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"Feasibility study of the expansion of a municipal solid waste landfill"

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Alle mie nonne

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ABSTRACT

Despite the increasing recycling rate, the generation of non-hazardous special waste is increasing and, hence, new landfill volumes are needed. This thesis presents a case study of a landfill in the municipality of Grosso (Piedmont, NW Italy). The landfill is currently composed of three lots:

- Lot1, exhausted in 1996 - capacity 180,000 m^3;
- Lot2, exhausted in 2014 - capacity 494,020 m^3;
- Lot3, currently used, capacity 821,800 m^3.

The landfill receives about 50,000 t/y (43,482 t in 2021) and, to ensure its operation in the future, this thesis addresses the feasibility study of a new lot. Three different solutions were analysed with a phased approach: the first solution is a merged lot in the western side with a volume of 770,000 m^3; the second solution consists in separating the lot of solution 1 into two lots separated by the current access road, achieving a capacity of 701,000 m^3; and the last one is a lot lying on the existing ones with a volume of 110,000 m^3. This case study demonstrates the pros and cons of the three possibilities and it leads to the choice of the best solution.

ACKNOWLEDGEMENTS

Grazie al professor Casasso che con umanità e disponibilità mi ha guidata nel lavoro di tesi e ha alleggerito questo ultimo step del mio percorso.

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Non posso fare a meno di ripensare a quando nel mio paesino nel cuore dell'Abruzzo pensavo se la scelta giusta fosse stata partire o restare; cercavo di figurarmi questo giorno per capire che strada avrei preso. Oggi esco dalla scalinata dell'aula magna Giovanni Agnelli e sono grata a me stessa per aver creduto in me e per aver superato con brillante coraggio e determinazione tutte le sfide. Non sarei stata qua senza l'appoggio di mia sorella che mi ha sempre spinta a buttarmi in questa nuova esperienza. Sarebbe stato tutto più difficile non avendoti sempre dalla mia parte con i tuoi preziosi consigli e il conforto, sei per me un appoggio sicuro di cui non posso fare a meno e di cui mi fido ciecamente. Grazie per essere la mia migliore alleata, ma anche amica e famiglia.

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1 INTRODUCTION

1.1 Geographical, geological, and hydrogeological context.

The landfill addressed in this work is a non-hazardous special waste landfill located in Vauda Grande (Latitude: 45°16' 0" N, Longitude: 7° 34' 0" E), in the NNE part of the municipality of Grosso, in the province of Turin. The landfill is located at 1600 m from the inhabitant centre of Grosso, at more or less 1400 m from the hamlet of Madonna della Neve, at approximately 1300 m from Vauda di Rocca and around 1100 m da Vauda di Nole. However, near the landfill, i.e., within 1 km of distance, there are only a few scattered houses, as in Figure 1. There are some buildings at 500 m in the north side of the landfill, behind the bush and the brook. An industrial area is at more than one km in the south direction, only two industrial buildings are at 700 m of distance from the landfill.

Along the west side there are private terrains with a few houses, and across the eastern side is the natural reserve, "Riserva Naturale della Vauda".

The light circles in Figure 1 show the situation.

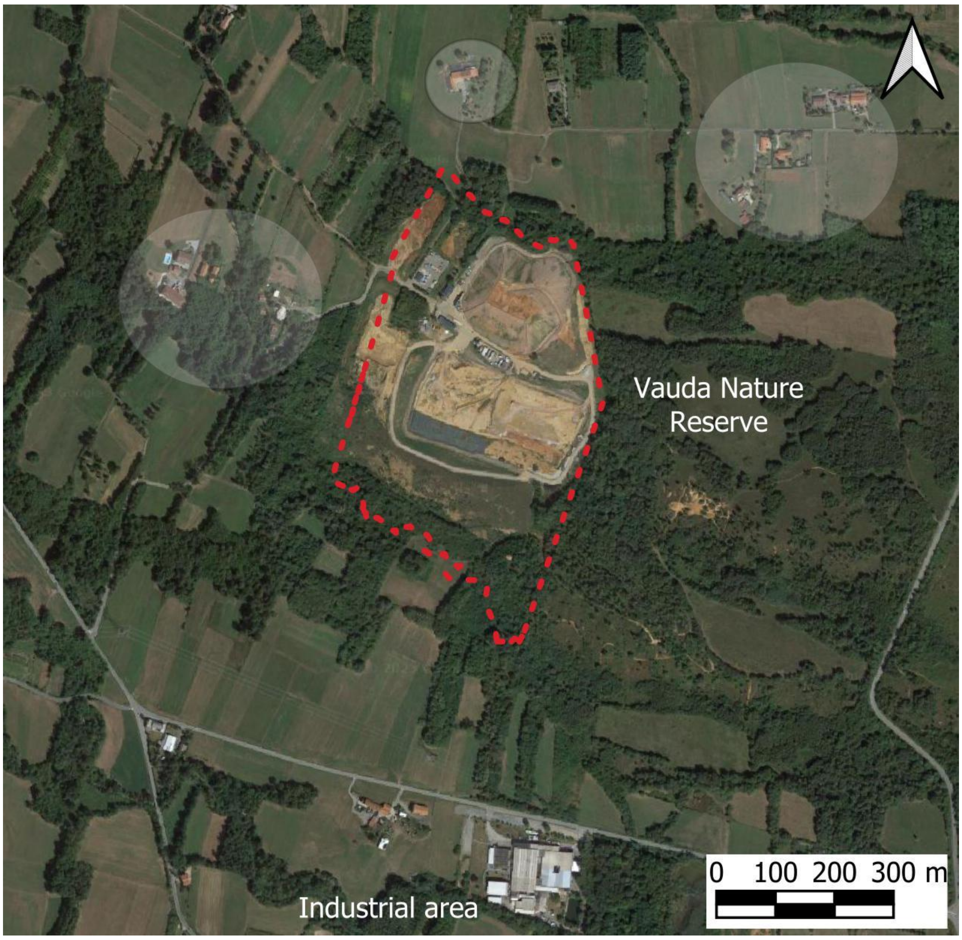

Figure 1: Position of the nearest buildings (light circles) and Nature Reserve.

The territory falls within the section no. 134.110 of Regional Technical Map, which is reported in Figure 2.

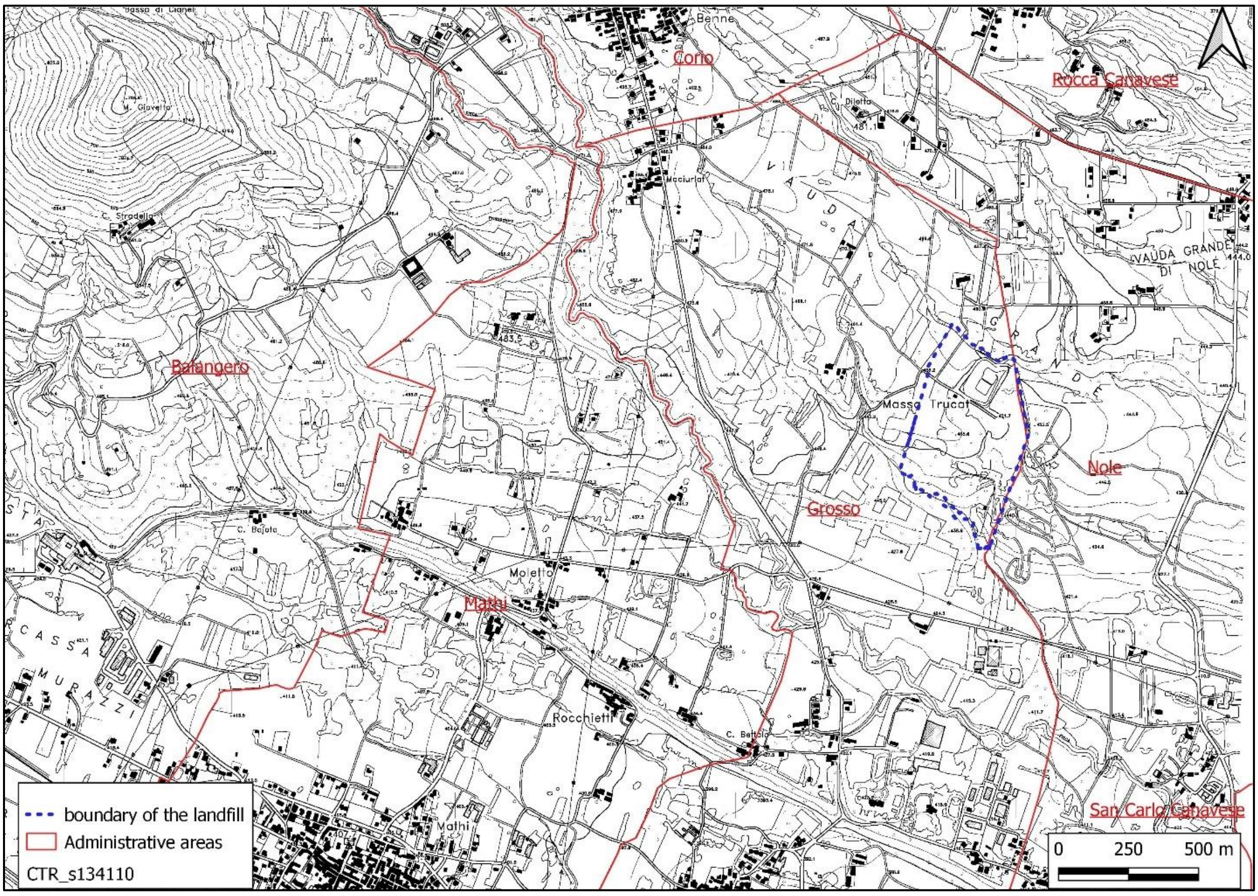

Figure 2: Extract of the section 134110, of the regional technical map.

