Environmental Management – Advanced Risk Assessment

21/11/2024

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AMDC, USAL

Co-funded by the European Union

MINE.IO

Mine.io aims to provide solutions that will build a novel mining digital ecosystem and a systemic structure for the implementation of Industry 4.0 in mining industrial environments.

- 25 partners
- 7 pilot use cases
- €14M budget
- 42 months

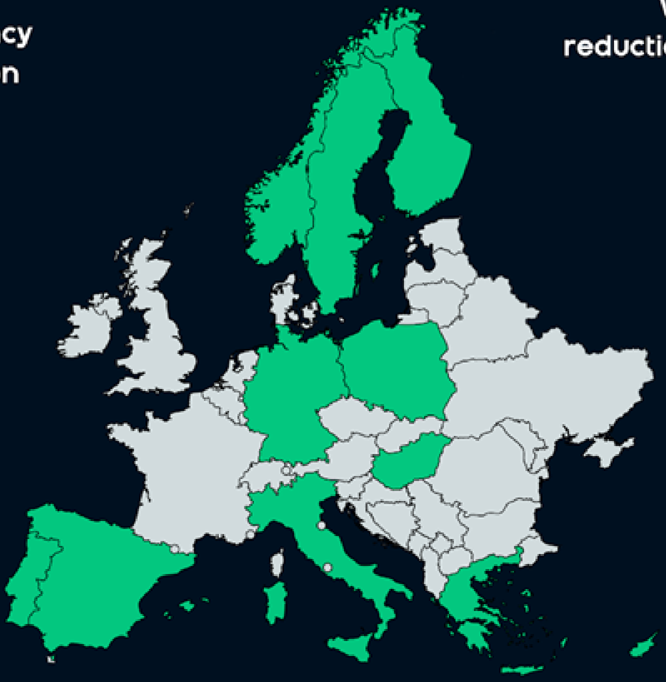
Increase of energy efficiency and production

Digitization of all mine procedures

Waste reduction and reuse

Workload optimization

Application marketplace



Environmental footprint reduction

Workflow automation

Electification of underground trucks

Co-funded by the European Union

Identification and Classification of MMW

- Types of mining waste:
  - Tailings (the fine waste material left after the extraction of minerals)
  - Waste rock (rock removed to access the ore)
  - Slag (by-products of metal smelting processes).
- Waste characterization
  - Detailed characterization of mining waste is critical, including its physical, chemical, and toxicological properties.
  - Factors like metal concentration, acidity (e.g., acid mine drainage), and presence of hazardous elements must be assessed.

Key Environmental Risks Associated with MMW

- Water contamination: Acid mine drainage, heavy metal leaching, and cyanide contamination from mining waste can lead to the degradation of both surface and groundwater. Metals like arsenic, lead, mercury, and cadmium are common pollutants.
- Soil contamination: Toxic substances from mining waste can infiltrate and degrade soil quality, making land unsuitable for agriculture or vegetation growth.
- Air pollution: Dust and particulates from dry tailings or waste rock can become airborne, affecting air quality and leading to respiratory issues for nearby populations.
- Biodiversity loss: Mining waste can destroy ecosystems and habitats, impacting biodiversity through soil degradation, pollution of waterways, and destruction of flora and fauna.
- Tailings dam failures: The structural failure of tailings dams, which store mining waste, can result in catastrophic environmental disasters, causing large-scale pollution and damage to ecosystems.

Regulatory Framework and Compliance

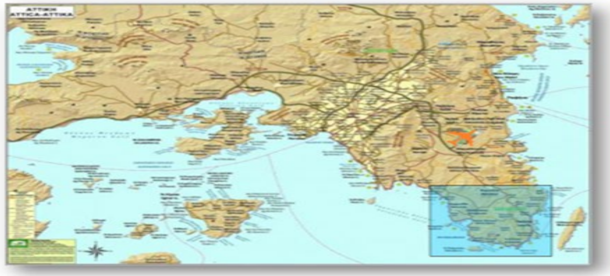
- Environmental Impact Assessments (EIA): EIAs are required before new mining operations begin, and they include a detailed analysis of the environmental and social impacts of mining waste disposal.
- Permits and licensing: Mining companies must comply with national and international environmental regulations, obtain the necessary permits, and adhere to waste disposal standards (such as European Union Directives or U.S. EPA regulations).
- Closure and reclamation plans: Mines are required to have detailed plans for closure, including the management of mining waste and the restoration of disturbed landscapes. This may include revegetation, land contouring, and long-term monitoring.

AMDC/LTCP

LAVRION TECHNOLOGICAL CULTURAL PARK

BUILDING THE FUTURE ON THE RUINS OF THE PAST..

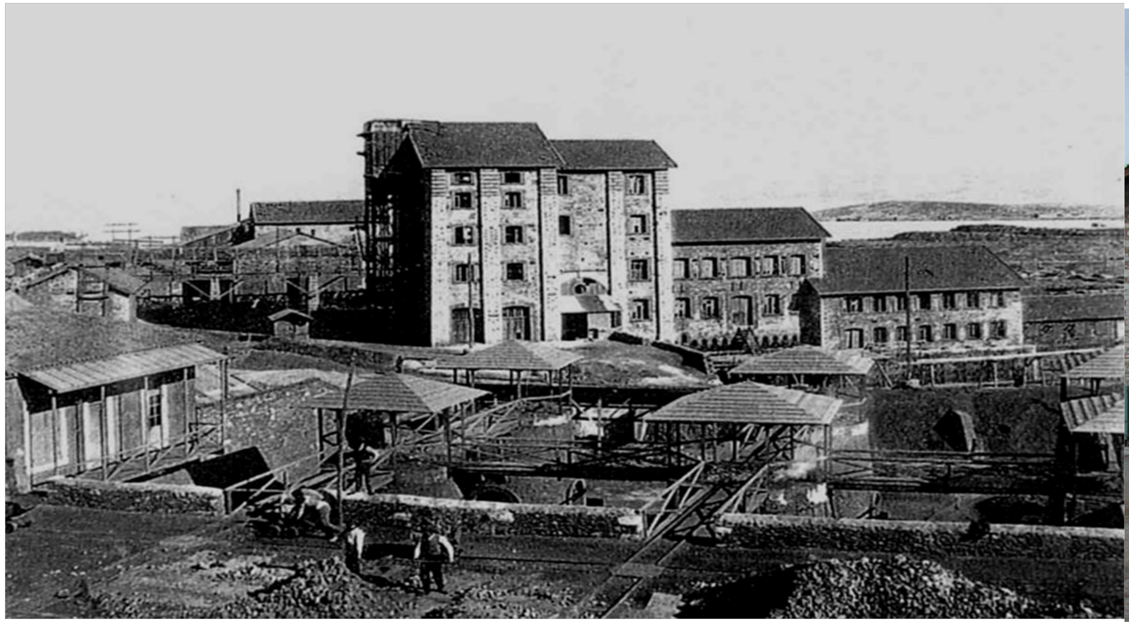
LAVRION



The southern part of Attica peninsula

- Prof. Dimitrios Kaliampakos, Dean of School of Mining & Metallurgical Engineering, NTUA
- Assimakis Chadoumellis, Site Manager LTCP
- Dr. Vasileios Protonotarios, Chemical Engineer, MSc, Technical – Environmental Consultant

AMDC/LTCP – Now & Before



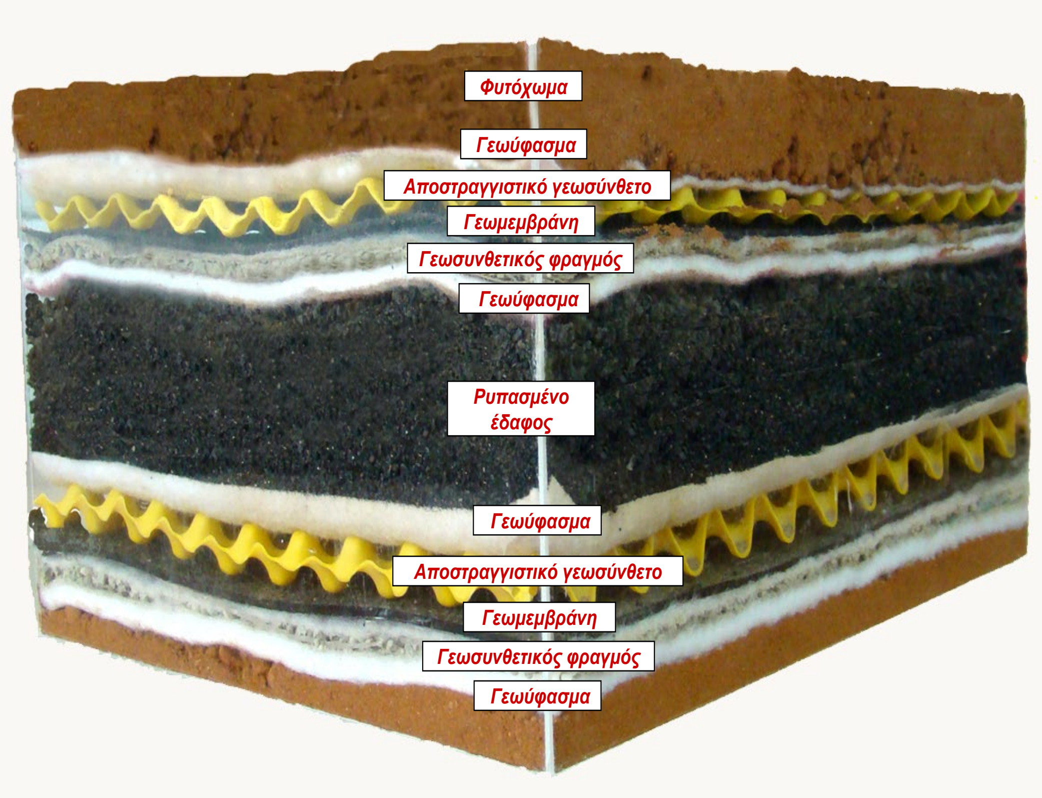
AMDC/LTCP – Background Technologies

Polluted Soils Repository ("Dry Tomb")

