstraction flows;
- Groundwater flow regime change by increasing local speed filtering and minimizing the flow in the depression funnels extending areas (arising from the drainage process);
- Changing the natural drainage of the region;
- The change of the erosion process dynamics with global implications in the hydric balance of the water basin (soil type, vegetation, hydraulic gradients).

The impact on surface water quality is manifested in particular by:

- increased vulnerability to pollution of all aquifers, particularly the phreatic ones;
- changing the chemical composition of groundwater due to the infiltration of various substances and slurries.

As the coal extraction in the area by open pit mining will continue in the future, and it is conditioned by the drainage works, the effects of drainage will grow and therefore measures must be taken to limit the influence area of the drainage works. Such measures will lead to reducing problems related to water supply to the localities in the area.

The influence of drainage on groundwater resources in adjacent areas of Roşia de Jiu open pit are shown in table 3.7 [A.36].

Table 3.7 Impact of drainage on the regime and water quality

Activity	Types of impact					
	Reducing the piezometric level	Changes in the hydraulic regime	Subsidence, disappearance of aquifer formations	Increased vulnerability to pollution	Change of groundwater chemistry	Change of surface water chemistry
Hydrotechnical works	L1	-	L1	L2	L2	L2
Preliminary drainage	R3	R2	L2	L3	L2	L1
Combined drainage	R3	R2	L1	R2	R2	L2

L - local character; R - regionally; 1 - low impact; 2 - average impact; 3 – major impact

Analyzing the table 3.7 it can be seen that the impact of the actual drainage works is felt particularly on hydrodynamic regime of groundwater and surface water, it has a regional character and intensity from mild to severe. Some forms of impact generated by the drainage of aquiferous formations are the reduction of the height of hydrostatic and piezometric level and increasing vulnerability to groundwater pollution, especially during preliminary drainage works.

3.3.4.1 Impairment of water supply for nearby communities

Following the lowering aquifer levels, there have been drastic cuts in water levels in wells supply water to neighboring municipalities, sometimes even their complete drying. The worst situation was reported in the town of Rovinari and localities Moi, Timişeni, Fărcăşeşti, Bâlteni, Vlăduleni and Rovinari platform.

To ensure water supply to the mentioned localities, the mining unit executed (by own funds), wells that feed on the artesian horizon and ductwork, but their functioning did not always gave the expected results and the water quality has changed due to changes in the chemistry of the groundwater. Regarding the city of Rovinari, because of the drainage system operating in Roşia de Jiu open pit, the water level in supply wells decreased by approx. 60 m, leading to a reduction of 20-30% of the captured flow. Consequently, the execution of new water catchments was necessary.

3.3.4.2 Decrease of groundwater resources

The drainage of aquiferous formations leads to the reduction of groundwater resources by draining and its discharge. Annual discharge of tens of millions of cubic meters of water, as measured by pump stations of Roşia de Jiu open pit, is a certainty.

Since the drainage effects spread to adjacent open pit areas through the depression areas they create, the phenomenon of reducing the volume of groundwater resources is amplified (paragraph 3.3). Recovery of these resources is virtually impossible in most cases because the geological formations structure is destroyed.

For this reason, it is necessary that, at least in the drainage activity, any dynamic resources from adjacent areas are not to be engaged. It requires the use of fundamentally new methods based on shielding aquiferous formations by antifiltering dams located on the outline of open pits.
Scientific literature [A.2], [B.44], [B.45] certifies that in the aquiferous formations shielding conditions, the volume of water drained within a open pit can be reduced by up to 10-20%.

3.3.4.3 Effects on flora and fauna

As a result of the reduction of the hydrostatic level of the phreatic aquifer, both flora and fauna in the area were quite affected [A.36].

Even if the herbaceous vegetation was not completely destroyed, productivity and balance of the characteristic ecosystems of the area have diminished significantly. In the adjacent perimeters of Roşia de Jiu open pit, aquatic and paludous vegetation have recorded the worst impacts. This type of vegetation is preserved only in close proximity to watercourses or along the guard canals, where characteristic plant species still exists, but in very low numbers.

The grasslands have been affected less than herbaceous vegetation, but in this case safety measures are necessary, measures to reduce the area of influence of the open pit drainage works, namely the avoidance of lowering the hydrostatic level of the phreatic layer.

Due to degradation of vegetation, food chains have been fragmented, which has reduced the efficiency in terms of energy and nutrient transfer. The invertebrate fauna has changed, finding a high share of arachnid in the area and a extremely small biodiversity of microartropods, which shows that there have been important ecological imbalances, since other key fauna species to the ecosystem have disappeared.

As regarding to the ichtyofauna from Jiu river, it appears that there were no reports of major problems caused due to release of water from Roşia open pit, there are still some valuable species. The most affected are the populations of reptiles and amphibians, which because of the disappearance of vegetation found refuge in more remote areas, being affected by the scarcity of reproduction ponds.

The number of mammals was reduced in the surrounding areas of open pit, particularly because of increased levels of noise and vibration. But the disappearance of species is excluded due to their ability to migrate to other areas nearby that have the same characteristics.

3.3.4.4 Subsidence of geological formations under the effect of dewatering works

There is the possibility that in certain areas of the depression cone formed around the open pit, the compaction of geological formations to occur by draining the free water through aquiferous rock pores. Consequently, the whole geological task is undertaken by the mineral skeleton of the rock, leading to significant subsidence, due to reduced porosity. Depending on the nature of the terrain, the coefficient of permeability and the thickness of the aquiferous formations and of the covering layers, the affecting land surface subsidence may have values between 2-3 m [A.2], [A.36].

Such compactions were reported in the northwestern part of Roşia de Jiu open pit, which affected the railways in the area, being also associated with a northeast slope slip on a fault surface. Other compactions were reported in the Rogojelu power plant. By lowering the piezometric level, the foundation land of the power plant is affected by supplementary compactions, besides the normal ones given by the load transmitted by the foundation. Since the power plant is located in the center of the Rovinari mining basin, this supplementary compaction can be caused by the drainage works running in all the open pits from the basin, but the largest share belongs to Roşia de Jiu open pit (open pit that discharges annually tens of millions m^3).

The compaction of the geological formations must be monitored through surface topographic markers. This can be done in parallel with the measurements aiming at tracking the deformations and estimating the stability of slopes and industrial objectives in the area.

3.3.5 Measures to reduce the impact on the environment of dewatering works

3.3.5.1 Shielding the aquifer formations

To prevent the transmission over long distances of the drainge effects to the adjacent open pit areas, waterproof screens are to be used, representing the perfect solution, used with good results internationally and nationally.

Thus, the execution of a shield in the extension of existing is proposed, whose aim is to protect the Rovinari city and Rogojelu power plant (figure 3.7) [A.36].

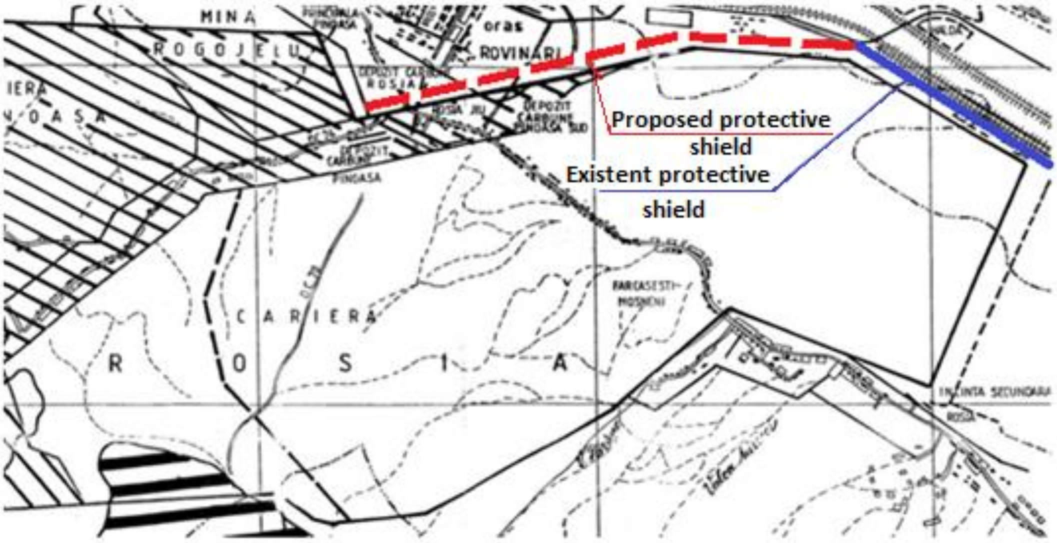


Figure 3.7 Location of the proposed protective shield

Concurrently, groundwater levels are to be monitored, (especially the groundwater aquifer) through the execution of hydro observation wells in the adjacent areas, and improving the system for monitoring land surface deformations using a network of landmarks.

3.3.5.2 Use of the water from the dewatering works

As shown, the groundwater resulting from drainage works from Roşia de Jiu open pit is discharged into the river, and the mining unit pays monthly penalties to the Romanian Waters Company, depending on the volume of water discharged. According to the analysis, this water can be a very important resource for needs of the local population.

Given the high costs of the drainage works, plus significant amounts paid as penalties for charging suspensions of the river Jiu, it is preferable to use the water from the drainage works for different purposes, imposed by the demand for water from nearby areas. Based on water quality characteristics and requirements of the local population, three main directions for the usage of water from drainage wells were identified:

- ✓ drinking water supply;
- ✓ use of water to irrigate crops in the area;
- ✓ water filling gaps remaining from the open pits to be closed due to the depletion of reserves.

Using groundwater resulting from drainage work involves performing a relatively simple project. Thus, it is necessary to build a collection and sedimentation basin, a pump station and a pipeline system to transport water to the points of use (figure 3.8). For use as drinking water, we must shift water from drillings through a water treatment plant [A.8].

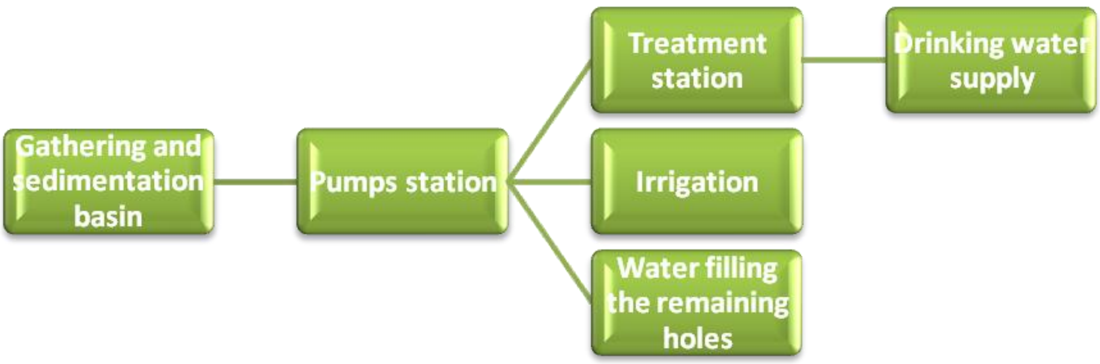


Figure 3.8 System for the use of the groundwater from the drainage works

Rovinari town, which has about 15,000 residents, is located nearby Roşia de Jiu open pit. The town has three main areas: residential area, industrial area and agricultural area. Suburban area, represented by the district Vart, has no drinking water supply network and its implementation should be speeded up. In the two colonies of this district, public water supply is still achieved from wells, some of which have dried up as a result of lowering the hydrostatic level of the aquifer horizon (due to drainage works). Rovinari town has agricultural land with an area of 840 hectares, planted with orchards and nurseries, vine nurseries, pastures, cereals etc. [A.8]. Both for drinking water and to irrigate crops, water quality must be within the standards set by the regulations. In table 3.8 there are the main indicators of the quality of the water discharged from the Roşia de Jiu open pit compared to legal standards.

Table 3.8. The quality of the water discharged from the Jiu Roşia open pit

No. crt.	Quality indicator	MU	CMA cf. NTPA 001/2005	Determined values
1	Ph	mg/l	6.5 – 8.5	7.12
2	CBO5	mg/l	25	11.55
3	CCOCr	mg/l	125	25
4	Fixed residue	mg/l	2000	172
5	Chlorides	mg/l	500	10.6
6	Sulphates	mg/l	600	46
7	Calcium	mg/l	300	38
8	Magnesium	mg/l	100	12
9	Phenols	mg/l	0.3	0.12
10	Iron	mg/l	5	0.1
12	Suspensions	mg/l	35	34

It is noted that from terms of quality, although it was considered as industrial wastewater, the water from the drainage works meets the standards, requiring minimal treatment works.

Restoring the hydrostatic level begins with the end of the drainage system operations, but this process can take a very long time. In the Rovinari mining basin several lignite open pits operate; some of which will be closed because of exhausting reserves in the future. Part of the water from the drainage work from Roşia de Jiu open pit may be used to fill the remaining holes. This creates a series of lakes that can take different uses, depending on the strategy of development of the area. The created lakes in the remaining gaps significantly contribute to a faster recovery of the groundwater levels [A.1].

3.4 Research on rainfall infiltration regime into the waste dumps body from mining basin Motru

3.4.1. Hydrometeorological regime of the area

Located in southwestern territory, in the Getic hills and orographic sheltered in the north and west by the Carpathian mountain chain, we appreciate that the Motru enjoy a temperate continental moderate climate.

Rainfall is relatively high, with average annual amounts ranging from 746 - 906 mm, but they can overcome up to 1180 - 1330 mm, or decrease to 430-580 mm. Maximum amounts of precipitation fell in 24 hours can sometimes exceed in appreciable quantities the average monthly. Thus, in Tg. Jiu in September 1968 there were 93.6 mm rain fell in 24 hours, the amount exceeded the 43.8 average mm monthly averages. At Apa Neagra, in July 1969 rainfall have totaled 154.2 mm within 24 hours, the monthly average being of 83.2 mm, and finally, at Matasari in July 1991, within 24 hours, 80.0 mm fell, with 25.8 mm more than average in July. Snow lasts on average 46 - 57 days annually, and its thickness can reach averages of 14 - 72 cm. Figure 3.9 presents are annual and monthly average precipitation and temperatures measured at weather station Tg. Jiu, period 1983 - 2006, compared to the corresponding multi hydrological measurement, period 1901 - 2006 and the variation in annual averages for that period can be observed [A.24].

