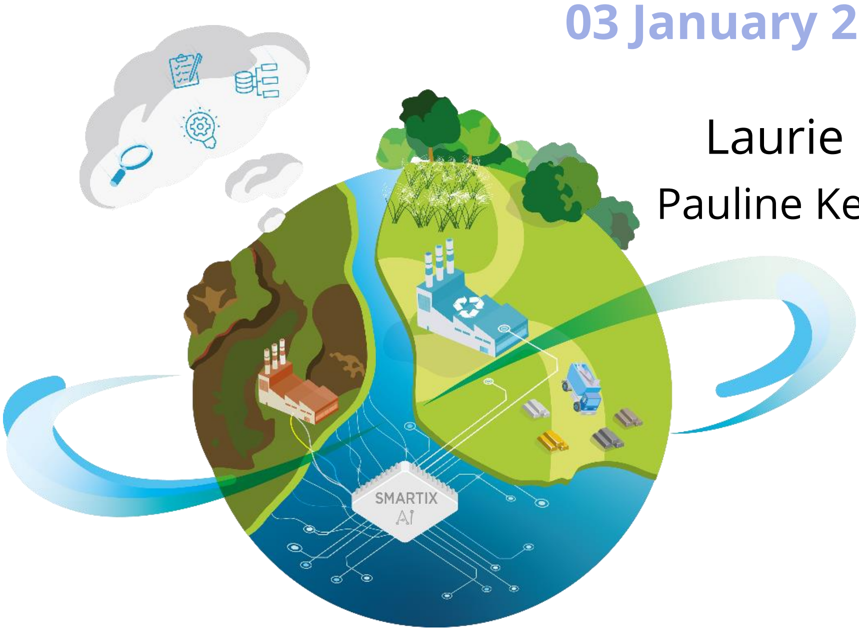
D.I2.3.1 Site specific report on excavation activities and civil engineering methods to be applied on Pompey site

03 January 2023



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ATRASOL

Version 2

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1 INTRODUCTION

The Pompey-Frouard-Custines steel complex, located 10 km from Nancy, was active from 1870 to 1986. The Pompey tailing pond was part of this complex, and was located to the southwest of the island of Ban-la-Dame, at the confluence of the Moselle and the Meurthe rivers. While the rest of the complex has been converted to host a business park in the 90's, the decantation basin has only been rehabilitated on surface and still contains an estimated 10 m depth of metallurgical wastes. According to Mocellin (2015) and Kessouri et al. (2021), taking into account the surface area of the pond (26 000 m²) and the estimated depth of the deposit, there would still be approximately 440 000 metric tonnes of steelmaking sludge, covering a total estimated volume of wastes equal to 260 000 m³ on Pompey site. Its potential as a source of secondary raw materials has led the Pompey site to be part of the three pilot sites of the NWE-REGENERATIS project.

This site specific report is a continuation of the previous historical, geophysical, 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.) during the REGENERATIS project. It aims at evaluating the most relevant excavation and civil engineering method to be potentially 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 the Pompey site. Previous investigations and analyses have revealed that the economic profitability of recovering metals from Pompey's metallurgical wastes is not guaranteed for the moment (Mignon, 2020). Therefore, **it should be noted that the excavation works mentioned in this report are recommendations and are not intended to be performed. They only represent an exercise carried out in the framework of the NWE-REGENERATIS project and could be useful as a demonstrator for other similar case studies. Because of the site scientific and educational interest as a study-case of long-term monitoring and management of former metallurgical sites, it is the object of a particular attention to ensure its long-term conservation.**

Biodiversity and other environmental protection measures to be taken before, during and after the works are not described in this report.

2 DESCRIPTION OF THE POMPEY SITE

2.1 HISTORICAL CONTEXT

2.1.1 The Pompey-Frouard-Custines complex

The activities of the Pompey-Frouard-Custines iron and steel complex began in 1872 and ended in 1986.

From 1872 to 1922, it was supplied with iron ore from Lorraine (commonly known as "minette", because of its relatively low Fe content and high P content). It required the development of specific processes in order to be used (Thomas process). From 1922 to 1986, the Pompey-Frouard-Custines complex started producing ferromanganese, a manganese-rich ferro-alloy, which requires both Fe ores and Mn-rich ores (40% and more). Mn ores were imported from various countries (Russia, India, West Africa, Brazil, South Africa, Australia, Morocco) according to international market trends. The iron crisis has caused a decrease in the use of the less competitive iron from Lorraine. The supply of Lorraine iron stopped in 1973 in favour of foreign ores (Kessouri & Gourry, 2020).

The coke used in the blast furnaces came from the coalfields of the Lorraine basin. The Lorraine iron ore had the advantage of having layers with a gangue that was sometimes more calcareous and sometimes more siliceous. This gangue property was advantageous for the production of slag, which results from the fusion of the ore gangue and requires a basicity index (CaO/SiO_2 ratio) of the ore gangue of 1.4. The mixture of these two types of ores in appropriate proportions makes it possible to generate a "self-melting smelting bed", to which it is not necessary to add a flux in the process. On the other hand, the manufacture of ferromanganese required limestone and magnesium fluxes (limestone, dolomite), or even barium fluxes, in order to neutralise the silica present in the Mn ores and coke ashes and to limit Mn losses in the slag. Thus, limestone was commonly added to the blast furnace during the production of Mn cast iron (Huot, 2013; Kessouri & Gourry, 2020).

After the decline in metallurgical activity, a programme for the development of the site and the retraining of personnel was undertaken. The steelworks were progressively demolished and the site became part of the business park and the multimodal platform, which extend from Custines to Champigneulles and now host nearly 150 companies. In the 1990s, the banks of the Moselle were rectified, the wasteland was filled in to make the land suitable for building and planting was carried out as part of the landscaping plan (Huot, 2013).

2.1.2 The Pompey settling pond history

During the ore reduction process in the blast furnace, part of the metals (Zn, Mn and Pb) may be volatilized. They will condense on the fine dust particles present in the fumes before being evacuated by the furnace. Two purifications of the gas are thus necessary in order to eliminate the dust and to allow an energetic revalorisation of the heat. A first dry purification will eliminate the large and medium-sized particles (>50 µm) by passing through dust pots, supplemented or not by cyclones. Secondary purification with water scrubbers will make it possible to eliminate the finest particles that are very rich in metals, which form metal-rich sludge. Although the sludge obtained could theoretically have been recycled to the blast furnace due to its high concentration of Mn and Fe, the high Zn and Pb contents would be detrimental to the ferromanganese production process. These sludges, generally concentrated between 5 and 40% of Zn, Mn and Pb, were stored in ponds, where they settled to form stratified deposits (Mocellin, 2015).

The site concerned by the REGENERATIS project has been one of these settling ponds and collected the sludge resulting from the wet cleaning of blast furnace gases from the Pompey-Frouard-Custines complex. Over time, the thickness of the deposit resulting from the settling of this metal-rich sludge has been estimated to be 10 m thick. The Pompey settling pond is located to the south-west of the island of Ban-la-Dame, at the confluence of the Moselle and the channelled Meurthe rivers, and extends over 2.6 ha. The exact date of its closure is not known, but based on the evolution of aerial photographs, the use of the pond would probably have ended around the 1950s. Measures taken in 1946 for the purification of blast furnace gases and the decyanidation of process water corroborate this hypothesis. These measures followed the malfunctioning of the settling pond and the subsequent spillage of potassium cyanide into the river, causing the death of thousands of fish. The discharge of large quantities of sludge and polluted water into settling ponds was thus abandoned, and dry gas cleaning was generalised instead of wet cleaning in order to limit the volumes of polluted water and favour their treatment. Piezometers were installed in the late 1980s to monitor groundwater quality upstream and downstream of the slag heap.

2.1.3 The Pompey settling pond, after its closure

2.1.3.1 What future for the site and its surroundings?

After the closure of the metallurgical activities and the acquisition of the entire Pompey-Frouard complex by the EPFL[1] in the 1980s, studies and rehabilitation work were undertaken, allowing to design and optimise the commercial reconversion of the entire site. After the constraints and potentials of the sites were assessed, the commercial conversion started in 1997 with the installation of the DELIPAPIER factory (now SOFIDEL) on the Ban la Dame site, next to the former Pompey settling pond (Fig.1).

