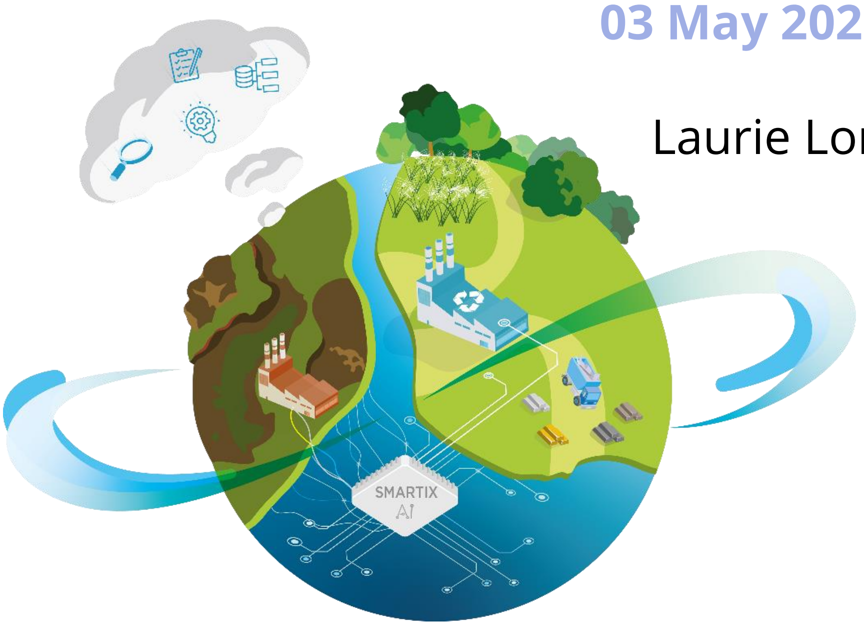
D. I3.3.1 Site specific report on excavation activities and civil engineering methods applied on Duferco site

03 May 2023



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ATRASOL

SUMMARY

List of Figures

List of tables

GLOSSARY

CTP : Centre Terre et Pierre

DEM : Digital Elevation Model

EMI : Electromagnetic Induction

ERT : Electrical Resistivity Tomography

IP : Induced Polarization

MAG : Magnetometry

MASW : Multichannel Analysis of Surface Waves

OSHA : Occupational Safety and Health Administration

PMSD : Past-Metallurgical Sites and Deposits

SRT : Seismic Refraction Tomography

Uliège : University of Liège

DAP: Diammonium Phosphate

1 INTRODUCTION

The DUFERCO site, located in La Louvière, was from 1853 to 2012 the ground of various metallurgical activities, which led to the deposit and backfilling of considerable quantity of metallurgical waste on the site. According to the historical studies carried out in 2020, the DUFERCO site was backfilled with a total volume firstly estimated at 5.630.000 m³. Based on old NGI maps, the backfill thickness could reach 10 to 15 m. It is mainly composed by mixed metallurgical wastes (mainly black and white slags, that could be mixed with sand or metal scraps), construction wastes, schistous carbonaceous materials and various earthy materials. The potential of the DUFERCO site as a source of secondary raw material has led it to be part of the three pilot sites of the NWE-REGENERATIS project.

This site specific report is a continuation of the previous geophysical, historical and analytical investigations carried out on the site (D.I2.1.1, D.I2.1.2, D.I2.2.1, D.I2.2.2 and D.T2.1.1.). It aims at evaluating the most relevant excavation and civil engineering method to be applied on site before the extraction activities. This report is intended to provide (1) a comprehensive site description focusing on the most relevant parameters for excavation and civil engineering works, (2) an excavation plan, including a description of the methods and equipment to be preferably used on DUFERCO, which were selected according to the results of the investigations carried out previously in the NWE-REGENERATIS project.

Previous investigations and analyses have revealed that the economic profitability of recovering metals from DUFERCO's white metallurgical slag is not guaranteed (Benoît Mignon, 2017). Thus, in practice, the recovery of the slag will not be based on the metal concentration; but rather from a civil engineering use.

This report is divided into two main parts:

1. In the first part (section 3), the proposed excavation plan is built on a theoretical method, which is based on the geoprocessing of maps obtained after geophysical investigations. It allows to select for excavation the most relevant areas, determined after geophysics.
2. The second part (section 4) of the report describes the excavation and pre-treatment work actually carried out on the DUFERCO site

2 DESCRIPTION OF THE DUFERCO SITE

2.1 HISTORICAL CONTEXT

The Duferco site is located in La Louvière, in the province of Hainaut (Belgium). Its surface of 120 ha extends in a narrow alluvial plain with sloping (east-west) foothills of colluvium. Initially, agriculture was the main activity. The site has hosted the "Ferme-tout-y-faut" since 1440, before the beginning of the industrial era (DUFERCO, 2020).

The first industrial activities date back to 1853, with the building of a cast iron factory, that was named after its owner: “Fonderies et Laminoirs Ernest Boucquéau”. After a change of ownership, the company, then owned by Gustave Boel, continued to expand and by 1897 had

1200 workers. Before it was dismantled during the First World War, the company had 2 blast furnaces, 2 batteries of 41 coke ovens, a Thomas steelworks with three converters, rolling mills, a Martin steelworks, forges, a steel foundry, etc. The factory reopened in 1924 and continued to develop, producing up to 200,000 tonnes of cast iron per year and 200,000 tonnes of steel. Production was increased between 1930 and 1940, in particular with the construction of an ore agglomeration/crusher, 2 new blast furnaces, a new battery of coke ovens and a 25-ton arc furnace. This modernisation was halted again during the Second World War, only to resume after the war. From 1947, monthly steel production rose from 30,000 to 120,000 tonnes (DUFERCO, 2020).

The crisis of the 1970s led to job losses and successive takeovers: the Boel works were acquired by the Dutch Hoogovens group in 1997, before becoming the property of the Italian-Swiss trader Duferco in 1999. Official closure of "Duferco La Louviere Produits longs" was announced in 2013. Most of the facilities are now demolished and/or dismantled.

From 1904 to 1969, the industrial exploitation led to a highly backfilling of some areas of the site, predominantly composed of by-product of the activity and raw material: slag, coke and ore. The backfill thickness could reach 15m, the higher in the north. According to the difference between the digital elevation model (DEM) of 1900 and 2008, the volume of backfill is estimated at 5.630.000 m³ (Isopach backfill map, based from the substraction of the Digital Elevation Model (DEM) surveyed in 2008 and the DEM from the early 1900sFigure 1) (DUFERCO, 2020).

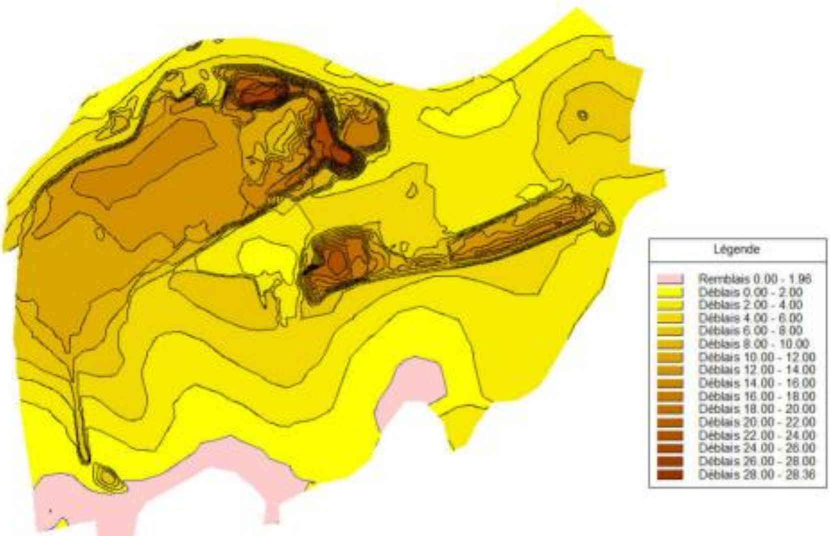

Figure 1: Isopach backfill map, based from the substraction of the Digital Elevation Model (DEM) surveyed in 2008 and the DEM from the early 1900s

Within the area identified for the disposal of metallurgical waste, several sub-areas can be distinguished (Figure 2) (DUFERCO, 2020), highly backfilled in the north, and rich of blast furnace dust in the south:

- Black slag deposit (+-500kt)
- LD slag deposit (+-450kt)
- Stocks of mixed materials (blast furnace dust, steelworks sludge, greasy sludge, etc.) intertwined with the white slag stockpile (+- 1135kt). In the centre and south of the area, only white slag at the core.

- The scrapyard covers a large surface to the west of the area
- Greasy sludge (+-50kt) to the south, annexed to the area where the blast furnace dust was stored

Based on the collected data, those areas could represent a significant recovery potential, as they contain an important volume of potentially recoverable materials (slag, dust and other residues from steel production). In the framework of the NWE-REGENERATIS project, the areas “scories blanches” and “merlon-tout-venant”, representing a total of +- 1135kt of material, were dedicated for recovery potential investigation.

The in-situ ecocatalysis experiment was performed on the area were blast furnace dust were identified (“Poussières de HFx” on Figure 2)