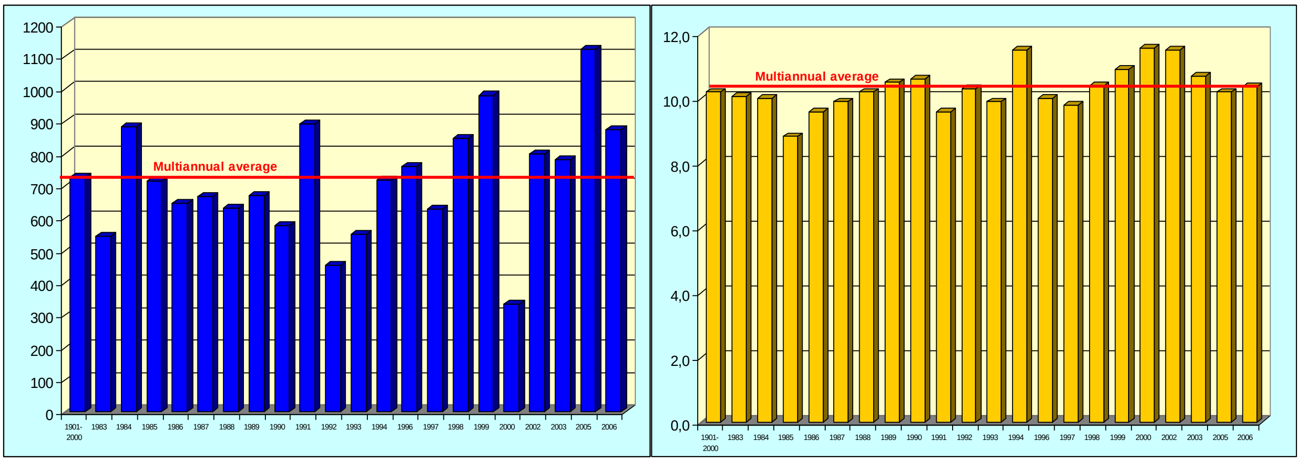


Figure 3.9 Average annual rainfall and temperatures

From the data emerges as a first conclusion that in the last 10 years of observations, mean values exceeded or reaching multiannual rainfall and temperature are relatively common, in eight years for rainfall and eight years temperature. High values of annual average rainfall were recorded mainly in 2004 and 2005 (1007.3 respectively 1121.9 mm than the multiannual average of 726.3 mm), leading to accumulation by infiltration of large quantities of water in the body of waste dumps, such being created favorable premises for triggering landslides. It states that in 2004, in July and November were exceeded the monthly averages rainfall of over two times, and in July 2005 exceeded the monthly average of 3.9 times.

3.4.2. Determination of infiltration

Field tests conducted concluded that the main source of water from waste dumps body comes from rain, without being excluded the possible infiltration from and from within the natural slopes in the area.

To establish the quantity of infiltrated water in the dump body from precipitation, depending on the type of land, can be used models based on simplified mechanisms of infiltration [B.30], [B.31]:

- ✓ models based on *Hortonian mechanism,* that appeal to potential infiltration simplified equations derived from Richards' equation, assuming a potential infiltration variable in time and obtaining the net rain by comparing rain intensity with potential infiltration;
- ✓ models based on the *principle of basin,* which is based on the assumption of the total infiltration of rain up to saturation, after which infiltration becomes null.

Other models for infiltration determining are empirical models, most used in practice are the following:

- ✓ the model Soil Conservation Service (SCS);
- ✓ influx coefficient method.

3.4.2.1 Hortonian mechanism

If the rain intensity is lower than the potential infiltration, all precipitation water infiltrates, and infiltration is equal to rain intensity; if instead rain intensity is higher than the potential infiltration, the effective infiltration is equal to the potential infiltration [B.9], [B.30], [B.31]:

$$f(t) = \begin{cases} i(t) & \text{for } i(t) < f^*(t) \\ f^*(t) & \text{for } i(t) \geq f^*(t) \end{cases} \qquad (3.10)$$

The soil refusal, equal to the difference between rain intensity and infiltration, is:

$$p(t) = \begin{cases} 0 & \text{for } i(t) < f^*(t) \\ i(t) - f^*(t) & \text{for } i(t) \geq f^*(t) \end{cases} \qquad (3.11)$$

During rainfall, infiltration potential intensity decreases with increasing ground moisture. If rain intensity remains higher than the potential infiltration, infiltration occurs after the function f*(t) until the end of rain. This is the case where precipitation is very intense or land has high initial moisture. If rain intensity is lower than the top potential infiltration, initial infiltration, which is equal to the intensity of rain, penetrates the ground until the moment tr when potential infiltration is equal to the intensity of rainfall and then shallow flow begins. In that moment t_r, cumulative infiltration $F(t_r)$ is equal to the height of the precipitation $h(t_r)$. After the moment tr until the rain intensity becomes again smaller than the potential infiltration, net rain intensity is the difference between rainfall intensity and infiltration potential.

Horton's laws [B.31] of potential and relative cumulated infiltration:

$$f^*(t) = f_\infty^* + \left(f_i^* - f_\infty^*\right)e^{-kt} \tag{3.12}$$

$$F^*(t) = f_\infty^* t + \frac{f_i^* - f_\infty^*}{k}\left(1 - e^{-kt}\right) \tag{3.13}$$

where:

f_i^* - initial potential infiltration;

f_∞^* - limit infiltration for saturated soil;

k - parameter that defines the potential infiltration rate reduction.

Horton's law parameters depend on soil characteristics. Values proposed by ASCE Manual (American Society of Civil Engineers) [B.65] are shown in table 3.9 and the values proposed in the model recommended by ILLUDAS (The Illinois Urban Drainage Area Simulator) [B.66] are shown in table 3.10. Table 3 presents the classification of land after the Soil Conservation Service [B.67].

Table 3.9 Horton's formula parameters (A.S.C.E.)

Function type	f_i^*	f_∞^*	k
	(mm/h)	**(mm/h)**	**(h^{-1})**
increased (highly permeable soils)	117	17	5.34
standard (medium permeable soils)	76	13	4.14
low (low permeability soils)	76	6	4.14

Table 3.10 Horton's formula parameters (ILLUDAS)

Soil group	f_i^* **(mm/h)**	f_∞^* **(mm/h)**	k **(h^{-1})**
A	250	25	2
B	200	12.5	2
C	125	6.5	2
D	75	2.5	2

Table 3.11 SCS-CN method: soil classification by Soil Conservation Service (SCS, 1968)

Group	**Description**
A	*Very low flow potential*: coarse sands with small content of dust and clay, gravel, very permeable
B	*Moderately reduced flow potential*: most of the sandy soils coarse less, but with high infiltration and saturation capacity
C	*Moderately high flow potential*: fine soil with a high content of clay and colloids, but lower than those in group D. they have a reduced capacity of infiltration and saturation.
D	*Very high flow potential*: most of the clays with high swelling capacity, but also thin soil horizons that form near the surface almost impervious land.

As described in table 3.11, the mixture of material from the waste dump of Rosiuta quarry fall in groups C and D.

The corresponding curves of the Horton's law for the two groups of parameters The curves, illustrated in figure 3.10, are different, because the ILLUDAS values are almost always much higher than the ASCE values. The difference between these values can be explained by the fact that values proposed by the ASCE are covering for any possible conditions, while those recommended for a simulation model that ILLUDAS refers to average conditions.

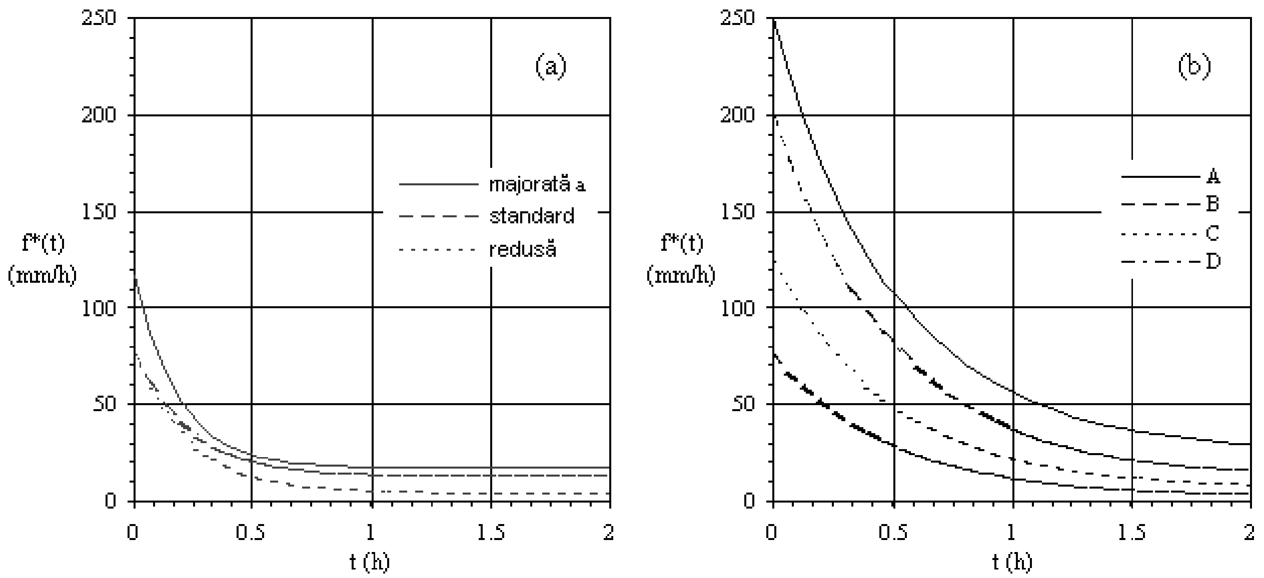


Figure 3.10 Infiltration capacity after Horton's law: a) ASCE and b) ILLUDAS

In terms of terrain features from waste dumps EMC Motru, respectively land with low permeability (groups C and D classification Soil Conservation Service) from calculations made by the methodology (table 3.12) were obtained two types of curves for potential and relative cumulative infiltration (figures 3.11 and 3.12), in terms of occurrence of precipitation lasting eight hours and a higher intensity than the potential infiltration [A.24].

Table 3.12 Calculation of the potential and cumulative relative infiltration

t (h)	f*(t) (mm/h)		F*(t) (mm)	
	ASCE	ILLUDAS	ASCE	ILLUDAS
0	76.00	125.00	0.00	0.00
0.5	14.83	50.09	17.77	40.70
1	7.11	22.54	22.64	57.73
1.5	6.14	12.40	25.87	66.05
2	6.02	8.67	28.90	71.16
3	6.00	6.79	34.91	78.60
4	6.00	6.54	40.91	85.23
6	6.00	6.50	52.91	98.25
8	6.00	6.50	64.91	111.25

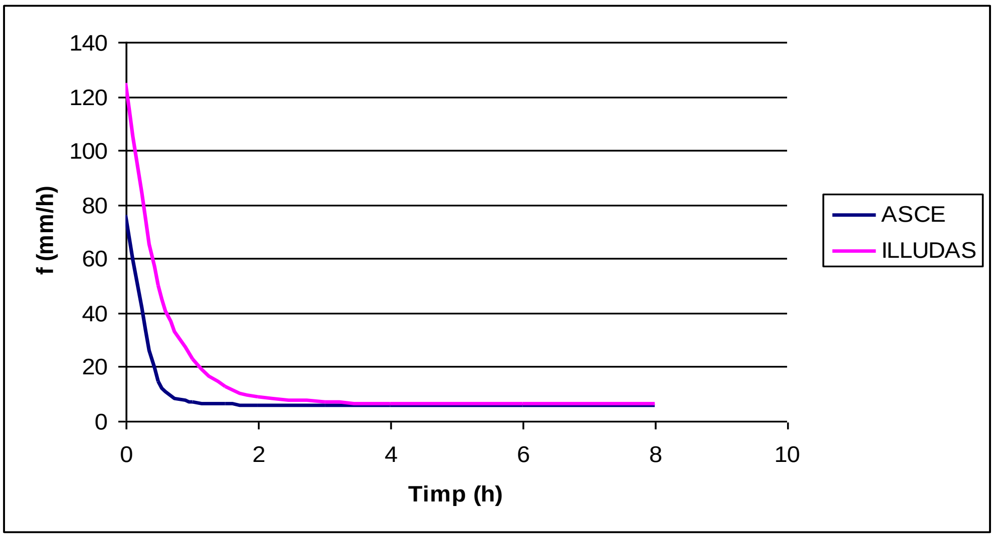


Figure 3.11 Potential infiltration of the dumps material

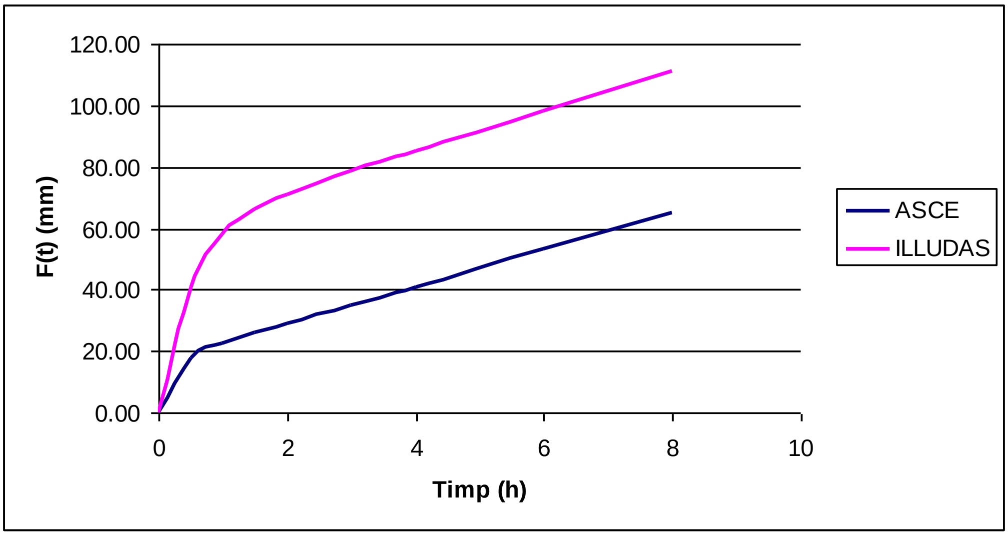


Figure 3.12 Relative cumulative infiltration of the dumps material

Analyzing the potential infiltration curve is observed that is a reduced curve by ASCE method and corresponding to groups C and D according to the ILLUDAS method. Water infiltration is greatest in the first hours after the start of precipitation, then decreases asymptotically tending to zero and corresponds to long-term precipitation conditions, accumulation of water are formed on the dumps surface. Regarding the relative cumulated infiltration, it increases sharply in the first hours after the start of the phenomenon of precipitation and relatively slow in the next hours. Infiltration process can continue as long as surface moisture decreases on account of the occurrence of internal drainage and evapotranspiration.

3.4.2.2 SINTACS method

According to this method, for determining the effective infiltration the following steps must be performed [B.9]:

- ✓ identifying existing meteorological and hydrological stations in the area and in the close proximity;
- ✓ temperatures and precipitations historical data series homogenization for periods of at least 20 years;
- ✓ calculation of monthly and annual mean of precipitations and temperatures data for each measuring station;
- ✓ calculating the mean annual of corrected temperature T_c depending on precipitation;

- ✓ calculating the functions: rainfall - quota respectively corrected temperature - quota;
- ✓ calculating the mean quota q;
- ✓ calculating the mean precipitation P;
- ✓ calculating the real evapotranspiration ER;
- ✓ calculating the specific effective precipitation Q;
- ✓ identification of potential infiltration coefficient χ, on the basis of the surface lithology;
- ✓ calculating the specific effective infiltration.

Basic information needed to evaluate effective infiltration are the historical hydrometrics and thermo series, for an observation period of at least 20 years on the monthly average recorded in all stations located within and near the area of study. Monthly average temperature values are corrected for precipitation, whereas the rate of evapotranspiration, the same soil and climatic conditions, the rate depends on soil moisture and thus, ultimately, of precipitation. As a result, in Turc's formula (1954) mean air temperature is corrected for precipitation to take into account different humidity conditions.

Formula proposed for temperature correction:

$$T_c = \frac{\sum P_i \cdot T_i}{\sum P_i} \qquad (3.14)$$

where: T_c - average annual temperature correction;
P_i - recorded monthly average precipitation;
T_i - recorded monthly average temperature.