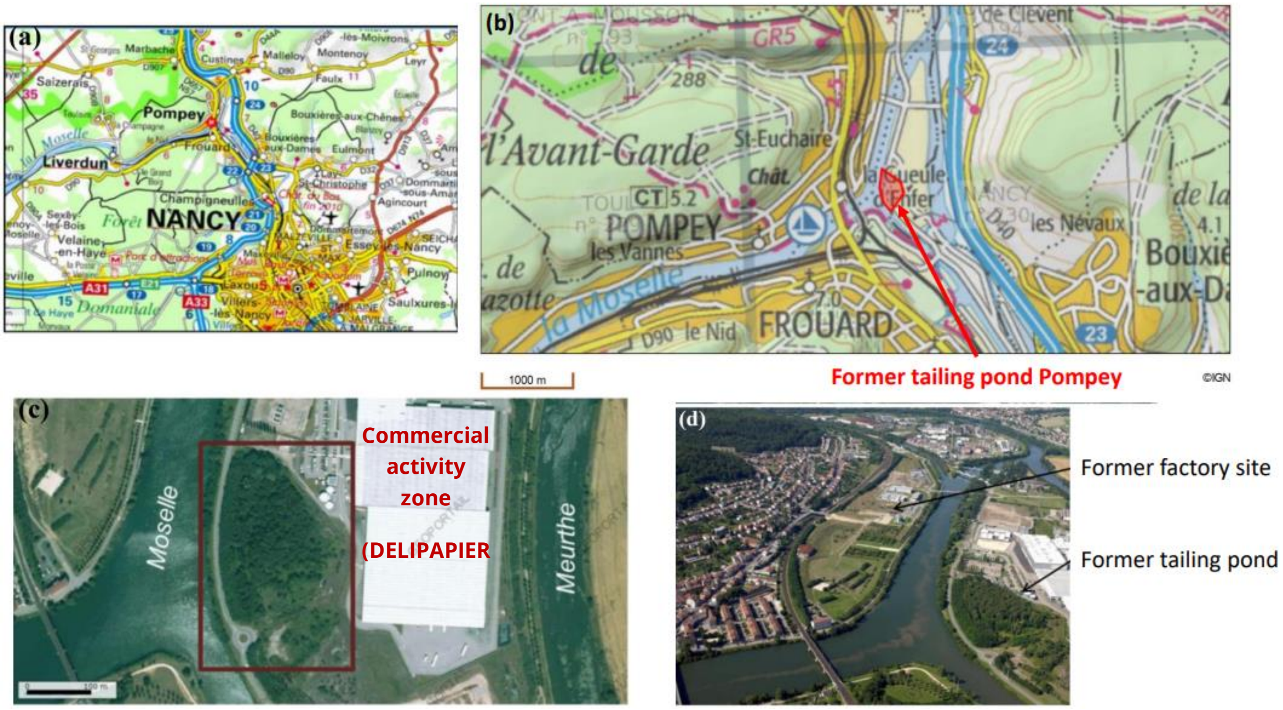


Figure 1. Location of the former Pompey settling pond, (a and b) geographical maps and (c and d) aerial images, from (Kessouri & Gourry, 2020, adapted from Huot, 2013)

The studies carried out on the former Pompey settling pond (geotechnical studies, geochemical studies, other soil studies) and in particular the environmental studies, led its exclusion from the commercial area, given its content in potentially polluting and geotechnically unstable materials. Access to the settling pond has therefore been restricted and does not constitute a walking area. The dike bordering the Pompey settling pond site was planted with a curtain of black locust trees in 1997. A forest ecosystem gradually developed over the rest of the pond,

[1] Etablissement Public Foncier de Lorraine

including a diversified deciduous vegetation, more or less dense depending on the location (SEMACO, 2011). The establishment of such a forest ecosystem on a "Technosoil" composed of iron and steel material has been considered as a real scientific curiosity as it raises the question of its functioning (Huot, 2013). It is still currently being researched and investigated. In view of its heritage, scientific and educational interest as well as for its demonstrative value in terms of long-term monitoring and management of former metallurgical sites, it is the object of a particular attention to ensure its long-term conservation.

2.1.3.2 Findings from previous research and investigations

On Table 1, a summary of the main investigations and research performed on the former Pompey settling pond is available.

Table 1. Investigations and research performed on Pompey site

RESEARCH STUDIES		
Type	**Author, Date** ***Title and/or Description***	**Main relevant conclusions**
Soil characterisation	(Schwartz et al., 2001): *Description and characterisation of a soil profile: pH, texture, CEC, C, N, P, Fe and metal contents.*	Soil profile: layers composed of greyish materials with a schistose structure and blackish pasty materials, from steel-industry by production decomposition; topped by a humus-rich topsoil
Analysis of compounds (zeolite, silica forms)	(Sauer & Burghardt, 2006): *The occurrence and distribution of various forms of silica and zeolites in soils developed from wastes of iron production*	Several soil properties determine whether amorphous silica or zeolites are formed. Amorphous silica is enhanced by decreasing pH and increasing Mg content. $CaCO_3$ increase the development of amorphous silica and inhibit zeolite formation. Zeolite is positively influenced by Na and K concentration, as well as longer period of water saturation in the soil.
Evaluation of the technical and economic feasibility of the valorisation of products from the leaching of steelmaking sludge.	(Mocellin, 2015) *Secondary metal resources, hydrometallurgical upgrading of steelmaking residues for zinc value, manganese and lead*	This thesis made it possible to develop a leaching process for depolluting sludge with a high concentration of Zn, Mn and Pb from the Pompey site, producing a pure $MnCO_3$ concentrate and a residue of Pb concentrate that can be reused by pyrometallurgical means. Although part of the site decontamination costs can be compensated by the recovery of Mn, the techno-economic study showed that there was a loss of Can$186.96/t of treated sludge, this loss being

		greater than the costs of in-situ containment of the site (estimated at Can$30-163/t).
Phytoextraction, soil-plant transfer, biodiversity	(Huot, 2013) *Formation, operation and evolution of a "Technosoil" on steel sludge*	The development of biological activity on this "technosoil" is enabled by the ability of the materials to provide nutrients and water, and is also linked to the low availability of potentially toxic compounds (metallic elements) to plants. This low availability is due to the specific characteristics of the sludge (nature of the bearing phases, alkaline pH, high CEC, high specific surface and high water retention capacity) and also due to the environmental conditions that are not very favourable to the solubilisation and transport of metals.
INVESTIGATIONS		
Type	**Date, Author,** ***Title and/or Description***	**Main conclusions**
Soil studies (geotechnical, characterisation, investigation)		
Soil and foundation surveys	(FONDASOL, 1993) *Soil and slope stability study for the widening of the access road to the Pompey-Frouard-Custinnes center*	The test pits reveal backfill consisting of more or less silty schlamm, sands and gravels with various debris, followed by sandy silts, sands and gravels and mediolithic sandstones. Mechanical properties are poor in the underlying schlamm and silt backfills, good in the natural sandy-gravel backfills, sands and gravels, and excellent in the sandstone bedrock.
Additional studies and investigations of the settling pond for the landscaping plan	(ANTEA, 2001a, 2001b, 2002a, 2002b, 2003, 2004; SEMACO, 2011) (ANTEA, 2001b, 2001a, 2002b) *Feasibility study for the installation of an impermeable cover (clearing; cover either in natural material (clay), or in HDPE or VFPE*	(ANTEA, 2001b, 2001a) : The soils are delicate to excavate and sensitive to water, which will require the use of suitable earthmoving equipment and will probably cause delays in case of unfavourable weather. The upstream-downstream piezometers show a significative change in the composition of the water in terms of K, NH_4, NO_3, Mn and free and total cyanides, as it passes through the settling pond. The levels have also changed in the Moselle compared to the 1984 data. The technical and financial comparison of the

	membrane, or in bentonite geocomposite (ANTEA, 2002a, 2003) *Risk assessment* (SEMACO, 2011) *Servitude*	different containment options shows that the bentonic geocomposite cover solution with a central dome (allowing meteoric water to be evacuated to a peripheral ditch) is the most suitable to implement. (ANTEA, 2002b): The 36 excavations carried out with a mechanical shovel made it possible to delimit, to within 10 m, the southern limit of the former settling basin (ANTEA, 2002a, 2003): Hydrogeological context of the site: Due to the high dilution effect and the non-use of the water in the pond, the impact of the presence of the pond on the Meurthe has been considered negligible. Potential pollution risk: chemical analyses show that the sludge from the settling pond represents a potential pollution risk for heavy metals (barium, chromium, lead and locally antimony, cadmium, copper, mercury, zinc) and cyanides. Despite the stabilising role of the plants, 10 to 20% of the surface area of the pond may present a risk through ingestion, direct contact or inhalation. The simplified and then detailed risk assessments showed that the risk to human health (walk scenario) and the environment was acceptable, given the hypothesis and the recommended use of the site. (SEMACO, 2011)*:* The scope of the servitude and their uses is restricted and cannot be changed without a compatibility study with the soil conditions.
NWE-REGENERATIS : Geophysical studies	(Kessouri & Gourry, 2020) *DI.2.1.1. Site specific report summarizing available historical data on Pompey site* (Kessouri, Ryckebusch, Ardito, et al., 2021; Kessouri, Ryckebusch, Caterina, et al., 2021) *DI2.2.1 and DI2.2.2. Site specific report on geophysical survey and sampling*	(Kessouri & Gourry, 2020) Report providing historical data on the type of ore, the processes used, geographical information and other relevant historical information of the site (Kessouri, Ryckebusch, Ardito, et al., 2021; Kessouri, Ryckebusch, Caterina, et al., 2021) Reports describing the geophysical results and the link with sampling data. The aim being 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.

NWE-REGENERATIS : Mineral processing lab-scale tests	(Mignon, 2020) *DT2.1.1. Report on Mineral Processing lab-scale tests on samples from Pompey site (2020)*	The sieving of the samples did not seem to have impacted its chemical composition, except for iron, which concentrated in particle size fraction <600 microns. The magnetic fraction was composed of 28-30% iron, with various other non-ferrous metals. Manganese was mainly found in the non-magnetic and low-magnetic fraction, but its grade remained too low (1-12%w/w) compared to that observed in a common ore (~40%)

In addition to the research activities already mentioned in Table 1, the GISFI report (2014) mentions other scientific publications, master's thesis, technical and internship reports on phytoextraction experiments, biodiversity characterisation, rate of litter decomposition,... From these different studies, it has been shown that:

- The Pompey site shows a high diversity of plant species, 50 species have been recorded. Among them, only 5 show sublethal concentrations of metals but no signs of toxicity. Despite the high metal content, the biological activity is similar to a forest soil. If we look at organo-mineral associations, we can see that metals (Zn, Cu, Pb) are integrated into the aggregates and enter the biogeochemical cycles induced by the organisms.
- The phytoextraction trials using the plant *Thlaspi caerulescens* have not been very successful.
- The litter of the Pompey site has a faster decomposition rate than the control sites. The leaves seem to stand out for their high metal and K and Mg content. They also tend to have less lignin and polyphenols.