The towns closest to the landfill are Nole, Rocca Canavese and Corio.

The site is in a plain bordered by Stura di Lanzo river and Malone river, and there are three main terraced areas (Figure 3):

- the highland of Vauda Grande.

  It joins with the mountain of Giovetto and Rolei on the west side. The secondary hydrographic network has drawn small depressions of few meters and the altitude reaches 450 m a.s.l. in the zone of the landfill. The north boundary is more recent than the south boundary and so there is an asymmetric morphology. The river Fandaglia is the north boundary from the highland of Corio with a gradient of 50%. Instead on the south boundary there is a 30 m slope with a gradient of 15-20%. The south slope was drawn by Stura di Lanzo. The gradient in the zone of interest is 2.5%.

- an intermediate highland in the zone of Moletto and Vauda di Nole.

  This surface is narrow and stretching from west-north-west to east-south-east. It is on the southern part of the previous highland and the south boundary is a slope of 30-40 m with a gradient of 30-40%.

- the south highland with the inhabited of Mathi, Grosso, Nole is southern the previous slope. It extends from north-west to south-east and it reaches an hight of 2-3-km between Grosso and Nole and his hight reaches 4 km in S. Maurizio Canavese.

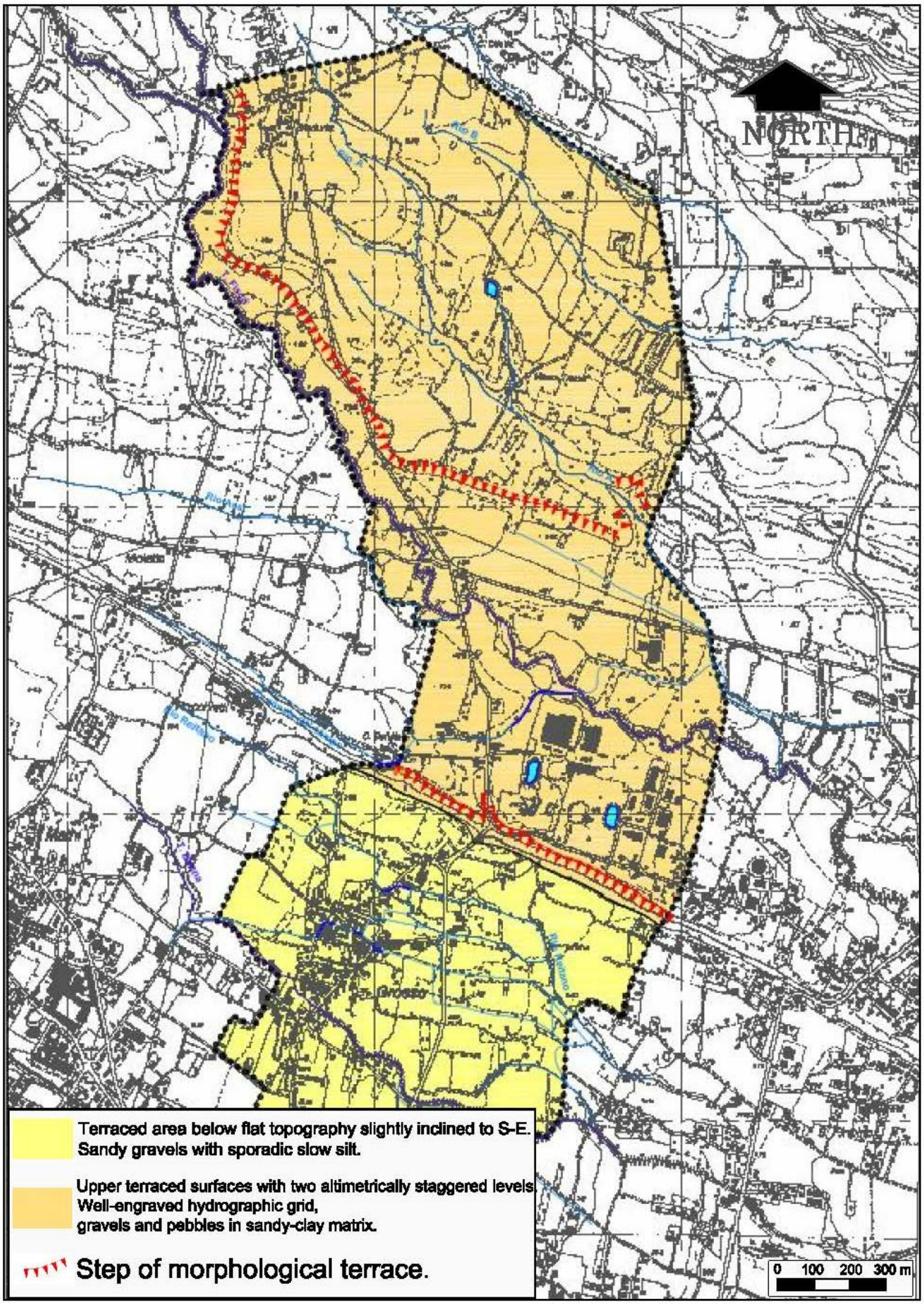

Figure 3: Three main terraced areas in the municipality of Grosso.

The geological composition is characterized by coarse alluvial deposits; there are different sandy gravel layers and pebble layers with a sandy matrix and a silty matrix. The surface is red because there is a significant claying due to the atmospheric agents.

Near the zone there is the mountain peak of Balangero, as in Figure 4. This alpine landscape is a source of debris, so the alluvial deposit is reach of clasts and breccias with sharp edges.