The next step is assessing the value of annual average rainfall and average annual correct temperature, by applying the determined correlation. These values are used to calculate the effective precipitation, actually touching the ground. To calculate the parameter first actual evapotranspiration ER must be determined by using Turc's formula.

$$ER = \frac{P}{\sqrt{0{,}9 + \left(\frac{P^2}{L^2}\right)}} \qquad (3.15)$$

where: ER - actual evapotranspiration (mm/year);
P - mean annual total precipitation (mm/year);
L – the ability of the atmosphere evaporated..

$$L = 300 + 25 \cdot T_c + 0{,}05 \cdot T_c^2 \qquad (3.16)$$

Knowing the value of ER, effective precipitation Q is obtained simply:

$$Q = P - ER \text{ (mm/year)} \qquad (3.17)$$

To calculate the infiltration, SINTACS methodology proposes two ways to approach different to the case of an impermeable or low permeability soil and the permeable land.

In the first case infiltration obtained by multiplying the appropriate value of effective precipitation infiltration coefficient χ, for the existing rock type:

$$I = Q \cdot \chi \text{ (mm/year)} \qquad (3.18)$$

If a highly permeable ground, use the total amount of P (without decreasing evapotranspiration), which is multiplied by an infiltration coefficient χ (table 3.13) mainly based on texture:

$$I = P \cdot \chi \text{ (mm/year)} \qquad (3.19)$$

Table 3.13 Types of soils and infiltration coefficient values

Soil type (IPLA)	**Infiltration coefficient χ**
Clayey	0.03
Mixture	0.10
Predominantly clayey	0.05
Predominantly dusty	0.10
Predominantly dusty-clayey	0.07
Predominantly sandy	0.30
Predominantly sandy-clayey	0.25
Sandy	0.40

Using SINTACS method for evaluating infiltration for Motru EMC dumps, taking into account pluviometric data series for 21 years and stored material characteristics (in particular the share of different types of rocks), were obtained the data presented in table 3.14.

It indicate that the rate of infiltration was counted a value of 0.4 because, although the landfill material is predominantly sandy clay, the high degree of mellowness (where fresh material is deposited) is a favorable condition for producing water infiltration from precipitation. [A.24].

Table 3.14 Effective rainfall infiltration dumps body

	Year					
	2000	**2002**	**2003**	**2004**	**2005**	**2006**
P	333.40	798.10	780.50	1007.30	1121.90	871.90
T_c	12.04	15.10	10.99	13.32	12.66	12.76
L	688.27	849.56	640.99	751.26	717.88	722.76
ER	312.99	597.78	505.64	613.28	613.66	568.13
Q	20.41	200.32	274.86	394.02	508.24	303.77
I	8.16	80.13	109.94	157.61	203.30	121.51

From the data presented in the table result the following conclusions:

- ✓ as opposed to the hortonian mechanism that refers to the potential infiltration, using SINTACS method aims to determine the effective infiltration, reported to an observation period of one year;
- ✓ the evaporable capacity of the atmosphere in the region of location of waste dumps is relatively high, which means that a large part of water from precipitation evaporates (for the years under study, specific effective precipitation, namely that part of precipitation that actually touching the land, is less than half of the total precipitation);
- ✓ the average effective infiltration is very low in dry years (such as 2000) and can achieve part of the 5th annual average precipitation if very rainy years (2005 case).

On the hydrometeorological regime following findings are made:

- ✓ maximum amounts of precipitation fell in 24 hours can sometimes exceed the average monthly by appreciable quantities. For statistical analysis shows that the area studied, at least every 10 years rainfall fell in 24 hours can reach 76-105 mm; every 20 years, the maximum quantities of rainfall fell in 24 hours can be between 87 - 124 mm; every 50 years between 102-160 mm, and once in 100 years they can total 115 -190 mm;
- ✓ having regard to the low permeability of the material stored in waste dumps belonging to EM Rosiuta, mostly heavy rain infiltration occurs with accumulation, and by deposititing material over the water accumulated on the surface of steps leads to increased water pressure in the dumps body;
- ✓ potential infiltration was determined by hortonian mechanism, using for this purpose ILLUDAS and ASCE methods. ASCE method reveals that potential infiltration in the waste dumps occurs after a small curve, due to low permeability of the material stored and for the case of an 8-hour precipitation, infiltration potential decreases from 76 mm/h in the start to approx. 6 mm/h after an hour and a half, then maintaining this value. ILLUDAS method leads to higher values of infiltration potential, respectively 125 mm/h at the beginning of precipitation and 6.5 mm/h when it ends;

- ✓ relative infiltration determined by the same methods shows relative increase in the range of 8 h from 0 to 64.91 mm (ASCE) and from 0 to 111.25 mm (ILLUDAS). Infiltration phenomenon continues after rainfall stops, due to internal drainage that occurs as a result of a high degree of mellowness;.

On how water accumulates in the waste dumps the following comments are made:

- ✓ accumulation of water is based on precipitation infiltration and from springs;
- ✓ water infiltration is enhanced by rocks mellowness and rainfall intensity and duration;
- ✓ the phenomena of swelling clay rocks reduces the rate of infiltration, but in the same time gave in changing in the same degree of consistency and resistance characteristics of rocks;
- ✓ water disposal capacity by saturated rocks is low and, lack of seepage on slopes, even if the water level is high, indicates a low permeability of rocks and lack of posibilities for aquifer currents to occur.

Further research by some experiments in situ may contribute to a better understanding of how water is stored in the waste dumps and their hydrodynamic regime.

3.5 Studies on groundwater levels in the dumps of Rosiuta open pit

Over time, the dumps of Rosiuta open pit were affected by numerous instability phenomena, and among their causes include the geotechnical conditions, the shape and nature of the base land, the nature and characteristics of the rocks from the direct foundation and from the dumps, the depositing technology, partial execution of hydrotechnical and drainage works and, not least, the presence of water in the structure of the deposited material.

The investigations in the field led to the conclusion that the main sources of water in the dumps body were particularly precipitations, and infiltrations from the slopes and valleys on which the dumps are built (paragraph 3.4).

3.5.1 Hydrogeological regime of water inside the dumps body

Infiltration of water inside the dumps was and is favored by the granulometric structure, the high degree of loosenes and weak consolidation of the deposited rocks, the existence of areas of stagnant water and lack of works to insure slopes for their uniform drainage.

The aquferity of the deposited rocks is assessed through the coefficient of infiltration and filtration coefficient (also called the Darcy permeability coefficient). The coefficient of infiltration refers to the downward movement as a result of ingress of surface water. Water infiltration takes place through intergranular spaces to the extent of satisfying the water retention capacity of the rocks from the unsaturated zone, until it meets the hydrostatic level, after that, the water infiltrated increasing the hydrostatic level.

Infiltration is influenced by gravity, rocks porosity, temperature, viscosity and content of dissolved salts, its value being dependent on the existence or absence of hydraulic connection with eventual aquifers zones that can change its character.

Due to water infiltration due to rainfall or underground aquifer currents, due to the presence of infiltrations from slopes, in all exterior dumps of Rosiuta open pit, groundwater that saturates the rocks sometimes to shallow depth of about 1-8 m and even more small is present. There were observed drastic fluctuations of the hydrostatic level inside the dumps body, depending on the intake of water from precipitation and/or infiltration or on the drainage possibilities.

The filtration coefficient, which defines the movement of groundwater under the action of a unitary hydraulic gradient, through a porous medium saturated with water, depends on the characteristics of the mineral skeleton of the rock and the characteristics of the water flowing through the pores. The main factors influencing the value of the filtration coefficient are: porosity and pore geometrical characteristics, mineralogical nature of the land, water specific weight, size of the hydraulic gradient, the dynamic viscosity of water and the stratification of rocks.

To characterize the permeability of rocks, filtration coefficient is determined based on calculation relations or by laboratory and field research.

Determination of the filtering coefficient was done in the laboratory using variable gradient permeametry, given the argillaceous nature of the deposited rocks. Values obtained from laboratory measurements ranged between $2.4 \cdot 10^{-5}$ and $1.045 \cdot 10^{-2}$ cm/s for Rogoazelor Valley dump and between $4.18 \cdot 10^{-6}$ and $3.25 \cdot 10^{-4}$ cm/s for Ştiucani dump [A.20].

Since the presence of groundwater in waste dumps is influenced by storage and disposal of water capacity of the rocks, these characteristics were also studied, and the results of laboratory tests are given in table 3.15.

Table 3.15 Hydric characteristics of the deposited rocks

Rock type	Waste dump	Total porosity n [%]	Pore index ε	Natural humidity W [%]	Quantity of water	
					absorbed k_w [%]	released k_c [%]
Dusty clay	Rogoaze	43.14-45.70	0.75-0.84	26.4-27.7	62.65-76.70	17.6-18.75
Clayey dust	Rogoaze	42-44.65	0.68-0.80	25.8-27.64	70.2-78.30	18.60-21.35
Dusty clay	Ştiucani	44.8-47.38	0.72-0.89	28.5-32.8	55.5-63.20	17.80-20.05
Sandy clay	Ştiucani	48.20-50.23	0.8-0.94	32.3-38.9	54.34-57.20	22.4-26.00
Clayey sand	Ştiucani	44.80-53.25	0.81-0.96	30.16-41.28	53.90-69.32	24.28-32.30

For sandy rocks it was recorded a storage capacity coefficient of approx. 53 - 69% and for clayey rocks of 55 - 78%. The share of released water for sandy rocks is approx. 24 - 32% and for clayey rocks of about 17 - 20% from the total stored water volume. On the values mentioned, there are some uncertainties related to laboratory measurements that do not reflect the degree of compaction of the rocks in the dumps.

The values obtained confirm that the mixture of rocks, from the exterior dumps of Rosiuta open pit, releases the water hardly and in a small amount. Therefore it is assessed that gravitational drainage of water stored in the dump through dewatering wells will be ineffective, as a result of long time dewatering, small influence radius and very low flow rates. Low flow rates were confirmed by experimental pumping performed after completion of some drilling (from 0.7 to 1.4 m^3/day and drilling).

3.5.2 Evolution of the hydrostatic level in the dumps

To monitor the hydrostatic level of groundwater in waste dumps, between 2002 and 2007 were executed hydro observation drilling cased with filtering columns, namely: 16 drillings in Rogoazelor Valley dump, 10 drillings in Ştiucani dump and 14 drillings in Bujorăscu Valley dump. In time, some of them were destroyed due to landslides or were covered by the deposited material, as the filtering columns were not extended. Table 3.16 presents the hydrostatic level determined in some drilling from the three dumps [A.20].

Table 3.16 Situation of the piezometric levels in hydro observation drillings

Location (dump)		Rogoaze			Bujorăscu Mic				Ştiucani			
Drilling no.		HO.9	HO.13	HO.15*	HO.3	HO.5	HO.7	HO.13	HO.3*	HO.4**	HO.6**	HO.7**
Depth (m)		69.5		56.0	45.0	68.0	67.0	61.0	60.50	58.80	58.00	64.00
Elevation (land)		311.28	348.85	331.26	297.00	320.00	337.00	335.3	321.0	322.00	310.00	319.00
Length of the aerial column (m)		1.0	1.0	0.80	0.70	0.80	0.70	1.30	0.80	1.20	0.90	0.90
Depth of the hydrostatic level/Piezometric level	28.06.2007	7.60/ 304.68	20.20/ 329.65	0.40/ 331.66	18.50/ 279.20	-	-	-	0.0/ 321.80	2.00/ 321.20	2.16/ 308.75	3.00/ 316.90
	23.07.2007	7.90/ 304.38	20.60/ 329.25	0.45/ 331.71	17.80/ 279.90	11.75/ 309.05	5.60/ 332.10	1.95/ 334.65	0.0/ 321.80	1.85/ 321.35	2.30/ 308.60	3.70/ 316.20
	22.08.2007	7.70/ 304.58	20.50/ 329.35	0.30/ 331.56	17.65/ 280.05	11.60/ 309.20	5.50/ 332.20	1.85/ 334.75	0.0/ 321.80	1.60/ 321.60	2.20/ 308.70	3.50/ 316.40
	07.11.2007	2.90/ 309.38	-	-	7.40/ 290.30	11.61/ 309.19	5.70/ 332.0	-	-	-	-	-
	03.03.2008	2.50/ 309.78	15.20/ 334.65	0.65/ 331.91	12.10/ 285.60	12.34/ 308.46	-	14.08/ 321.92	0.16/ 321.64	1.20/ 322.00**	1.15/ 309.75	0.90/ 318.97
	03.04.2008	2.69/ 309.59	16.05/ 333.80	0.68/ 331.38	12.25/ 285.45	9.10/ 311.70	2.07/ 335.63	-	0.14/ 321.66	1.20/ 322.00**	1.41/ 309.49	1.20/ 318.70

* drillings with water level above land elevation.
** drillings with water level at ground level

From the analysis of data derived from measurements, the following conclusions can be drawn:

- ✓ The level of groundwater is variable in the three dumps, the highest being in Ştiucani dump and the lowest in Bujorăscu dump, thus it was assess that the rocks deposited in Ştiucani dump are more clayey and have a higher capacity to retain water. This assessment correlates with the geotechnical research results for the deposited rocks.
- ✓ For the same dump variations of the hydrostatic level are found not only between drillings located at different elevations, but also for drillings located at the same elevation, reflecting different permeability and water retention capabilities of the deposited rocks. They are dependent on the heterogeneity of the deposited rocks, heterogeneity which manifests itself both vertically and on the surface of the dumps steps, but also the possible presence of water accumulated during deposition of rocks. Rocks heterogenity was highlighted during the execution of geotechnical and hydro observation drilling. The hydrostatic level variations depend on the presence of precipitation. In rainy periods (November 2007 and early March 2008) there were increases of the hydrostatic level up to approx. 5 m - drillings HO.9 and HO.10 - Rogoazelor Valley dump and even up to 10 m - drilling HO.3 - Bujorăscu dump, depending on local conditions, which have adverse effects on stability by increasing the pore water pressure, worsening the resistance characteristics of rocks, changing the state of consistency and by reducing the bearing capacity of rocks.
- ✓ The presence of water in some drillings at or near the ground elevation - drillings HO.4; HO.6 and HO.7 of Ştiucani, HO.12 - Bujorăscu and even above ground elevation - drillings HO.1; HO.3 Ştiucani and HO.14; HO.15 Rogoazelor Valley, indicates the presence of areas with ascensional waters, as a result of local hydrogeological and morphological conditions and not due to the existence of a aquifer current inside the dumps. A particular case is represented by drillings HO.5 and HO.7 from Bujorăscu dump, where the piezometric level rose between 3 and 10 April 2008 was under the influence of overloads created by depositing works executed in step 340-355 m. The increase in external pressure leads to an additional pore water pressure, which on the one hand influences the movement of water in rocks, and on the other hand, by acting on effective efforts that influences the structure of the rocks and thus their deformations. The manifestation of this phenomenon induces the assumption that for other drillings with ascending level is likely that the lithological efforts are responsible for the rising of the water level.
- ✓ Existence of wetlands on Rogoazelor Valley and Ştiucani dumps is related to: the presence of uneven areas where water accumulates during precipitation, the presence of a high piezometric level and low permeability of rocks that do not allow drainage/circulation of groundwater.
- ✓ Low permeability of rocks and the absence of underground currents is reflected by different levels of groundwater from neighboring drillings. Thus for drillings HO.14, HO.15 and HO.9 - Rogoazelor Valley dump, where the difference in the H.L. are of approx. 21 - 22 m for a distance of 350 - 400 m (I = 0.55 to 0.06); drillings HO.7 and HO.5 respectively HO.13 and HO.5 of Bujorăscu dump with differences in H.L. of 24 and 25 m for distances of 165 m and 150 m and hydraulic gradients I = 0.145 - 0.166; drillings HO.3 or HO.4 and HO.6 in Ştiucani dump where differences in H.L are of 12 - 12.5 m for intervals of 365 and 225 m, with hydraulic gradients of 0.03 and 0.053, without water reaching the surface as seepage.
- ✓ All findings pointed to the conclusion that we can not talk about a specific regime of groundwater inside the dumps, and a proper assessment of the hydrogeological regime of water inside dumps body requires further research through new hydro observation drilling whose location must follow certain geometry, depending on the obtained results and conclusions.
- ✓ Hydro observation drillings are required for the knowledge of developments in the H.L. inside the dumps, in order to direct the depositing works towards areas with low levels. This is because the reduction of the H.L. reduces pore water pressure and the external pressure exerted by the deposited material is taken the mineral skeleton through the contact areas of mineral particles or rock fragments. In this way the microstructure of the system changes over time, the water in the pores will gradually dissipate, and between the granules bonding forces will appear sufficient to balance the loads due to external shearing efforts, which corresponds to rock consolidation.