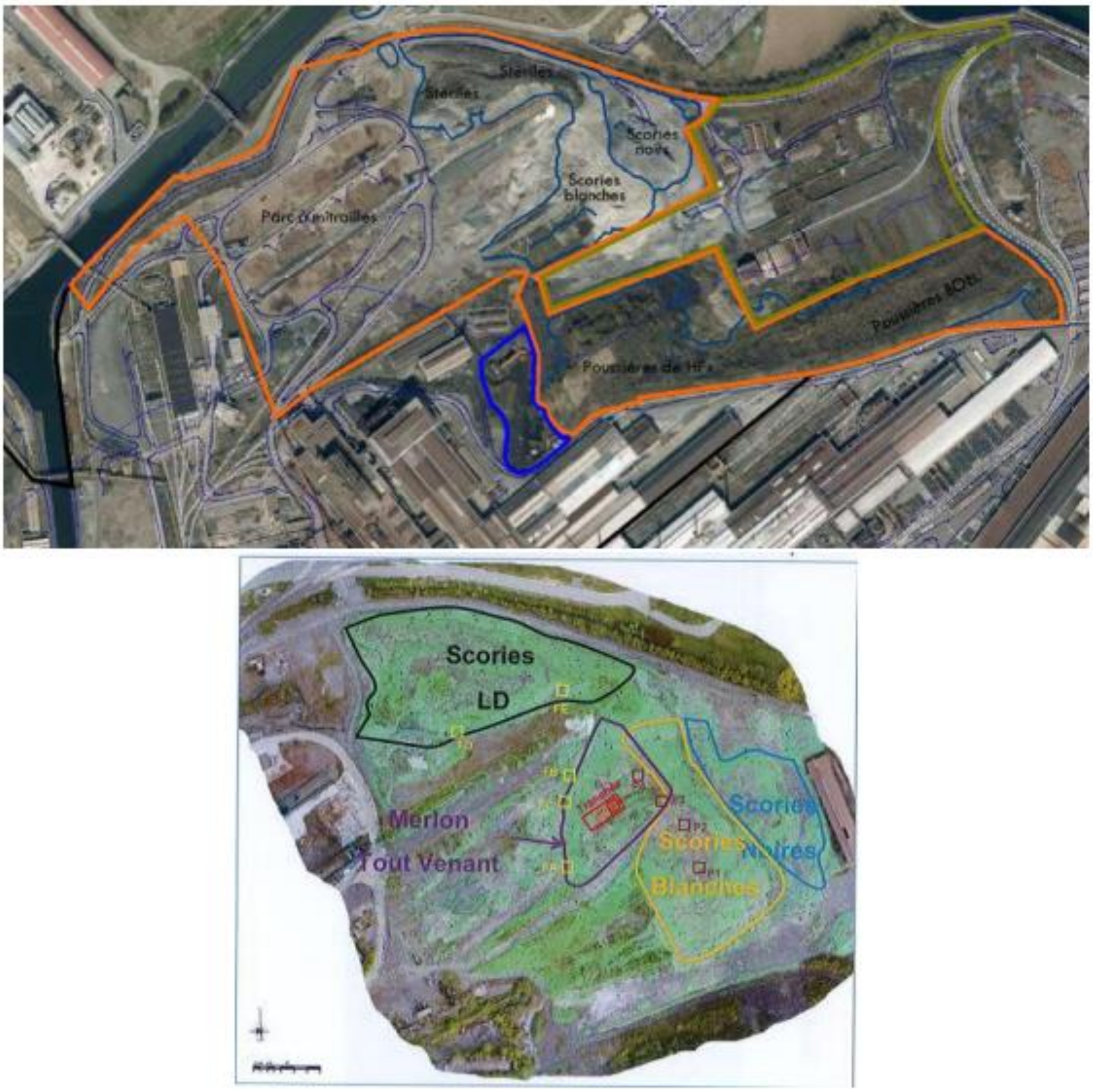

Figure 2: Sub-areas identified for the disposal of metallurgical wastes; by-product and scrap storage area (orange boundary); in electric blue: greasy sludge stockpile; below: zoom on the area of the slag heaps with their alternative name

2.2 PREVIOUS INVESTIGATIONS AND WORKS

The geophysical characterisation was mainly focused on the white slag and old factory areas, represented respectively in green and orange in the Figure 3.

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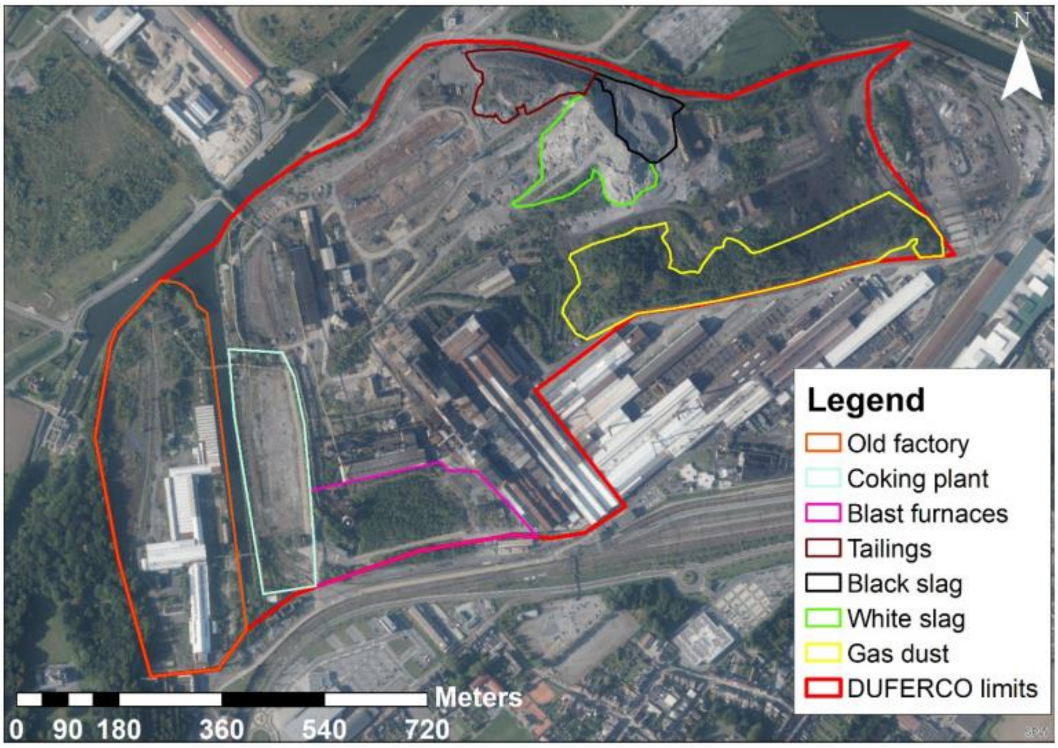

Figure 3 : Overview of Duferco site and the different areas

Table 1 provides a summary of the main investigations and research carried out that are relevant to this report.

Table 1: Previous investigations and researches performed on DUFERCO site

PREVIOUS NWE-REGENERATIS INVESTIGATIONS		
Type	**Date, Author,** ***Title and/or Description***	**Main conclusions**
Soil studies (geotechnical, characterisation, investigation)		
NWE-REGENERATIS : Historical studies	*DI.3.1.1. Site specific report summarizing available historical data on DUFERCO site* (DUFERCO, 2020)	Report providing administrative data, historical data on the type of ore and the processes used, geographical /environmental information and other relevant historical information of the site such as findings of the investigation campaigns carried out in 2007 by Environ and in 2011 by Siterem. This report gives a detailed description of the sub-areas of the metallurgical deposit, including a first estimate of the volume, but also a description of the environmental conditions. In particular, it indicates that the white slag area is heterogeneous and mixed with other by-products of the steel industry. It indicates that given the presence of backfill over the entire site, the presence of interconnected water pocket can be assumed on the surface, i.e. a surface water table with a temporary profile. Even though the focus was on the most risky activities (the old factory area, blast furnace and coking plant), the soil studies carried out in 2007 and 2011 show that pollution is found throughout the site: heavy metals, but also PAHs, cyanide and other polluting compounds.
NWE-REGENERATIS Geophysical studies	*DI2.2.1. Site specific report on geophysical survey on site* (Caterina et al., 2021)	Reports describing the geophysical results of the geophysical survey, that were performed on DUFERCO from September 28 to October 2, 2020. The geophysical characterisation was mainly focused on the white slag and old factory areas. On white slag area, the geophysical methods used were ERT, IP and SRT. ERT and IP offered the most promising results to detect high metal content areas.

	DI2.2.2. Site specific report on traditional pre sampling and post sampling investigations (Benoit Mignon, 2021)	Report describing the sampling carried out on the basis of the geophysical investigation and the characterisation of these samples in the laboratory. The analysis of these samples allows the correlation report to be drawn up, making the link between the geophysical and the laboratory measurements.
	DI2.2.3. Correlation report of characterisation studies based on information from geophysical and traditional investigation (Manrique et al., 2022)	Report presenting correlation between the geophysical measurements and geochemical analysis. The aim being in the end to estimate the thickness of the deposit and locate specific areas of interests. The geophysical maps obtained from these campaigns are then used to define the excavation plan. In the report, a strong positive correlation is shown between Mn-V, K-Si, Ti-Si, Cr-Mg, Ti-K and Cr-K and a strong negative correlation between Ca-Si and Al-Fe. The resistivity increases with the concentration of K, Si and Ti, while the chargeability has a strong positive coefficient of correlation with the V, Mn Cr and Fe. It means that the concentration of V increases with the concentration of Mn, Cr, Fe and leads to an increase of chargeability. Despite a good consistency between laboratory and field geophysical data, these results show the small-scale geochemical variability of the Duferco deposits. Nevertheless, the report provides clear evidence of the link between geophysical properties and geochemical elements, and represent a strong basis to build the RAPIDM model, useful to delineate areas of interest and estimate volumes.
NWE-REGENERATIS : Mineral processing lab-scale tests	*DT2.1.1. Report on Mineral Processing lab-scale tests on samples from DUFERCO site (2017)* (Benoît Mignon, 2020)	Report describing the results obtained from the crushing, sieving and separation techniques of the metallurgical samples (White slag, LD slag, “merlon tout venant” slag) taken from DUFERCO. The analytical fractions of these wastes did not seem very encouraging. Indeed, the magnetic fraction showed iron content charged with unwanted mineral elements (silicon, magnesium, calcium and aluminum). Besides, the presence of metals of high economic importance remained minor; zinc, copper, nickel and cobalt were present in trace amounts, precious metal and rare earths were totally absent. A recovery of the residues reveals to be economically unattractive considering current metal prices (but the situation may change in case of prices increase).
	DT2.1.2. Preliminary report on Mineral Processing lab pilot scale tests on samples from	Report describing the results from the pilot scale test performed, including crushing, screening and magnetic separation equipment. Crushing allowed metallic scraps to be released from the mineral gangue. Screening allowed to reduce the particle size range, therefore improving the efficiency of the subsequent separation processes. Finally, the eddy current separation allowed the recovery of

	DUFERCO site (2021) (Benoît Mignon, 2021)	metallic fractions (Fe,Al,etc…) and the concentration in some fractions of the metals that may be recovered through extraction processes by hydro- and pyro- metallurgy. However, most of the fractions obtained were of little interest in term of metal content. It was therefore decided to explore other recovery options of these metallurgical wastes, i.e. recovery as by-products in civil engineering. This decision led to further tests: geotechnical tests to assess the stabilization potential of the fines (<10mm) as a substitute for quicklime, tests on the granular part (between 10 and 30mm) to assess the mechanical properties as a sub-base aggregate. The results of these tests were promising in terms of mechanical properties, but require further testing to eliminate the risk of swelling.
NWE-REGENERATIS:	*DI3.3.3. Site specific report of the on-site demonstration for vegetal production and ecocatalyst synthesis* (Janus et al., 2022)	Report describing the methodology used to grow ryegrass on the DUFERCO site, for the purpose of ecocatalyst production. In total 615g of ryegrass were obtained on the unamended plot and 675g of ryegrass on the plots amended with DAP.

3 EXCAVATION AND CIVIL ENGINEERING METHODS TO BE APPLIED ON SITE

3.1 EXCAVATION PLAN AND PLANNING

3.1.1 Material and methods

The excavation maps proposed in this first part are mainly based on the GIS processing of the maps extracted from the RAPIDM model built using the correlation between geochemical and geophysical data (for more information, please refer to the reports "*DI2.2.1. Site specific report on geophysical survey on site"* (Caterina et al., 2021)*; "DI2.2.2. Site specific report on traditional pre sampling and post sampling investigations"* (Benoit Mignon, 2021) *and "DI2.2.3. Correlation report of characterisation studies based on information from geophysical and traditional investigation"* (Manrique et al., 2022)).

Three categories of materials have been identified using these correlations:

- Category 1: materials rich in Fe, Mn and other metallic elements, will be call "cat 1" hereafter;
- Category 2: with intermediate values (mixture of different materials);
- Category 3: material rich in silica and poor in Fe (inert materials, which may be suitable for use in civil engineering, e.g. as backfill), will be call "cat 3" hereafter.

Category 2 corresponds to the majority of the deposit, but is of little interest as it represents intermediate concentration values both for minerals and metals. The focus is therefore on categories 1 and 3, category 1 being potentially attractive for the recovery of metals; and category 3 being potentially suitable for its content of mineral inert materials, with a possibility of recovery in civil engineering, e.g. road recovery.