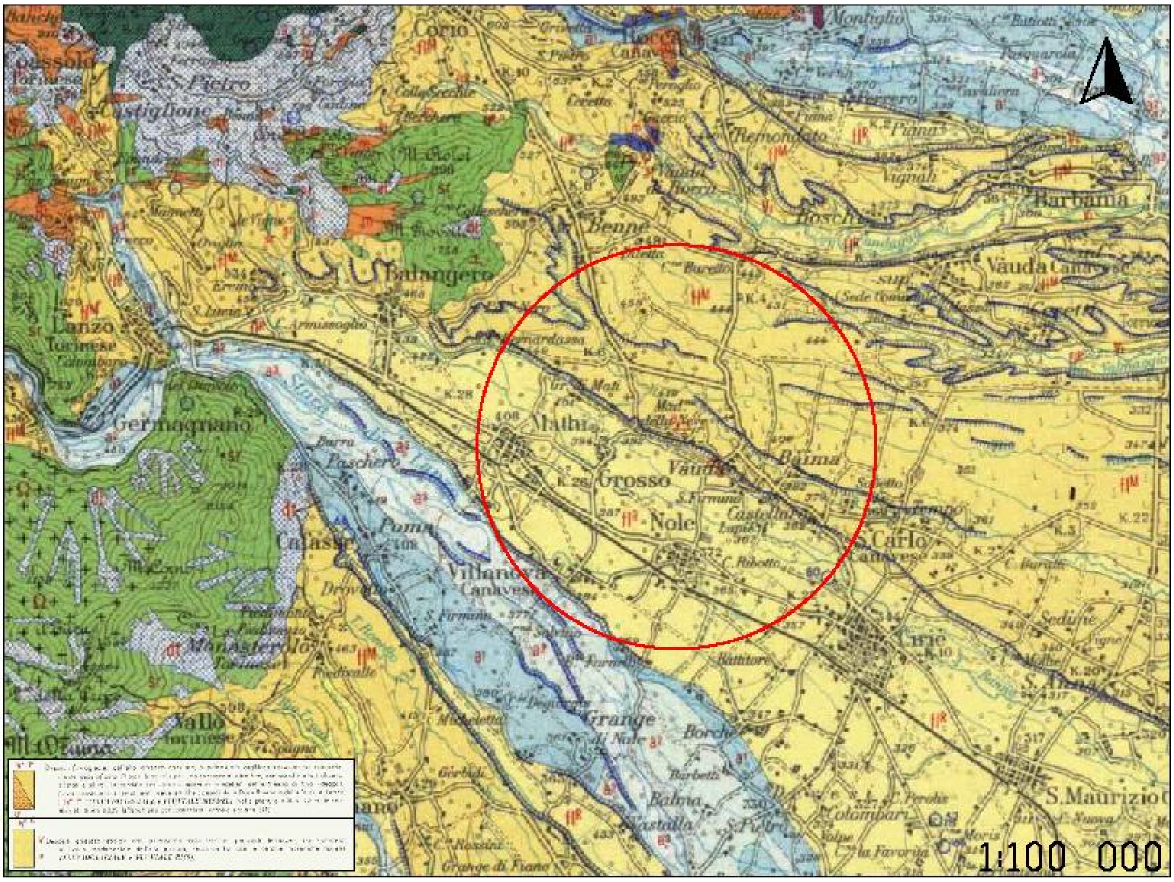

Figure 4: Extract of the sheet 56 "Torino" of the Italian geological map (1:100000).

The geo lithological composition is clarified in Figure 5.

The main rivers are Stura di Lanzo and Malone. The first one is at 3.5 km at south-west, its topographic level is 50 m smallest than the level of the area. The second one has the same level and distance in respect to the area but is in north direction as in Figure 6.

The minor river is instead the Fandaglia stream at the end of a slope at 1.4 km from the site. This brook is not perennial, i.e., there are some dry periods in absence of rain due to not impermeable soils. The Fisca river is the only one with a perennial water flow, it is at 800 m away from the area. The average flow rate of Fisca river is 0.40 m^3/s.

In Figure 6 is also visible a small stream along the north boundary ("Rio B in Figure 7") of the landfill but anyway this is not a flood risk area.

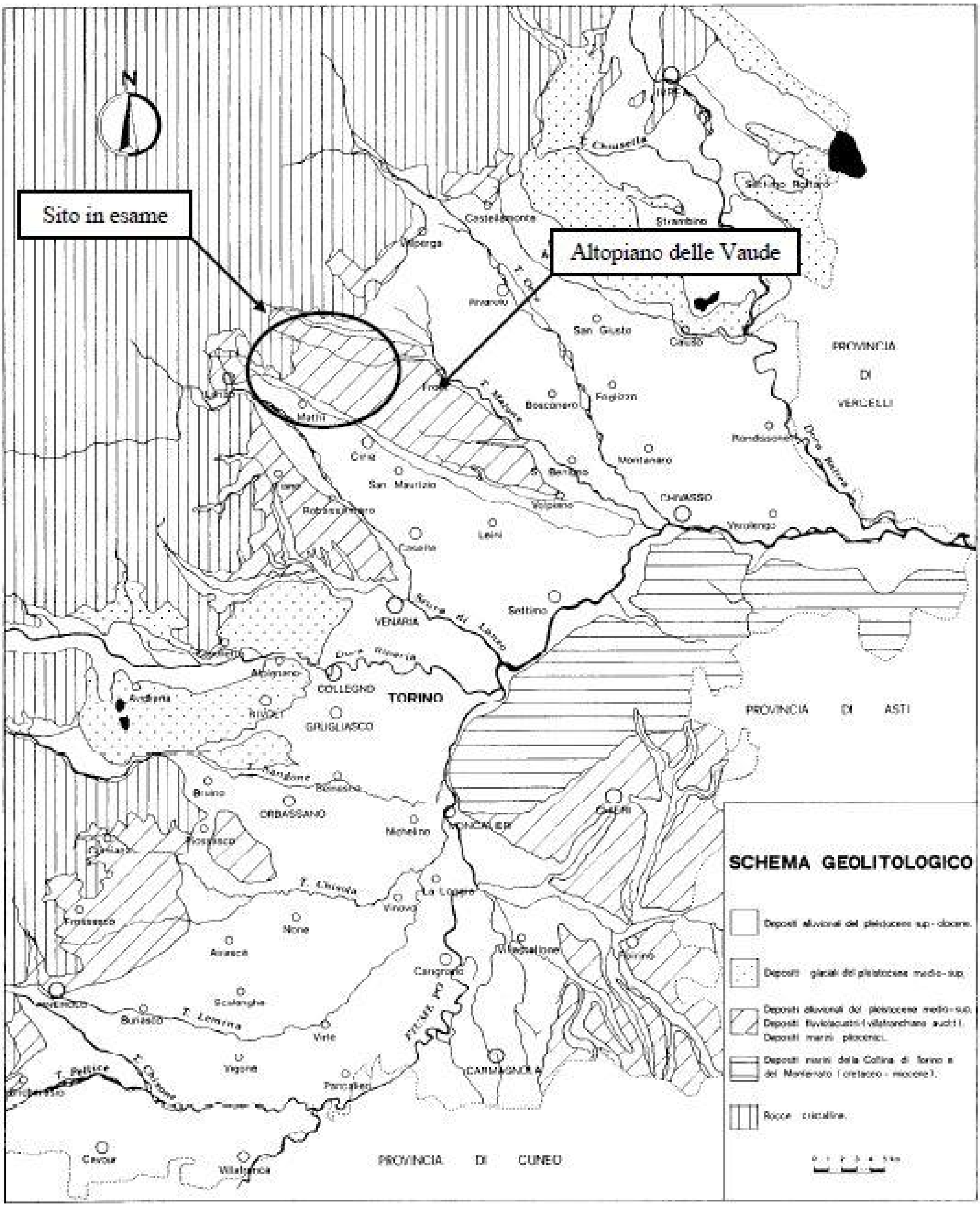

Figure 5: Geolithological scheme of the province of Turin. Source: Bortolami and Filippini, 1990 [1].

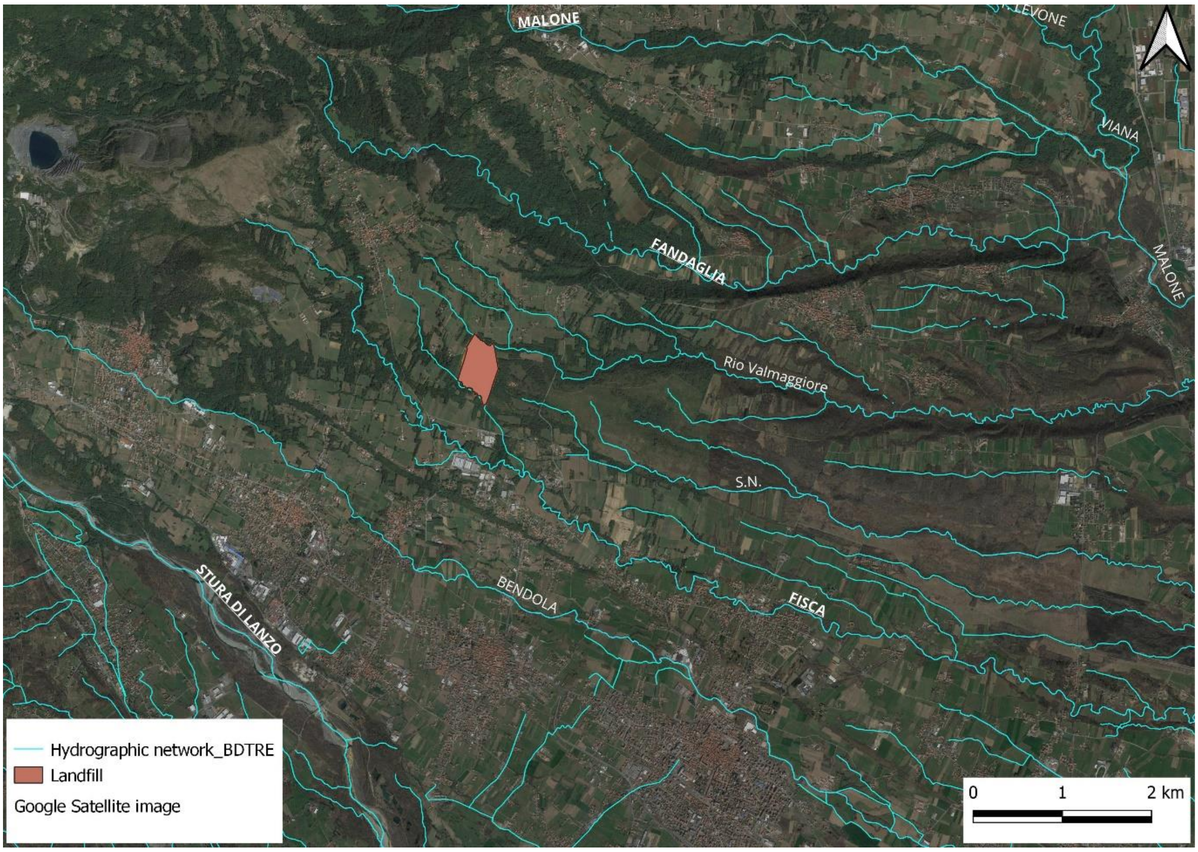

Figure 6: Water streams around the landfill.