3 EXCAVATION AND CIVIL ENGINEERING METHODS TO BE APPLIED ON SITE

3.1 EXCAVATION PLAN AND PLANNING

3.1.1 Material and methods

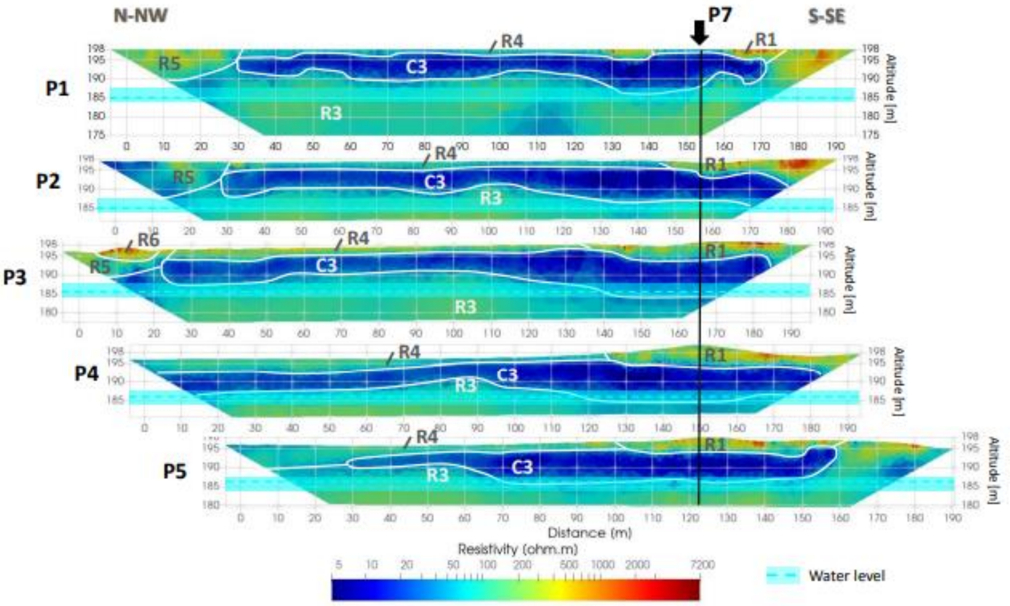
The excavation maps are mainly based on GIS processing of the maps obtained after geophysical investigations "DI2.2.1. Site specific report on geophysical survey on Pompey site" and "DI2.2.2. Site specific report on traditional sampling investigations on Pompey site (FR)" (Kessouri, Ryckebusch, Ardito, et al., 2021; Kessouri, Ryckebusch, Caterina, et al., 2021).

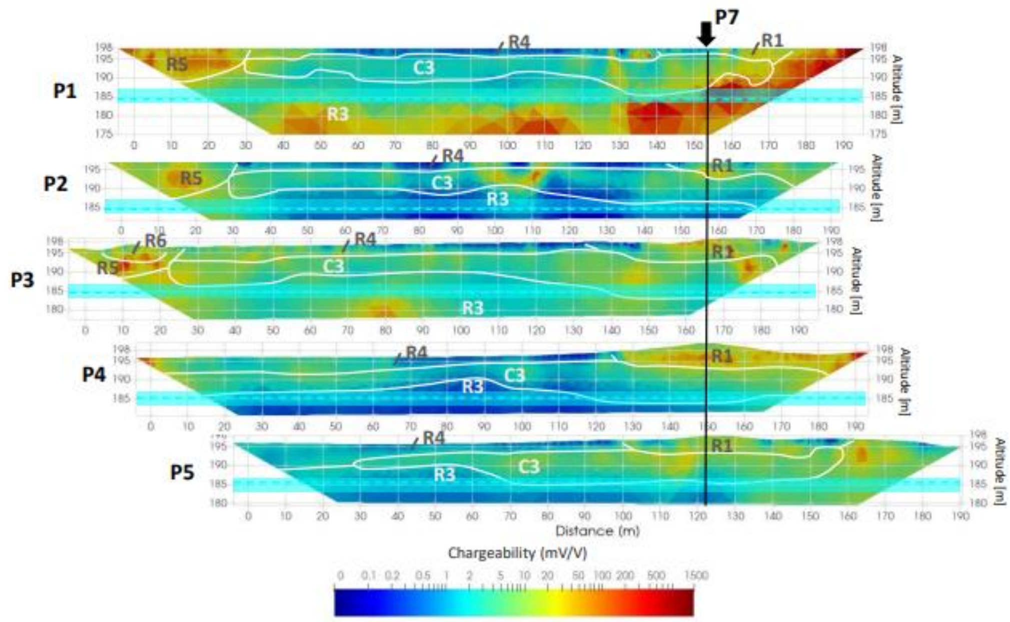
As a reminder from report DI2.2.1., data processing of resistivity and chargeability obtained from the ERT profiles (Fig. 2) allows to obtain the metal factor (MF), which is expressed as the ratio between chargeability M and resistivity ρ:

$$MF = 2000.\frac{M}{\rho}$$

Where MF is expressed in 1/(Ohm.m), M in mV/V and ρ in Ohm.m.

The Metal factor is particularly important regarding the geophysical detection of metallic elements, and therefore for the REGENERATIS project, as the lower the electrical resistivity and the higher the chargeability, the higher the probability of containing metallic elements is (Kessouri, Ryckebusch, Caterina, et al., 2021).





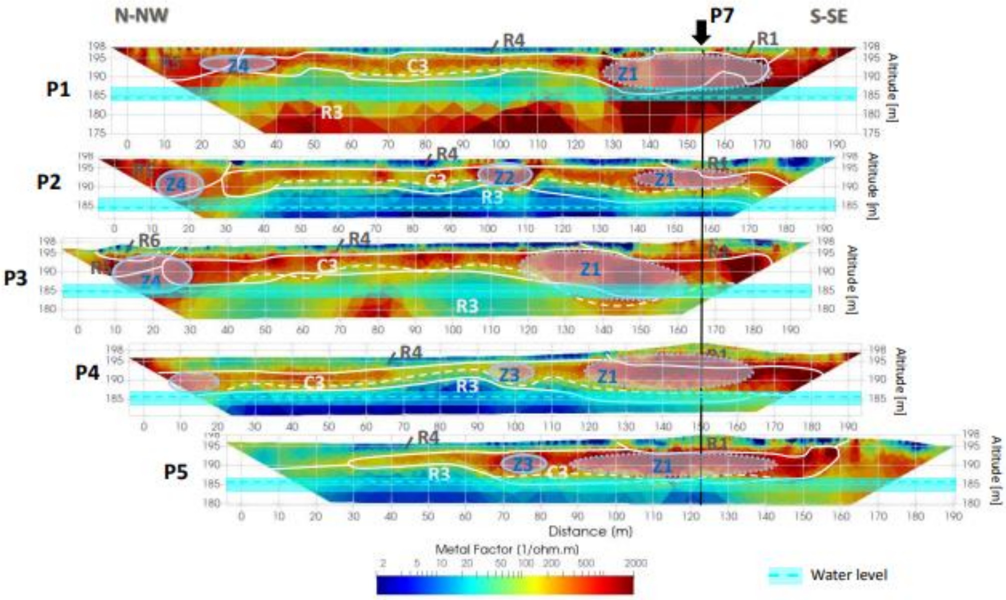


Figure 2. From top to bottom, TDIP profiles of electrical resistivity tomography, chargeability tomography and metal factor tomography, from (Kessouri, Ryckebusch, Caterina, et al., 2021)

The combination of TDIP profiles with electromagnetic methods (Fig. 3.) provides a 3D overview of the volume of the settling pond. Areas with high material recovery potential (high metal factor) are designated by z1, z2, z3 and z4 in Figure 2. These areas are extrapolated in 3D in the same way as the rest of the profiles. z2 and z3 being quite close to z1, it will be seen later that they will constitute a single zone referred to as “z1 and z2 zone" (cf. section 3.1.2.2.).

a)

b)