The top and bottom elevation points for categories 1 and 3 were received, and then interpolated via QGIS with the Inverse Distance Weighting (IDW)-method (1m spatial resolution) to obtain Digital Terrain Models (DTM).

As illustrated in Figure 4, thanks to the geoprocessing of these rasters, it is possible to obtain the depths (both for cat 1 and 3) to be excavated, also in the form of DTM:

- The digging depth to reach the top of the excavation volume is obtained by subtracting the raster of the elevation of the ground surface and the elevation of the top of the excavation area.
- The total depth to be excavated from the surface is obtained by subtracting the surface elevation and the bottom elevation of the excavation area.
- The DTM of the depth (or thickness) of the excavation area (cat 1 or 3) is obtained by subtracting the elevation of the top of the excavation area and the elevation of the bottom of the excavation area.

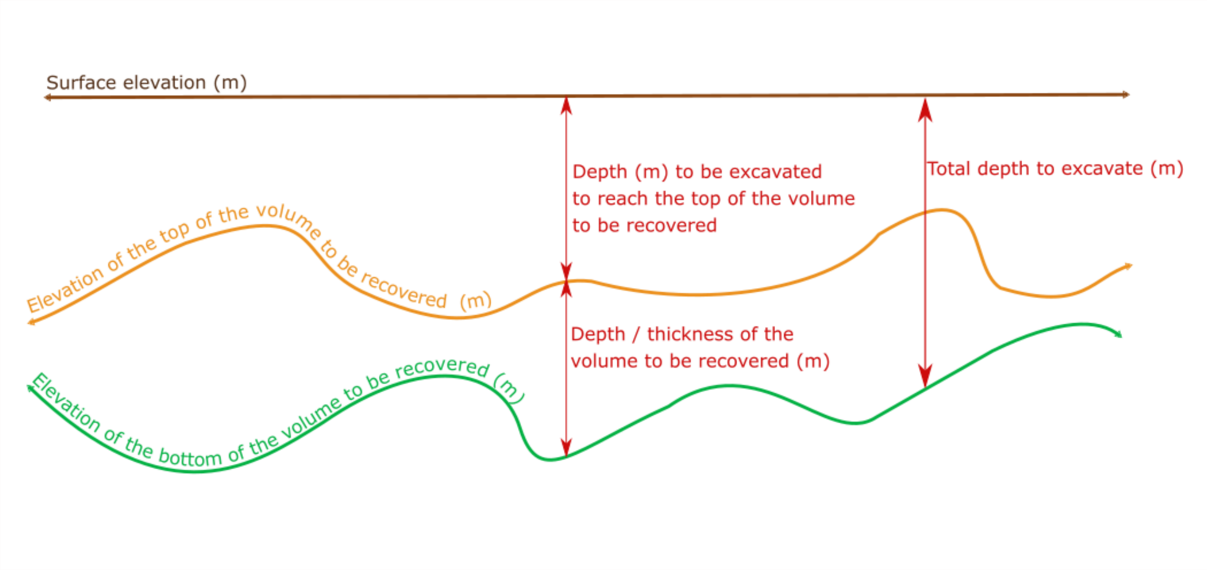

Figure 4: Schematic representation of the DTMs that can be obtained by raster geoprocessing

After geoprocessing, the digital terrain models obtained are raster formats, representing for each pixel of 1m dimension a different value (expressing the depth to be excavated). This format is not really the easiest to use in practice, as it would be complicated and extremely costly to indicate a different depth to be excavated for each square metre. A reclassification of the pixels was therefore applied, with a number of classes determined using the distribution (histogram) of pixel values.

After that, the classified rasters were successively sieved down so that single pixels and small groups of pixels could be removed, until an image is obtained that is both sufficiently free of noise, but without losing too much information.

The surface required for each excavation depth was realized by polygonising the classified rasters, and grouping each polygon with equalling pixel value. A different buffer was then applied for each excavation depth, allowing for the secure slope of α=h/L=4/10 (~21.8°) around the excavation area, in order to ensure its stability (Figure 5 and 6).

The buffers were applied to the midpoints of each class.

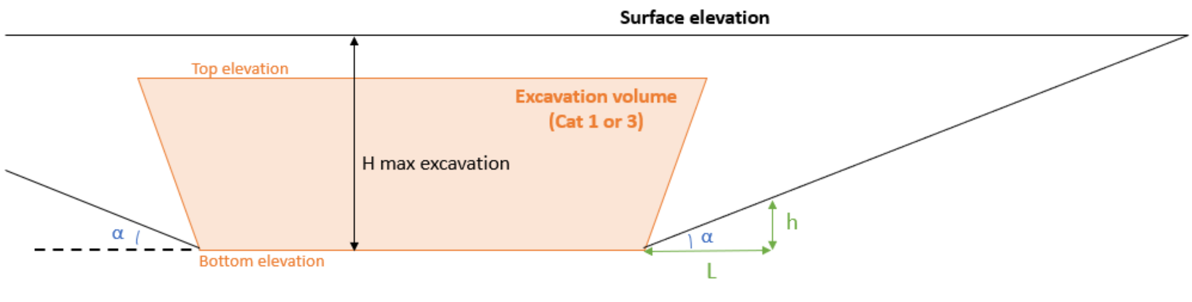

Figure 5. Schematic representation, illustrating the slope (α= arctan($\frac{h}{L}$)) to include to the excavation zone in order to ensure its stability.

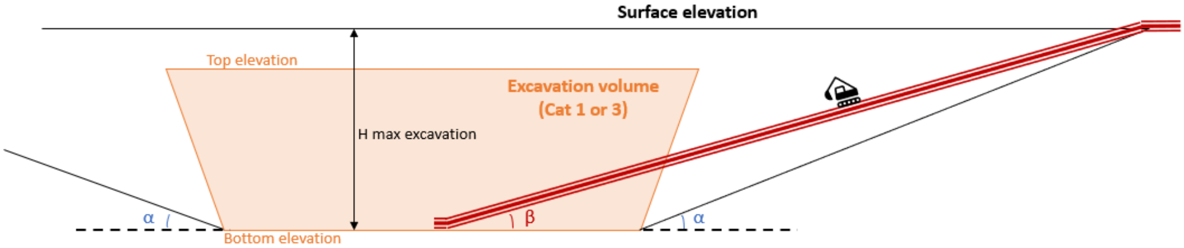

Figure 6. Schematic representation, illustrating the ramp to include if the slope needed for the machinery operation (β) has to be < α

3.1.2 Geoprocessing results and discussion: excavation plan

3.1.2.1 Cat 1 and 3 IDW

Figure 7 and 8 show the DTM of the elevations of the top and bottom of the cat1 and 3 deposit, as well as surface elevation, interpolated using Inverse Distance Weighting (IDW)-method (1m spatial resolution).

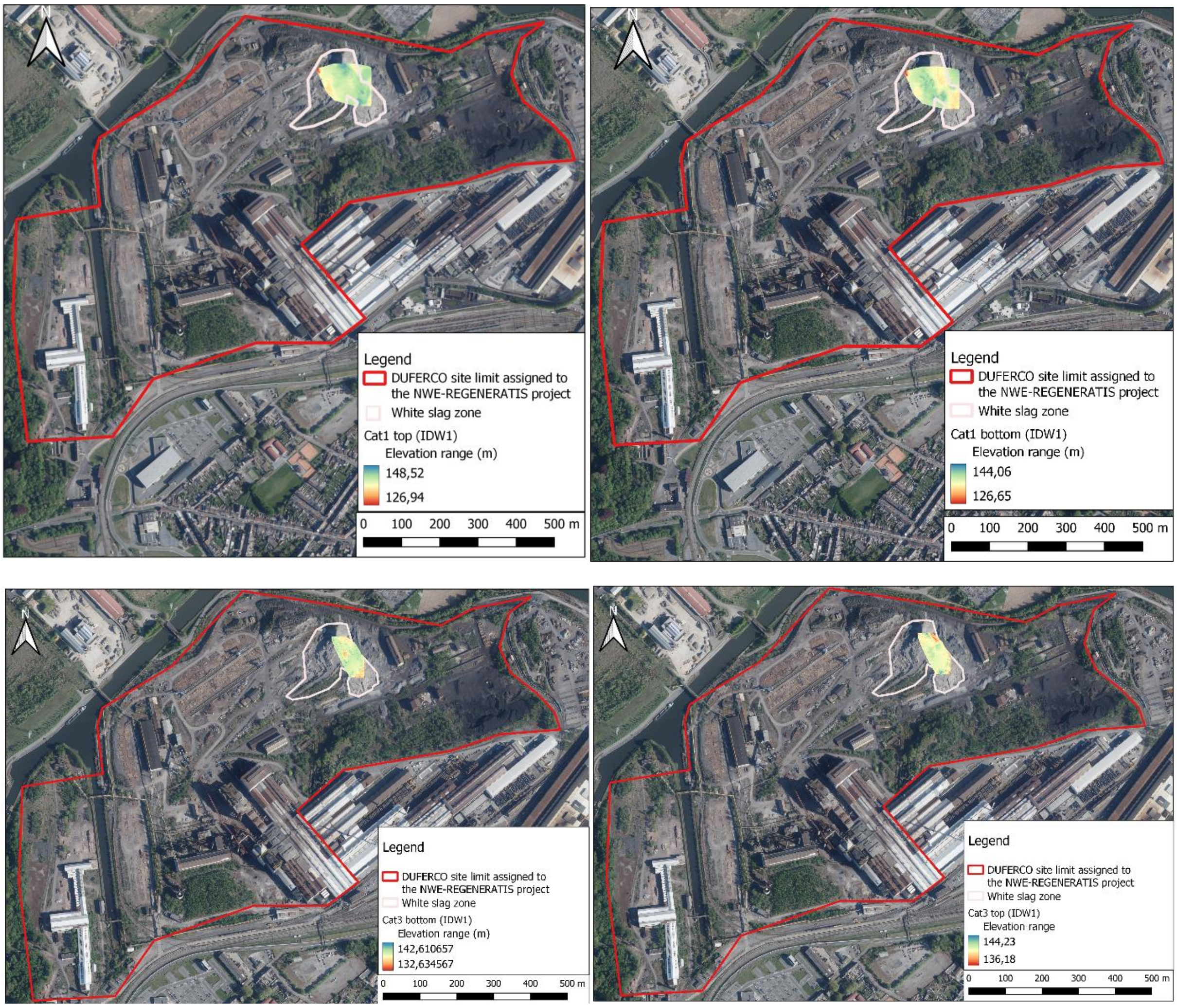

Figure 7: Top and bottom elevation DTM for cat 1 (above) and 3 (below), and location in the DUFERCO site