In Figure 7 there is an extract of the municipal general urban plan (PRGC) of Grosso. The brook along the north boundary of the landfill is framed by an area of respect classified as IIIa (the orange one in the figure).

The IIIa class is not a constraint for the landfill but only for the buildings, in this case the limitation is only the space for the maintenance of the riverbed.

The zone for the maintenance is 5 m from the brook according to the Norms of Implementation of the P.A.I. (Extract Plan for the Hydrogeological Structure) no.18 of 26 April 2001: "In order to allow maintenance with mechanical means in artificial drainage networks, the areas of respect along the consortial channels are extended, compared to art. 140, letter e) of the Regulation referred to in the Royal Decree 8 May 1904, n. 368, up to 5 meters".

The expansion from 2 m to 5 m is due to the transition from manual to mechanized maintenance.

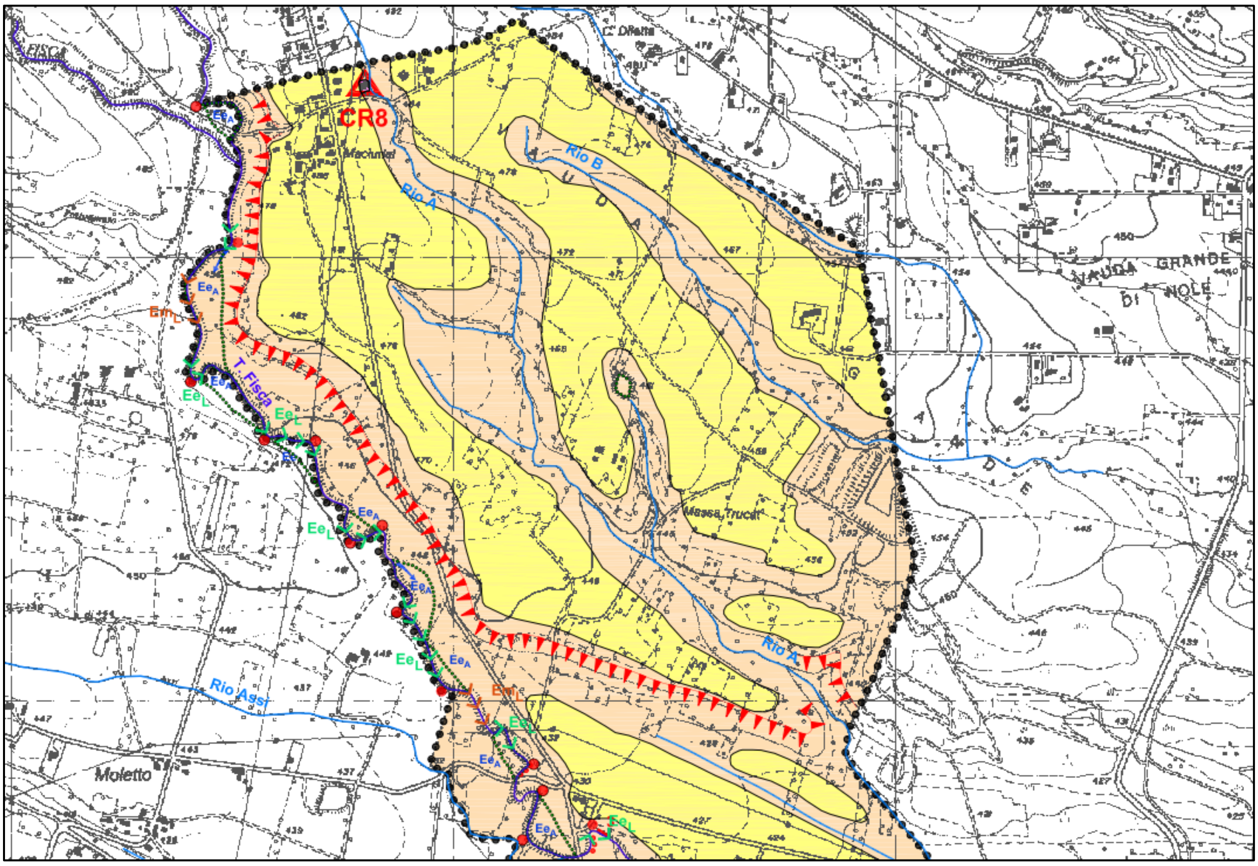

Figure 7: Extract from the municipal general urban plan of Grosso.

An important tool for the characterization of the soil are the surveys.

The first survey was performed in 1983 with a depth of 35 m below the ground level (b.g.l.). The inspection depth increased in 1992 with surveys of 120 m and 160 m b.g.l.. Finally, five piezometers were built in 1998 around the perimeter of the landfill (PZ1-PZ5 in Figure 8) with depth of 55-60 m b.g.l., and 12 observation wells with depth of 20 m b.g.l. were installed in 1999.

In 2008 the PZ3 piezometer was replaced by an observation well (PZ6) with 80m depth b.g.l., as in Figure 8.

Some tests were made to define the hydraulic conductivity of the ground. The hydraulic conductivity ranges from $6.76 \cdot 10^{-8}$ m/s to $1.51 \cdot 10^{-5}$ m/s according to the results of the tests performed in the piezometers PZ1-PZ5.

In addition, three other Lefranc test were performed in 2008 during the perforation of PZ6. The results are in Table 1.

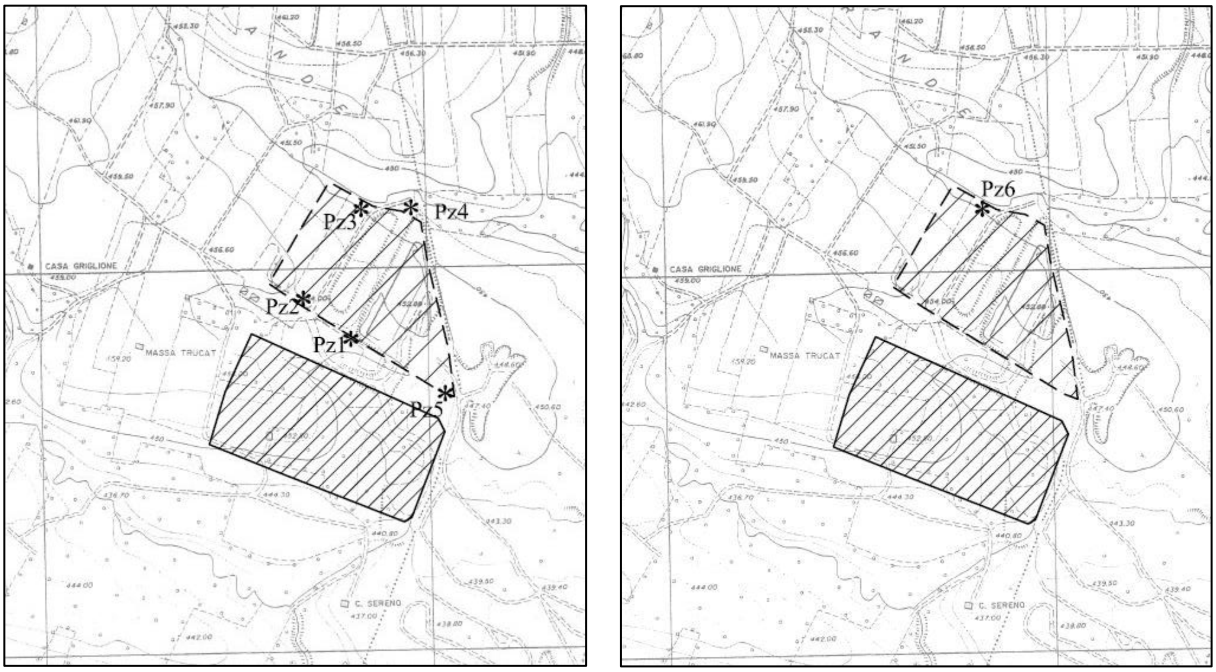

Figure 8: Surveys around the second lot.