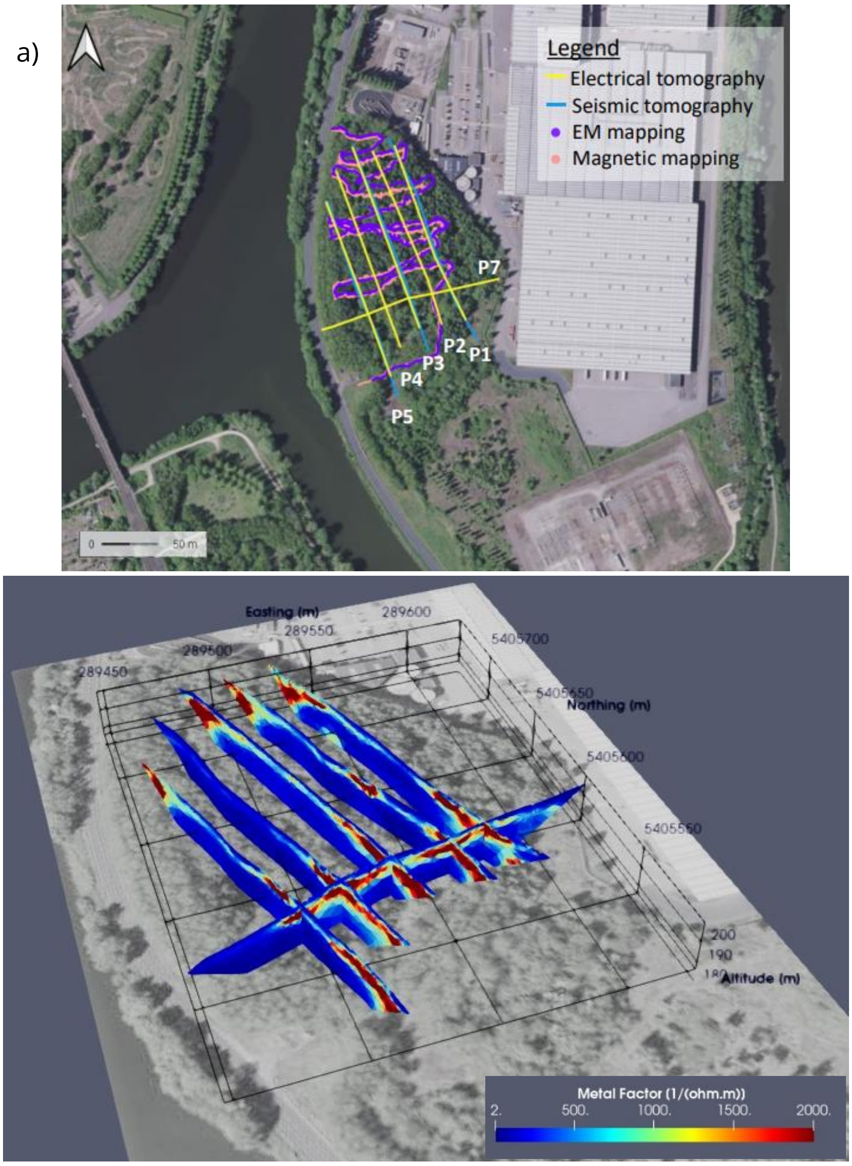


Figure 3. a) Location of the different geophysical profiling and measurement, b) 3D visualisation of the profiles.

From the resulting 3D volume, 2D maps can be extracted at each selected altitude using interpolation techniques between TDIP profiles. As the basin depth appears to be at an altitude of 190m (NGF) from the geophysical profiles (Fig. 2), 2D maps illustrating the metal factors were extracted at an altitude of 190m, 194m and 197m (Fig. 5). These maps were used to establish the areas to be excavated, as shown in Figure 4:

- The 2D geophysical map at elevation 190m is used to establish the excavation zones from elevation 190m to 192m
- The 2D geophysical map at elevation 194m is used to establish the excavation zones from elevation 192m to 196m
- The 2D geophysical map at elevation 197m is used to establish the excavation zones from elevation 196m to 198m

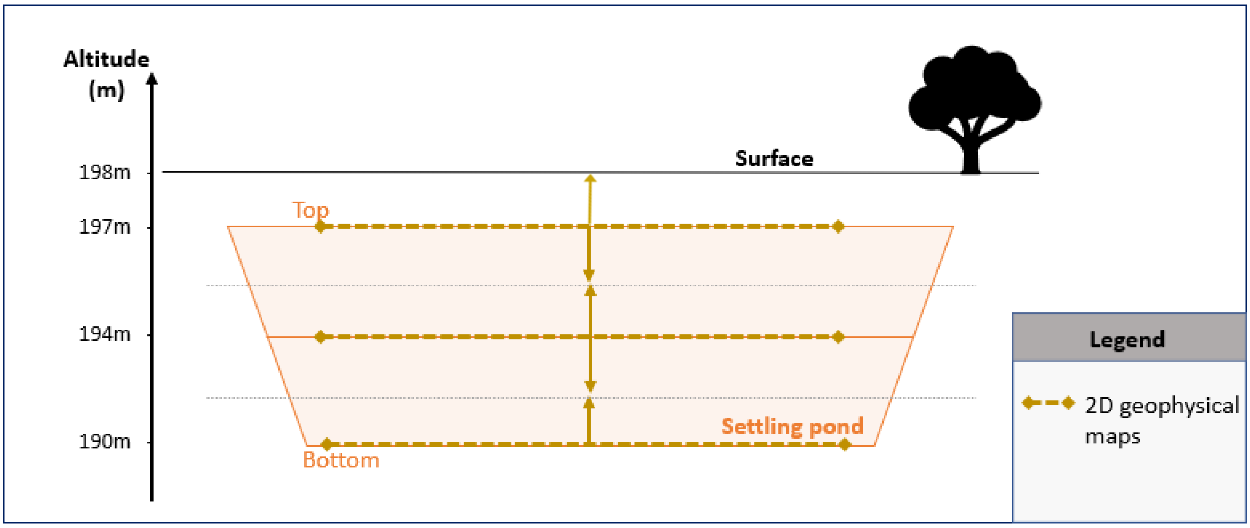


Figure 4. Schematic representation of the implantation of excavation plans according to the morphology of the pond and based on the 2D geophysical maps at elevation 190m, 194m and 197m.

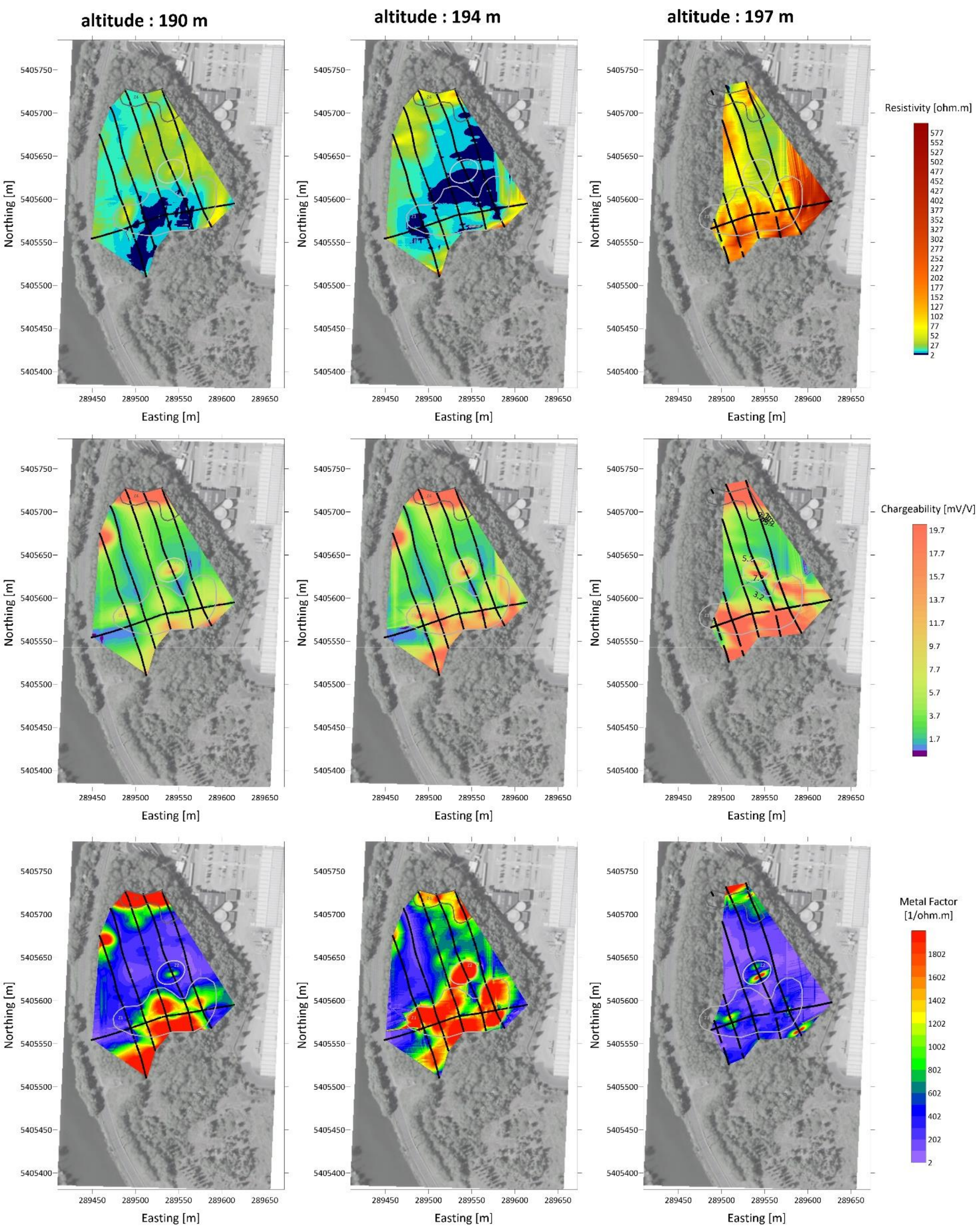


Figure 5. Illustration of the 2D geophysical map at elevation 190m and 194m obtained from the interpolated TDIP profiles. Black points indicate the position of the electrodes at the surface of the ground (for 197, they are ales points and the map is smaller because some parts of the plan are already above the ground surface). The grey lines are surrounding the are interpreted as with the highest metal factor, and thus with the highest metal recovery potential.

3.1.2 Excavation plan and discussion

3.1.2.1 Excavation zones identification

Using the methodology explained in section 3.1.1 and using QGIS desktop 3.22.8, the excavation areas were identified (Fig. 7), which correspond to the areas with the highest metal factors. The 2D geophysical map at altitude 197 m revealed only very small areas with a high metal factor (Fig. 6). These areas were therefore considered to be of negligible value for metal recovery, and it was decided from this map that no material would be valorised from altitude 197m to altitude 196m. We will see in the rest of this section that the small areas identified from 2D map at altitude 197m are part of the zone that would still have to be excavated to an altitude of 196m in order to reach the high metal factor zones identified from the map at altitude 194 m (Fig. 6).