Ex-Situ but On Site

Repository Waste Concentration's

Parameter	Average Concentration (mg kg^{-1})	Limit Industrial Use (mg kg^{-1})
Pb	24,628	2,000
As	5,300	140
Cd	117	60
Zn	35,669	360
Mn	7,960	-
Fe	152,598	-
Cu	2,548	91



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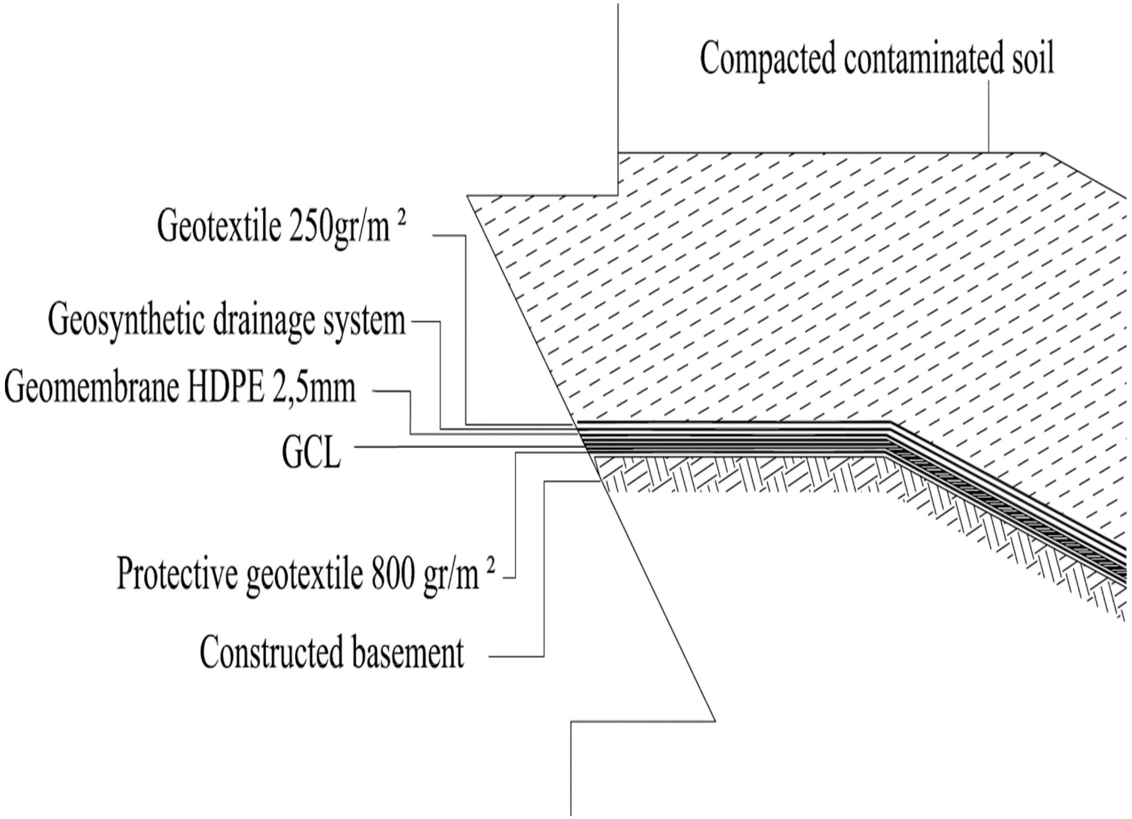
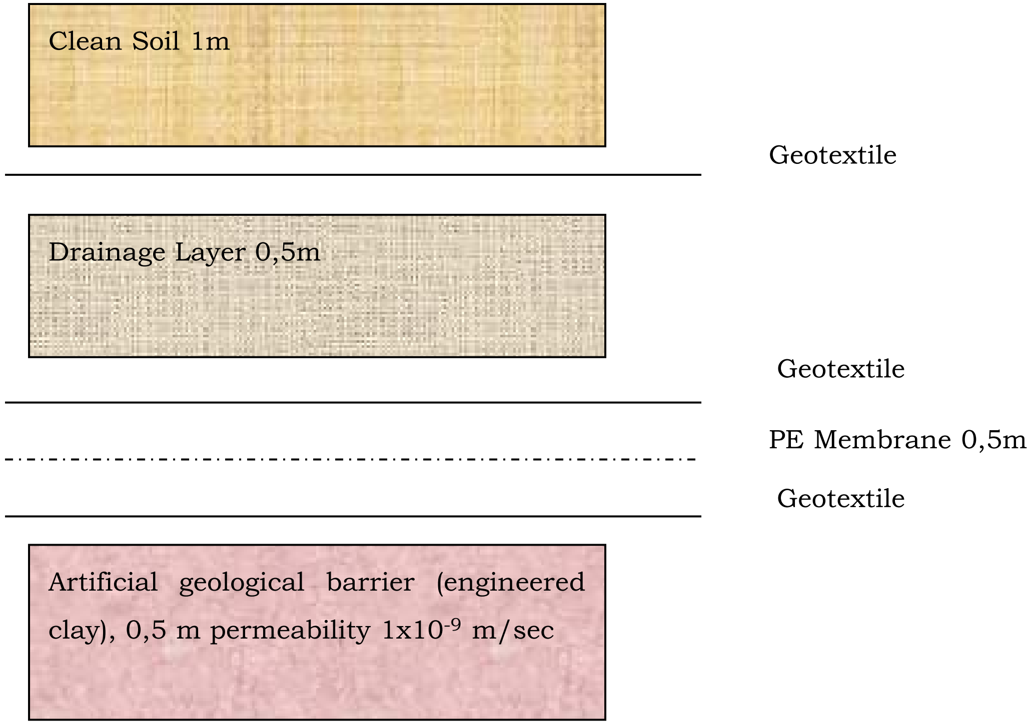
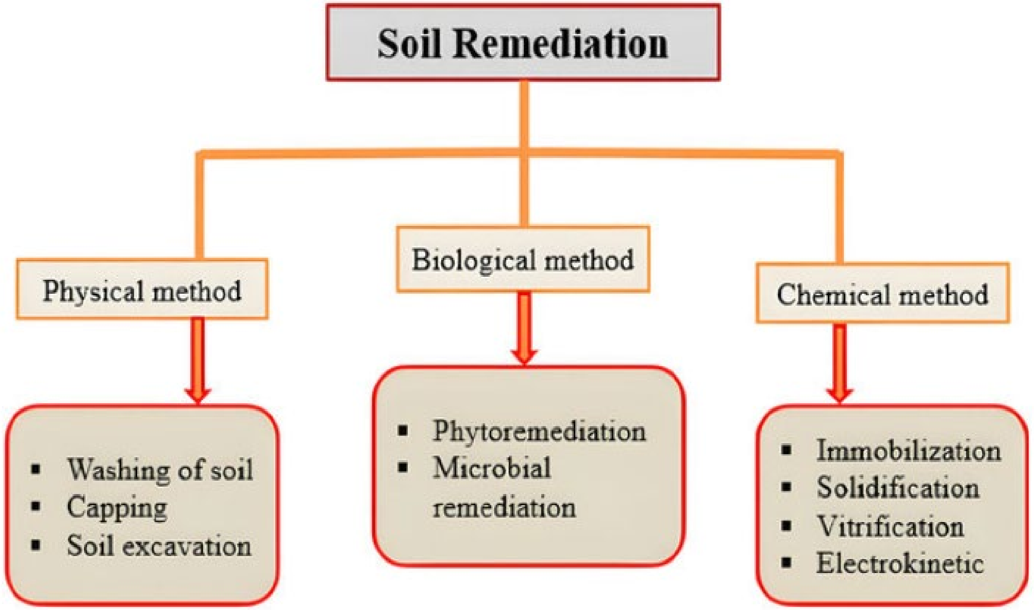
Repository Cover/Bottom Structure