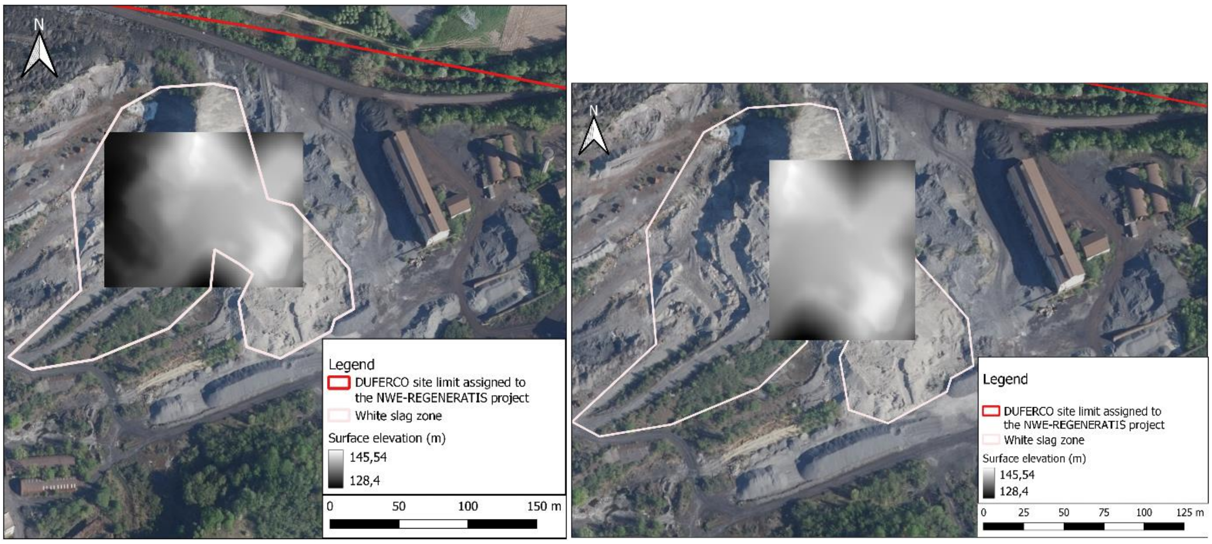

Figure 8: Surface elevation (m) cut to cat1 (left), cut to cat 3 (right)

3.1.2.2 Cat1 Geoprocessing

Figure 11 to 12 show the geoprocessing steps for the Category 1 deposit (depth to reach the top of the deposit: figure 9 and 10; thickness of the deposit: Figure 11 and 12).

The geoprocessing to reach the top of category 1 deposit (Fig. 9 and 10) shows that a large area is at a negative depth, which means that the ground surface is assumed to be deeper than the top of the deposit, which is not possible. The source of the problem is probably the surface raster, which was probably constructed using points based on another method/reference value, given that the geoprocessing of the thickness of the deposit (Fig.11 and 12) doesn't reveal negative values. The 2-pixel sieve applied to the geoprocessing of the top of category 1 only keeps class 2, which indicates depths between 0 and 2 m. It can be considered negligible compared to the thickness of the deposit, which can reach up to 12m.

It was therefore decided to use only the thickness of the deposit to determine the excavation depth and volume[1]. The geoprocessing for category 1 thickness includes (Figure 11):

- Obtaining the thickness map, by subtracting the elevation map of the bottom of the deposit from the elevation map of the top of the deposit
- Reclassification into new pixel classes (2m-thickness classes)
- Further sieving of the reclassified map, to obtain a map that expresses a happy medium between removing enough noise, without removing too much information either. In this case, the 5-pixel sieving seems sufficient.

[1] To further confirm this decision, geoprocessing of the total excavation depth was still determined using the surface DTM and the DTM of the elevation of the bottom of the deposit. These geoprocessing revealed a slightly different shape of the deposit compared to using only the top and bottom of the deposit to obtain the thickness of the deposit. These results are available in the Appendix A but are not used for the excavation volume.

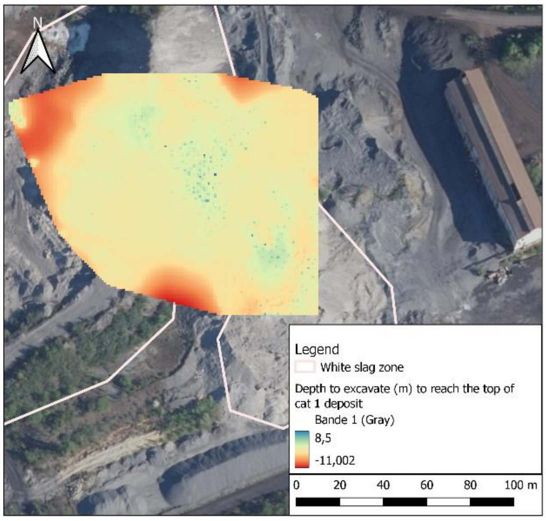

Figure 9: Depth to reach cat 1 top, raw IDW

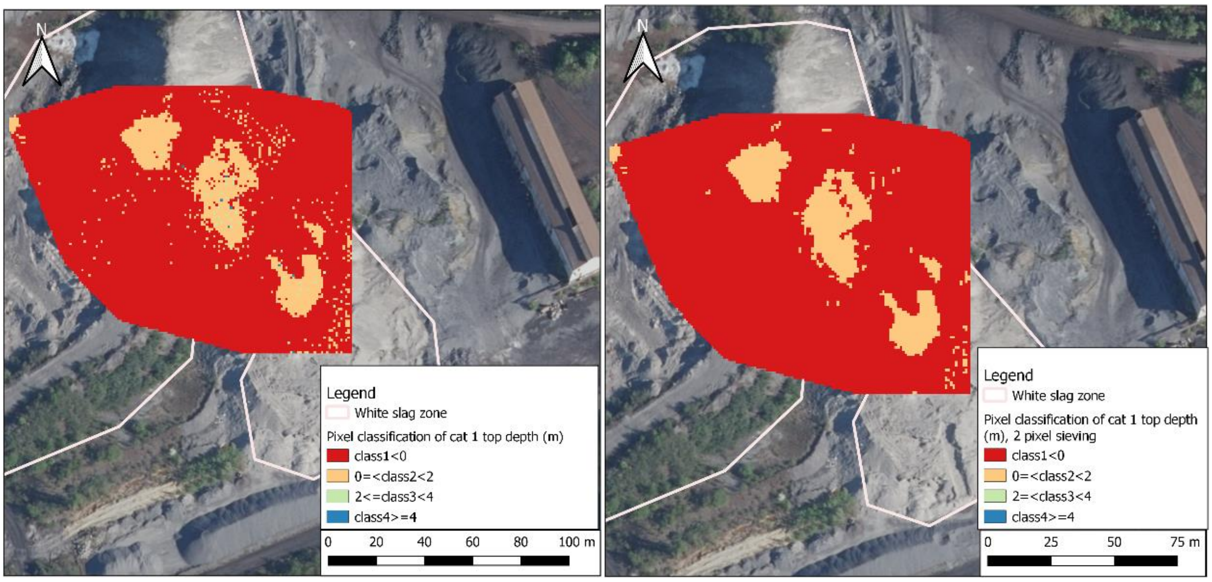

Figure 10 : Depth to reach cat 1 top, after classification (left), and 2-pixel sieving (right)

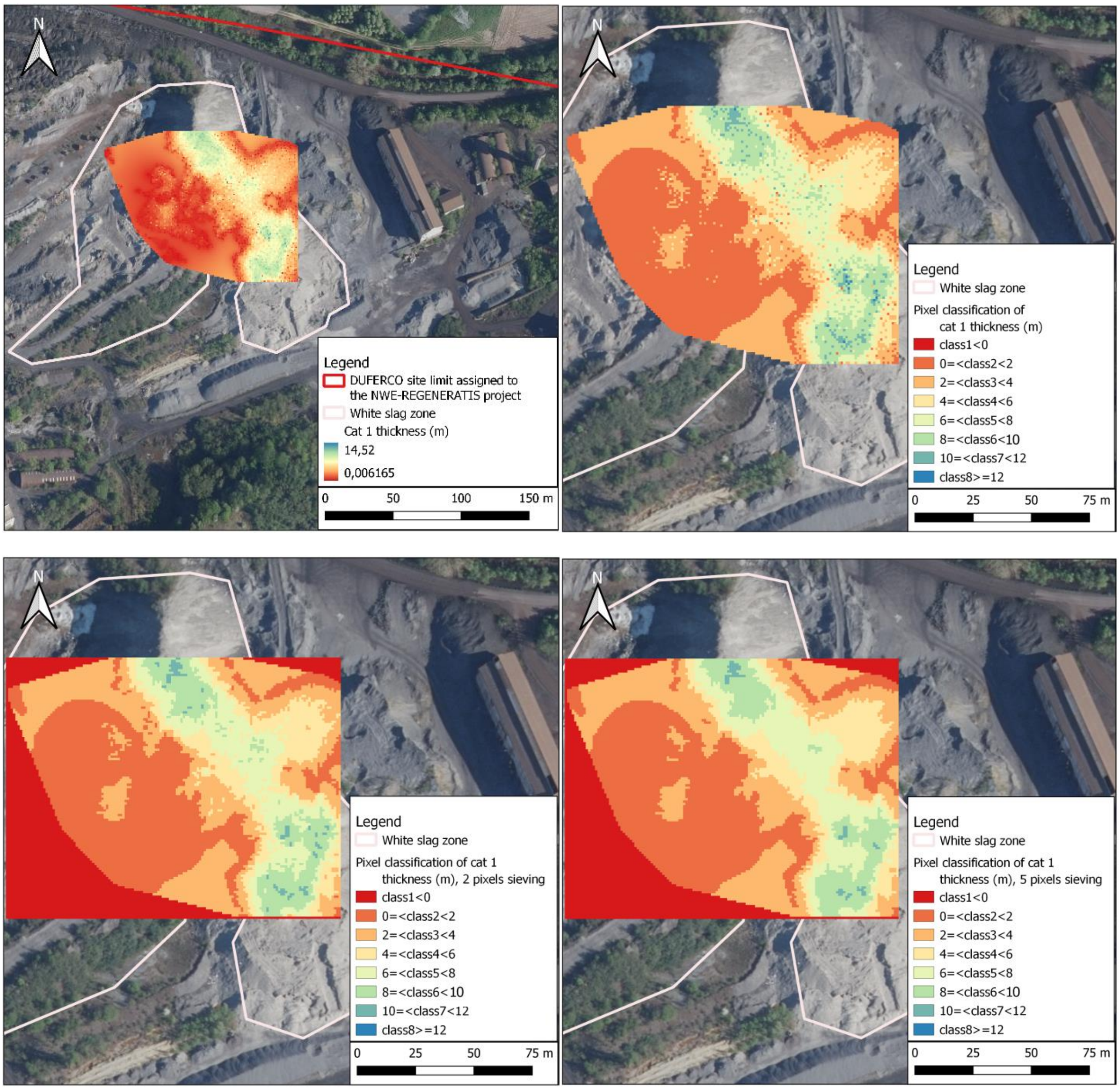

Figure 11 : Cat 1 thickness: geoprocessing steps

Then, from the obtained map sieved to 5 pixels, we can calculate the volume that it represents thanks to the area covered and the depth of the midpoint for each class. The total recoverable volume for cat 1 deposit, estimated by QGIS, is equal to 46707m³.

To obtain the total area to be excavated, a buffer zone must be applied around each category to be excavated, in order to take into account the safe slope to be applied for the excavation to be stable. This area is shown in Figure 12.