Table 1: Values of hydraulic conductivity derived from the Lefranc tests performed in 2008.

	Depth [m]	Hydraulic conductivity [m/s]
I Lefranc	60.5	$5.5 \cdot 10^{-9}$
II Lefranc	67.75	$5.9 \cdot 10^{-6}$
III Lefranc	78.5	$9.2 \cdot 10^{-8}$

The hydraulic conductivity is correlated with the depth, in particular the smallest value is due to silty layers. There is an aquitard at 55-60 m b.g.l. due to the presence of a loamy sandy level, it originates a possible suspended aquifer.

The bottom of the aquifer is at 90 m b.g.l. (Figure 10), that is, 30 m below the aquitard.

The hydrogeological structure is strictly related to the local morphology, isopleths curving at south-east of the site, due to the presence of slopes that cause the lateral drainage (Figure 9).

The depth of the groundwater is very high, indeed also the surveys at 100 m depth did not reach the aquifer. Only the survey S2 (depth of 160 m b.g.l.) reached the water table at 130 m b.g.l.. in 1992. The suspended aquifer, corresponding to the sandy silty layer at 55-60 m b.g.l., has a temporary presence of water.

These results are confirmed during the construction of the observation well PZ6 in 2008.

In conclusion the groundwater is at 130 m b.g.l. and it is isolated by all the coarse deposits with low average permeability of the upper layers and by the levels at fine grain size.

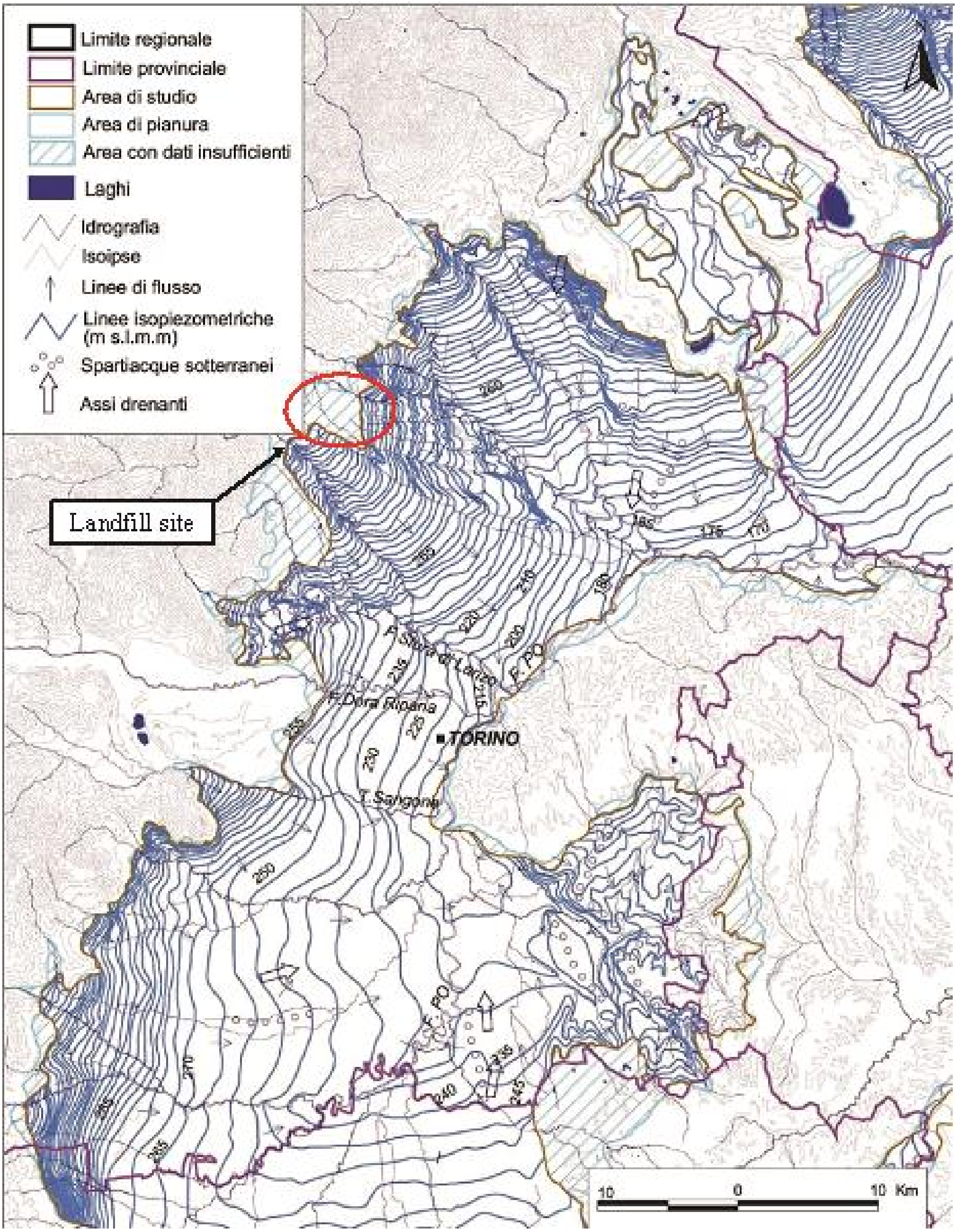

Figure 9: Isopleths of the hydraulic heads of the shallow aquifer in Piemonte, as measured in Summer 2002. Source: Water Protection Plan of Piedmont Region [2].

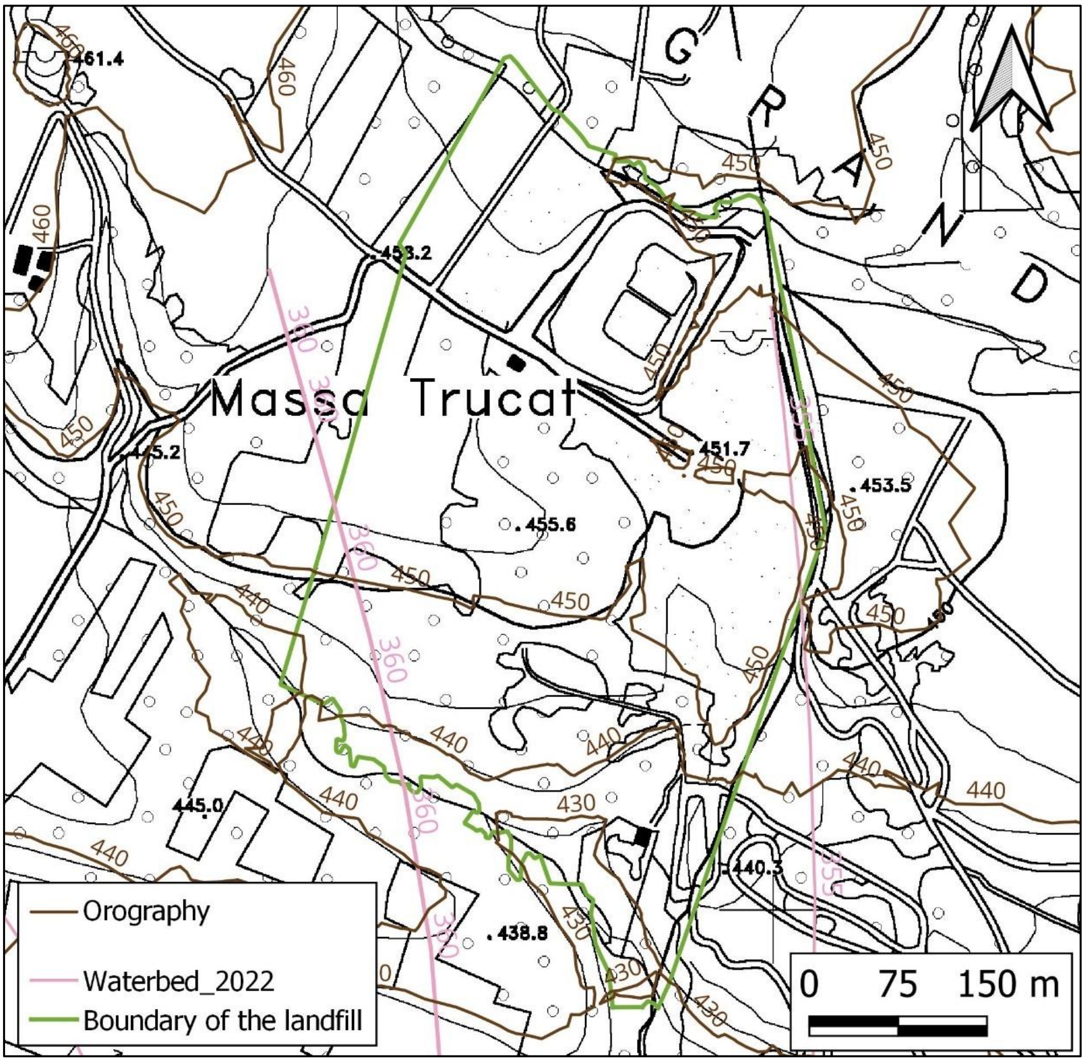

Figure 10: Spatial distribution of the ground elevation (brown lines) and of the bottom of the shallow aquifer (pink lines), both expressed in m a.s.l., in the area of the landfill (boundary in green).