Soil Remediation Methods Vs Cost



General Category	Remediation Technology	Indicative Unit Price (€)
Excavation and containment	Excavation and disposal to landfill	$74/m^3$
In situ physical containment by means of engineering systems	Engineering capping	$22–44/m^2$
	Encapsulation (shallow cut-off wall)	$59–89/m^2$
	Encapsulation (deep cut-off wall)	$104–178/m^2$
Treatment	Bioremediation	52–67/t
	Vitrification	59/t
	In-situ vitrification (5 t/h)	225–319/t
	Soil washing	45–52/t
	In situ chemical oxidation	$59–119/m^3$
	Soil washing ex situ	43–171/t
	Stabilization/Solidification ex situ	45–170/t
	Landfarming	48/t
	Pump and treat	30–120/t

Repository Main Features

- Total Area 18.000m^2
- The project cost a total of 3.500.000€, which corresponds to approximately 27 €/tn or 32€/m^3.
- Minimize health hazards (i.e., cut the pathways via which the hazards are transmitted)
- Allow the safe use of the site for recreational purposes
- **Facilitate the reverse process in which the wastes could be mined and used as valuable materials in the future**

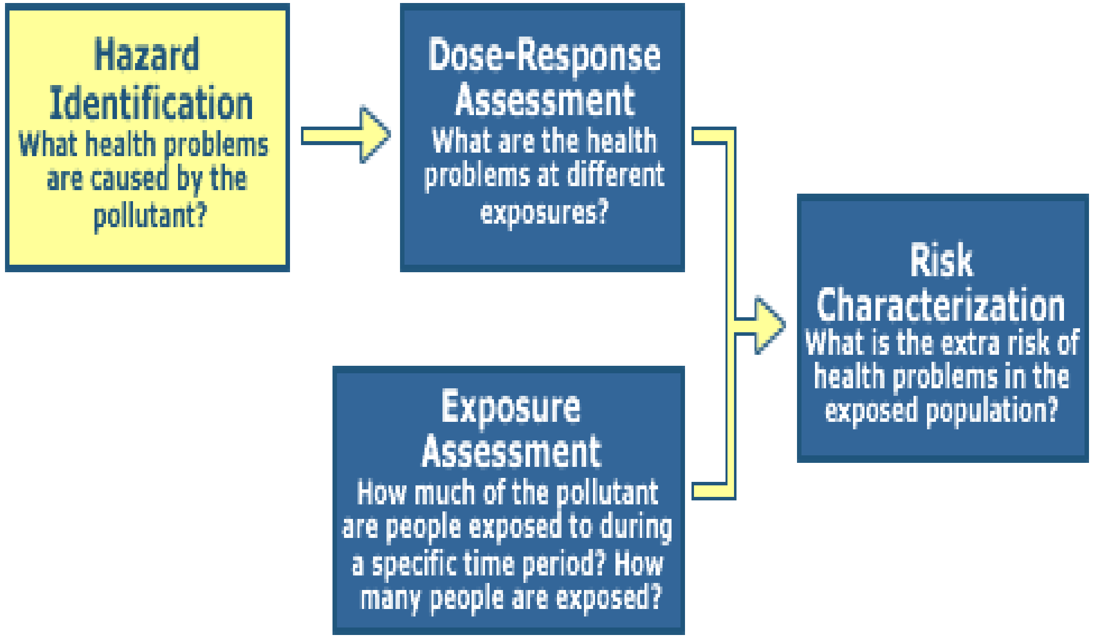
Dry Tomb as a “future mine”

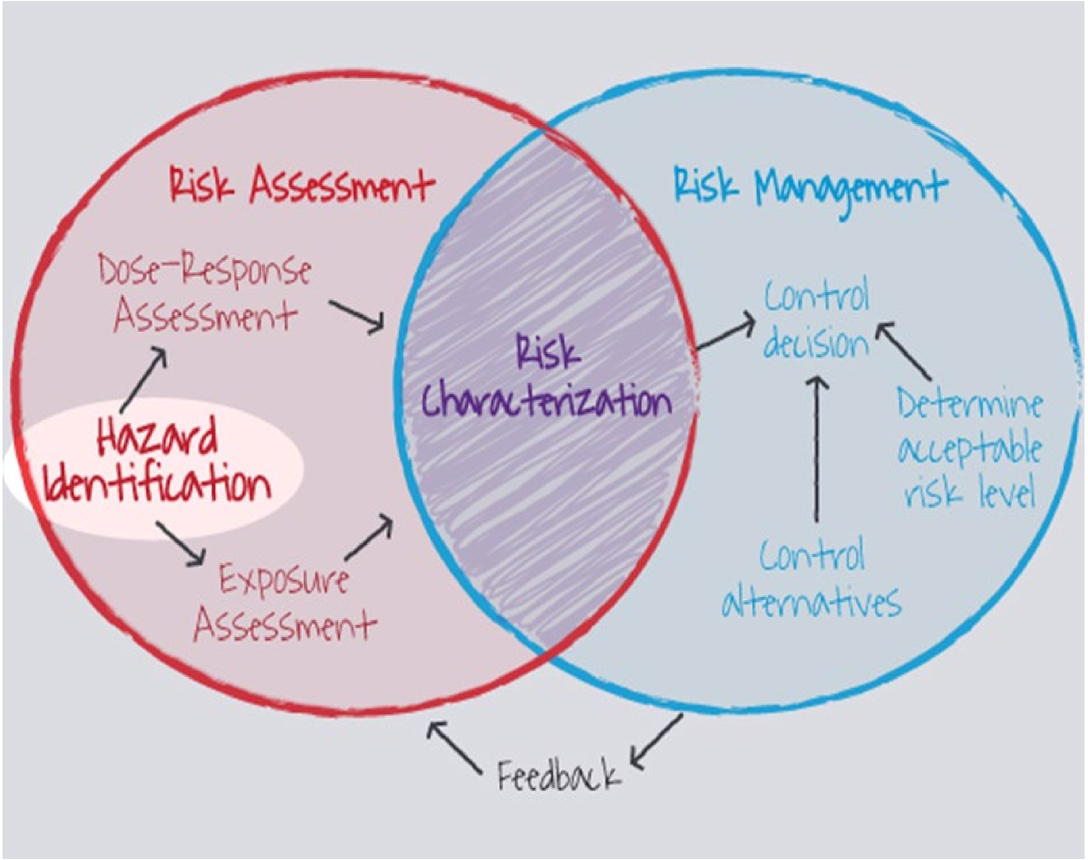
- Continuous resource depletion creates the need for the exploitation of ‘poor’ ores on one hand and the rapid technological evolution on the other hand may transform existing mine waste dumps into the mines of the future at a known location.
- For example, the quantity of copper located in all kinds of waste repositories is about 300 million tons, an amount corresponding to more than 30% of the remaining reserves in known ores.
- In such cases, a risk-based approach may be quite effective in providing an environmentally sound and economically viable solution without jeopardizing the opportunity to recover valuable resources in the future from today’s waste.
- **Risk-targeted methodologies examine the chain of “Hazard → Pathway → Target” and aim to break the links**
- This way, risks can be managed e.g., eliminated, transferred, reduced, encapsulated, or retained with respect to an acceptable risk level taking into consideration critical factors of the problem under investigation (e.g., environmental pollution, finance, regulation, social effect, etc.).