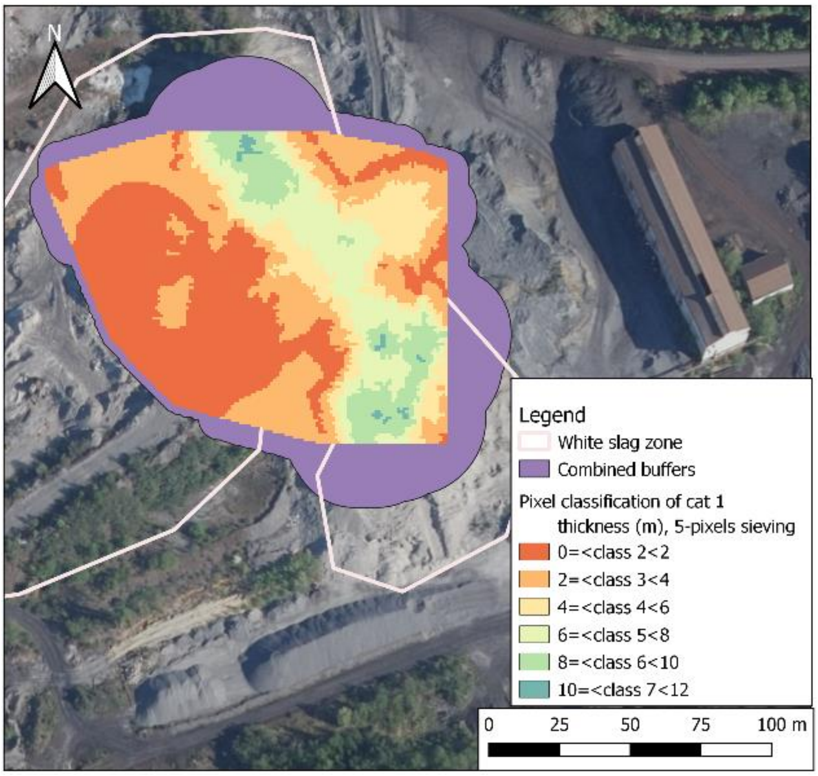

Figure 12: Cat 1 combined buffer zones

3.1.2.3 Cat3 Geoprocessing

As for category 1, it is also found that the use of the surface raster gives negative values during geoprocessing, which means that the ground surface is assumed to be deeper than the top of the deposit. As this is not possible, the DTMs of the surface and the bottom of the deposit were only used to define the thickness of the deposit, and thus the total depth to be excavated, as was done for category 1 above. The geoprocessing is shown on Figure 13, and consists of the same steps as for category 1, except that the selected degree of sieving is 4 pixels. The total recoverable volume for cat 3 deposit, estimated by QGIS, is equal to 12948 m³. The total area to be excavated is shown in Figure 14 and includes the buffer zones applied to each category to make the excavated area stable.

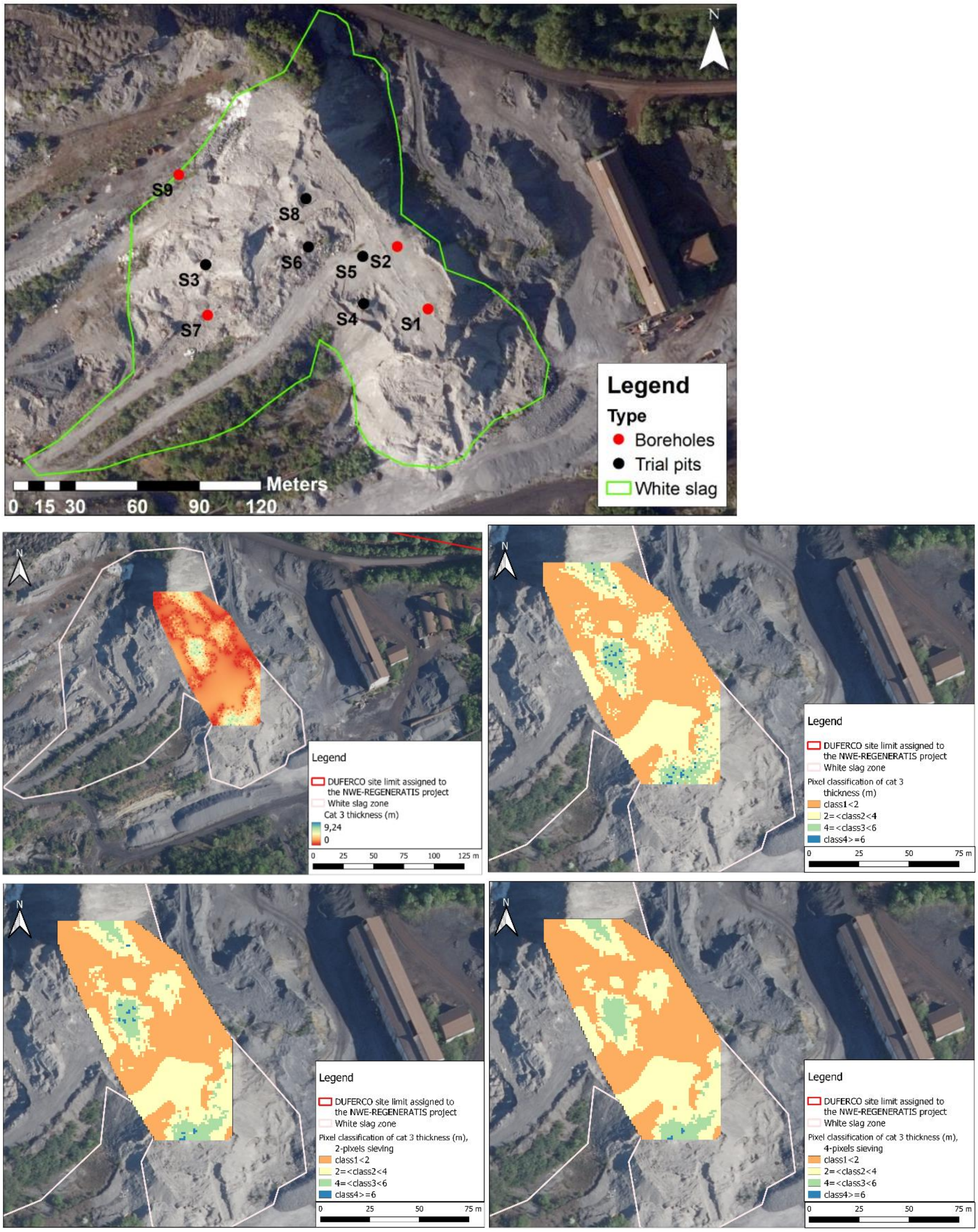

Figure 13 : Cat 3 thickness: geoprocessing steps

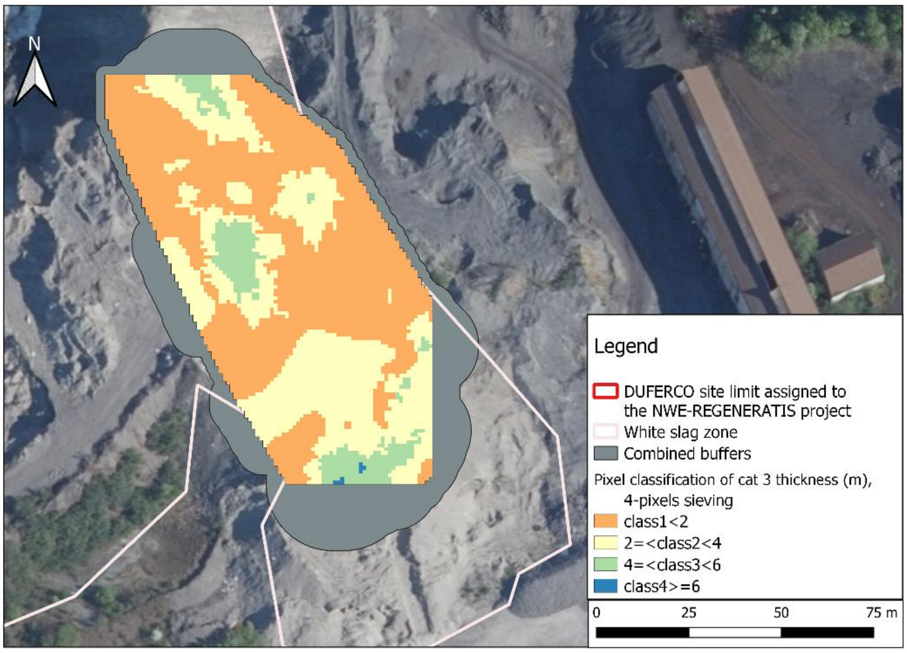

Figure 14: Cat 3 combined buffer zones

3.2 Theorical interpretation and recommendations for excavation

It is only possible to determine the most appropriate excavation technique (type of equipment, planning management) by knowing certain site and deposit specific parameters, that include:

- Characteristics of the materials to be excavated
- Workload
- Machine workspace

A description of the parameters and information that were available to us prior to the site work is provided below, together with their impact on the excavation work.

3.2.1 Site and deposit excavation parameters

The slag heap is divided into different parts, as shown on the Figure 15. Those of interest for the NWE-REGNERATIS project are the SC13, called pocket slag and the “Merlon tout-venant” SC7 and SC8, described below. The other areas out of the white slag heap were not concerned by all the analysis previously made and neither by this report.

The map and data were provided by Duferco Wallonia.

Slag name / usual by-product name	White slag /pocket slag	Merlon tout venant
Internal reference (see Figure 15Figure 15)	SC13	SC7, SC8
Volume (m^3)	54 795	43 318

Volumetric mass (t/m^3)	1,8	Undetermined (2,07[2])
Estimated weight (t)	98 631	90 000
Physical composition	Fine and white slag, homogenous on surface of the heap, including centimetric mineral elements of the refractory type	Mostly white slag (80%) containing various wastes (20%) such as cables, steel plates, pallets, big-bags, refractories, etc. (coarse metal wastes being easily recoverable)