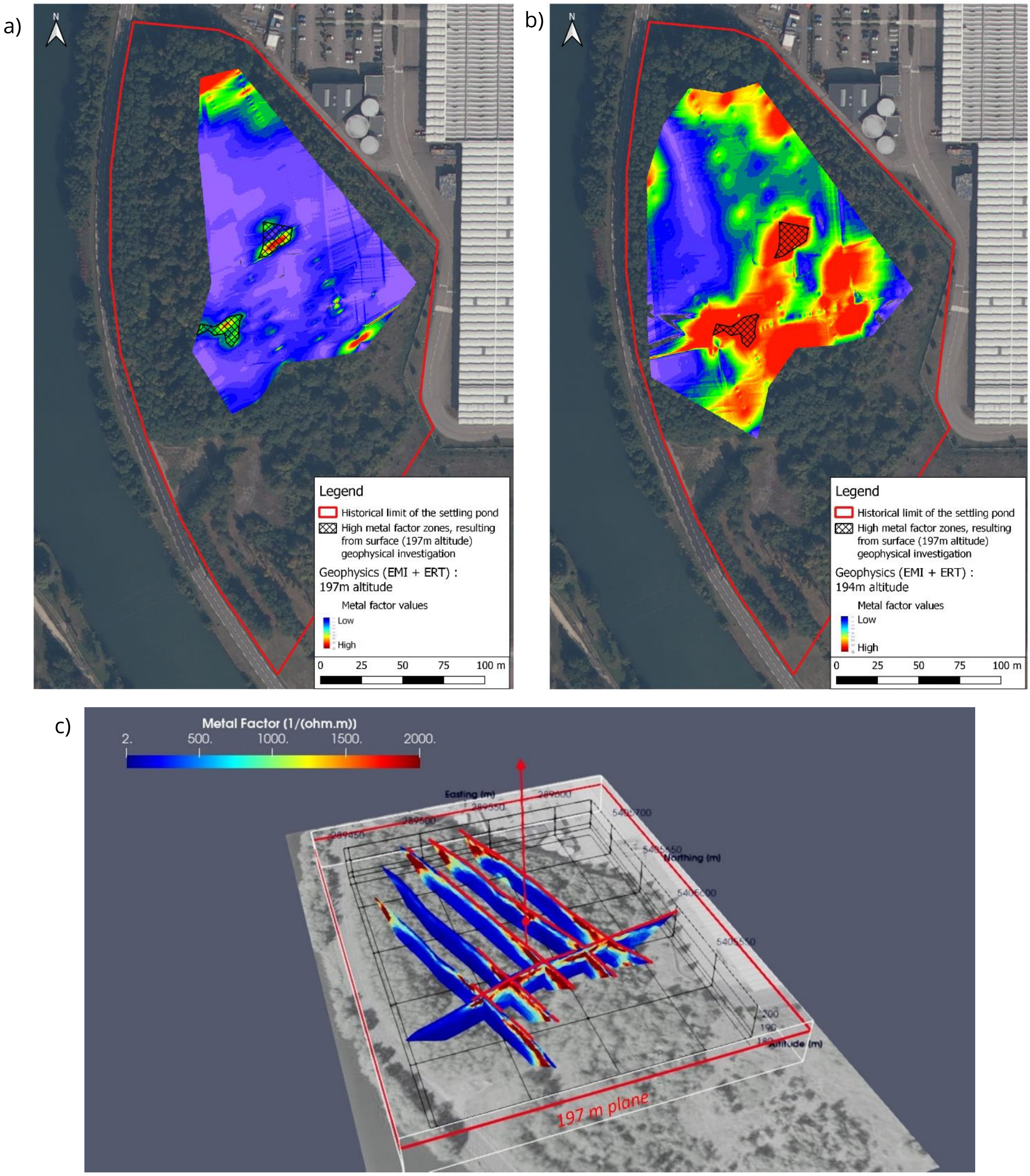


Figure 6. a) The hatched areas represent the high metal factor areas detected from the 2D geophysical map at elevation 197m. The high metal factor zone detected in the north (in red) has been neglected because, as it can be seen in c), it is present only on the edge of only one profile, which corresponds to an area where the sensitivity of the electrical data is lower. b) Although comparatively negligible, these small hatched areas overlap with the large high metal factor area detected from the 2D geophysical map at elevation 194m

The high metal factor areas identified from the 2D geophysical maps at elevation 194m and 190m would have to be excavated, they are shown in Figure 7. The metallurgical sludges composing the settling basin being geotechnically unstable materials, care will be taken to apply a secure slope of α=h/L=4/10 (~21,8°) around the excavation area, in order to ensure its stability. A schematic representation illustrating this secure slope is shown on Figure 8. This secure slope not necessarily being equal to the maximum slope allowing the circulation of excavation machinery, it must also be checked. If it should be gentler than h/L, an access ramp to the excavation area will have to be placed to allow access to the machinery to the bottom of the pit (Fig. 9).

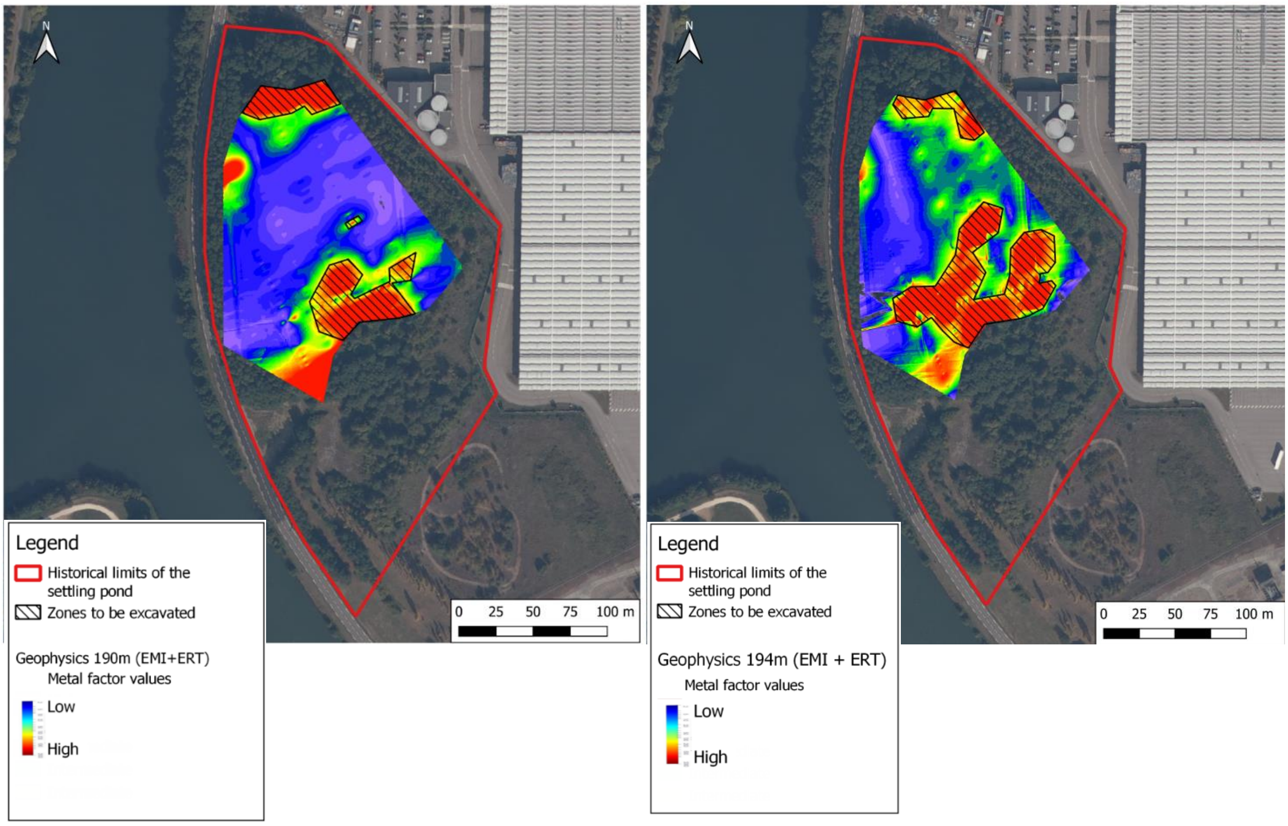


Figure 7. Zones to be excavated (hatched zones), identified from the 2D geophysical maps at elevation 194m (right) and 190m (left)

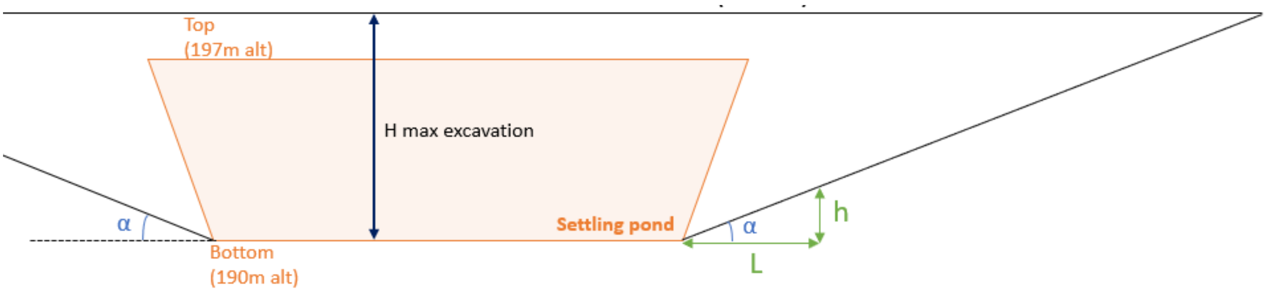


Figure 8. Schematic representation, illustrating the slope (α= arctan($\frac{h}{L}$)) to include to the excavation zone in order to ensure its stability.