Main Disadvantages of "Dry Tomb"

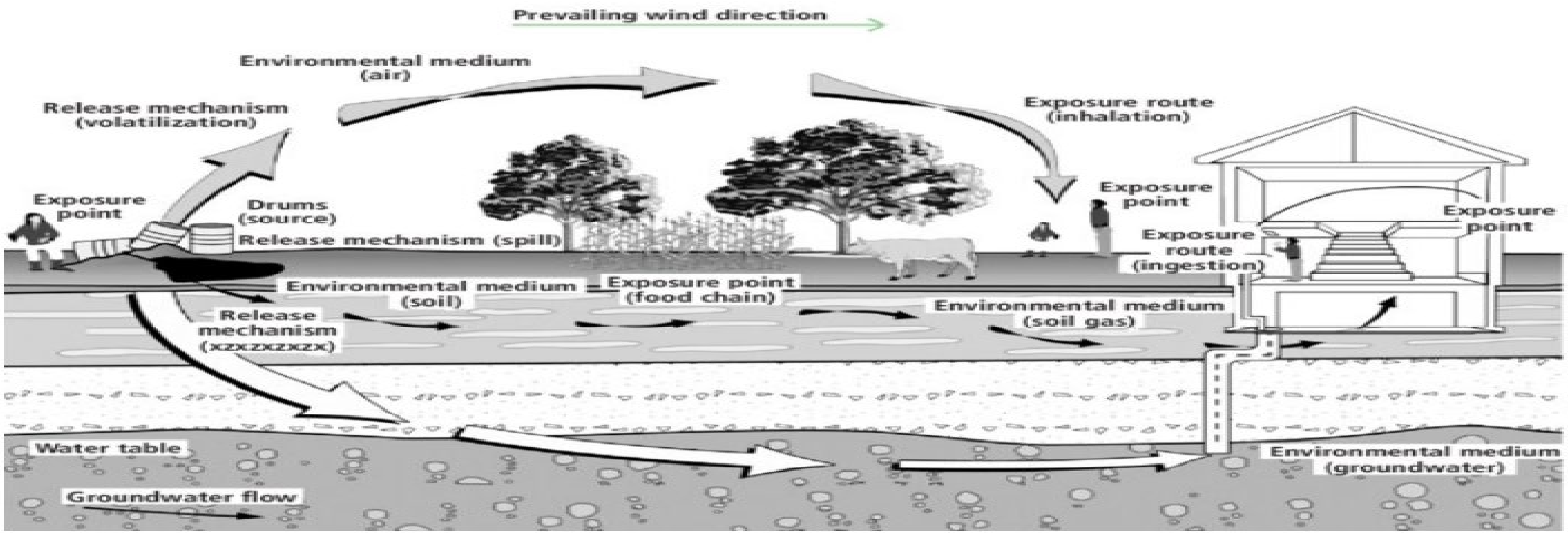
- Pollutants remain in the area without reducing their concentration, however they are cut off from all external interventions
- The difficulty of calculating the time of effective protection is multiplied in relation to the cover, since in addition to the top cover, the underlying waterproofing of the waste must be monitored.
- The maintenance/repair of the waterproofing layer, especially in case of damage, is a particularly difficult and expensive process and practically requires re-excavation and transport of waste
- Significant limitations arise in the future uses of the land, especially when it has to be taken into account in geotechnical calculations, in addition to the surface layer and the underlying waterproofing.

The 4 Step Risk Assessment Process

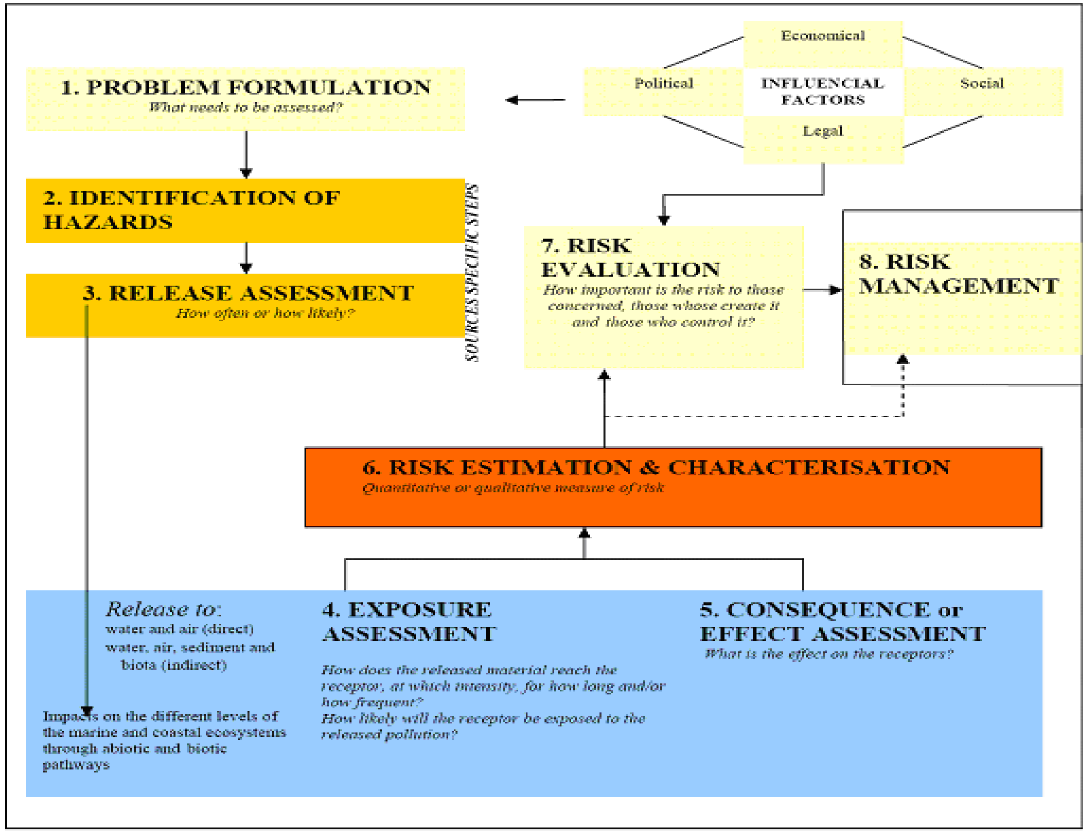


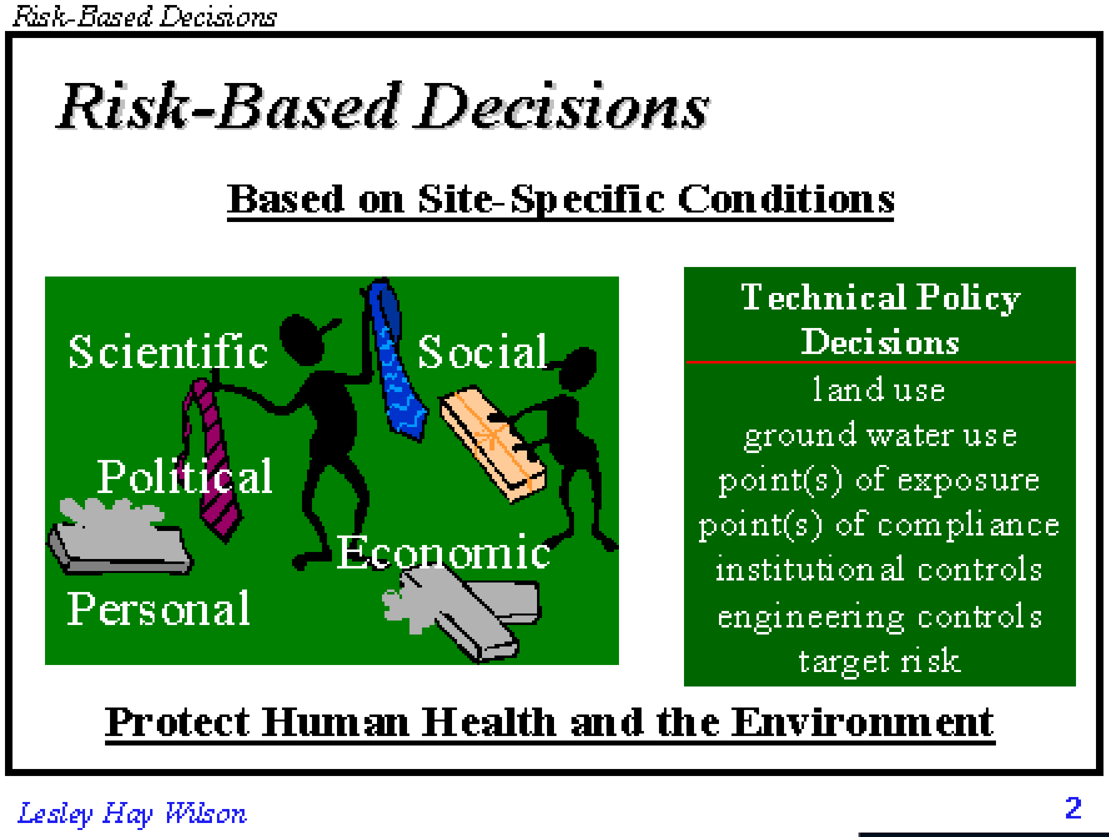


Framework for human exposure of contaminated sites. Source: Public Health Assessment Guidance Manual (2005 Update)



Risk Assessment – Risk Management





Deterministic Approach to Risk Assessment – Risk Carcinogenic Effects - Ingestion - Worker

$$R(w.c.ing) = \frac{C\ x\ EF\ x\ ED\ x\ IR\ x\ SF}{AT\ x\ BW}$$

C = Average Ground Concentration (mg/Kg)

EF = Exposure Frequency (250days/year)

ED = Exposure Duration (25years)

IR = Ingestion Rate (100mg/day)