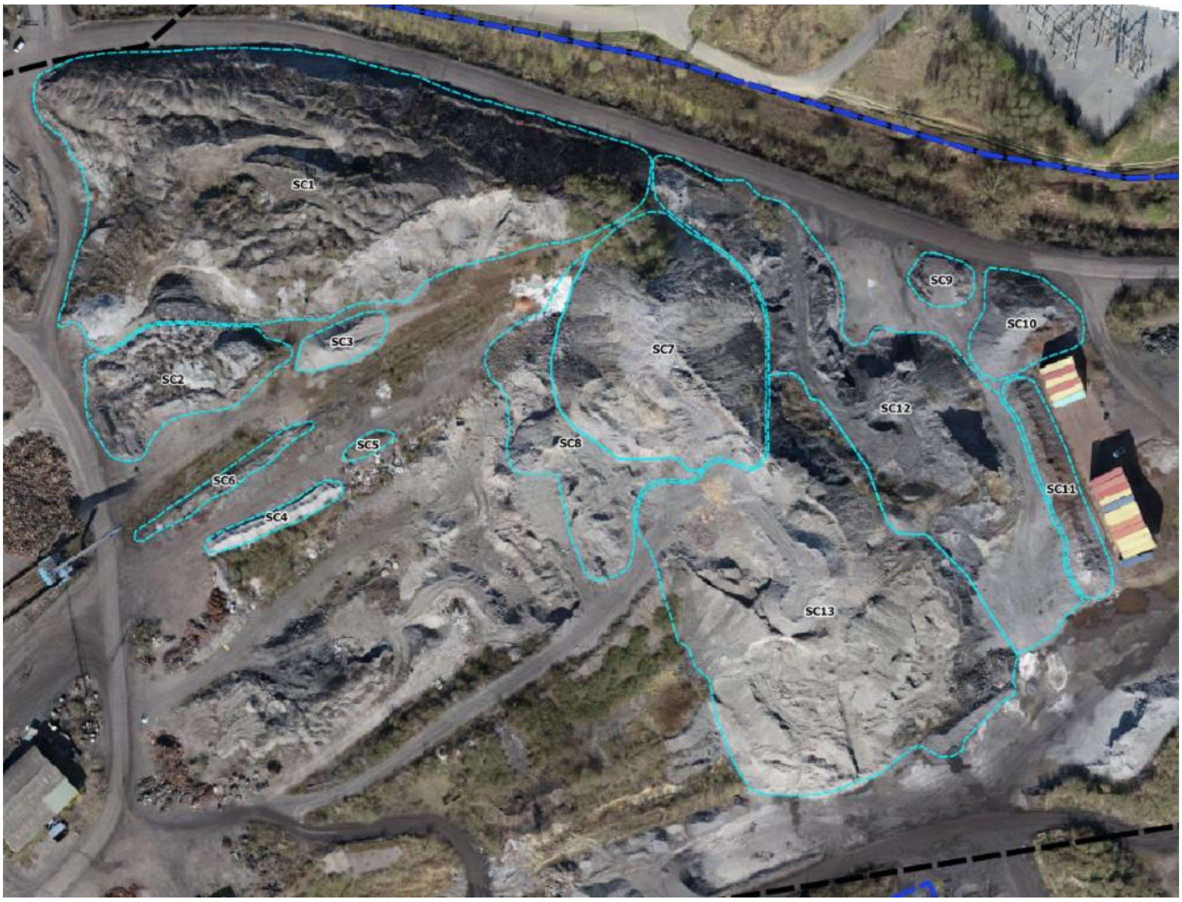

Figure 15 : backfilled heaps of the north-east part of Duferco site

The heterogeneous properties of the slag heap might disturb groundwater flows, and lead to the presence of a perched water table in the backfill that cover the entire site. It might be interesting to take it in account, as it can make earthwork conditions very delicate.

Hardness issues were occurred in the white slag heap. The top layer of the white slag heap revealed to be very hard, probably due to compaction and chemical reactions between highly reactive slag and water. Buried scatterers are also present. However, the

[2] Estimated value obtained by dividing the given mass with the volume

measured/calculated bulk densities of SC13, SC7/SC8 are 1,8 and 2,07 respectively, which is not unusually high for materials of this type.

The site is easily accessible by the truck entry by the east of the site. As it is no longer in operation, there is sufficient space to store the needed machine park. Moreover, the historical report informed that white slag heap summit is flattened and accessible via a ramp to the west. A trench (15x10 m and 7 m deep) has already been dug at the "PC" location, in the Figure 16 below.

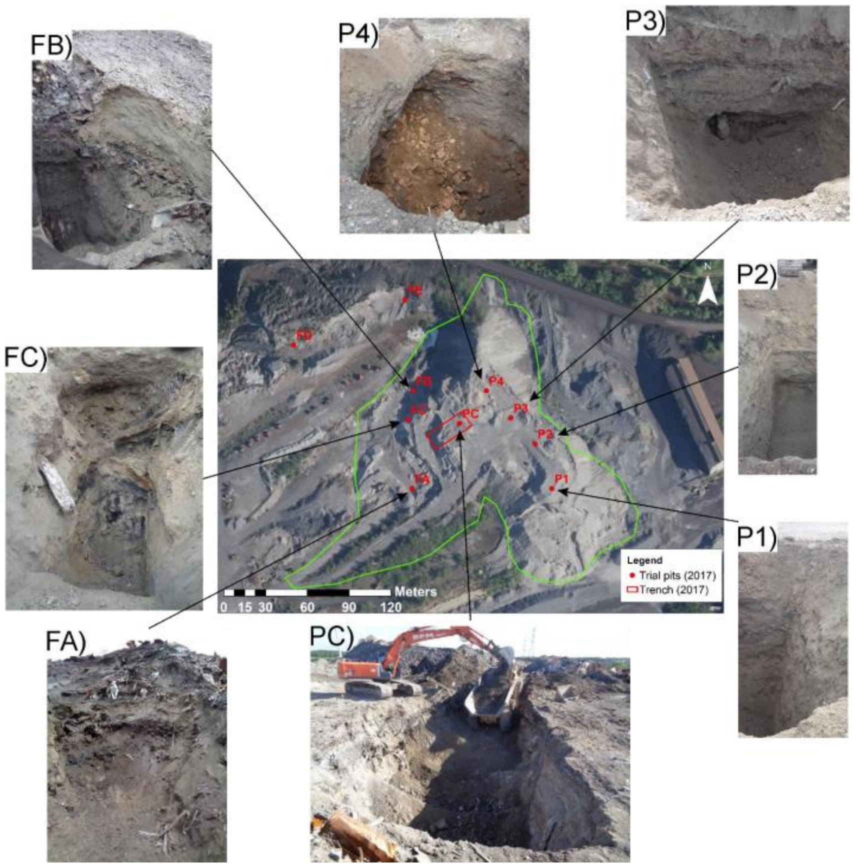

Figure 16 : Map of the trials pits and the trench carried out in 2017, from the report D. I3.2.1 Site specific report on geophysical survey on site

3.2.2 Process and planning

It would be a selective slice excavation, with the areas to be excavated corresponding to the maps constructed in section 3.1. Several material storage zones would be needed, depending on their composition and the necessary pre-treatment required on site (pretreatment would probably mostly be crushing, screening and magnetic/eddy current separation). The number of stockpiles will correspond to the number of fractions selected for recovery plus stockpiles for non-recoverable material. The constitution of the material flows and stockpiles therefore depends on both the quantity to be excavated and the pre-treatment flow sheet. These stockpiles should be located as close as possible to truck access so that their loading does not interfere with excavation on the site. An example of site management is presented on the Figure 17.

The characteristics of the site and deposit do not pose major problems for the use of conventional excavation machines (excavators, dump trucks, dumpers, bulldozers, etc). However, as previously mentioned, a hard layer of indurated slag could be present on the surface while digging and therefore require the use of special equipment, such as a jackhammer. Attention will also be paid to the risk of reaching a perched layer in the backfill.

The machine park might consist of two to three tracked shovels (25 – 30T of capacity) and dump trucks. The first shovel could be used to work on the white slag heap and to fill the first dump truck, while the second one is discharging. The second shovel is used to feed the in-situ treatment facilities, directly or with an intermediate truck, its size depending on the capacity of the treatment facilities. Still depending on the characteristic of the facilities, a third dump truck receive the final product and lead it to the secondary storage area. The third shovel fill in the trucks where the content is finally exported or put back in the site. For the access of the white slag heap, access ramps for machinery must be provided, with a maximum slope of 4/10.

Figure 17 : General overview of an example for the site organization

4 EXCAVATION AND PILOT TEST CARRIED OUT ON THE DUFERCO SITE

This part of the report was provided by the contractor who carried out the on-site earthworks, Wanty.

4.1 INTRODUCTION

The areas of slag that were excavated are the areas around points S1, S2, S4 and S5 on the one hand and between S3 and S9 on the other hand (Figure 18).

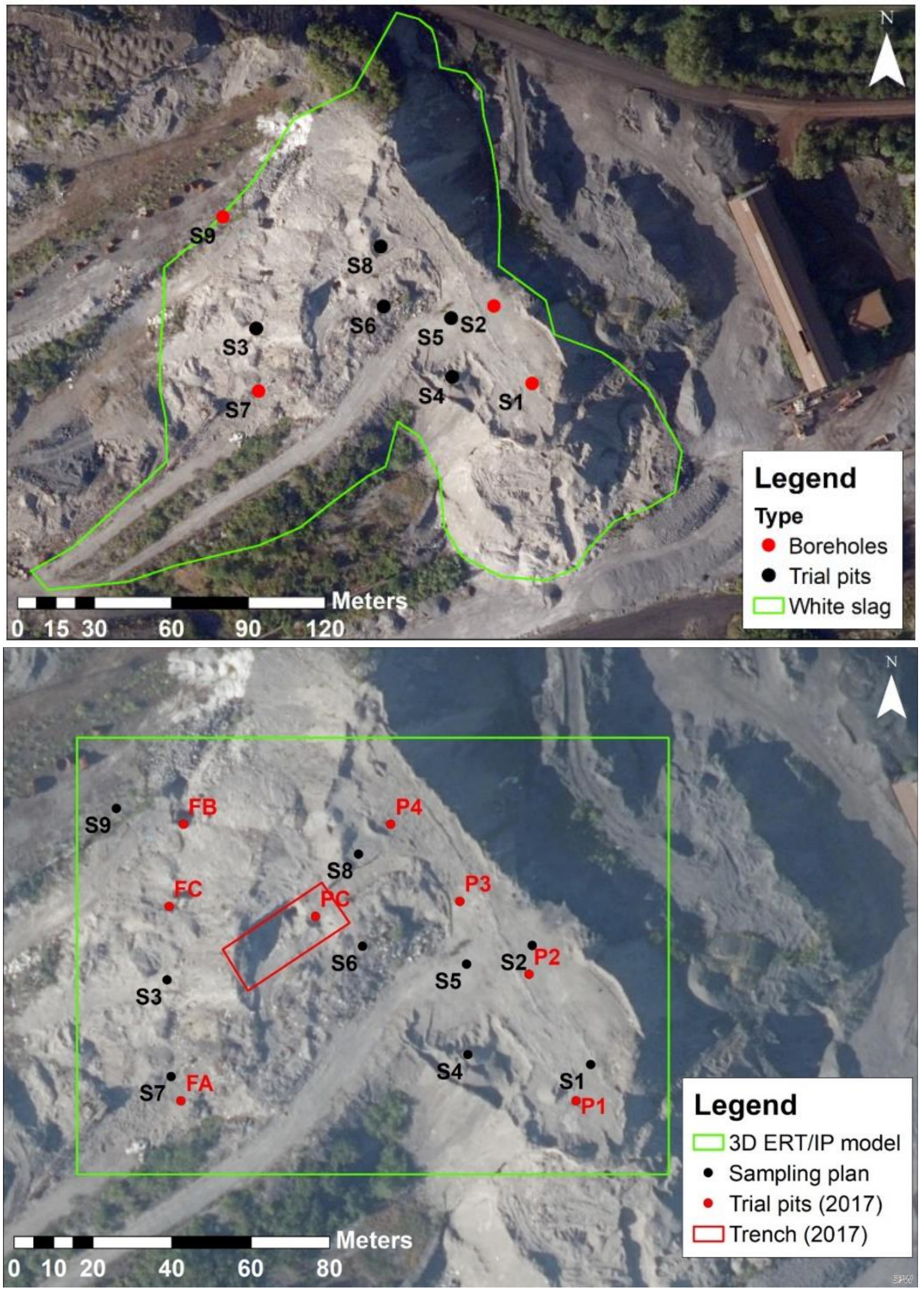

Figure 18: Excavation zone for pilot test, maps provided by DUFERCO.

The pilot test for the recovery and valorisation of materials from steel slag is divided into two batches:

- Recovery of valuable materials such as aggregates and fines from slag;
- Demonstration that fines can be used for soil stabilisation and as sub-base for aggregates.

The principle of the treatment consists of recovering materials from a batch of approximately 3,000 tonnes of slag on the DUFERCO site in La Louvière in order to reproduce the previously determined protocol (on a laboratory and semi-industrial scale) on an industrial scale, by producing two experimental boards:

- A board made up of aggregates used as a sub-base;
- A board made of soil stabilised in part by slag fines.