Another important aspect is the weather conditions.

The climate is subcontinental with a weak water depression in summer without period of aridity. The average yearly rainfall height is 1,256.6 mm.

The Padana plain is characterized by weak or absent winds al ground level. The percentage of calm winds is 70% with a speed ranging from 1 to 3 node (1 node = 1 nautical mile/hour = 1.852 km/h).

The east winds are always present in Piedmont region. They are present in high pressure conditions, during spring or in the warmer hours.

The west winds instead are linked to the opposite scenario with low pressure and temperature. They came from alpine valleys.

1.2 Development stages of the landfill

1.2.1 Situation up to 2008.

The area was divided in two lots. The first one was built in the late 1980 and was exhausted on 29 June 1996. Roughly triangular in shape, with a net area of 12,250 m^2, it occupies the northwest sector of the area and now is recovered. The second one is in the west side of the previous one and it is divided in two sub parts, the northern sector and the southern sector. These two sub parts were ready in 1999 and run out in 2008, Figure 11. In 2008 the area of lot 2 amounted to 16,537 m^2. The depth of the bottom of the reservoir ranged from a minimum of 18.50 m to a maximum of 27.40 m.

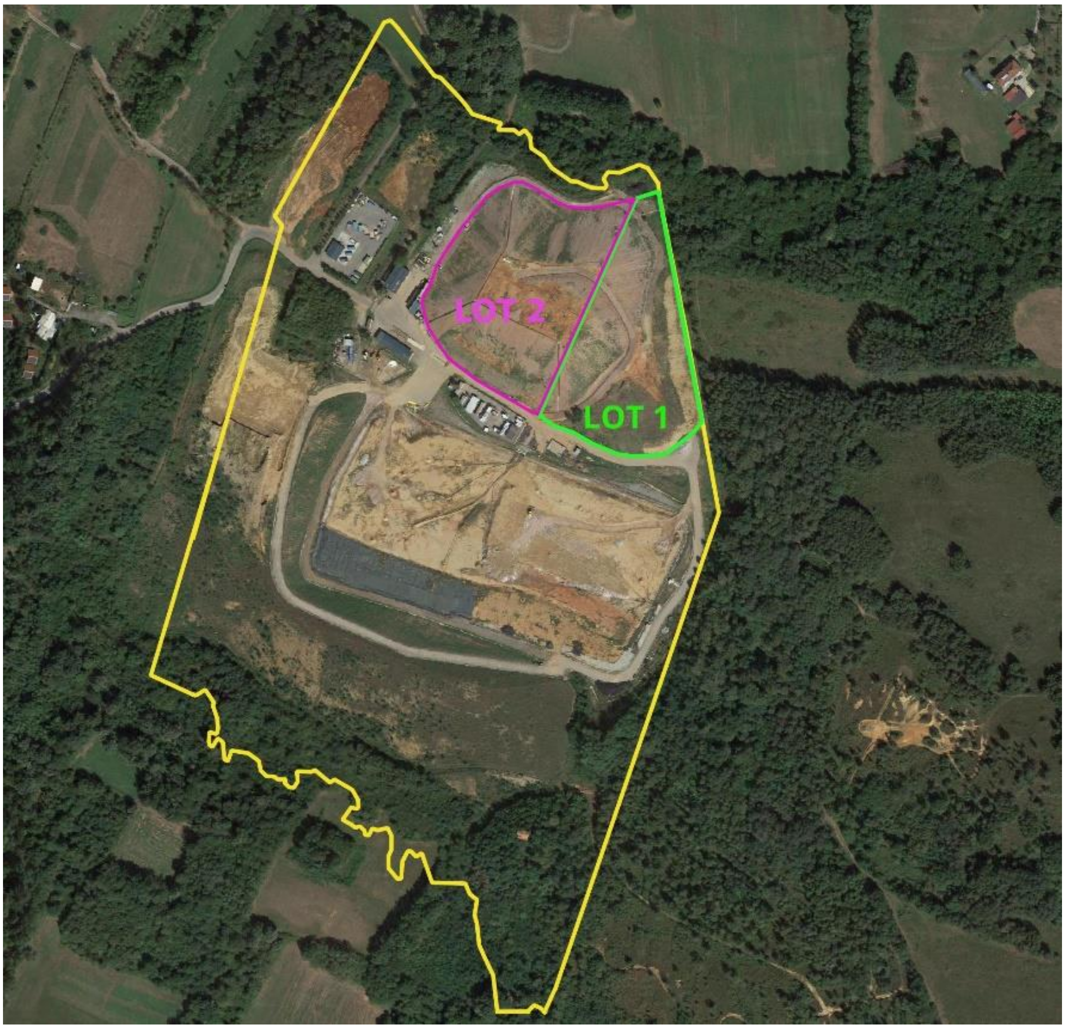

Figure 11: Situation up to 2008. Lot 1 in green line and lot 2 in pink line.

In 2007 there was a preliminary investigation in order to use the area between the first and second lot, the slopes of this new part are built against the previous two landfills.

Figure 12 is a scheme of the evolution of the landfill, instead Figure 13 is a technical design of this expansion.

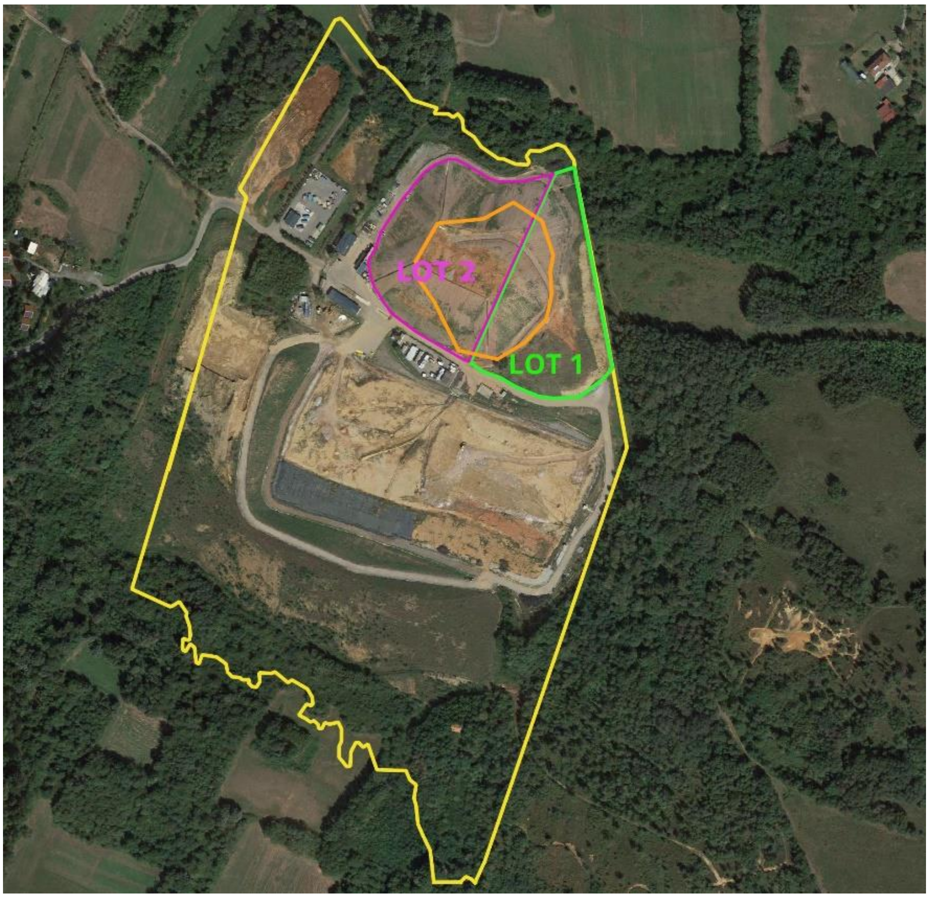

Figure 12: Scheme of the evolution of the landfill in 2008. Elevation and unification of lot 2 and 1 in orange line.