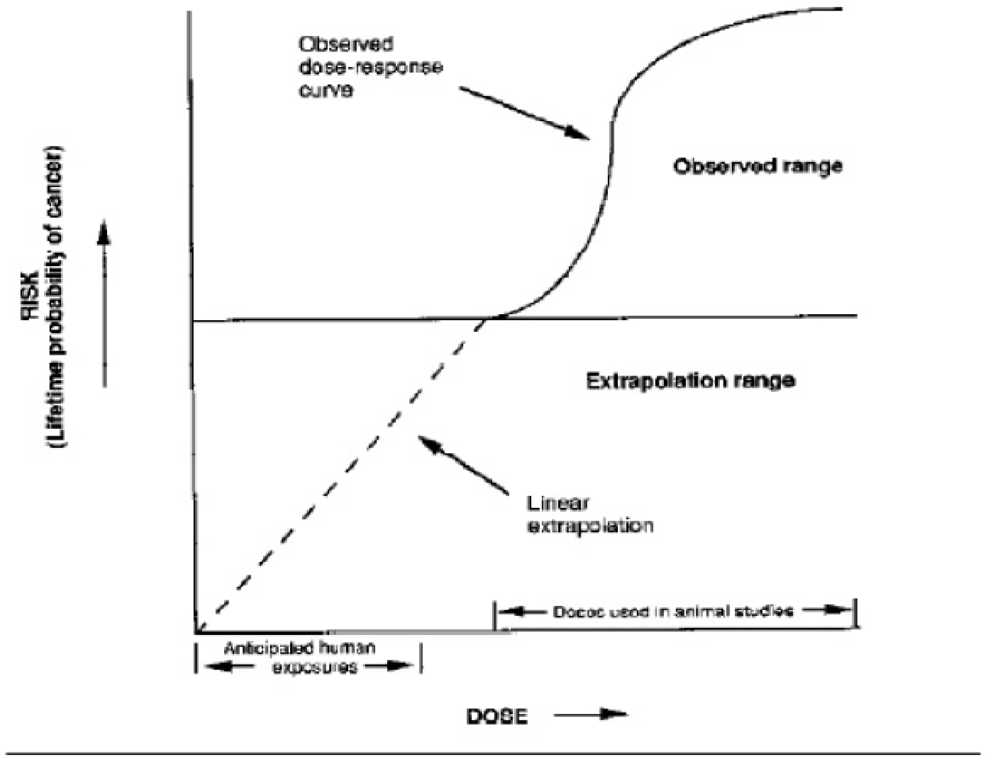
SF = Slope Factor (ingestion) $(mg/kg\ day)^{-1}$

AT = Average Exposure Time (365days/year x 70years = 25.500days)

BW = Body Weight (80Kg)

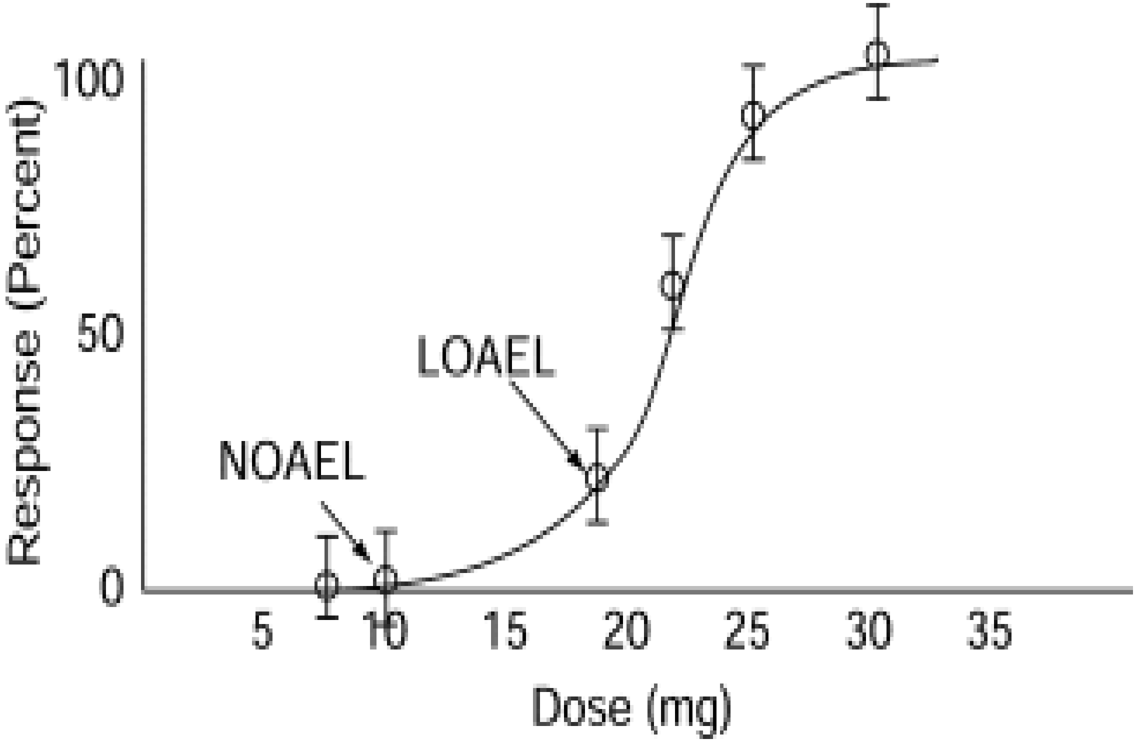
*1,2 lit/day if water

Acceptable Risk = 10^{-6}



Risk Non-Carcinogenic Effects - Ingestion - Worker

- $$\mathrm{HQ}(w.nc.ing) = \frac{C\ x\ EF\ x\ ED\ x\ IR\ x\ \frac{1}{RFD}}{AT\ x\ BW}$$
- C = Average Ground Concentration (mg/Kg)
- EF = Exposure Frequency (250days/year)
- ED = Exposure Duration (25years)
- IR = Ingestion Rate (100mg/day)*
- RFD = Reference Dose (ingestion) $(mg/kg\ day)^{-1}$
- AT = Average Exposure Time (365days/year x 70years = 25.500days)
- BW = Body Weight (80Kg)
  - *1,2 lit/day if water
- **Acceptable HQ = 1**



PARAMETER	As	Cd	Cu	Pb	Fe	Zn	Cr
RfD	3,0E-04	1,0E-03	4,0E-02	-	7,0E-01	3,0E-01	3,0E-03
SF	1,5E+00	-	-	8,5E-03	-	-	5,0E-01
RfC	1,5E-05	1,0E-05	-	-	-	-	1,0E-04
IUR	4,3E-03	1,8E-03	-	1,2E-05	-	-	8,4E-02
ABS	0,03	0,001	-	-	-	-	
GIABS	1,00	0,025	1	1	1	1	0,025
RBA	0,6	1	1	1	1	1	1

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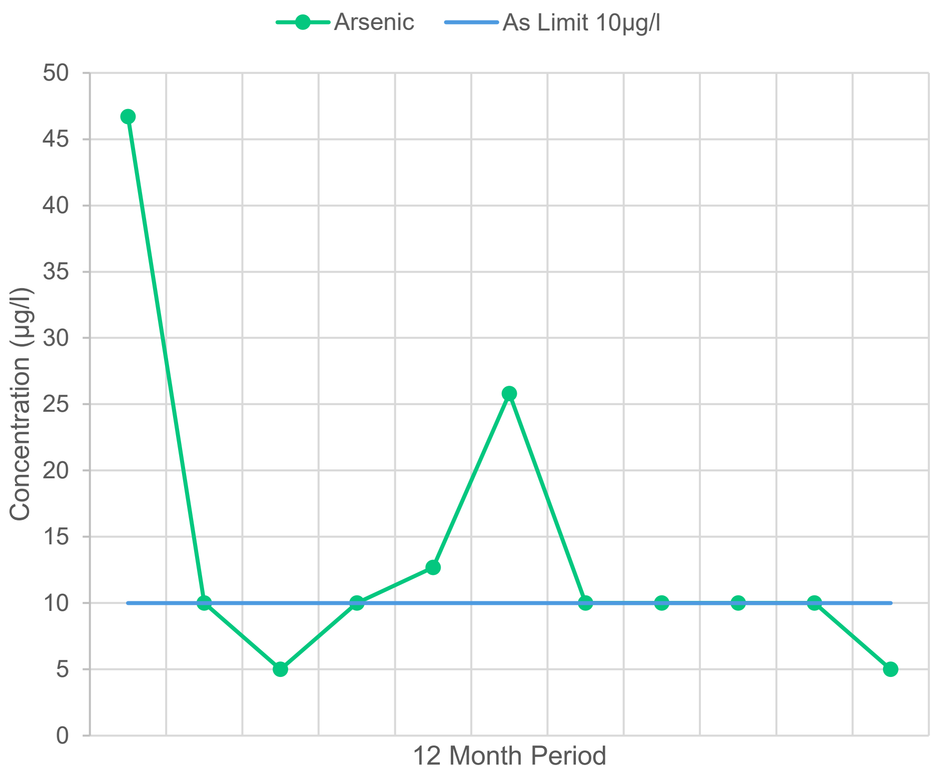
Risk Without Repository