These boards will *in fine* serve as a platform for demonstrating the technical feasibility of the process thus developed.

Table 2 : Summary of project/ market objectives

Objective	Expected results
Valorisation of pocket slag fines (white slag)	Valorisation as a stabilising agent for clay/loam soils as a partial replacement for lime
	Valorisation of gravel fractions as a substitute for natural aggregates as backfill/sub-basements for road/infrastructure construction
Refine operational conditions (implementation of test protocol determined in the laboratory)	Via the production of two experimental boards, proposal(s) for improving the industrial process

4.2 Report on Batch 1 - Recovery of materials

Table 3: Masses of slag processed and masses of each of the fractions obtained

Type	Mass (in tonnes)
Raw materials (DUFERCO global stock)	3.263
Unwanted supplementary materials (removed before implementation)	216
Materials subject to the process	**3.047**
Ferrous metals	57,69
0/10 screening 1	1.484,60
10/20 screening 1	342,50
20/32 screening 1	295,40
0/10 freshly ground slag fines	198,50
10/20 unmatured	27,80
20/32 not matured	54,30
10/20 matured	28,30
20/32 matured	54,60
Non-grindable materials	32,80
Mud	34,20
32/56 crushed (max crusher setting)	192,90
Loss on the ground	243
	Quantity (in litres)
Acetic acid solution (at a rate of 50l/tonne)	4.145

Table 4: Technical characteristics of the equipment used

Type	Model
Screening machine	Warrior S1400 (stage 1)
Shovel	30 tonnes
Bull	Hitachi 10108
Screening machine	Mc Closkey S130 screen (stage 5)
Trommel	
Hopper	
Manitou	
Other	- Generator set - Magnet separator

4.2.1 Description of the operations carried out

4.2.1.1 Flow-sheet

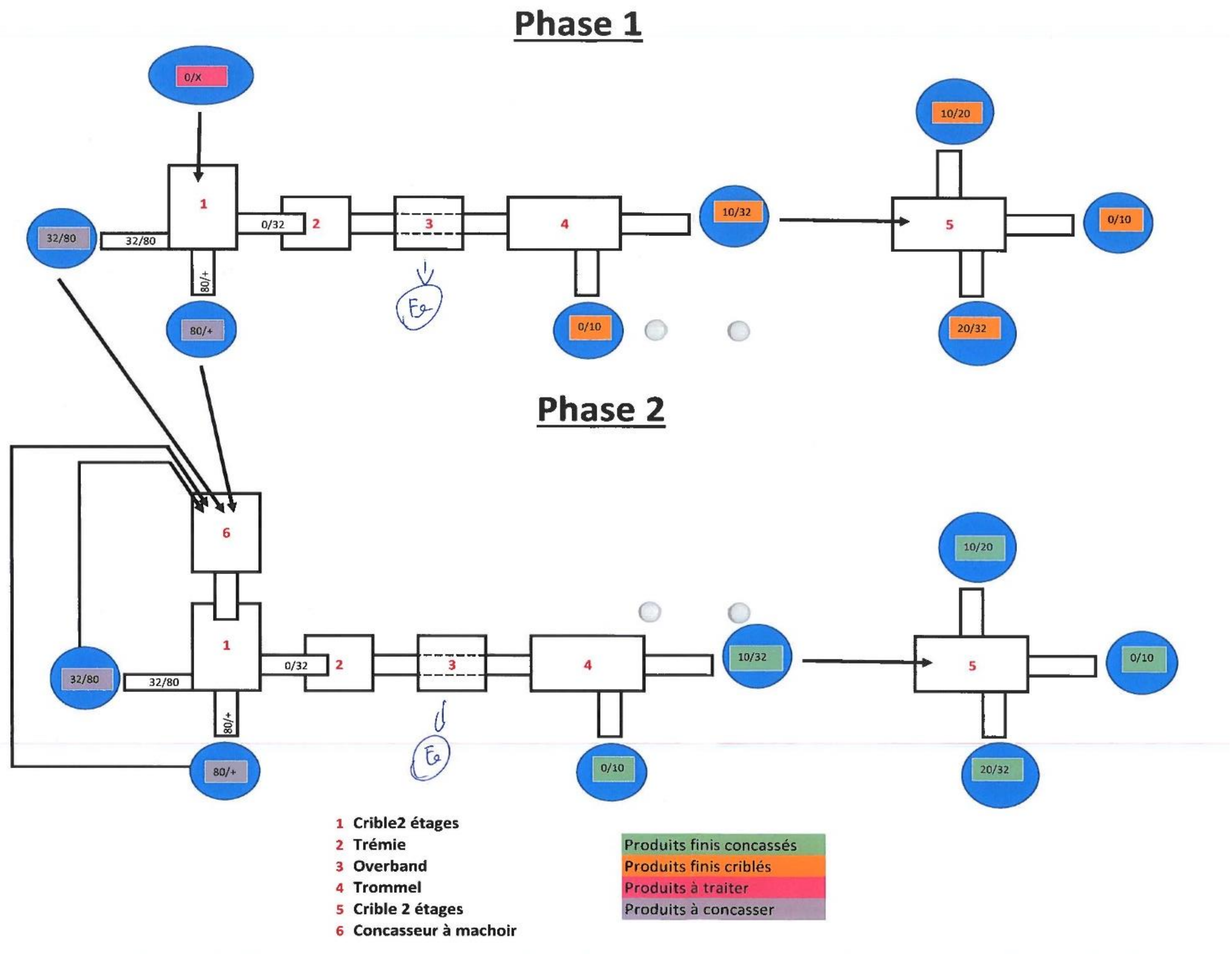

Figure 19: Treatment process flow-sheet

The treatment process for batch 1 consists of the preparation of the different fractions (fines, matured and unmatured aggregates) using *mineral* processing techniques (crushing, screening, magnetic separation).

After a first passage of the raw material (0/X) through a 2-deck screen (phase 1 - step 1), it is divided into products of grain sizes 0/32 and 32+. These two grain sizes determine the two phases in the flow sheet (*see* Fig. 19).

Phase 1: After the first screening (step 1), the 0/32 grading products must pass through a hopper (step 2) and a magnetic overband (step 3) for deferrization. After this deferrisation, the remaining products pass through a trommel (step 4) for a first separation between the 0/10 and the 10/32. The latter are brought one last time to a second 2-deck screen (step 5) in order to obtain the finished screened products of 0/10, 10/20 and 20/32 calibre.

Phase 2: The 32/+ (32/80 and 80/+) graded products, after the first screening, must pass through a **jaw crusher** (step 6) prior to the second passage through the 2 deck screen (step 1) in order to obtain 0/32 graded products. The latter will then follow the same steps as the screened products from stage 1. The products resulting from phase 2 are finished crushed products of 0/10, 10/20 and 20/32 calibre.

4.2.1.2 Chronological description of the operations

- ➔ Start-up: equipment brought in on 17 March / site secured and prepared for start-up on the following Monday;
- ➔ Week of 20-24 March :
  - o 20: installation of the machines of the product processing line;
  - o 21 and 22: start-up of phase 1 - stage 1 (first screening) but breakdown of the system set up for stages 2-3 (deferrisation of 0/32) and therefore solution to be found,
  - o 23: screening operation without deferrisation in order not to lose time (direct access to stage 6 of phase 2 for the 32/+),
  - o 24: installation of the crane with magnet for deferrisation of the 32/+ products (only - system implemented: spreading the 32/+ on the ground and passing a magnet over it via crane to remove the bulky metal elements→ step not included in the flow-sheet);
- ➔ Week of 27-31 March :
  - o 27: continuation of the deferrisation operation of the 32/+,
  - o 28: end of the deferrisation operation of the 32/+ and installation of the crusher,
  - o on 29th : crushing (crushing 32/+, after deferrisation - step 4 of phase 2) + separation of a crushed 0/10 heap (10 tonnes) with tarpaulin covering + sprinkling of the selected heaps with the acid solution for maturation;
  - o 30: crushing (end of crushing operation - stage 5 of phase 2) and further application of the acid curing solution;
  - o 31: start of screening of 0/32 (passage through the crusher - stage 6 - which is equipped with a magnet for deferrisation in order to resume phase 1)
- ➔ Week of 03 to 07 April :
  - o 03-04-05 April: 0/32 screening (end of the deferrisation operation via the crusher on 04/04; the balance of the 0/32 material was passed through the screening line on 05/04);
  - o 06/04: end of the work site (recovery of equipment) - The various piles (sorted with indicative signs) are left on site in order to respect the minimum 2-month period before the implementation of the two experimental plots.

4.2.1.3 Summary of operations and stages

Phase / stage number	Operations carried out	Remarks
1-2/ 0	Setting up - Preparing and securing the site - Installing the equipment of the treatment line	
1/1	Sorted heap passed through a WARRIOR screen (grain size 0/X), which screens into 0/32 and 32/+.	
1/2-3-4	The 0/32 had to pass through a small hopper (step 2 - *see fig. 22*) and onto an overband to remove the iron (n°3) before passing through a trommel (n°4) to bring out a screened 0/10 and a screened 10/32.	In the screening phase, problem encountered during the deferrisation of the product: unsuitable equipment (both for the hopper, which is too small, and for the conveyor, which is not adapted to the magnet) - (*see point e*)→ move on to phase 2 pending solution
2/6	The 32/+ are passed through a jaw crusher (step 6), after having been deferrized (spreading the material on the ground via a bull and passing a crane equipped with a magnet over it to remove the bulky metal elements)	The pile of 32/+ had a lot of iron and ferrous elements→ decision taken to pass the whole pile to the magnet with a crane→ operation carried out via a bull to spread the material on the ground (bin by bin) and pass the magnet over it in order to recover everything before shredding. This operation took about 4 days in addition to the initial deadlines
2/1	The products of phase 2 are passed through a screen (32/+ grain size), which screens again into 0/32 and 32/+.	As deferrisation has been done beforehand, there are no steps 2-3 for phase 2. Subsequently, the 32/+ mixture was reintroduced a second time to be sure of the crushing: there was still a residue (not of 80/+ but of

		32/56 because the jaw crusher cannot crush below 32 mm; for a solution of crushing the 32/56 into 0/32, an impact crusher must be provided (*cf. Observations*)
2/4-5	Recovery of the screening line after crushing (trommel - n°4) to have a crushed 0/10 - in this heap, recovery of 10 tonnes for tarpaulin covering (requested by the specifications) and balance on another heap. The 10/32 screened material is then passed through a McCLoskey screen (2 deck screen - no. 5) which then produces 10/20 screened, 0/10 screened and 20/32 screened.	
1/2-3	Resumption of phase 1 - solution to put the 0/32 in the crusher (n°6) as it is equipped with a magnet	
1/4-5	Final screening of 0/32 into 0/10, 10/32 and 20/32	
-	After all the previous steps (crushing/screening), separation into 2 heaps of 10/20 and 2 heaps of 20/32 - One heap of each particle size was sprayed with acetic acid in a solution of the order of 50L/tonne of the solution prepared beforehand→ allows two "mature" calibration heaps to be made Each pile is listed with a signpost	

4.2.1.4 Photos

Figure 20: Starting stockpile (arrow indicating the part of slag with too many exogenous elements removed directly)

Figure 21: Slag with too many exogenous elements removed directly

Figure 22: Equipment used (above: deferrisation pre-treatment)