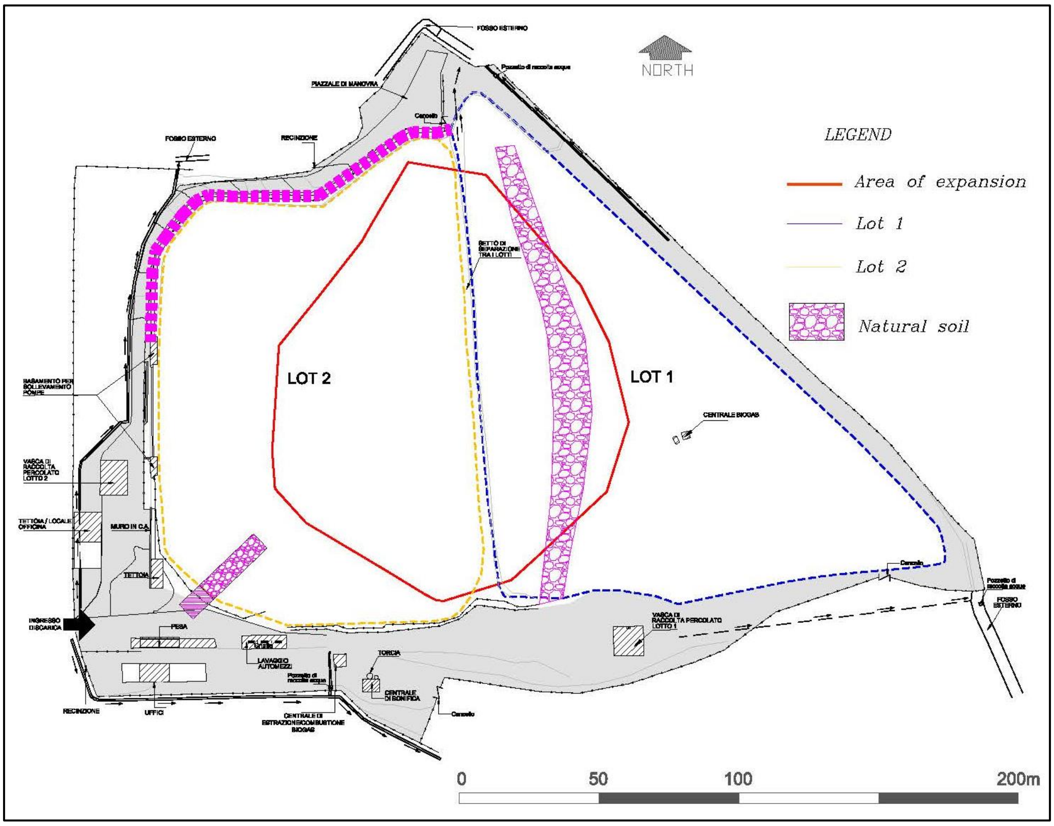

Figure 13:Expansion of the second lot.

The volume of waste disposed of rose of 85,300 m^3, i.e., 294,480 m^3 to 379,780 m^3, and the total surface of second lot increased to 21,500 m^2 with the use of this inner part.

The expansion was designed in order to contain the waste of the area of C.I.S.A. until 2013.

During this year there was also the preliminary study for the construction of the third lot at south of the previous parcel, next to the "Riseva naturale orientate della Vauda".

The third parcel of landfill was designed with a capacity of 388,000 m^3 (net volume is 349,200 m^3 considering a 10% of middle layers), an extension of 37,542 m^2 and an hight between 11.0 m and 24.5 m.

The hight of the first lot decreased of 60-80 cm due to the subsidence. For this reason, during the enlargement of the second lot, a layer of 426 m^3 of natural soil was placed in the upper part of the first lot (section of 2.13 m^2, length of 2 m). This precaution avoided that the leachate of the elevation reached the first exhausted lot rather than the second lot that was in exercise, Figure 14.

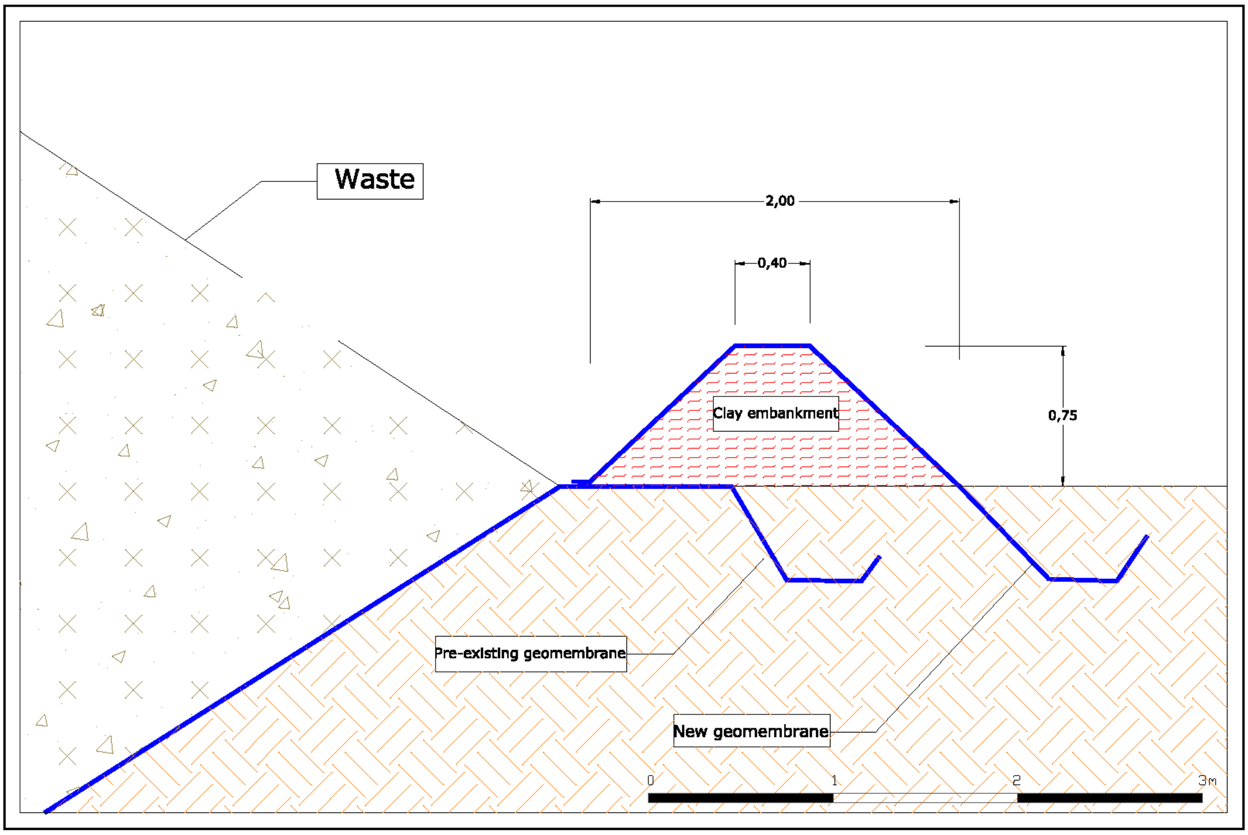

Figure 14: Clay embankment to contain the leachate.

1.2.2 Expansion performed in 2010.

Volume of the second lot was expanded of 62,220 m^3 and the total volume become 442,000 m^3 in respect to the previous 379,780 m^3. This extra volume was obtained with a redesign of the slopes and with a small increase of the upper level.

The gradient was fixed at 40% (1:2.5, more or less 21.8°) for all the size of the second lot of the landfill. On the other hand, the gradient decreased on the top of the lot and was made a semi-flat surface.

With this new design, the top level was increased of 2.5 m and the total hight is 469 m in respect to the previous 466 m.

During this period the construction of the third lot was divided in two sectors to have the south part already in exercise when the other part is in construction.

The scheme of the first design of lot 3 is in Figure 15.