Based on observations of hydro observation drillings and investigations, the following are recorded:

- ✓ the presence of groundwater is noticed in all the dumps of Rosiuta open pit, with a plus for Ştiucani dump, where H.L. are higher;
- ✓ water distribution inside the dumps is uneven, there are found areas with higher and lower H.L. The existence of these areas is related to the structure and nature of the deposited material and the conditions during depositing (precipitation, accumulation of water in uneven areas etc.).
- ✓ changes in H.L. are dependent on rainfall (is lower in periods of low rainfall and increases during periods of intense rainfall, which is normal and indubitable).
- ✓ increased H.L. is also due to overloads caused by depositing works. Under their influence the pore water pressure increases and the compaction of rocks, which leads to a rise of the H.L. and migration of water towards areas more favorable to filtration.
- ✓ knowing the H.L. inside the dumps is essential for avoiding negative mining phenomena and guiding the depositing works. For this purpose, hydro observation drillings should be executed on the steps of the dumps, and they must be extended with their ascension. Regarding the location of the drillings is estimated that a network of 200 m x 100 m is appropriate under the current state of knowledge of the groundwater regime.

Combating water ingress inside dumps is possible only through leveling and compaction works of the deposited rocks and through a better management of surface water (drainage, collection and routing of surface water). For this purpose, it is proposed to equip the technological lines with leveling and compacting machines. Leveling and compacting works of rocks will reduce water infiltration both inside the dumps and especially the presence of free water, which leads to the formation of local hydrogeological structures and the manifestation of pore water pressure.

CHAPTER 4

MODELS AND METHODOLOGIES FOR THE ECOLOGICAL LAND RECONSTRUCTION

The main intervention for the elimination of mining impact is the rehabilitation of the affected areas at the end of exploitation, and consists in establishing all the necessary measures to prepare the area for an environmentally compatible reuse.

4.1. General considerations

Currently, both in the abandoned and in the active opencast mines, interventions to accelerate the natural recovery of degraded land are executed, which can start spontaneously at the time of closure, but that takes a long time and the results are usually uncertain. Techniques for intervention in these strong anthropic areas, with accelerating role for the recovery and reuse of land varies substantially depending on various factors, figure 4.1 [A.1].

Figure 4.1 Factors that influence the recovering techniques of the degraded land

Basis of any intervention for ecological rehabilitation, so in terms of mining, is linked to obtain a biological and morphological variety maximum, and finally, to adapt to the territorial context. To this end, it is appropriate to design rehabilitationof the landscape so as to obtain a morphology of the territory as close to the natural shape, eliminating geometric shapes, which unambiguously identifies an anthropic action. There are multiple intervention techniques and differ depending on the type and the area on witch rehabilitation is carried out, but often it is recommended to execute some experimental tests on small surfaces, to highlight the factors influencing the success of recovery.

Regarding the choice of plant species, it is based, on the one hand, on the study of vegetation in the area, and on the other hand, must take into account the physical, chemical and biological characteristics of the fertile substrate and the early, robust and resistant species that are suitable for growth under extreme conditions. It is possible to foresee a gradual replacement sequence, natural or artificial, from pioneer species, to finally reconstruct plant associations present in the area before the beginning of extractive activity.

A proper rehabilitation of areas affected by opencast mining must respond to a clear end (naturalistic area, recreation area, industrial area etc.) and, if the goals are not compatible with each other, it is necessary to choose clearer and well motivated goals.

Lately, we hear increasingly more about the multiple reuses of the areas affected by the mining industry, which is mainly due to the increase in population density and economic activities. Multiple uses imply overlapping of uses and functions of land, as long as they do not interfere with each other but even complement. Especially when there are remaining empty spaces in the area, which can be filled with water, there are many possible combinations of use.

Remaining holes of former opencast mines can be filled with water, thus taking over various functions, ranging from industrial to recreational ones, or can be used for storing industrial waste or household waste. Such directions can be identified for the redevelopment of empty mining spaces, as shown in figure 4.2 [A.1], [A.26].

Figure 4.2 Directions to reuse of the remaining holes

The choice of combinations of different reuse types can be achieved quickly using the matrix in table 4.1 [A.33].

Table 4.1 Possible combinations of the reuse types

Water \ Land	Natural reservations	Agricultural recultivation	Forest recultivation	Grassing	Leisure and sport	Buildings
Naturalistic lakes	3	2	3	2	1	0
Fishing	2	3	3	3	1	1
Water management	2	2	3	2	1	1
Water sports and recreation	1	2	2	2	3	1
Pisciculture	0	2	2	1	0	0

3 very good 1 limited
2 good 0 excluded

4.2 Global approach of the process of ecological land rehabilitation

The decision process regarding the development of mining areas after the termination of mining operation represents a challenge for all policy makers involved in terms of planning and use of land areas, landscape planning and environmental planning, which also means a great responsibility. Such a decision must take into account a whole series of challenges, which concern on the one hand, the ecological characteristics that define the region, and on the other hand, the structure and social and cultural demands of the population.

Among the many reasons that support the need to rehabilitate the land affected by mining are [A.1], [A.9]:

- ✓ eliminating the risk of sliding of positive landforms, arose by storing different types of residues from industrial activities (such as, for example, waste dumps, slag heaps, domestic and industrial dumps);
- ✓ eliminating the negative visual impact of areas with lunar aspect (characteristic for the opencast mining);
- ✓ damaged areas need reintegration into production and / or ecological cycle of the regions in which they are situated, leading to regeneration of their economic potential and create prerequisites for sustainable development;
- ✓ improving environmental quality;
- ✓ reducing slopes and also the reduction of erosion intensity and accelerating the installation of vegetation.

In all cases the remodeling of degraded land by any human activities, should start from the type of use that caused the damage and must consider the new use of the land. There is a fundamental relationship between the shape and morphology of the land and the type of reuse, which can be decisive in choosing the new use. If the final function of the land area in question is not decided from the beginning, then remodeling must be executed so as to leave room for multiple reuse opportunities. Ideally, however, the land remodeling should be made considering the type of reuse, in order to design rigorously those measures that are required for a particular situation.

The main objectives of remodeling works for an industrial landscape are:

- ✓ establishing reusability of materials and equipment;
- ✓ reshaping the land by leveling with or without materials brought from elsewhere;
- ✓ filling the remaining empty spaces with water or waste rock material;
- ✓ decontamination of land;
- ✓ creating waste material storage possibilities from other areas.

Global approach of environmental rehabilitation of a large area is necessary because, under the principle of globality and inter-causality, the territory is a large and complex living organism, whose biological characters and perceptible forms result from dynamic overlapping of multiple natural and cultural components, whose interactions are adjusted and calibrated over time, while living the rhythm of autonomous life and capable of self-sustaining [B.11].

Any landscape is also unique and irreproducible, the result of physical and cultural overlapping of many components of different origin (natural or cultural), whose actions always produce original situations.

For such regions, planning and management must relate to a unique design, able to consider the inner landscape, without excluding any of its parts. One of the causes for erroneous landscape planning refers to the consideration of land only in its subdivisions or leaving portions of territory outside the planning.

To create conditions for ecological rehabilitation, the waste dumps and empty spaces remaining from the opencast mining activity, must go through a process of improvement, which refers mainly to level the surface, and topsoil cover. The main purpose of improvement works is to eliminate the danger of technical accidents (such as landslides), to model the terrain so that it corresponds to the chosen type of reuse and to restore the hydrogeological equilibrium of the region.

In figure 4.3 are summarized the necessary measures for several types of land reuse (forest and agricultural re-cultivation, sowing with grass seed, water filling of empty spaces from opencast mines) [A.1].

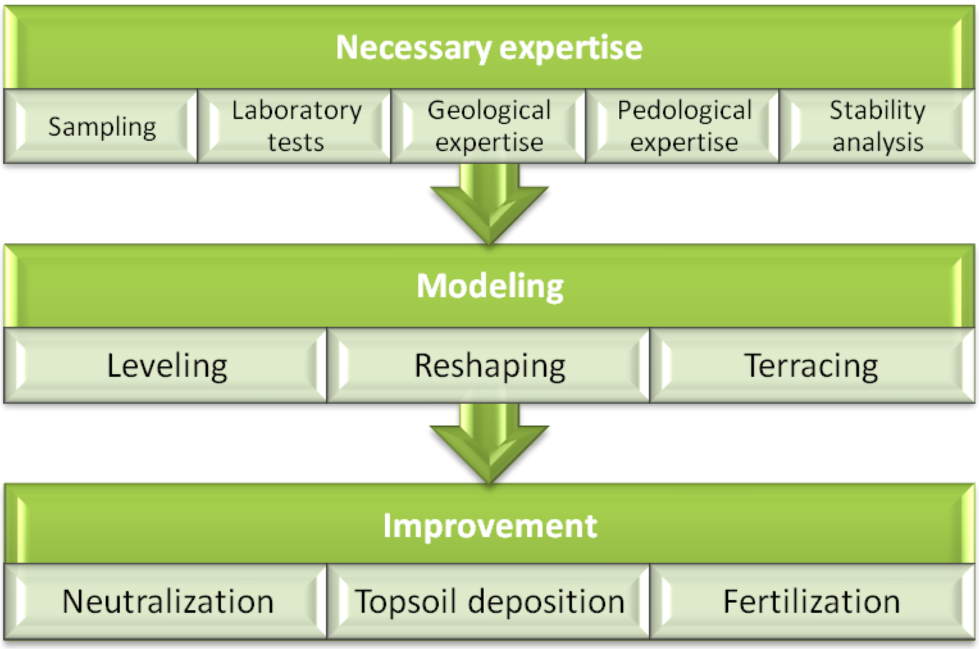


Figure 4.3 Land fitting out measures

4.3 Modeling the ecological reconstruction of an area affected by mining

For the recovery and reuse of the terrain degraded by mining activities, there are a number of options, and choosing one of the possible reuses depends on geological, technical and economic conditions, as well as public interests.

4.3.1 Developing the model

In the developed case study, the situation at a particular point in time is as follows: in a mining basin, where coal is being exploited, there are 8 operating open pits, located either only in the floodplain of a river or partly in the floodplain and hilly areas. The 8 open pits are served by 4 external waste dumps, and 7 open pits have reached the final depth and began building interior dumps. The topsoil has been removed selectively prior to the commencement of exploitation and dumping activities, and has been deposited in 5 locations, in the vicinity of the open pits, for use in the reconstruction and revegetation of the terrain (figure 4.4) [A.33].

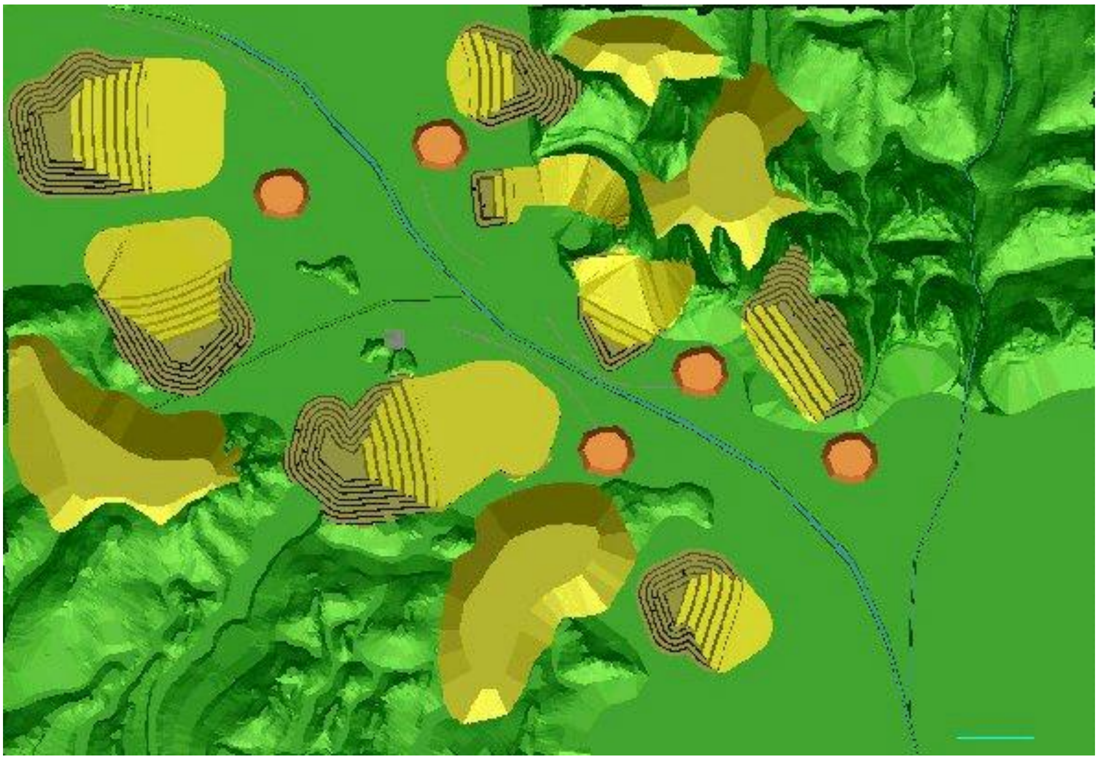


Figure 4.4 Phase I

Two of the 8 open pits will be depleted of their reserves over the next 3 years, and another two are to be closed in the next 8 years. The other 4 open pits remain active for at least 18 and 30 years respectively. The remaining holes of the first 4 open pits to be closed will be utilized to deposit the waste material resulted from the other 4 active open pits, measure that avoids the occupation of additional land for outside dumps, on one side, and the creation of negative landforms that would lead to the fragmentation of the landscape, on the other side (figure 4.5).