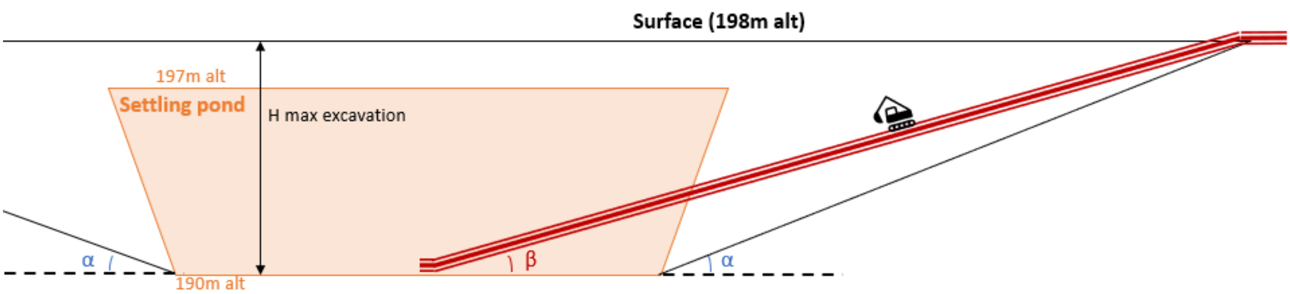


Figure 9. Schematic representation, illustrating the ramp to include if the slope needed for the machinery operation (β) has to be < α

In order to take into account this safe slope (α), the area to be excavated will necessarily be larger than the volume to be excavated delimited with the help of geophysical maps. To illustrate this, a buffer zone has been applied around the area to be excavated, as follows (Fig.10):

- the excavation area identified at 190m elevation is 8m below the surface. To take into account the safe slope of h/L=4/10, the buffer zone will be 20m around the excavation area.
- the excavation area identified at 194m elevation is 4m below the surface. To take into account the safe slope of h/L=4/10, the buffer zone will be 10m around the excavation area.

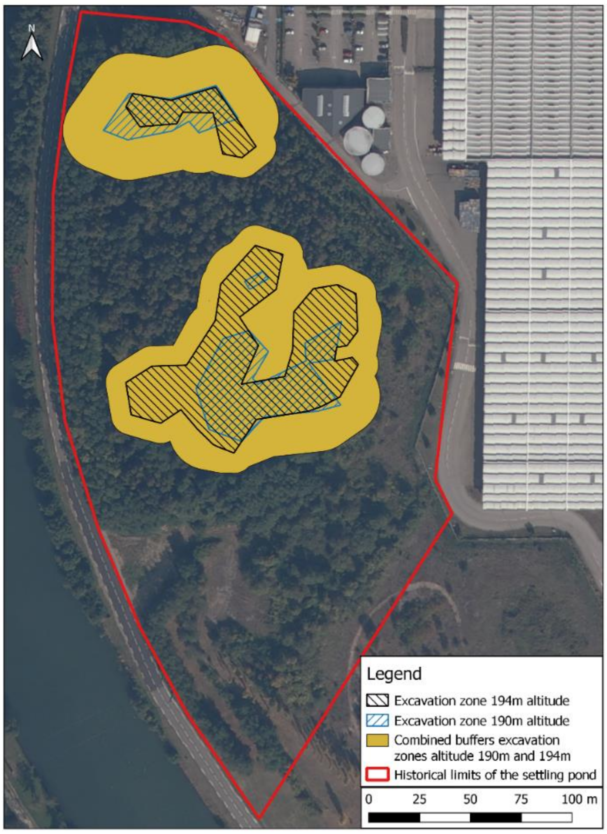


Figure 10. Buffer zones applied around the excavation areas identified

3.1.2.2 Preparatory work

Before starting the excavation of the volume that needs to be recovered, it is necessary to carry out several preparatory work, illustrated in Figure 11. As the site is densely forested, the areas to be excavated (buffer zones included) must first be cleared before excavation work can begin. A dedicated area for soil storage and vehicle transit must be defined (approx. 2000m², 50m long x 40m wide), as well as a road connecting it to both excavation areas (at least 8m wide to allow the passage of trucks/dumpers in both directions). The available space also allows for the possibility to construct a road extension to link the storage and transit area to the "chaussée du Ban-la-Dame" (approx. 500 m²).

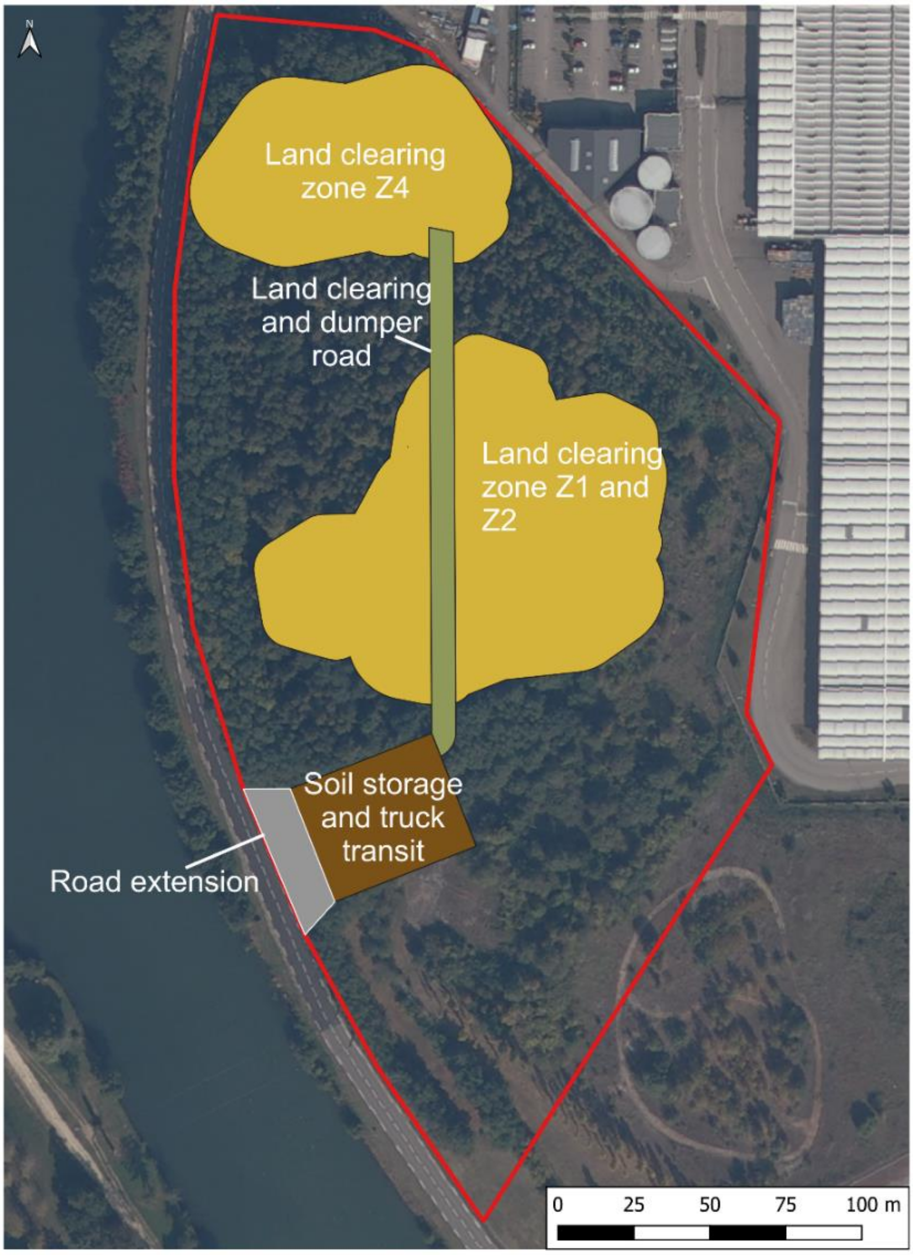


Figure 11. Preparatory work to be carried out and dedicated areas before excavation can begin.

3.1.2.3 Excavation

After all preparatory work and the construction of necessary infrastructure, the first area to be excavated is the northernmost volume z4. For this purpose, the machine park required for the excavation will consist of:

- 2 dump trucks designed for the transportation of the recoverable materials (in this case the blast furnace sludge), mainly travelling between the road extension and the treatment centre, via the main roads.
- 2 dumpers, designed for the short distance transportation of the excavated material on the Pompey site, between the excavation area and the soil storage and transit area.
- These dumpers would be loaded and unloaded by 2 excavators, one located on the z4 area and the other located on the temporary soil storage area