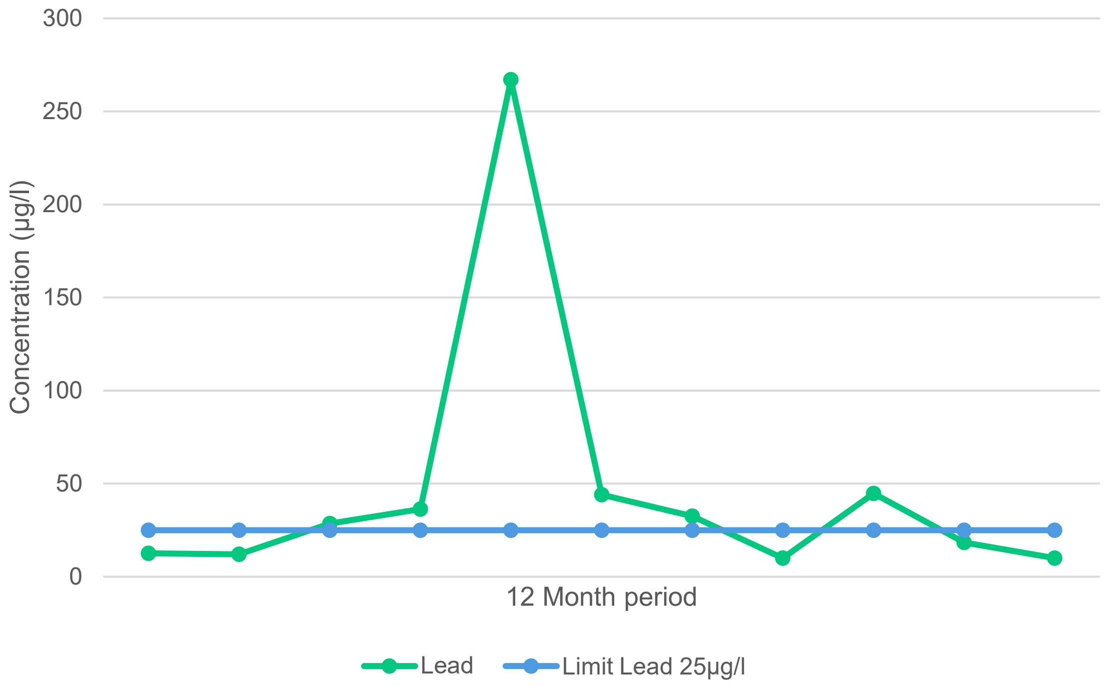
Carcinogenic-Inhalation	$Risk = \frac{C \times URF \times 1000 \times EF \times ED \times (1/PEF)}{AT \times 365}$	$R = 50 \times 10^{-6}$
Carcinogenic – Ingestion	$Risk = \frac{SF \times C \times 10^{-6} \times EF \times ED \times IR_{soil}}{BW \times AT \times 365}$	$R = 1500 \times 10^{-6}$
Non-Carcinogenic - Inhalation	$HQ = \frac{C \times EF \times ED \times (1/PEF)}{RfC \times AT \times 365}$	$HQ < 1$
Non-Carcinogenic – Ingestion	$HQ = \frac{C \times 10^{-6} \times EF \times ED \times IR_{soil}}{RfD \times BW \times AT \times 365}$	$HQ = 3$

Main Risks and Questions involved now

- Stability of the embankment
- Status of the isolation measures
- Water intrusion on the waste mass
- Hazardous Metals/Metalloids escape from surface or underground
- Surface status (topsoil layer and geotextile)
- Groundwater Status
- Distribution of metal compounds within the waste mass
- Balance the risk and the benefits if metal exploitation is considered

Monitoring Results – Groundwater (Only accessible Route)





Risk Calculations - Groundwater

- Risk for Arsenic - Carcinogenic Effects – Ingestion of GW – Worker = 7,78 X 10^{-5}
- Risk for Lead - Carcinogenic Effects – Ingestion of GW – Worker = 1,47 X 10^{-6}
- Total Risk Carcinogenic Effects – Ingestion of GW – Worker = $(R_{As} + R_{Pb}) = 7{,}93 \times 10^{-5} > 10^{-6}$
- Calculations made by using average concentrations
- Risk doubled if inhabitant is considered instead of worker

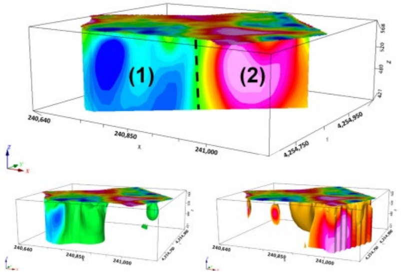
Mine i.o. Project: CURRENT ASSESSMENT - DATA COLLECTION

DInSAR

Subsidence control

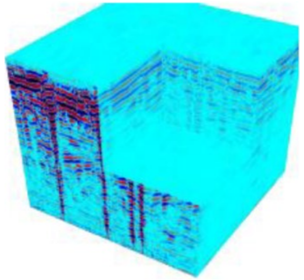
Drone - Magnetometer

Potential metals content



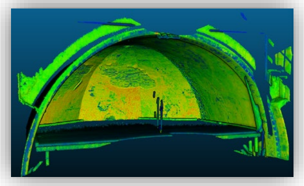
GPR

Status of isolation measures



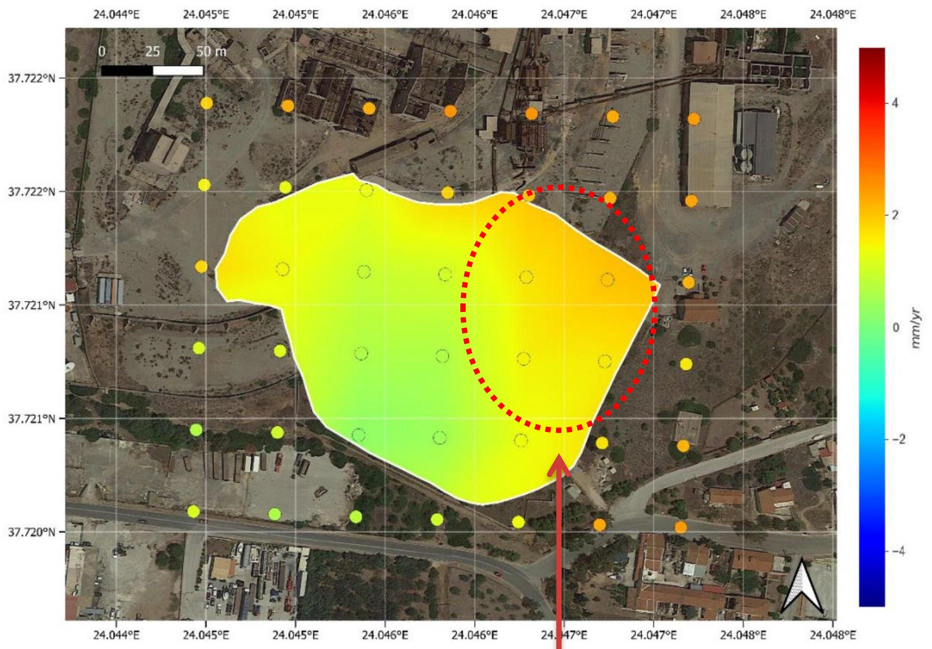
LiDAR-SLAM

3D surveying



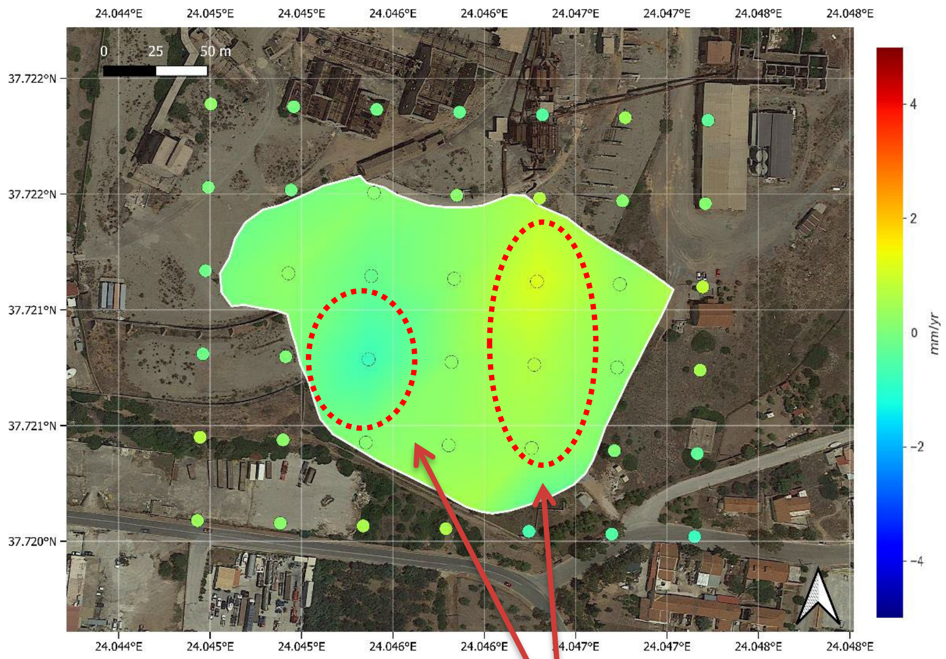
1. **USAL**
2. **USAL + ACC**
3. **USAL**
4. **USAL + ACC**

DinSAR – RESULTS - Proactive risk management



Vertical deformation

Results show a higher risk of vertical movement in the orange zones, especially at the east and northeast.