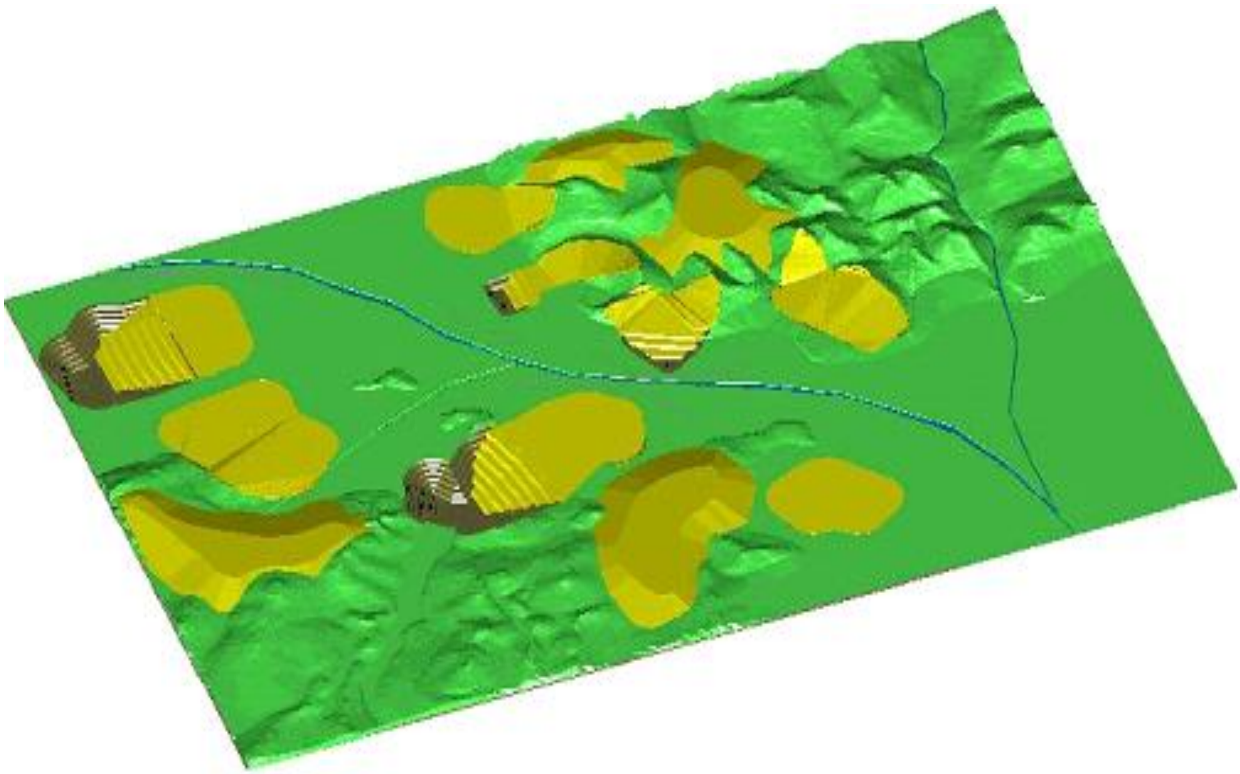


Figure 4.5 Phase II

External waste dumps, built mostly in a hilly region, will be recultivated with forests, with the purpose of a harmonious integration into the surrounding landscape. The interior waste dumps will be constructed according to the needs imposed by agricultural recultivation, taking into account the favorable natural conditions and the needs of local residents.

The remaining holes of the last 4 open pits will be filled with water. Filling will be made artificially, with water taken from rivers that cross the area and directed to the pits trough a system of pipes and channels (to these being added the water from rainfall and aquifer formations). According to the use matrix outlined above, lakes thus formed can be used effectively for fishing and water management (providing the necessary water to irrigate the new crops during dry periods) or, if necessary, some of them can be arranged for recreational use or watersports (figure 4.6).

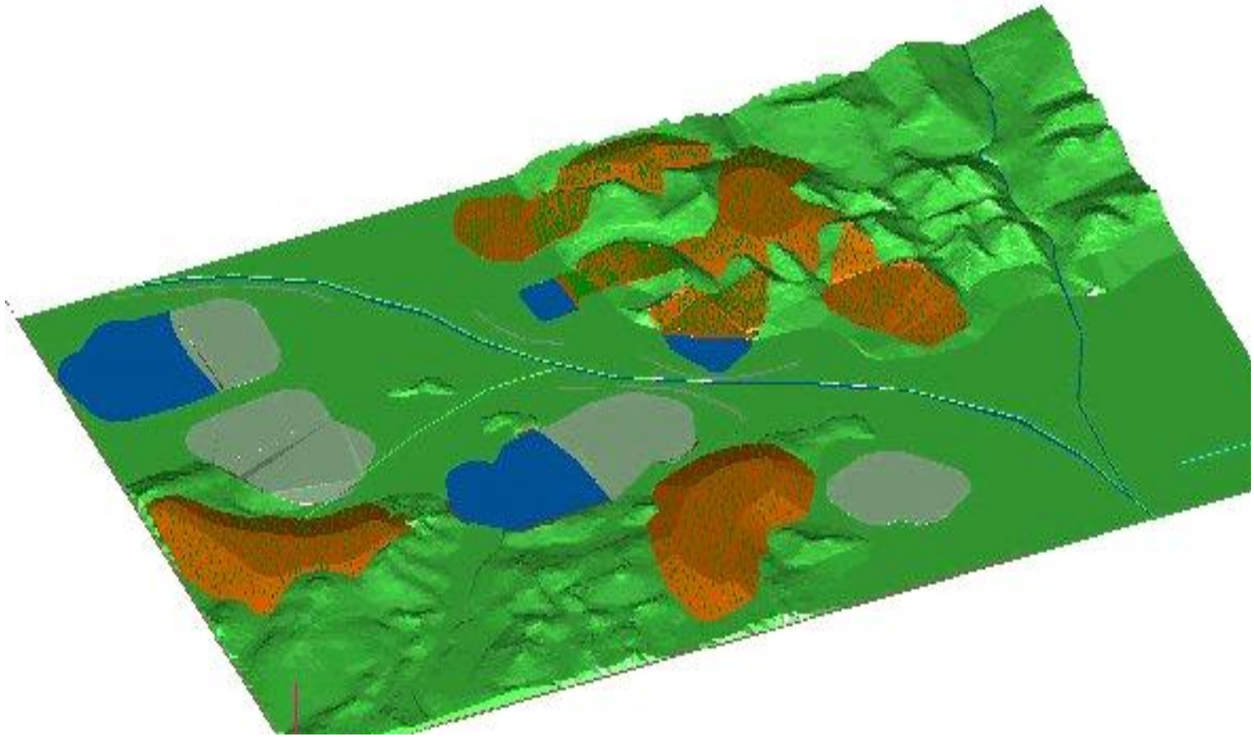


Fig. nr. 4.6 Phase III

Initial data processing and graphical process of ecological rehabilitation were conducted using a module of the MineSight software that was designed by Mintec Inc. Company Tucson, Arizona for mining design.

4.3.2 Application of the model for the Rovinari mining basin

The Rovinari mining basin contains lignite deposits located along the Jiu river valley. Coal deposits in this sector are predominantly located in the floodplains of the rivers Jiu and Tismana, being extracted especially in open pits. Almost half of the exploitable reserves of lignite from North-Western Oltenia belong to the Rovinari mining basin.

Starting from the virtual model shown above, the Rovinari mining basin has been chosen for the case study, because it is the region most affected by the exploitation of lignite in open pits. Over time, in the Rovinari mining basin, 11 open pits were functional, of which, during the course of the study, 6 were active [A.16]. During the year 2015, following the restructuring program of the mining activity in Oltenia, it was decided that South Peşteana was to be closed, leaving functional the following open pits: Roşia de Jiu, Pinoasa, Tismana I and II, Rovinari (with the perimeters East Rovinari and Gârla) and North Peşteana (figure 4.7).

Figure 4.7 Location of the lignite open pits in Rovinari mining basin

As a result of the mining activity, large surface areas have been take out of the agricultural, forestry and natural circuit (paragraph 1.3.1), that were partially or totally damaged. According to Romanian legislation, mining units are required to bear the costs of ecological reconstruction of terrains taken into use, so that, over time, some of these areas can be recultivated.

Recultivation activity was accomplished sequentially, as the land areas were released from their technological loads, without any plans or reconstruction projects to take into account the structure of the terrain and landscape left after the cessation of the entire mining activity in the area.

After analyzing the specific natural conditions, the climatic factors and the microclimate specific to the area, as well as the order in which the mining activity will cease, there have been three possible reuse options established for the terrain affected by the mining activity, presented in table 4.2.

Table 4.2 Ecological reconstruction options for Rovinari mining basin

Open pit / Type of reuse	East Rovinari	Tismana I+II	Pinoasa	Roşia de Jiu	Noth Peşteana	South Peşteana
Option 1	Development of an dendrological park	Agricultural recultivation	Filling the remaining hole with water	Agricultural recultivation	Filling the remaining hole with water	Forestry and agricultural recultivation
Option 2	Development of a recreational area	Development for motor sport practices	Municipal waste dump	Forestry recultivation	Forestry recultivation	Fertile soil deposit recovered from Peşteana North and Roşia de Jiu
Option 3	**Development of a mining museum**	**Development for forestry and fishery**	**Forestry recultivation**	**Filling the remaining hole with water**	**Exterior dump for Roşia de Jiu**	**Fruit-growing trees and vineyard recultivation**

When establishing the final use of the terrain after ecological reconstruction, option 3, the following arguments were considered:

- ✓the need to integrate the new areas into the surrounding landscape;
- ✓ physical demands of the resident population regarding land re-allotment;
- ✓land morphology and the exposure of slopes (open pits and waste dumps)
- ✓pedological characteristics of soil;
- ✓available water resources and the necessity to reconstruct the hydrostatic level;
- ✓the costs of interventions;
- ✓cultural demands of local population.

The concept of ecological reconstruction of areas affected by activities from the Rovinari mining basin meets the following objectives of the national strategy for reconstruction of mining areas, through the concept of sustainability:

- ✓ returning to the economical circuit of as much surface area as possible from the occupied terrain;
- ✓ the morphological and landscape reconstruction of the terrain;
- ✓ water filling of remaining holes;
- ✓ development of community activities that can use the available assets from closing mining units;
- ✓ employing community members in environmental reconstruction and recovery activities;
- ✓ payment of all compensations related to land use.

As a result, one can consider that these proposals lead to both reducing the dangers of environmental pollution of the studied area and restoring of the environmental factors to a level as close as possible to the one prior the mining activity, in the context of sustainable development.

4.4 Water filling of the remaining hole – case study Urdari open pit

Exploitation area of Urdari open pit is located in the southern part of Rovinari coal basin, Urdari village, Gorj county, 40 km south of Tg. Jiu municipality, respectively 15 km west of Ţicleni town, in the hilly area west of the Jiu river.

To highlight the climate of the area were analyzed and interpreted values of meteorological parameters taken from the closest weather stations, namely Tg. Jiu and Apa Neagră. The monthly averages of air temperature at the two meteorological stations in the studied area shows that the coldest month of the year is January (average temperature is -2.5°C at both meteorological stations). The hottest month is July (average values between 20.6°C - 21.4°C). It should be noted that the average temperatures in December are positive, and the mean annual temperature ranges between 9.7°C and 10.6°C. Generally the highest monthly precipitation amounts are recorded in the months from late spring or early summer (May and June) or autumn, in October, and the annual average rainfall is 762.81 l/m^2.

Predominant vegetation in the area of Urdari open pit is the specific to the hilly area of Oltenia and includes deciduous forests. As tree species present in the area are mentioned beech (Fagus silvatica), evergreen (sessile) oak (Qurcus petraea, Quercus dalechampii, Qurcus polycarpa, Quercus robur, Quercus cerris, Quercus frainetto). Forest areas alternate with meadows and farmlands. Representative crops in the area are corn, grasses, potatoes, etc. On small areas there are orchards and vine plantations.

From the possible reuse options for remaining holes, naturalistic rehabilitation is chosen by forming a natural lake, which is within the area's landscape, by raising the water level from the current elevation of 157.3 m to 162 m, remodeling the open pit through slope stabilization, covering the operating platforms with topsoil, and planting vegetation specific to the ecosystem.

Since the open pit is surrounded by woods, for future lake shores forestry recultivation was chosen, which is less costly and has beneficial results. The species that are recommended for this kind of work in the area where is located the remaining hole is acacia, because it is a species characteristic of the area in which is located the remaining hole.

4.4.1 The current situation of the remaining hole of Urdari open pit

The remaining hole is located in the exploitation area of Urdari open pit (figures 4.8 and 4.9) in the southern part of Rovinari coal basin. The remaining hole covers about 14 hectares and the base is located between the elevations 145 to 152 m. It has a length of 950 m, a width of 220 m and the depth is between 13 to 16 m. [A.26].

Figure 4.8 Urdari open pit (satelite image)

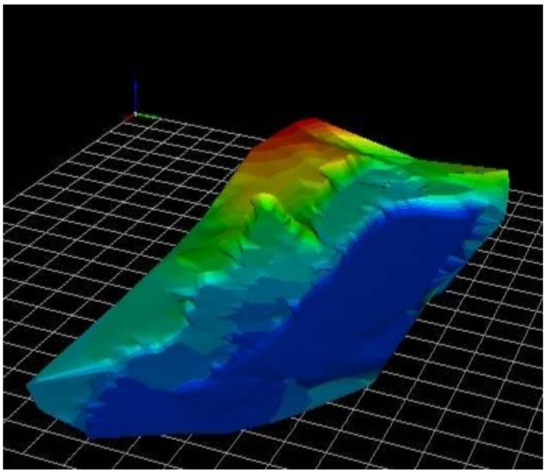


Figure 4.9 Urdari open pit (3D model seen from the east side)

Analyzing the current situation in the field, the main categories of deformation are the erosion and shallow and/or profound landslides on the final slopes of the open pit.
Erosions are represented by ravines (gullies) and actual erosion. Ravines appear on the western and south western slopes and are caused by the absence of a drainage system for runoff water. Shallow landslides are present on the southern lower slope, and the profound ones are found on the second step whose height is 40 m and slope angle exceeds 50°.
Marginal slope stability is one of the major problems in the rehabilitation of the remaining hole. Stability analysis for the remaining hole's slopes of Urdari open pit was performed using the specialized geotechnical software Slope. Values used in stability analysis for volumetric weight, cohesion and internal friction angle are presented in table 4.3.

Table 4.3 Physico-mechanical characteristics used in the stability analysis

Type of rock	Volumetric weight γ_{nat}, (kN/m^3)	Cohesion c, (kN/m^2)	Internal friction angle φ (grade)
Mixture of rocks from the open pit's slopes	18.98	19.80	17.00

Taking into account the geometric configuration of the open pit and nature of rocks, a stability analysis was performed considering that the slip occurs most likely after circular contour surfaces. For determining the stability reserve the slopes geometry was reproduced the mentioned software, the stability coefficient being calculated for each slope taken into account. The stability analysis did not take into account the pore water pressure, because the material is granular and has a high permeability which allows the possibility of a rapid gravitational drainage and after the filling of the remaining hole with water to the projected height, the pressure generated by the lake on the slopes increases the normal unit effort and thus increases the friction on the sliding surface.

Stability analysis was performed using three of the most popular computational methods, namely the methods of Fellenius, Bishop respectively Janbu and had analyzed slopes with heights between 20.21 and 40 meters with slope angles between 43 and 53 degrees, located on the southern and western sides.

Three sections were analyzed (two cross sections and one longitudinal section), made on the original plan of situation, namely the upper and the lower slopes.

Stability analyses results revealed that for one of the cross sections the stability coefficient has a subunit value (0.66 respectively 0.86 after Fellenius) meaning that both the upper and lower slopes are unstable [A.26].

For the other sections analyzed the stability coefficient has values higher than one, values which lie just above 1.3 (after Janbu), recommended by the technical requirements for design, construction and preservation of the final pit slopes.

In figures 4.10 and 4.11 are presented the analyzed profiles and the critical slip surfaces (for which the values of the stability coefficient are below one after Fellenius), for the lower and upper slopes of one of the cross sections.