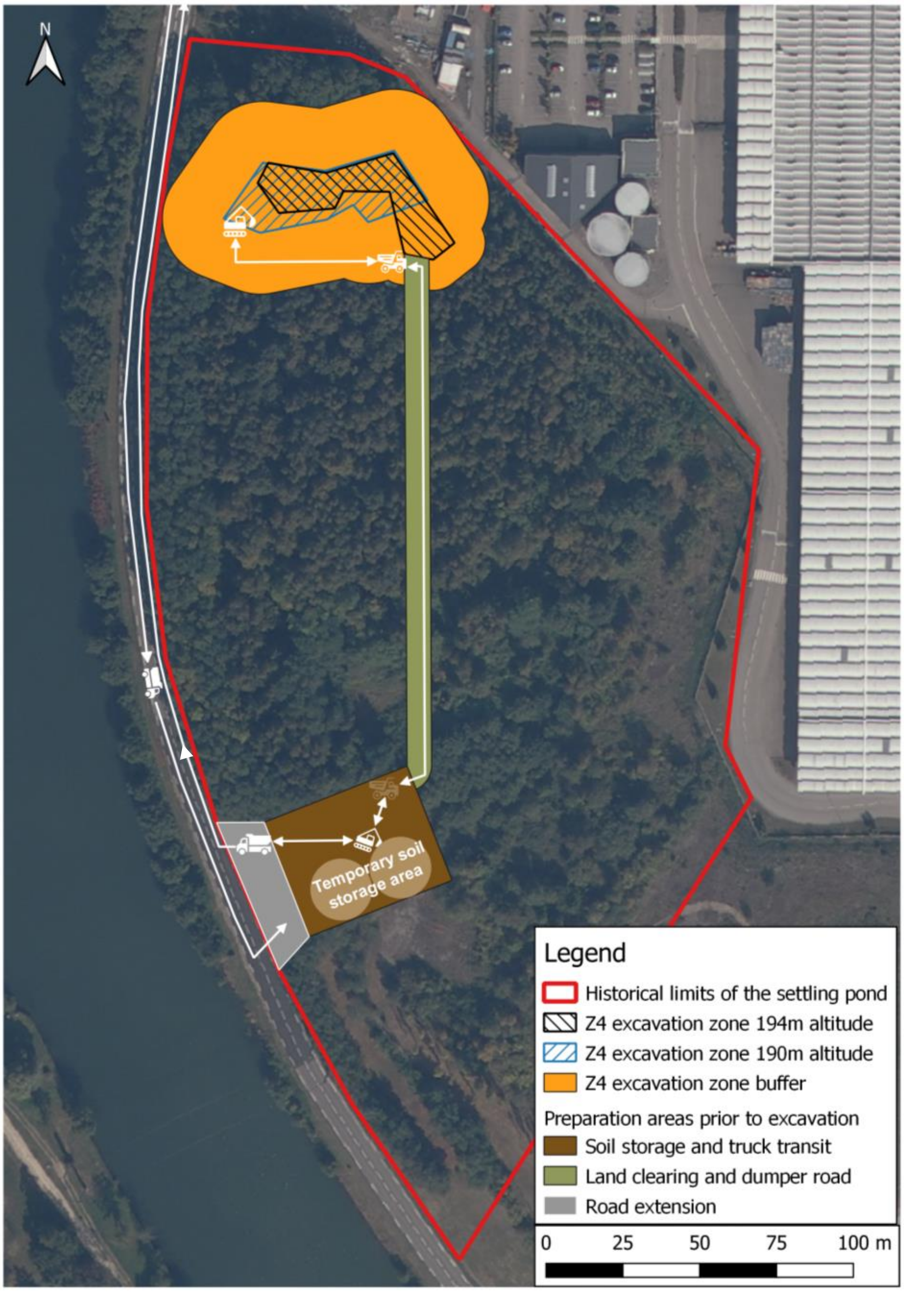


Figure 12. z4 excavation

While the z4 area is being excavated, the temporary soil storage area will be separated into two separate groups:

- on the one hand, the recoverable materials, i.e. the blast furnace sludge
- on the other hand, the excavated soil that will have to be backfilled on the site when the z4 excavation area will have to return to its initial state (re-levelling, road destruction).

After the excavation of the z4 area is completed and as mentioned, the z4 area will be backfilled with the soil set aside on the temporary soil storage area, and part of the constructed road will have to be destroyed, at least the part that connected the z4 area to the z1 and z2 area.

Once the z4 area has been reclaimed, the excavation of the z1-z2 zone can be carried out in the same way as for the z4 area, except that one less dumper may be used (so we will probably use only one dumper instead of two) since the excavation area and the temporary soil storage area are quite close to each other (approx. 20m apart). Once the excavation of this zone is done, the z1-z2 area will also have to be backfilled with the non-valuable material that were stored during the excavation in the temporary soil storage area.

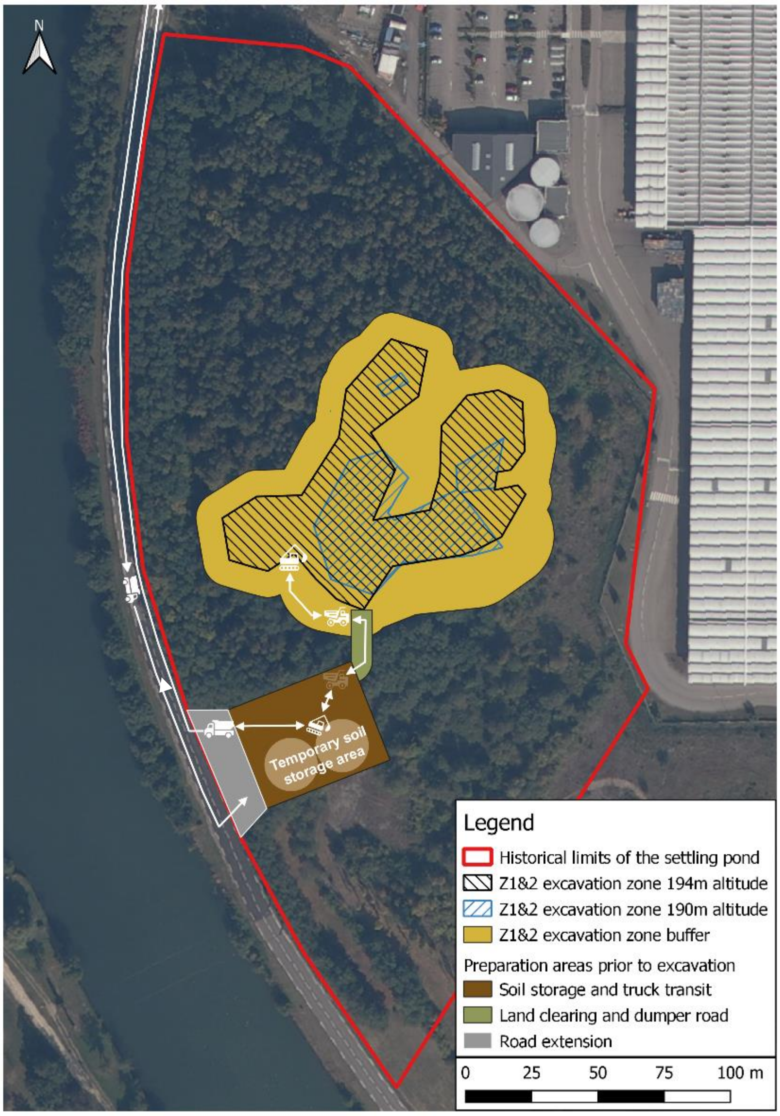


Figure 13. z1- z2 excavation

3.2 Recommendations

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 each of these parameters and their impact on the excavation is provided hereafter.

3.2.1 Site and deposit excavation parameters

3.2.1.1 Characteristics of the materials to be excavated

The most valuable part of the Pompey settling pond is, not surprisingly, the backfill material, which is composed of metallurgical sludge. According to Mocellin (2015), a first characterisation would have identified that the sludge layer has on average 13% Mn, 6,4% Fe, 2,4% Pb and 2,1% Zn.

Pompey settling pond is composed of heterogeneous material with a predominant presence of blast furnace sludge, which are fine materials that are very wet and sensitive to water, making earthwork conditions very delicate. They also contain levels of indurated slag (0.2m thick) and various waste materials (wood, scrap metal, tyres).

The results of lab tests show that the sludge is wet to very wet (water content varying from 20.6% to 223.1%), with 96% fine elements (<5mm) and 63% very fine elements (80µm), a low density (γ_d=0.59g/cm³, or 0,6T/m³) and a water content at the proctor optimum of 95.6% (very difficult to compact (ANTEA, 2001b). The geotechnical tests carried out by FONDASOL (1993) show that the mechanical characteristics of shlamm backfill can vary greatly, which explains the use of a safety factor of 1 to estimate the stability of the slope (see location of drillings in Figure 2). The shear strength parameters of sludge were estimated at 18 degrees for the angle of friction (ϕ') and 3 to 4.3KN/m² for the cohesion coefficient (C') (Appendix A).