Horizontal deformation

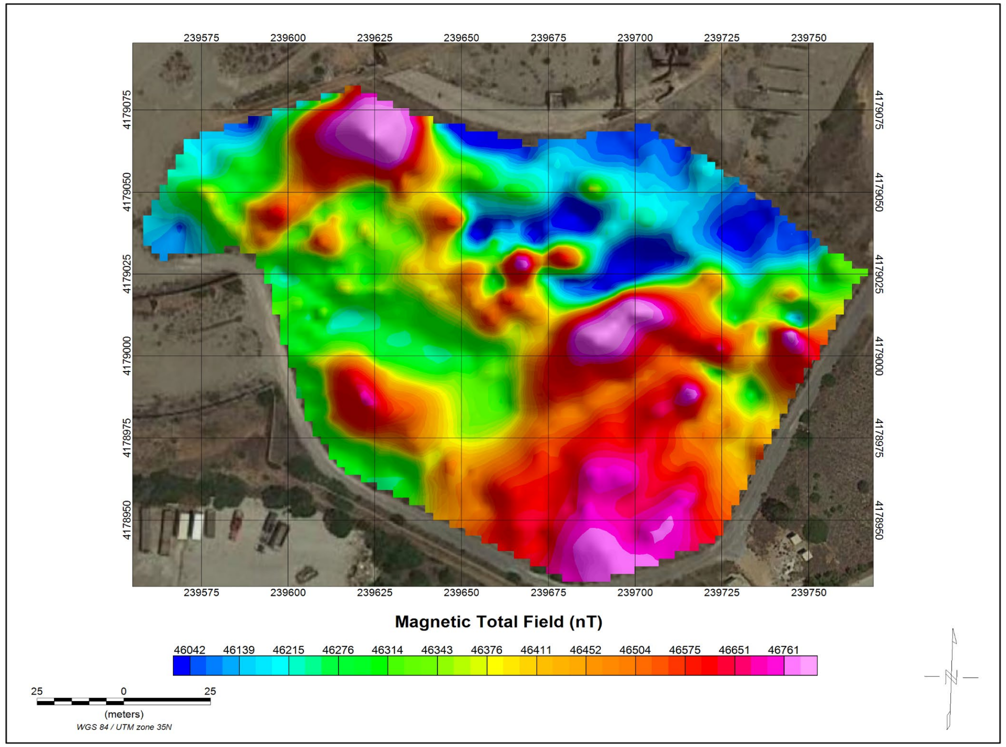
Less evident (maximum of 1mm/year), an area to the northeast with positive velocities, and at the west of the centre, with negative velocities

It is generally considered that the changes analysed over the last 5 years demonstrate that the embankment has quite good stability.

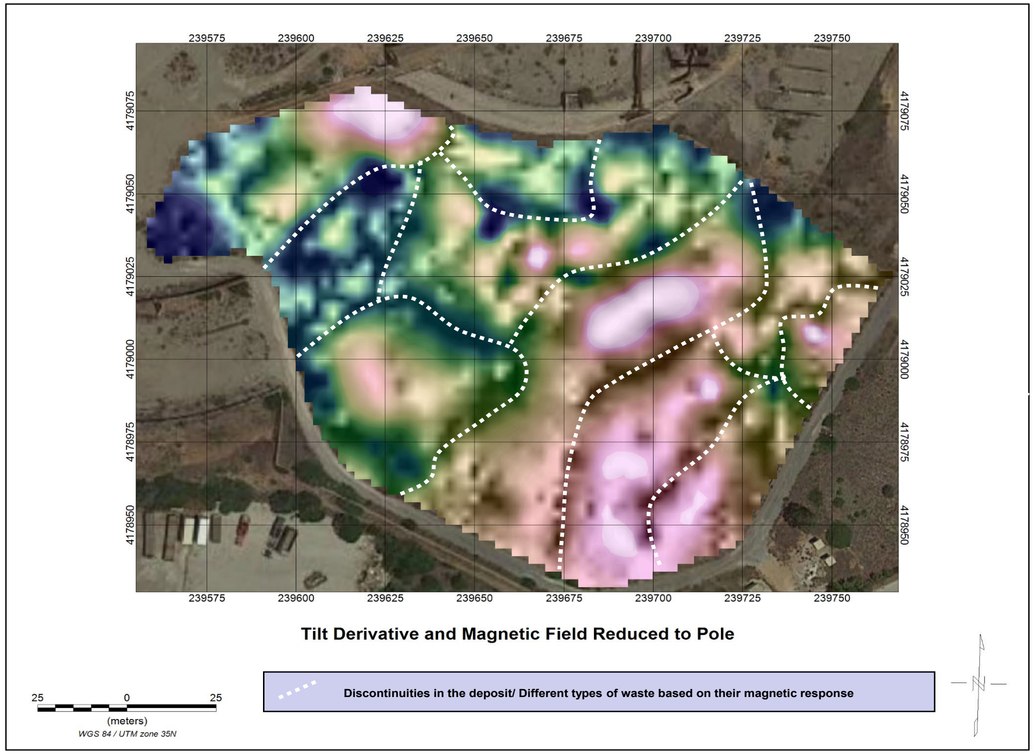
DRONE MAGNETOMETER

- **Mobile unit, ultra-light proton magnetometer GEM GSMP-35U**
- **CERVERUS UAV**
- Profiles: parallel with a maximum linear spacing of 10 m.
- Flight speed of 5 m/s.
- Sampling interval of 100 ms (10 measurements per second).

DRONE MAGNETOMETER – RESULTS - Understanding the spatial distribution and concentration of waste



Magnetic Total Field (nT)