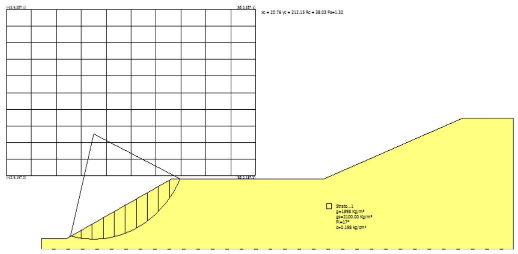


Figure 4.10. Cross section, the lower slope

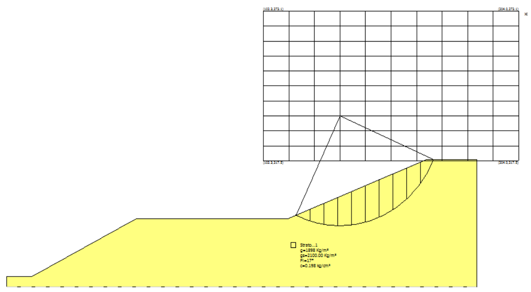


Figure 4.11 Cross section, the upper slope

In order to avoid the sliding of the general slope of remaining hole during and after filling with water, is required the execution of remodeling works, whose role is to ensure an adequate stability reserve.

4.4.2 The design of the development works for the remaining hole

Reshaping the steps (figure 4.12) to increase the stability reserve and ensure the necessary conditions for the particular type of rearrangement, namely naturalistic recovery, will be made by both known methods from top to bottom and from bottom up [A.1].

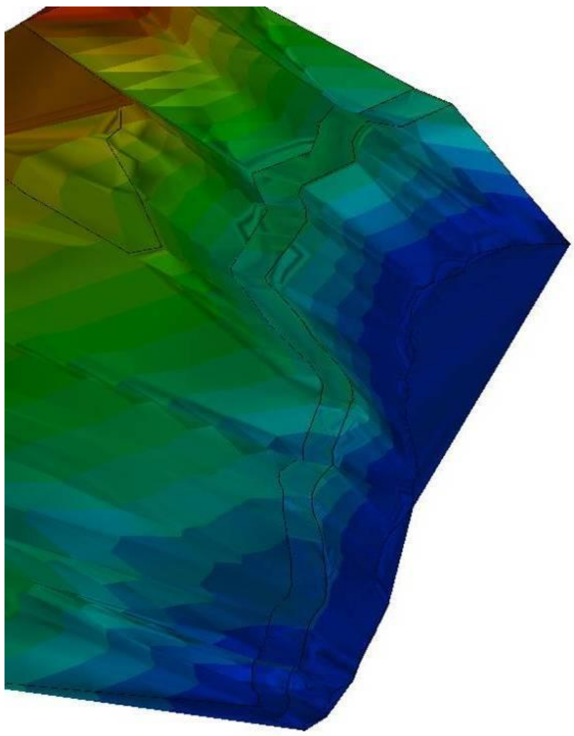


Figure 4.12 Reshaping the southern side (view from the eastern side)

For Urdari open pit the method from top to bottom will be used for the upper slope and for the lower slope which is in contact with the existing lake the bottom up method, involving the excavation and movement of material from the bottom of the slope to its top. Reshaping is required especially for the southern slopes of the cross section for which the values of the stability coefficient were below one. After completion of the reshaping works, a new stability analysis was made (figure 4.13) for the general slope thus formed.

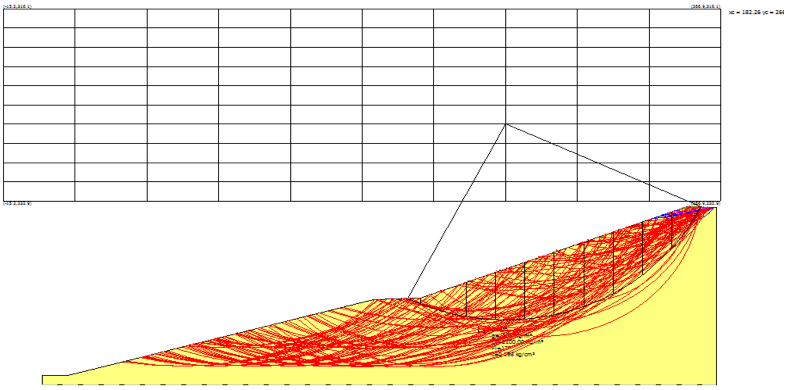


Figure 4.13 Cross section, general slope after reshape

Stability coefficient values obtained after completion of the reshape works indicate a considerable increase from under one to 1.37 (after Janbu). This value is above 1.3 recommended by current standards, which means ensuring a sufficient stability reserve to allow a safe continuation of rearrangement works.

Reshaping works involves the movement of large volumes of material in order to achieve the projected slopes geometry (volumes of material resulting from excavation and refilling works).

The total volume of material for accomplishing the designed reshaping works is 417,593.47 m^3 (figures 4.14 and 4.15) of which 40,281.42 m3 refilling material on the right half of the southern side of the open pit. For moving a volume (V1) of 278,396 m3 from the total of 417,593.47 m3 bulldozers will be used, and for the rest of 139,197.47 m3 excavators. Bulldozers will be used for top to bottom method and excavators will be used for bottom to top method, for reshaping the lower slope in contact with water [A.26].

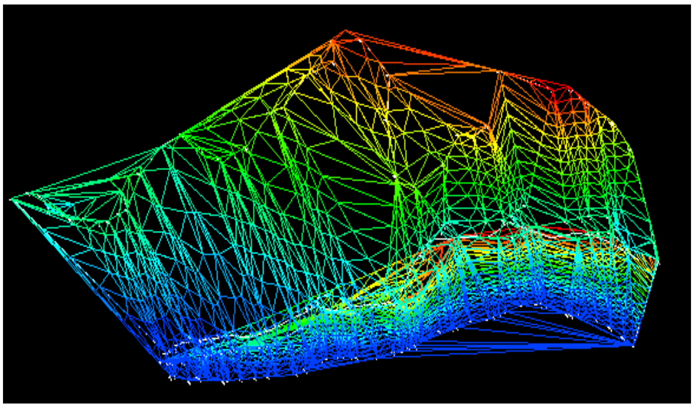


Figure 4.14 Prisms generated for calculation of the total reshaping volume

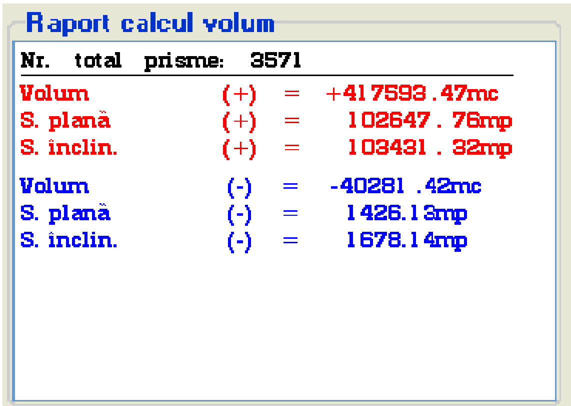


Figure 4.15 The total reshaping volume of material

Because the chosen of rearrangement type involves the increase of the water level from the lake, from the current level of 157.3 to 162 m is necessary to elevate the eastern bank.

As a result it was calculated the volume of material necessary to build a superelavation dam on the eastern bank from 164 to 170 m, resulting a total volume of 381,453.27 m^3 of material required (figure 4.16).

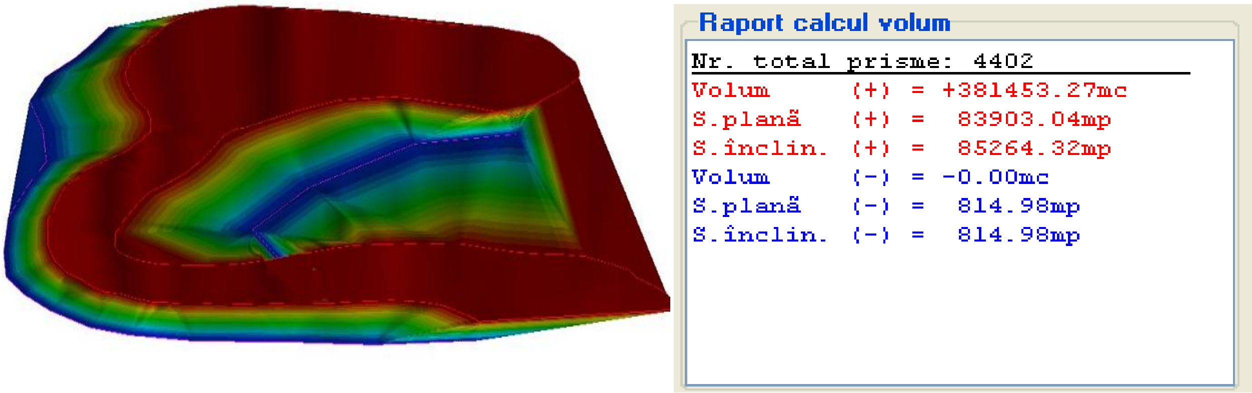


Figure 4.16 Calculating the volume of material from the superelevation dam

Correlating the two volumes, for the dam construction and the one from the reshaping works, it can be observed that if we decrease from the total volume of material from reshaping works the volume of material needed for refilling works, the remaining volume of material is fairly similar to the one necessary for the dam construction. The remaining material, 4141.22 m^3, will be deposited on the top step of the interior waste dump (on the north side).

This can be seen as an advantage in designing the redevelopment works for degraded terrains by the fact that the material is not transported over long distances, for construction of projected elements or to be stored (if surplus material results from reshaping works), thus eliminating the problem of occupancy of new areas of natural terrain.

4.4.3 Water filling of the remaining hole

The water filling of the remaining hole aims to increase the level of the existing lake from 157.3 m to a projected level of 162 m. To provide the necessary conditions to achieve the projected level it was proposed the construction of a dam on the eastern side, which leads to an elevation of the terrain from 164 m to 170 m.

Because there is no permanent water course near the open pit, and costs to build a feed pipe are very high, to ensure the volume of water required to raise the water level up to 162 m, respectively 316,294.76 m^3 (figure 4.17), it was chosen to fill the remaining hole in a natural way (by intake of water from rainfall) [A.26].

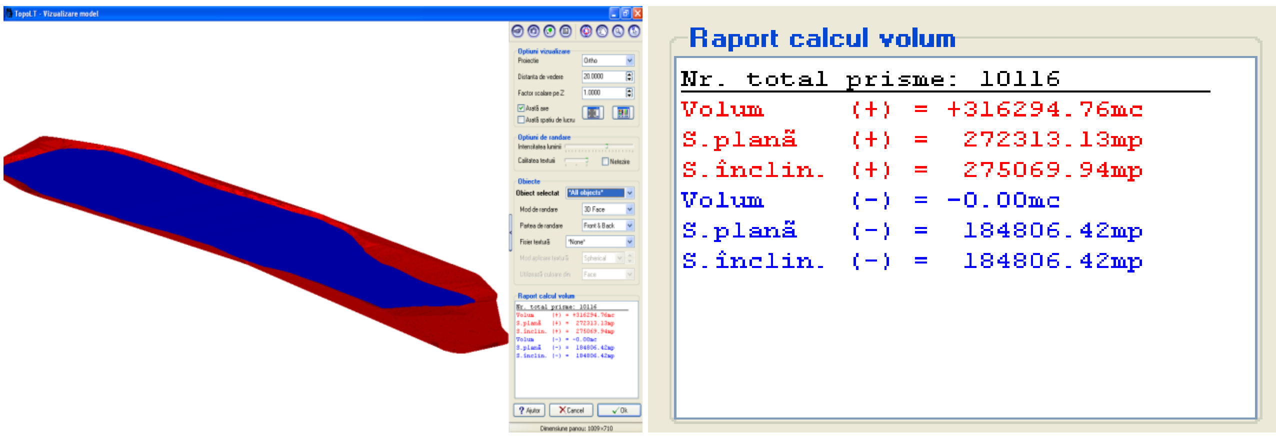


Figure 4.17 Volume of water required to increase the lake's level from 157.3 to 162 m

For this purpose it was considered as retention surface only the surface of the new formed lake (at 162 m) without considering the contribution of runoff water from the surrounding slopes. Also in the calculations evapotranspiration and infiltration were taken into account.

The total retention area calculated is about 140,000 m^2, which means that for an annual average effectively rainfall of 377 l/m2 requires approx. 6 years to achieve the projected water level by filling the remaining hole in a natural way.

According to analysis, water quality is in the second category, suitable for installation of flora and fauna characteristic to the bioclimatic floor.

Reshaping volumes, the dam volume and the required volume of water were calculated using the specialized software Topo LT. The designed works and the configuration of the area can be seen on the situation plan in figure 4.18 [A.26].

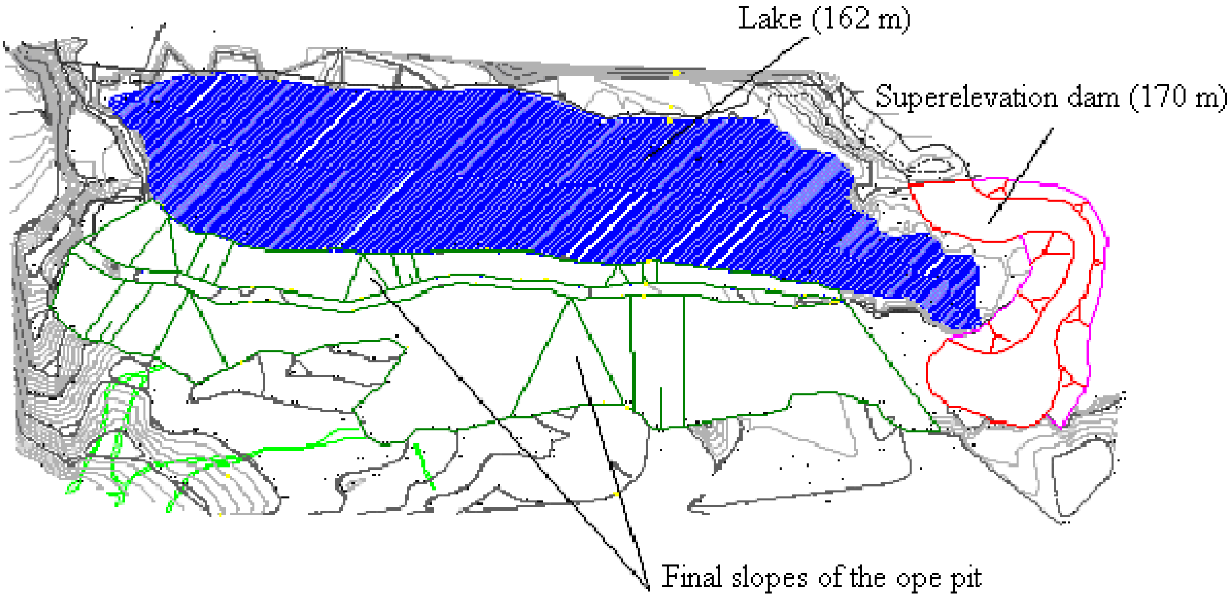


Figure 4.18 Urdari open pit situation plan after redevelopment

Reconstruction of areas affected by mining in Oltenia, beside being an obligation of the current legislation, is a necessity given the large areas of land affected in this region. The case study presented in this paper considered an advantageous type of redevelopment and rehabilitation (ecologicaly and economicaly) for the remaining hole of Urdari open pit, namely its reintegration into the natural environment.

Thus, by reshaping the final slopes a reserve of stability in accordance with the current requirements is ensured and the construction of the superelevatin dam ensures the conditions necessary for increasing the water level from the lake formed in the remaining hole up to 162 m.

The redevelopment works were designed so that the excess material resulting from reshaping works to be fully used for the construction of the superelevation dam, thus avoiding the occupancy of new areas of natural terrain necessary for storage of this material. The additional volume of material needed for the construction of the dam is minimal, this volume will be deposited in the interior waste dump (minimum costs of transportation).