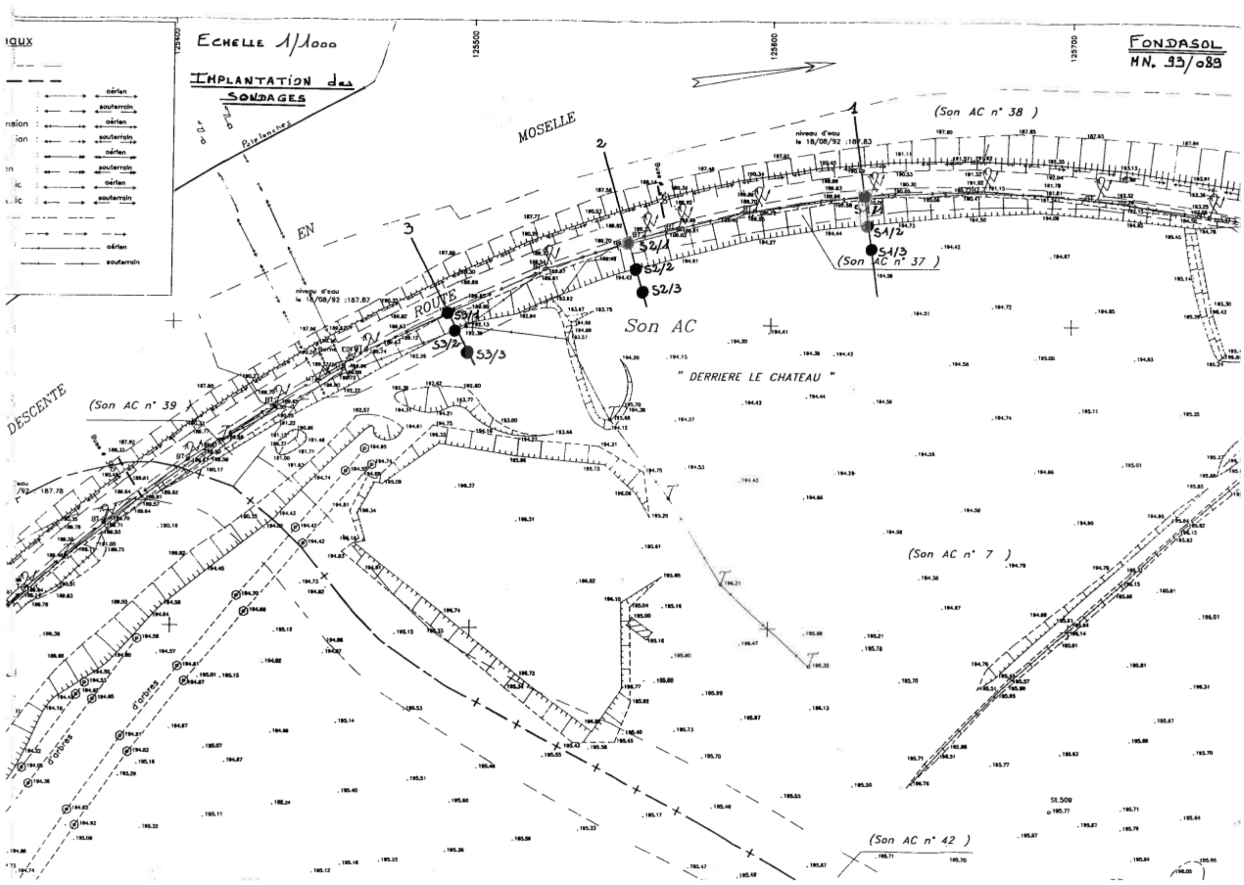


Figure 14. Location of drilling (S1,S2,S3) for the geotechnical surveys (geotechnical stability assessment for access road widening) (FONDASOL, 1993)

Thus, as these soils composed of blast furnace sludge are fine and very sensitive to water, their earthworks characteristics are poor. They are considered difficult to excavate and will require the use of suitable earthmoving equipment, mainly light, wide-tracked machines. The weather conditions will be decisive for the smooth running of the site, otherwise delays or even stoppages will occur in the event of unfavourable conditions (rainy weather for example).

3.2.1.2 Workload

According to Figure 4, the estimated volumes to be excavated are explained as follows[2].

Recoverable volume

Since the 2D geophysical map at elevation 194m is used to establish the excavation zones from elevation 192m to 196m (4m height), the total recoverable volume (without buffers) equals:

$$V_{194m} = V_{194mZ1-Z2} + V_{194mZ4} = A_{194mZ1-Z2} \times 4 + A_{194mZ4} \times 4 = 5110 \times 4 + 845 \times 4 = 23820m^3$$

Since the 2D geophysical map at elevation 190m is used to establish the excavation zones from elevation 190m to 192m (2m height):

$$V_{190m} = V_{190mZ1-Z2} + V_{190mZ4} = A_{190mZ1-Z2} \times 2 + A_{190mZ4} \times 2 = (2200 + 48) \times 2 + 1041 \times 2 = 6578m^3$$

The total estimated volume to be excavated is therefore equal to: $V_{194m} + V_{197m} = 30398m^3$

Non-recoverable volume (used as backfill and re-levelling material after performing the excavation)

To this must be added the non-recoverable volume that will have to be excavated and used as backfill to restore the site at the end of the excavation. It includes:

- the two metres of excavation of the entire buffer surface (from elevation 198m to 196m), which equals to:
$$A_{buffZ1-Z2} \times 2 + A_{buffZ4} \times 2 = 10998 \times 2 + 5631 \times 2 = 33258\ m^3$$
- the buffer zones volume to be applied to achieve the safe slope are estimated by subtracting from the volume of the truncated cone made by the buffer zone the internal volume of the inner cylinder:
$$V_{totbuff} = ((V_{buff194mz1-z2} - V_{194mz1-z2}) + (V_{buff194mz4} - V_{194mz4})) + ((V_{buff190mz1-z2} - V_{190mz1-z2}) + (V_{buff190mz4} - V_{190mz4}))$$

$$= \frac{4}{3} \times (A_{buff194mz1-z2} + A_{194mz1-z2} + \sqrt{A_{buff194mz1-z2} \times A_{194mz1-z2}}\ ) - A_{194mZ1-Z2} \times 4 + \frac{4}{3} \times \left(A_{buff194mz4} + A_{194mz4} + \sqrt{A_{buff194mz4} \times A_{194mz4}}\right) - A_{194mZ4} \times 4 + \frac{2}{3} \times \left(A_{buff190mz1-z2} + A_{190mz1-z2} + \sqrt{A_{buff190mz1-z2} \times A_{190mz1-z2}}\right) - A_{190mZ1-Z2} \times 2 + \frac{2}{3} \times \left(A_{buff190mz4} + A_{190mz4} + \sqrt{A_{buff190mz4} \times A_{190mz4}}\right) - A_{190mZ4} \times 2 = \frac{4}{3} \times (10026 + 5110 + \sqrt{10026 \times 5110}) - 5110 \times 4 + \frac{4}{3} \times (2894 + 845 + \sqrt{2894 \times 845}) - 845 \times 4 + \frac{2}{3} \times (8155 +$$

[2] Area calculated with QGIS maps

$2248 + \sqrt{8155 \times 2248}) - 2248 \times 2 + \frac{2}{3} \times (5418 + 1041 + \sqrt{5418 \times 1041}) - 1041 \times 2$ =22076m³

The total non-recoverable volume is therefore equal to 55334m³

Even if the estimated volume to be excavated is not negligible, the low geotechnical characteristics of the material is a limiting factor for the excavation and will imply the use of small machines as they need to be light.

3.2.1.3 Machine workspace

Both preparatory works and excavation works are likely to be heavy and costly, due to the unfavourable soil and site conditions.

As mentioned briefly in 3.2.1.1, the geotechnical characteristics of the steelmaking sludge and therefore of the environment in which the machines will operate is barely supportive to allow vehicle movement. It will require the use of suitable earthmoving equipment, mainly light, wide-tracked machines. The site being identified as in a flood zone risk (according to an IRSID study of 1984 (ANTEA, 2001b)), and the material to excavate being considered as highly sensitive to water, make the earthwork highly weather-dependant. Unfavourable weather conditions (even light rain) will stop and therefore delay the excavation.

Concerning preparatory works, the high vegetation density on the site will make the clearing costly, and the construction of a temporary road would probably be highly challenging, once again because of the bad geotechnical characteristics of the material to excavate. It is important to take measures to ensure the workers safety and to stabilise the soil. Besides soil stabilisation or compaction, another possibility is to use lightweight construction materials such as steel concrete plates or wooden plates to build a temporary platform. It is also recommended to ensure that the temporary road is designed and built to minimise loads on unstable soils and to regularly monitor the stability of the road during construction and after.

3.2.2 Other recommendations

Prior to the excavation works, a risk study will have to be carried out again given the proven pollution risk of the sludge. The aim is to assess the health risks and in particular to assess the danger of dispersion in the air during the site excavation, and therefore to see if it will be necessary to plan to use pressurised cabins.

Fortunately, the volume to be excavated is at the limit of the water table (184m to 187,5m) and it will not be necessary to dig below it. However, a safe slope should still be made when excavating, and a collection ditch and pipe should be installed to pump the water out into the nearby rivers. Given the proven risk of leaching into water, the water will probably need to be treated before discharge to surface waters. Care will also need to be taken to ensure that suspended solids are kept to a minimum in the discharge water. The water will therefore be let to settle before discharge, and the sludge resulting from the settling process will be left somewhere on the site.

During the geophysical campaign, several site features important for the excavation were identified (See Figure 3 for a reminder of the location of profiles P1 to P7):

- At the level of the measurements, *Fallopia japonica* plants were identified. Measures (in line with the national/regional legislation) should therefore be taken before and during the excavation to prevent the spread of the plant and to protect the environment.
- The punctual presence of exogenous material such as concrete slabs, metal bars and large blocks of hard material (P7, at the edge of the building: old cement slab; P3-P5 around P7: concrete block located above a mound), which would probably require the occasional use of a ripper or hammer, should be noted.
- On P1, P2, P3 but outside the area to be excavated, there is a pile of asbestos and mixed-waste material, which will probably require measures specific to hazardous materials.
- The presence of gas in the volume to excavate is unknown. In practice, if the presence of gas would become suspicious, one could use mobile PID sensors + artificial noses (CH_4, CO_2, O_2, SO_2 + other more specific stuff), or rely on organoleptic clues (weird smell, bubbles in ponds/rivers, etc)

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APPENDICES

Appendix A- FONDASOL (1993)

3.1) - <u>Voie en front de talus</u>

a) - Estimation des caractéristiques mécaniques des sols

- <u>Méthodologie</u>

Les caractéristiques mécaniques des remblais de schlamm pouvant varier fortement, nous avons recherché leurs caractéristiques minimales afin d'obtenir un coefficient de sécurité égal à 1.

A partir de cette analyse ainsi que des résultats des essais pressiométriques pour les sables et graviers, nous avons pu estimer les caractéristiques mécaniques suivantes :

<u>Remblais de schlamm plus ou moins limoneux</u> (profils 1 et 2)

φ'_1 = 18 degrés

C'_1 = 3 KN/m2 (profil n° 1) = 0.3 T/m2 # 0.03 daN/cm2

C'_1 = 4.3 KN/m2 (profil n° 2) = 0.043 daN/cm2

<u>Remblais sablo-graveleux</u> (profil 3)

On pourra prendre en compte les caractéristiques mécaniques suivantes

φ'_2 = 30 degrés

C'_2 = 0 KN/m2

<u>Sables et graviers naturellement en place</u>

φ'_3 = 35 degrés

C'_3 = 0 KN/m2