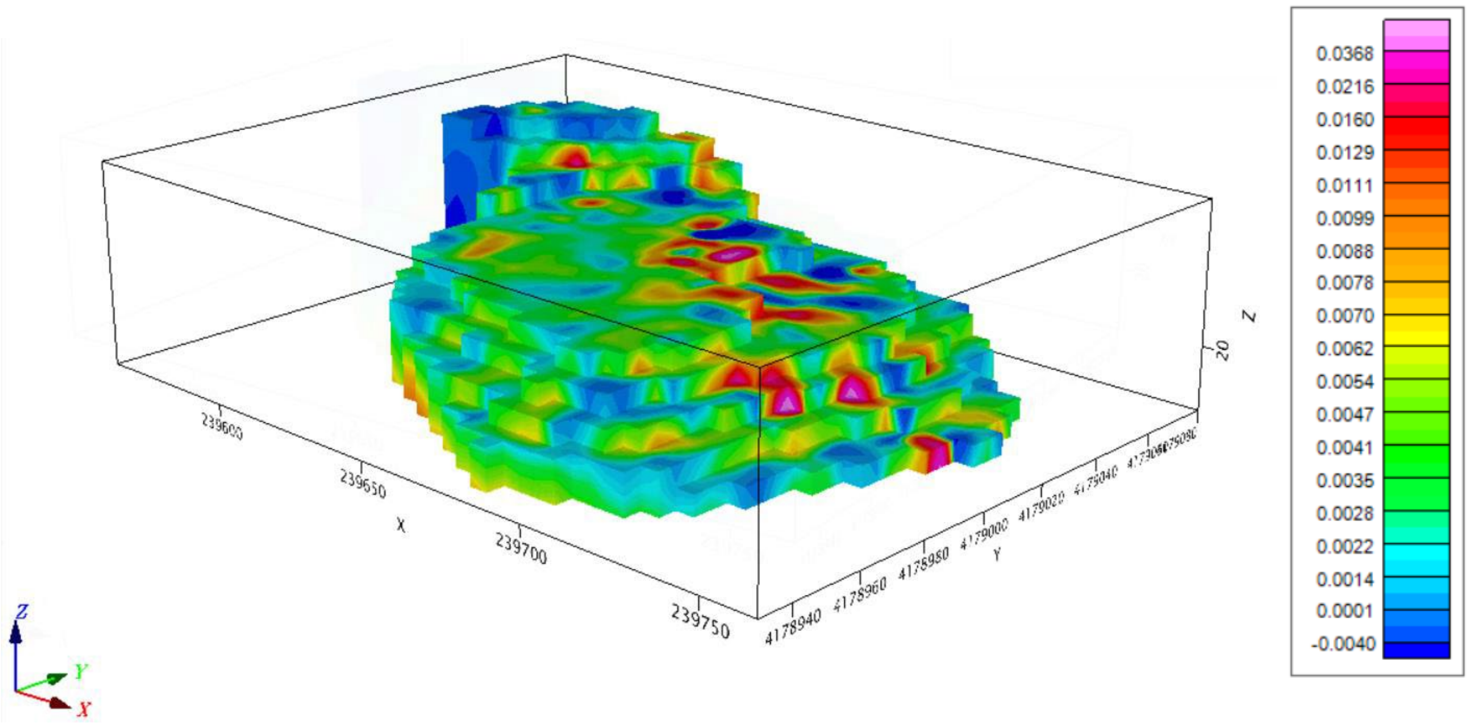


Tilt Derivative and Magnetic Field Reduced to Pole

The zones with high values are probably related to areas of higher concentration of ferromagnetic materials, such as iron.

DRONE MAGNETOMETER - RESULTS

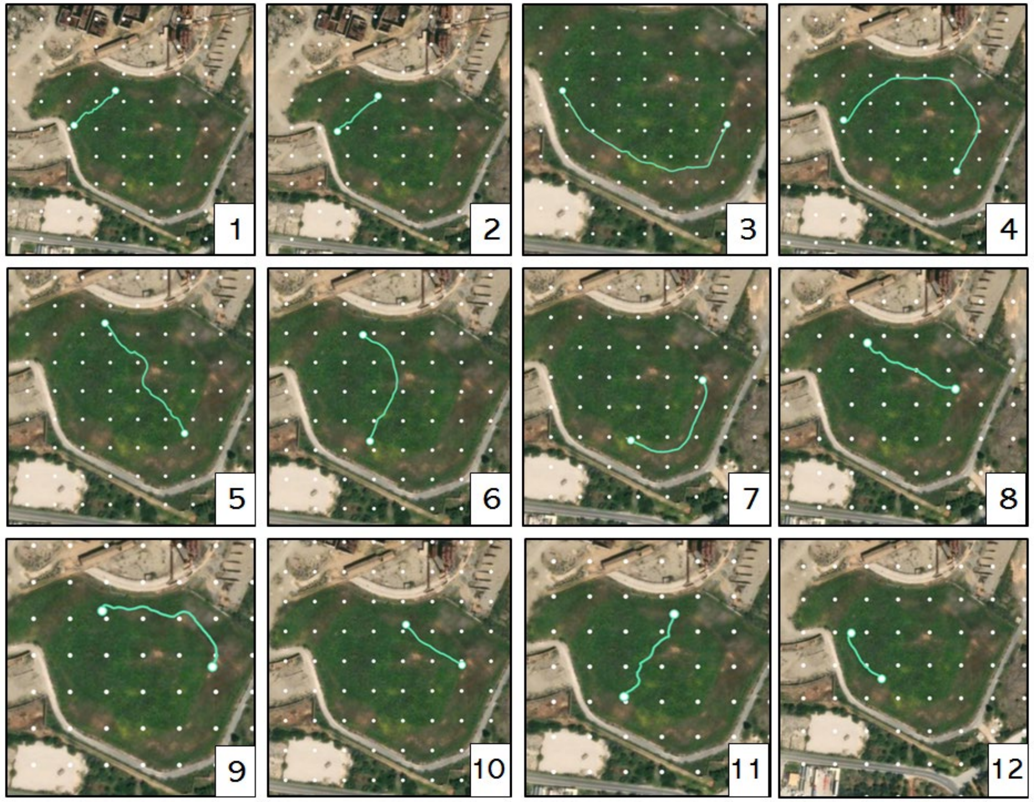
Magnetic susceptibility (SI)



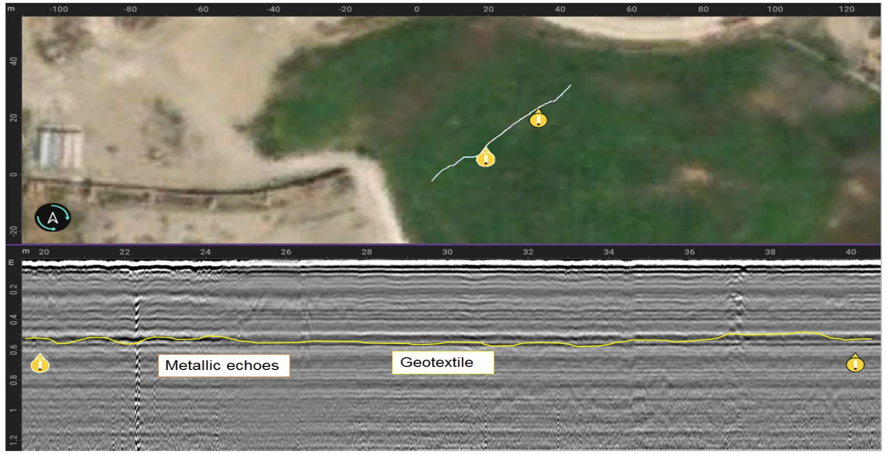
Negative low susceptibility values correspond to areas where there is a higher proportion of materials with a low content of ferromagnetic materials and diamagnetic ones such as lead, arsenic, cadmium and zinc.

GROUND PENETRATING RADAR

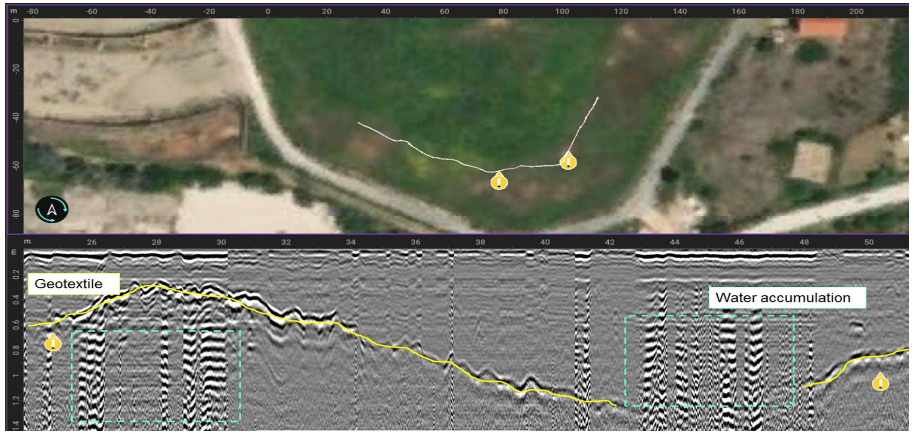
- **GPR – GS8000**
- **Processing software Insights**



GROUND PENETRATING RADAR – RESULTS – Detecting Possible Pollution Pathways



The preliminary results shows the location of the first layer of geotextile, which was originally placed at a depth of 1 m. This layer is found with quite significant continuity in some areas of the structure.



However, more altered areas are found, where the first layer of geotextile distributed in variable depth, showing altered areas with **possible accumulation of water** and mixing of the horizons of vegetal soil and layer of drainage material.

Main Conclusions

- **DInSAR** provides real-time, precise monitoring of ground deformation and structural stability. It supports proactive risk management, allowing operator to identify and address potential issues before they escalate, **thus reducing environmental and health risks** associated with hazardous waste containment.
- **Drone magnetometer** provides detailed, non-invasive data that aids in understanding the spatial distribution and concentration of waste. By integrating this data into environmental risk assessments, operator can better understand the potential threats posed, prioritize areas for remediation, and reduce health and environmental risks.
- **GPR** provides essential data by revealing hidden structures, detecting potential contamination pathways, monitoring landfill stability. By identifying and characterizing subsurface features and potential hazards, GPR plays a critical role in mitigating environmental risks, informing remediation, and ensuring the safe, sustainable management.

Future Work

- **Future work**
  - Monitoring humidity in the mining deposit at different strategic points.
  - Correlation of humidity measurements with ground-penetrating radar results to determine the status of deeper insulation layers.
  - Integration of all technologies and definition of the remediation techniques to be used, as well as the possible routes for recovery of potential minerals
- **Quantify the risk by**:
  - Estimating rate of deformation
  - Define the degree and rate of slope movement
  - Performing precise risk zoning, helping prioritize high-risk areas
  - Identifying high-risk zones for leachate
  - Locating potential leachate pathways
  - Leakage Quantification
  - Detailed assessment of cap and liner condition