By creating a lake with naturalistic functions in the remaining hole, the impact generated by the emergence of a negative landform in the area is almost completely eliminated on one had, and on the other an aquatic habitat is created that contribute to improving the biodiversity.

Populating the lake with local species of fish (characteristic to the bioclimatic floor) is able to attract species of birds, which contributes to the development of a new ecosystem in the area of a higher quality then the one currently existing. The reforestation of adjacent areas will help to repopulate the area with characteristic fauna species, ensuring an even grater improvement of biodiversity.

By transforming an area heavily affected by mining, characterized by anthropogenic landforms (excessive geometrization of slopes of the open pit and internal waste dump), in an area that fits easily in the natural environment is able to increase terrain value, providing multiple opportunies for its future use.

4.5 Establishing the optimal type of ecological restoration of degraded lands

Ecological restoration of degraded lands by human activities is certainly the most interesting theme and the most stimulant domain of application in landscape architecture in the coming years. Ecological restoration consistently makes reference to the principle of unity of landscape, understood as a unique living organism and therefore, to a good overall management, without allowing the dangerous distinction between good and bad landscape. Ecological reconstruction and rehabilitation of degraded lands must be carried out in accordance with the political and economic objectives of the country and it represents the process of improving degraded lands to return to their initial capacity or to ensure future use as well as the removal, reduction or neutralization of contaminants that affect human health and/or the productivity and integrity of ecosystems.

Because a choosing of the reuse type strictly on the basis of principles of ecological planning is in many cases insufficient, it was considered necessary to develop a methodology that takes into account several indicators and parameters to perform a successful rehabilitation [A.1].

4.5.1 Types of ecological restoration and ecological fundamental principles

There is actually an extremely wide range of hypothetical reuses of degraded lands to face any situation or needs, most often applied is: *naturalistic restoration* – which aims to recreate the natural cadence of the degraded landscape, including specific measures for environmental protection; *restoration for recreation and leisure* - is similar to naturalistic restoration, in addition providing specific structures; *productive restoration* - is indicated for areas with high agricultural productivity, in which the degraded land is inserted, thereby achieving a solution of continuity; *other reuse* as construction of residential and commercial buildings, hotels, construction of military installations, runways and cemeteries, productive and technological installations.

When the goal is to establish the optimal ecological restoration option of a degraded land there must be considered the seven fundamental principles of ecological planning, which essentially derive, in the most modern operational and descriptive practice, from the field of studies conducted by McHarg [B.37], for which reason it uses many terms and definitions that are derived from american experiments and from their successive validation in european landscape conditions: *1. The principle of globality or inter-causality; 2. The principle of ambiental autonomy; 3. The principle of minimum sizing and reversibility; 4. The principle of economy; 5. The principle of respect for tradition; 6. The principle of transparency and democracy; 7. The principle of respect for the demands of the population.* Often they partially overlap and can not be clearly defined, reason why some definitions may appear to be imperfect and repeatable. In reality, their separation derives from a normal descriptive necessity, and how they are divided and classified serves only to make available operative classifications, to render intelligible characters and to create a specialized terminology.

4.5.2 Proposed methodology

Given the above, was elaborated a methodology for determining the optimal ecological restoration option of a degraded land, comprising basically four phases (phase III is only needed for ecological restoration projects of naturalistic, recreational or productive type) [A.32].

- *Phase I*

The first phase that must be undertaken is the initial consultation of the public and decision factors (the current owner of the land; local, county or regional administration, etc.). In fact, this first phase takes into account principles no. 5, 6 and 7 and can be materialized in the form of public debates in which different types (or even different versions of a particular type) can be considered for the ecological restoration of the degraded land in question.

In this phase the main role should belong to the resident population of the area of interest, the decision factors having rather the role to provide information on the land in question (strategies and plans for landscaping, who is the owner and his obligations, initial use of the land, affected area etc.). The presence of a person with experience in ecological restoration of degraded lands is necessary, to act as a moderator of the discussion, but that can intervene in order to eliminate unrealistic restoration proposals.

➢ *Phase II*

When taking into account several possibilities of ecological restoration of a degraded land it must be started from the current situation on the site (in terms of regional climate, the morphology of the land, the surrounding landscape, environmental risks present in the area etc.) and keep in mind the final goal (ecologically and economically). This second phase is intended to implement into the decision-making process of the principles 1, 2, 3 and 4. Table 4.4 presents a selection matrix (A) for the ecological restoration options based on the first three fundamental principles of ecological planning.

Table 4.4 Matrix A – initial selection of the ecological restoration options

Indicator / **Type of ecological restoration**	**Climate**							**Environmental risks**			**Total points**
	C1 - Temperature	**C2 - Precipitations**	**C3 – Wind regime**	**C4 – Land inclination**	**C5 – Stability conditions**	**C6 - Accessibility**	**C7 – Presence of permanent water sources**	**C8 – Flooding**	**C9 – Vegetation wildfires**	**C10 – Seismicity**	
T1 - Naturalistic					[orange]	[orange]					
T2 – Recreation and leisure	[orange]	[orange]	[orange]	[orange]	[red]	[red]	[orange]	[red]	[red]	[orange]	
T3 - Productive (agriculture)*	[red]	[orange]		[red]	[red]	[red]	[red]	[orange]	[orange]		
T4 - Productive (forestry)*	[orange]	[orange]			[orange]	[orange]	[orange]	[orange]	[orange]		
T5 - Productive (orchards)*	[red]	[orange]		[orange]	[red]	[red]	[red]	[orange]	[orange]		
T6 - Productive (vineyards)*	[red]	[orange]		[orange]	[red]	[red]	[red]	[orange]	[orange]		
T7 - Other**					[orange]	[orange]					

Relative importance of the indicator to the ecological restoration project	
[red]	Major importance – minimum accepted 2 points
[orange]	Medium importance – minimum accepted 1 point
	Low importance (relatively unimportant) – o points accepted

* will specify the species proposed (multiple versions of the same type may exist, for example T4a, T4b etc.);
** will specify the type of reconstruction.

C1 - Temperature is an indicator of major importance for T3, T5 and T6, because deviations from optimal conditions can lead to underdevelopment or unripe of crops/fruits, therefore this indicator can not be compensated. For T2 and T4 the importance is medium because the degree of tolerance regarding deviations from optimal is considerably higher.

C2 - Precipitations are considered to be of medium importance because for T2 is considered to be a limiting factor (suitable for recreation and leisure in certain periods) and for T3, T5 and T6 is considered that a moderate deficit of precipitations may be offset by irrigation works. For T4 the importance is regarded as medium because the degree of tolerance in terms of deviations from optimal and its limits of variation are considerably higher.

C3 - The wind regime has medium importance for T2 (factor of discomfort) and is considered to be a limiting factor (suitable for recreation and leisure in certain periods).

C4 - The inclination of the land has medium importance for T2 (because it requires the construction of specific structures). For T4 and T6 the importance is given by the requirements of orchards and vineyards (lands of average slope, preferably in terraces). The major importance of land inclination for T3 lies in the need to ensure the requirements for mechanized agriculture. Classes of land inclination were established based on scientific literature [A.1].

C5 - Physical stability of the land is an indicator of the utmost importance for almost all types of ecological restoration (given that they involve the presence of humans and equipments that could be endangered in case of landslides). It can be considered of medium importance for T1 as naturalistic restoration requires human presence only in the actual work execution phase, and for T4, as forestry restoration also implies an improvement of stability conditions through the reinforcement effect of the roots. The assessment of land stability is conducted by adapting legal regulations [B.62].

C6 - Accessibility is also an indicator of the utmost importance for T2 as a recreation and leisure areas are destined to people and for T3, T5 and T6 because productive restorations involve permanent access of workers and machinery. For T1 the accessibility is important in the phase of work execution (limited in time) and for T4, although is a productive type of restoration, is one on medium or long term, and therefore do not require permanent access.

C7 - The presence of permanent water sources is considered of major importance for T3, T5 and T6, and must be seen as closely linked to precipitation. That is when precipitations are deficient compared to the optimum required by some species (or in periods with droughts) a constant source of water needed to compensate by irrigation. This indicator may be viewed as an important for T4 only during the installation of the seedlings.

C8 - Floods are an indicator that can be considered eliminatory for T2. For T3, T4, T5 and T6 as an indicator of medium importance, it can be compensated by fitting drainage systems.

C9 - Vegetation wildfires are an indicator that can be considered eliminatory for T2, while for T3, T4, T5 and T6 as an indicator of medium importance, it may be compensated to some extent (closely related to the presence of permanent water sources).

C10 - Seismicity can be considered as having medium importance for T2 due to the risks posed to the population. The values of ground acceleration are consistent with the latest technical requirements in the field [B.55].

In the case of T1 the indicators considered to be of medium importance (during execution of reconstruction works) are stability and accessibility. The other indicators can not be considered as limitative or eliminatory, because the naturalistic recovery involves, generally, the use of species characteristic of the adjacent areas, which are adapted to local conditions.

In the case of T7, with the exception marked cells, the importance of indicators must be set for each case (for example: the wind regime is eliminatory factor when building a runway for aviation or may be insignificant in the case of planning a production space; in the same way, the seismicity can be vital in case of residential construction or may be insignificant in the case of planning a dendrological park). Apart from the considered indicators, in particular in the case of T7 (other types of uses), can be introduced more limitative or eliminatory conditions depending on the particularities of each situation.

The scores awarded to each of the indicators explained above (table 4.5) derived from several classifications available in the literature, but also from the experience in ecological restoration of degraded lands [B.12], [B.19], [B.34], [B.65].

Table 4.5 Scores attributed to land indicators (environmental characteristics)

Score / Indicator	0	1	2	3
C1	Major annual deficit/excess (>5ºC compared to optimal)	Moderate annual deficit/excess (3-5ºC compared to optimal)	Low annual deficit/excess (1-2ºC compared to optimal)	Optimal for the proposed version
C2	Major annual deficit/excess (>20% compared to optimal)	Moderate annual deficit/excess (10-20% compared to optimal)	Low annual deficit/excess (<10% compared to optimal)	Optimal for the proposed version
C3	Annual winds of 11-12 degrees on Beaufort scale	Annual winds of 8-10 degrees on Beaufort scale	Annual winds of 5-7 degrees on Beaufort scale	Winds of 1-4 degrees on Beaufort scale
C4	Very inclined land (>45º)	High inclination land (21-45º)	Inclined land (6-20º)	Practically horizontal (<5º)

C5	Land with active movements, involving large volumes of material	Land that can go into dangerous movements in certain conditions (heavy rainfall, earthquakes etc.)	Land with stabilized slides or that can be limited by technical measures	Stable land, for which sliding phenomena are not likely
C6	Inaccessible (steep slops)	Limited auto and difficult pedestrian access	Difficult auto and relatively facile pedestrian access	Auto and pedestrian facile access
C7	Within a radius over 500 m	Within a radius of 300-500 m	Within a radius of 100-300 m	Within a radius of 100 m
C8	Flooded land*	Floods in heavy rainfall conditions	Floods in special conditions (sudden snow melt + heavy rainfall)	Without flooding risk
C9	Annually during summer	In special conditions (years with prolonged drought)	Historically recorded (older then 20 years)	Not recorded in the area
C10	a_g between 0.35-0.40 (and over)	a_g between 0.25-0,35	a_g between 0.15-0.25	a_g between 0.10-0.15

* not to be confused with natural wetlands; a_g - peak values of ground acceleration.

Based on matrix A, shown in table 4.4, attributing scores according to the table 4.5 and taking into account the relative importance of indicators (which can be eliminatory) the total points obtained for each proposed type of ecological restoration can be calculated, by summing on each row.

This sum is not sufficient to prioritize the proposed types of ecological restoration. The reason for this shortcoming is the way how the relative importance of indicators it is distributed. Thus naturalistic restoration is likely to get the highest total (due to less restrictive or eliminatory conditions and because as stated earlier this type of restoration folds best on local environmental conditions). For these reasons it is necessary to introduce an economic coefficient, K_e, which in this stage takes into account the economic benefits expected to be obtained when applying the proposed types (and versions of a type) of ecological restoration (does not require substantiation through a pre-feasibility study). The total points obtained by summing are multiplied for each project with the appropriate economic coefficient, resulting equivalent scores. The values assigned to K_e are [A.32]:

- ✓ K_e = 1 – for T1 (in this case potential economic benefits related to landscape restoration, improving air quality, effects of human health, restoring local biodiversity, the eventual recovery of wild fruits, etc. can not be quantified objectively);
- ✓ K_e = 1.25 – for T4 (forestry plantations mainly intend the capitalization of wood, but the time required for the plantation to reach the age of harvesting with maximum economic efficiency may vary, depending on the species from 30 to 100 years, and so the economic benefits are expected on medium or long term);
- ✓ K_e = 1.5 – for T3, T5 and T6 (these types of productive restoration can bring immediate economic benefits, on short term, by capitalization of crops and fruits);
- ✓ K_e = 1÷1.5 – for T2 and T7 (for this type of ecological restoration the value of the economic coefficient must be established for each case. Thus, an area for recreation and leisure can bring economic benefits by levying an access fee or conversely, if the access is free, may not bring measurable benefits, what is true also in the case a dendrological park. On the other hand, a manufacturing facility can bring immediate economic benefits, and depending on the products value could be considered a coefficient K_e higher than 1.5).

By applying the procedure described above, the proposed ecological restoration projects can be grouped into four opportunity classes based on the equivalent scores obtained in phase II:

- ✓ 2 - 12 points – inappropriate projects;;
- ✓ 13 - 23 points – projects with reduced opportunity;
- ✓ 24 - 34 points – projects with medium opportunity;
- ✓ 35 – 45 (and over where K_{e1}>1.5) points – projects with high opportunity.

As it noted, in practice the most common types of ecological reconstruction of the waste dumps are naturalistic, recreational and leisure or productive (agriculture, forestry, orchards and vineyard), and if we consider the existence of multiple variants within the same type of reconstruction, occur the possibility that more projects to be classified in the same category of opportunity, by obtaining of similar or even equal scores. This case requires an another phase to differentiation of the proposed projects.

➢ *Phase III*

In this phase, to evaluate and ranking the ecological reconstruction projects that passed the second phase, were considered more indicators of soil fertility, and the possible presence of undesirable elements were considered (incompatible with productive restoration, that should also be considered for recreation or leisure restoration). Based on these indicators has been developed a new matrix B, table 4.6, the significance of the color (relative importance) being the same as in the matrix A from table 4.4.

Table 4.6 Matrix B for selection of the ecological restoration options

Indicator / Type of ecological restoration	I1 Soil structure	I2 pH	I3 Primary macronutrients	I4 Secondary macronutrients	I5 Micronutrients	I6 Humus content	I7 C/N	I8 SAR	I9 Conductivity	I10 Heavy metals	Total points
T1 - Naturalistic											
T2 - Recreation and leisure											
T3 - Productive (agriculture)*											
T4 - Productive (forestry)*											
T5 - Productive (orchards)*											
T6 - Productive (vineyards)*											

* will specify the species proposed (multiple versions of the same type may exist, for example T4a, T4b etc.)

In most situations it can be considered that the fertility indicators are of medium importance. This is due to the possibility of compensation of any shortcomings related to the elements of fertility through the application of amendments and/or fertilizers.

Heavy metals are considered of major importance for the productive types of ecological restoration because, as is known, they can migrate from the soil in the plant's body and then in the fruits. Because of the bioaccumulation effect they become unfit for consumption or in other words we can consider the harvest as compromised.