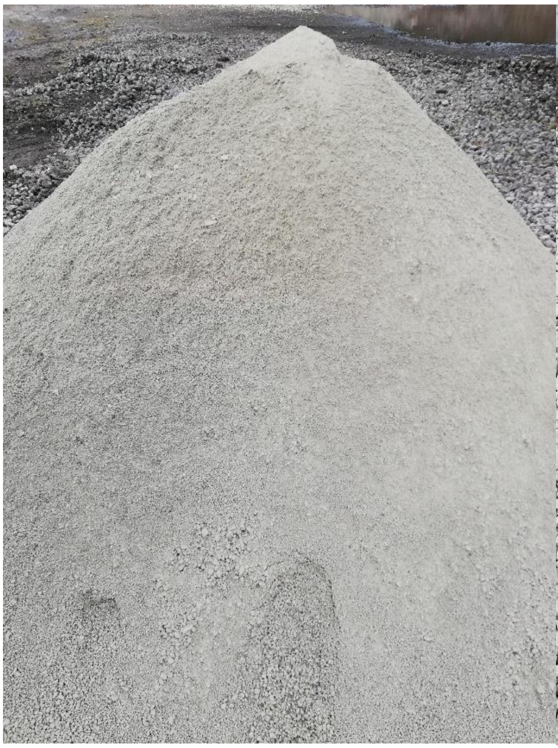

Figure 23: Screened 0-10 pile

Figure 24: 10-32 fraction screened before separation

Figure 25: Crushed 0-10 put under a tarpaulin

Figure 26: Spraying acetic acid solution

Figure 27: Screening 0-10 (right), 10-20 (foreground) and 20-32 (background)

4.2.2 Difficulties encountered

Difficulty encountered	Solution envisaged
Problem encountered during product deferrisation (stage 2): unsuitable equipment (between hopper + conveyor in relation to the magnet)	Pass the screened 0/32 into the crusher equipped with a magnet to overcome the deferrization + spread the 32/+ via bull before passing the crane overhead with a magnet to deferrize (remove the larger metal elements)

4.2.3 Comments

- There is still a lot of fines; the CTP stopped at the crushing fines but not at the screening fines (advice to Duferco to do an analysis on the screening fines to see the lime content and thus determine a potential recovery of this part);
- In order to compensate for the relatively high ground loss, a fixed installation should be provided in the immediate vicinity of the batch to be recovered (or bring the raw batch to be recovered close to the fixed installation);
- The deferrisation of the heap before crushing is essential and primordial and its implementation must be done either via a machine (in this case, provide for suitable equipment as the screens are rarely equipped with a magnet (equipment not owned by Wanty, moreover, the solution found by SATEA did not work, so

revision via crusher and magnet of the crusher) - or via a fixed installation→ *proposal*: envisage a deferrisation installation to be integrated into the overall line in the case of a fixed installation);

- The 200 tons set aside with the exogenous products could be passed to the screening: it is then necessary to envisage the implementation of a preliminary sorting table before any passage in the primary screen (*proposal*: to integrate a magnet at the end of the sorting table?); if an imposing element could cause concern in the process of deferrisation, it is necessary to envisage another crane with a magnet beforehand→ *proposal*: double passage for the deferrisation: a preliminary one for the imposing elements, a finer one at the exit of the sorting table;
- During the test, the slag was processed in 2 phases (screening and crushing) causing a loss of material and time between the two→ *proposal*: plan the line in one go, i.e. at the start of the 1er screen (3 decks for 0/10, 10/20, 20/32, 32/+, obtaining the targeted screened products). The 32+ leave towards a crusher (jaw crusher + magnet), which would first leave 0/80 or even 0/100 maximum; before the materials then go back to another 3-deck screen bringing out the targeted crushed products; the balance of the 32+ from this second screening would then go back to recirculation in a percussion crusher with magnet in order to obtain a maximum of the targeted crushed products

➔ If the various tests are validated, a complete treatment process could be proposed.

5 CONCLUSION OF THE ON-SITE EARTHWORKS

The excavation of a batch of 3,000 tonnes of slag on the DUFERCO site in La Louvière was successfully completed. The pretreatment did not encountered any issues, except for the small difficulty encountered during deferrisation, which was due to unsuitable equipment. All tests have provided interesting findings for further recovery.

The recovery options that are being explored are: 1) Recovery of valuable materials such as aggregates and fines from slag, to be use as a road sub-base; 2) Demonstration that fines can be used for soil stabilisation and as sub-base for aggregates. The amount of fines was greater than expected, which could lead to other recovery possibilities than what has been considered since.

Further tests are still needed to confirm the recovery options. If the various tests are validated, a complete treatment process could be proposed.

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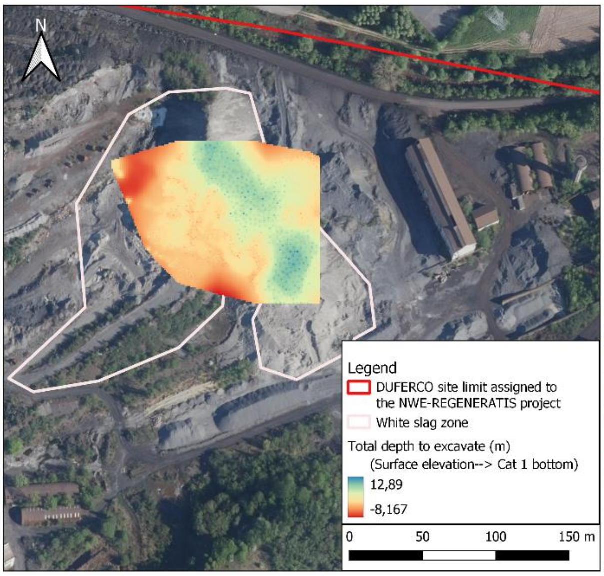
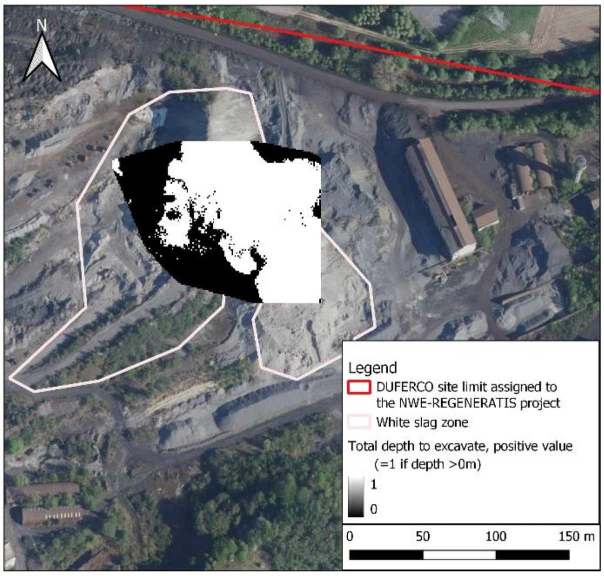
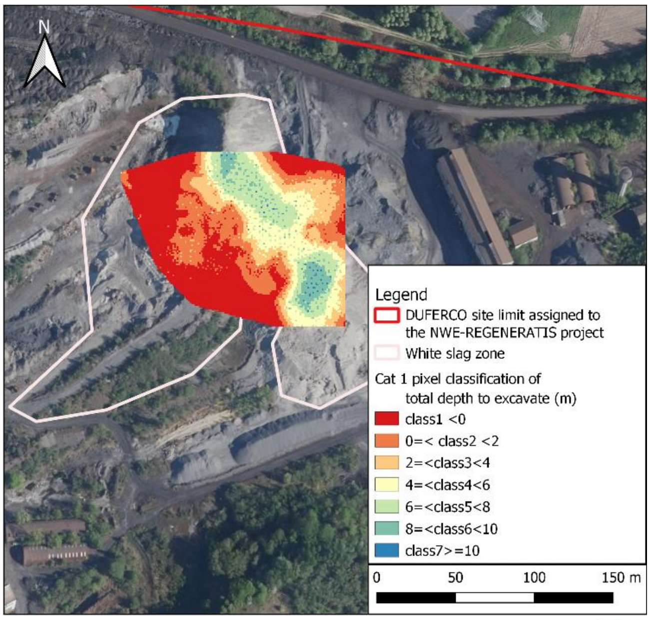
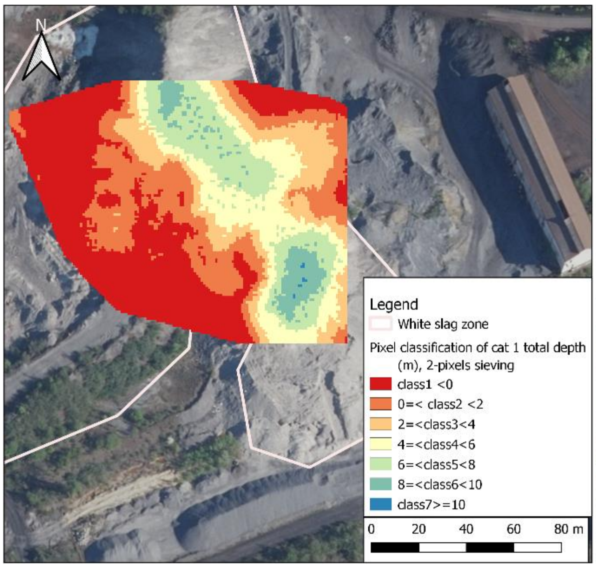
7 APPENDICES

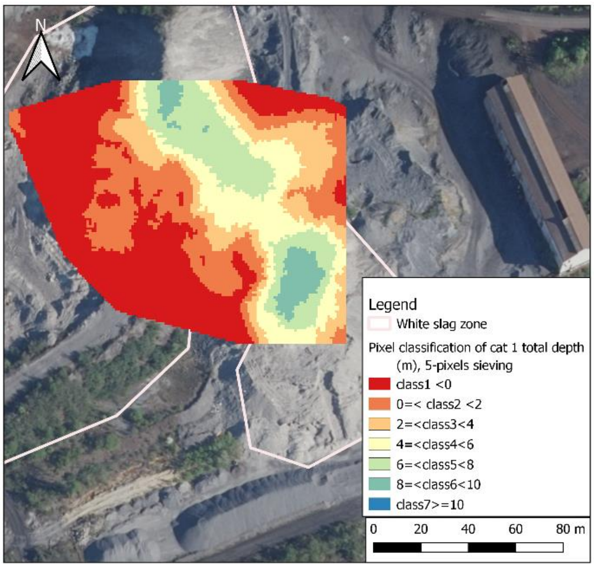
Appendix A: Cat1 total depth to excavate: geoprocessing steps











Appendix B: Layer attribute tables and area and volume calculations for each pixel category in QGIS

cl8_cat1diff_tam5vectorgroup — Total des entités: 7, Filtrées: 7, Sélectionnées: 0

	DN	area	volume
1	-2147483648	3157	3156,767
2	2	4685	4685,066
3	3	3615	10844,876
4	4	1579	7894,396
5	5	1756	12294,827
6	6	1123	10104,033
7	7	80	883,657

cl4tam4_cat3diffv3_vectorgroup — Total des entités: 5, Filtrées: 5, Sélectionnées: 0

123 DN = ε 123

	DN	area	volume
1	-2147483648	9685,513	0
2	1	3515,784	3515,784
3	2	2278,069	6834,208
4	3	507,780	2538,902
5	4	7,934	59,506