Similar to phase II, in table 4.7 are presented the scores given to the fertility indicators, values established based on the scientific literature. [B.12], [B.34], [B.54].

Table 4.7 Scores attributed to land indicators (fertility characteristics)

Score / Indicator	0	1	2	3
I1	Massive or damaged structure	Plate or columnar structure	Block or prismatic structure	Granular structure
I2	<4.31 and >9.01	4.31-5.00 and 8.41-9.00	5.01-5.80 and 8.01-8.40	5.81- 8.00
I3*	ADZ or ATZ	MZ-LDZ or MZ-LTZ	Adequate zone-LCZ	Adequate zone-OCZ
I4*	ADZ or ATZ	MZ-LDZ or MZ-LTZ	Adequate zone-LCZ	Adequate zone-OCZ
I5*	ADZ or ATZ	MZ-LDZ or MZ-LTZ	Adequate zone-LCZ	Adequate zone-OCZ
I6	<2 % (low fertility)	2-4 % (medium fertility)	4.1-6 % (high fertility)	>6 % (very high fertility)

I7	>15 (low fertility)	12-14 (medium/normal fertility)	9-11 (high fertility)	<8 (very high fertility)
I8	>20 mmol/l	16-20 mmol/l	11-15 mmol/l	<10 mmol/l
I9	>16 mS/cm (extremely saline)	8.1-16 mS/cm (highly saline)	4-8 mS/cm (moderately saline)	<4 mS/cm (slightly saline/non saline)
I10	>less sensitive uses intervention threshold	sensible uses intervention threshold (warning threshold less sensitive uses) - intervention threshold less sensitive uses	warning threshold sensible uses - intervention threshold sensible uses	<warning threshold sensible uses

* according to figure 4.19

I1 - The soil structure is determined by the way in which individual particles are attached and aggregated and the manner in which the pores are formed. Soil structure has a major influence on the movement of water and air, biological activity, root growth and seedling emergence. It depends on the environmental conditions in which the soil was formed, the presence of clays and organic matter, and the latest management practices [A.1].

I2 – Soil reaction is the property of the soil to act as a donor or acceptor of protons and its subtracting causes the reduction of cation exchange capacity and the increase of anion exchange capacity by adding particles with positive charges [B.12].). Generally the development of plants (especially cultivated ones) is best held on land with a weak acidic-neutral-weak basic pH, although there are species (especially trees) that prefer moderate acidic soils.

I3, I4, I5 - Depending on their proportion in the plant, the nutrients are divided into: primary macronutrients (N, P, K); secondary macronutrients (S, Ca, Mg) and micronutrients (Fe, Mn, B, Zn, Cu, Mo, Co). The evolution of plants according to nutrient content in the soil is illustrated by the curve shown in 4.19, which shows the dependence of plant growth, expressed as harvest and biomass production and nutrient concentration in the soil.

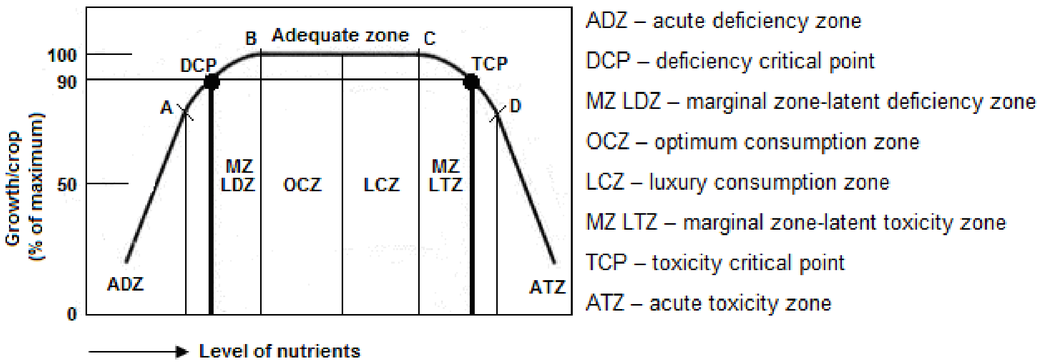


Figure 4.19 Dependence between plant growth and the supply of nutrients (Modified after Finck, 1992) [B.19])

Obviously this curve has a general character and the levels of nutrients that define the transition threshold from one zone to another must be determined for each species of plants considered in the process of ecological restoration of degraded lands.

I6 - Humus content of the soil affects the capacity of retention and cation exchange. It generally ranges from 2 - 6%, it determines the fertility and depends on: climatic factors (temperature, humidity), vegetation factors, culture technology (irrigated, non-irrigated), use of organic fertilizers, soil formation process [B.12].

I7 - The level of fertility of a soil can be assessed through C/N ratio (cellulose substances/protein substances). The C/N ratio shows the speed of decomposition in the soil of these two groups of substances. Soil fertility is greater as the C/N ratio is lower [B.12].

I8 - The excess of exchangeable sodium has adverse effects over the physical and nutritional properties of the soil, leading to reduced crop yields. To highlight the excess of sodium the SAR index can be used (sodium adsorption ratio), defined of the relationship 4.1 [A.1]:

$$SAR = \frac{Na^{+}}{\sqrt{(Ca + Mg)^{++}/2}} \qquad (4.1)$$

I9 - The excess of soluble salts in the soil leads to the occurrence of sterile areas, the development of a stunted vegetation or reduced crop yields and the expansion of these negative effects depends on the degree of salinity. The primary effect of the excess salt is to reduce the water availability in the rooting area of the plant, due to the osmotic pressure. The excessive concentration and the absorption of individual ions can become toxic to plants and/or can delay the absorption of other essential nutrients for plants.

I10 – The limits of heavy metals in soil and their correspondence with scores awarded (in Table 4) are in compliance with the regulations in force [B.54].

By summing the scores attributed to each project, taking into account the relative importance (achieving the minimum score for each indicator) a hierarchy of the ecological restoration projects according to their opportunity can be established. Depending on the total points obtained by each project they can be grouped as follows:

- ✓ 0 – 10 – projects with reduced opportunity;
- ✓ 11 – 20 – projects with medium opportunity;
- ✓ 21 – 30 – projects with high opportunity.

After this selection in terms of opportunity, the projects within the same group can be prioritized in accordance with the available financial resources.

For completing this final sub-phase there are required technical and economic calculations by which to estimate the implementation costs of each version that reaches this stage of selection. Thus assessments are required related to costs of physical development of the land, soil improvement and amendment, additional facilities (irrigation or drainage systems, fences, access roads etc.), purchase of biotic materials, labor costs etc. Thus, the considered reconstruction projects can be grouped in a final assessment matrix, C, presented in table 4.8.

Table 4.8 Matrix C - final evaluation of projects

Project name*	The available sum for the ecological reconstruction works	Falls into allocated budget **	Requires additional funds - can be provided from local funds ***	Requires additional funds - special funds for environment or European funds ***

* project name remains the same throughout the procedure (set in the matrix A);
** specifying the surplus;
*** specifying the additional amount estimated to be required.

- *Phase IV*

Within this phase participate again the interested public, decision makers and experts who evaluated the projects in phases II and III, phase IV being necessary to inform the stakeholders on decision process, thus ensuring the transparency in decision making on choosing of the optimal reuse of the analyzed land.

The aim of this study was to develop a methodology for determining the optimal type of ecological restoration of degraded lands, which can be made available to those working in this field, as a practical work tool. The methodology involves four successive selection phases, logically ordered, that can be adapted to solve various encountered situations (eroded lands, degraded lands by industrial processes or unsustainable agricultural practices, etc.).

PART III

ACADEMIC CAREER DEVELOPMENT PLAN

1. Objectives

Although being professor and hopefully doctoral supervisor could be seen as a career climax, professional standards tells us that the training and preparation of professors is a continuous struggle, and in for research, the volume and level of expertise of its objectives depends only on the researcher.

For these reasons, I believe that obtaining the quality of doctoral advisor forces me to impose even higher standards for myself in terms of both teaching side but especially the research to develop my academic career.

Career development plan follows the two specific academic components, namely the preparation of future generations of specialists, competitive on the labor market (didactic component), the continuation and diversification of scientific research.

Of course, to achieve these goals, own career development must be consistent with the strategic and operational plans of Research of the Faculty of Mines and the University of Petrosani. From this point of view, the fact that I am part of the Faculty Council and University Senate can be viewed as a positive aspect in my academic career development perspective.

Skills and competences acquired and confirmed on the field of coordination of research and teaching at a high academic level and the ability to initiate successful national and international collaborations in mining engineering and the environment, underlie the development plan of academic career and also give me a degree of confidence on its materializing.

2. Academic

2.1 Organization of education

Strategic objective: ensuring a quality education act, leading to skills training in programs of study in sheet of specialization and training the graduates to meet the requirements of the labor market can be achieved by:

- ✓ permanent renewal of content subjects I teach, in line with European standards and requirements of the labor market in Romania and the European Union;
- ✓ motivate and stimulate students, especially in the first two years of study, by organizing regular meetings with an informal character, in order to maintain their interest in the chosen specialization and preventing early school leaving;
- ✓ emphasizing the practical nature of seminars and laboratories and modernization of checking the knowledge acquired in these educational activities;
- ✓ stimulating study and preparation of individual student projects and essays and diversification by organizing debates (topical) announced;
- ✓ drafting approach the year in terms of teamwork, encouraging communication and collaboration ability of students;
- ✓ developing teaching materials (books and specialty manuals, seminar and lab guides, collections of tests and issues etc.) to come to the aid of teaching-learning programs of study participants;
- ✓ use in teaching (especially at the laboratory) of modern equipment in the endowment of the university and software specialist, so that graduates pass from one form preparation based mostly on theory to one that combines a usefully for future careers practice with theory;
- ✓ organizing visits to relevant economic objectives for the profession in preparing students for study programs coordinated by the department (of the three cycles of university education: bachelor, master and doctorate), for purposes of study and vocational guidance;

- ✓ improving the way students practice making so that, depending on the specialization, students benefit from active involvement in conditions related activities in preparing;
- ✓ establishment of thematic work license, especially doctoral dissertation and in accordance with the directions of the department's research and guidance, if possible, to themes that are provided by businesses, finalized by contracts and implemented;
- ✓ coordination of students in scientific research, selecting research topics being made according to the specific interests of students, so the theme can be developed gradually at graduation and dissertation projects and fully resolved at the level of doctorate;
- ✓ organization of round tables on topical issues for study programs with the participation of students, teachers and renowned specialists from various business units;
- ✓ support the efforts of graduates in employment and level of education and communication for the benefit of maintaining a highly useful feedback for improving curricula and teaching methods.

2.2 Relationship with students

Strategic objective: supporting and empowering students in terms of academic activities and the creation of conditions in which students can express their creative potential and learning through:

- ✓ achieve a real partnership with students and postgraduate students;
- ✓ encourage undergraduate, postgraduate and doctoral students in making assessments on the quality of teaching and come up with proposals for improvement by encouraging dialogue, completing non-personalized questionnaires for assessment of teachers and quality of teaching materials presented etc .;
- ✓ support the organization of regular meetings with students from study programs within the department, involving tutors and coordinators of study programs in which to discuss professional issues and even personal ones (insofar as they affect the educational process);
- ✓ support and guidance to students for obtaining mobility study and practice through ERASMUS +;
- ✓ ensuring communication between graduates and students of environmental engineering specializations (and not only) in order to support students in finding employment opportunities;
- ✓ support cultural activities of student organizations.

2.3 Promote the academic offer

Strategic objective: Promote the offer of training is extremely important and leads, in addition to increasing the visibility of the University of Petrosani, to attract a greater number of students, master and PhD students, achievable through:

- ✓ continuously promote and improve the visibility of the university and outcomes in teaching, research and cultural means media and promotional materials;
- ✓ promote programs of study in high schools by presenting detailed and attractive offer academic, professional and main outlets;
- ✓ organizing "open door" days for high school students, presenting the educational offer and the laboratories of the department, meeting with students and teaching students from different majors.

3. Scientific research activity

3.1 Organization of the research

Strategic objective: to adopt a coherent research strategy by identifying and supporting research directions in the medium and long run, involving students (especially master and doctoral) in interdisciplinary, achievable objective by:

- ✓ organizing groups of research on directions of related and/or complementary teaching disciplines;

- ✓ stimulation of interdisciplinary research;
- ✓ continuous upgrading, accreditation and maintenance of accreditation of laboratories subordinated department and offer more services (laboratory tests, project development contract with economic beneficiaries etc.);
- ✓ compiling a set of promotional materials to offer research, consultancy and expertise and their coverage by posting on the department's website and direct presentation to interested economic operators;
- ✓ accessing funds for the purchase of laboratory equipment and specialized software and upgrading existing facilities;
- ✓ dissemination of research by publishing scientific papers mainly in journals with ISI impact factor, proceedings ISI, BDI indexed journals, participation in prestigious international conferences and symposia;
- ✓ increase exchanges of experience and information with other institutions in the field, which will lead not only to my development as a researcher, but also to the prestige of the faculty department, and of the university;
- ✓ identifying of the national and international calls for research grants, stimulating participation with proposals and registration the department and/or research collectives on portals to research programs in partnership with European funding (with the possible identification of sources of financing and attracting partners in this type of economic research);
- ✓ involving students (especially the master and PhD) in research projects of the department and encourage them to participate in national and international scientific meetings.

3.2 Cooperation at national and international level

Strategic objective: Department involvement in joint projects with academic structures, research institutes and businesses, achievable through:

- ✓ maintaining and improving relations with specialists from other universities in the country and abroad, with similar areas of research;
- ✓ identification and realization of joint research projects (both for grant and contract research or fundamental research in various fields);
- ✓ intensify of the cooperation with major national research institutes;
- ✓ proposal of the PhD themes that allow double coordination, involving academics from other well known universities at home and abroad.

3.3 Future research directions

Topics addressed in the second part of habilitation thesis is extremely generous and is also of major interest to the scientific and technological communities worldwide, rely on scientific expertise accumulated over the years and this is why I believe that the future work research will be directed increasingly towards those fields.

Thus, I have identified a number of lines of research both at conceptual and methodological level and applied research, for which I pointed out the main results that can be achieved and implemented in teaching and in practice.

Conceptual and methodological scientific research

Research directions	Expected results
Developing tools for the identification, analysis and impact and/or environmental risk assessment in the industry (especially mining and quarrying)	Development of integrated methods for assessment of environmental impact/risk in the industry
Mining in the context of sustainable development	Integrating the concept of sustainable development strategies of communities in mining industry
National strategy in the mining sector	Improve and expand national plans and programs in the mining sector
Ecological reconstruction of areas affected by mining	Developing handbooks to identify opportunities for ecological restoration and ways for integrated approach
Stability of slopes and embankments	Improving the investigation techniques for massifs and slopes that present risk of landslides and increasing the accuracy of the stability studies by considering new variables in the model analysis

Applied scientific research

Research directions	Expected results
Studies and applied research on the identification, analysis and impact assessment and / or environmental risk	Projects for identification, analysis and impact assessment and / or environmental risk for various objectives to act as guides to best practices
Exploitation and utilization of the useful mineral substances	Optimizing current operating activities and identification, ie applying modern solutions in mining, focusing on technologies less aggressive towards the environment
Hydrogeological studies	Knowledge of groundwater regime and the restoration of aquifers in areas affected by mining activities
Ecological reconstruction of areas affected by mining	Comprehensive approach to ecological restoration of land affected by mining and the choice of optimal variants
Stability of slopes and embankments	Studies of specific situations designed to identify risk areas with a potential for landslides, identify the causes and factors that triggered landslides and design solutions stabilizing or maintaining them

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