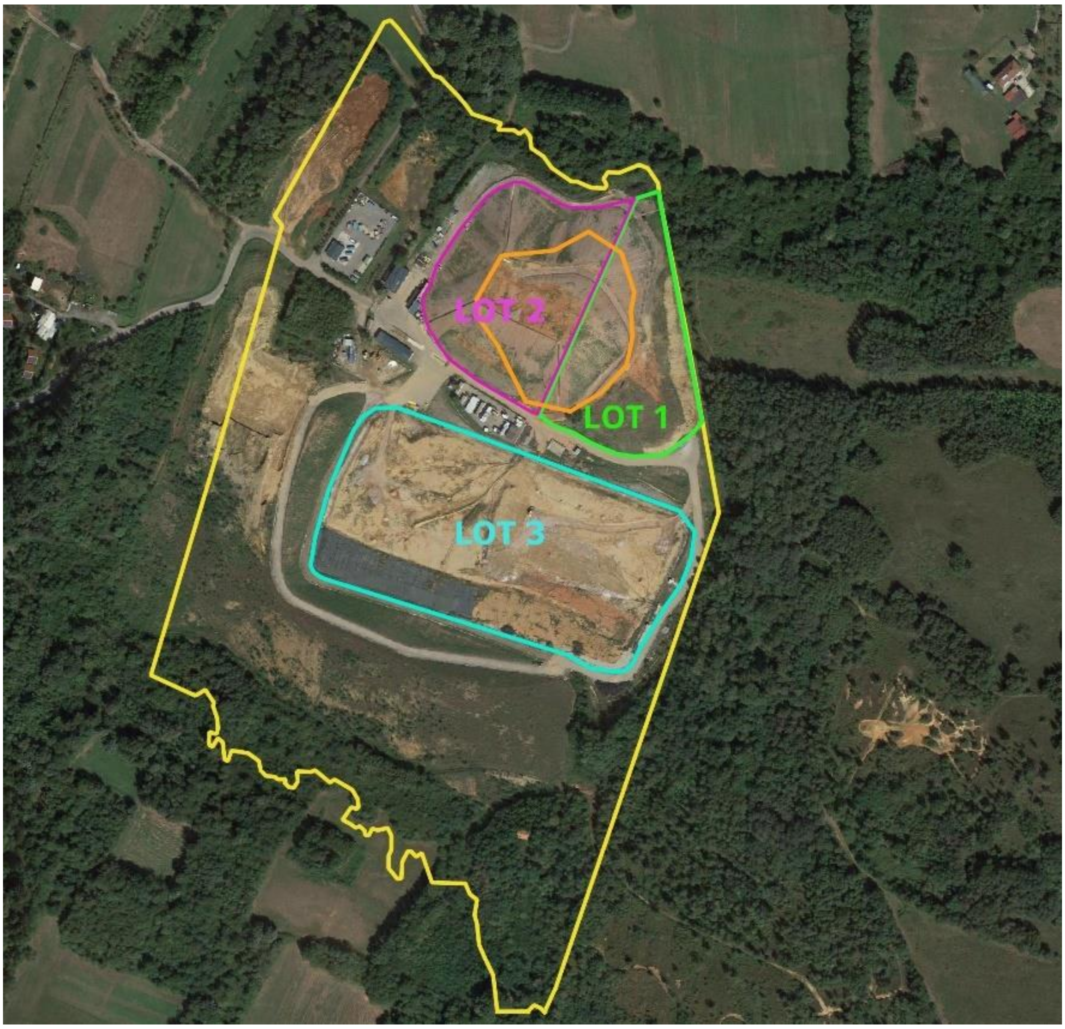

Figure 15: Expansion of the landfill with lot 3. Lot 3 in light blue line.

1.2.3 Expansion performed in 2016-2017.

The volume of the third lot was increased changing the gradient of the south and north slopes at 21°/22°. Furthermore, the thickness of the capping was decreased at 2.5 m (Figure 17) instead of the previous 3.5 m (Figure 16). In this way the layer composed of inert (0.8-1 m) was removed.

At this point the volume of waste in the third lot will be increased of 65,000 m^3, i.e., 45,500 t (0.70 t/m^3).

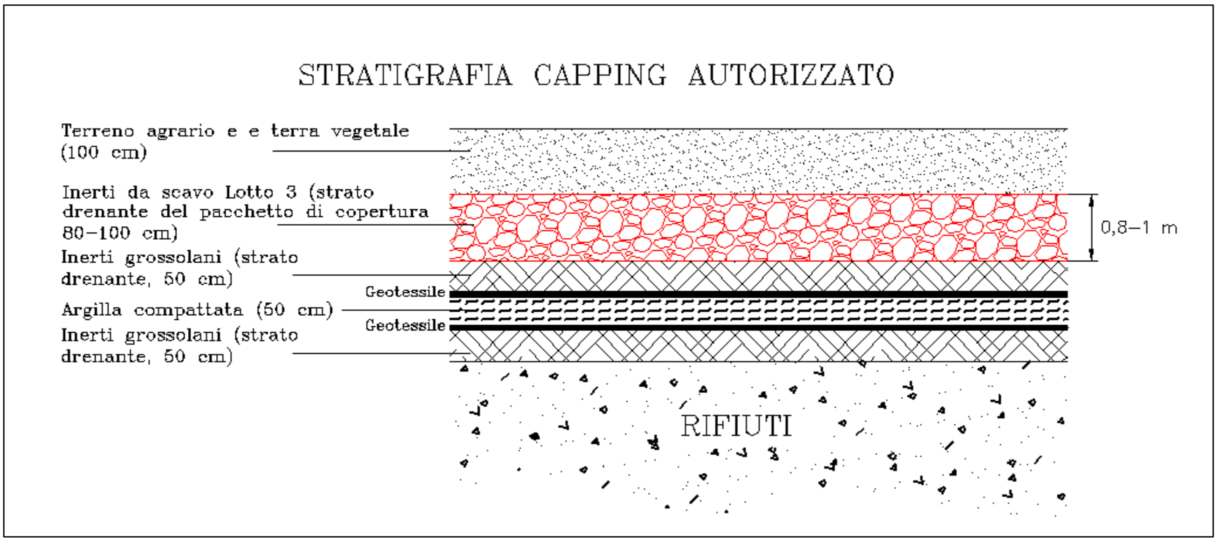

Figure 16: Previous scheme of the capping.

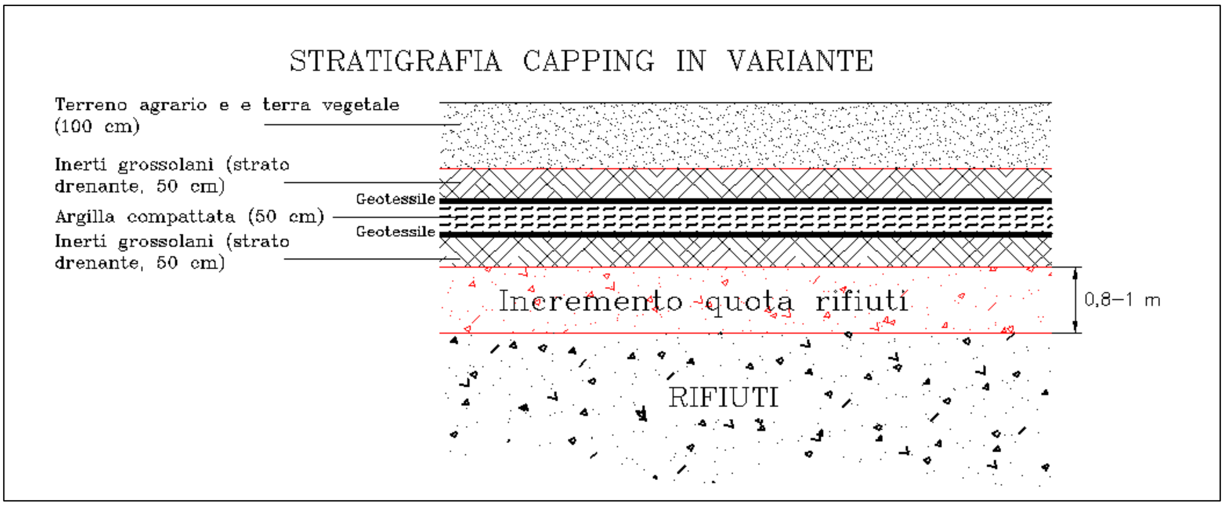

Figure 17: Current scheme of the capping in the third lot.

In 2017 the impermeabilization of the third lot was extended along the west and south slopes. This expansion was made by the excavated material of this last lot of the landfill. This situation is displayed in Figure 18.

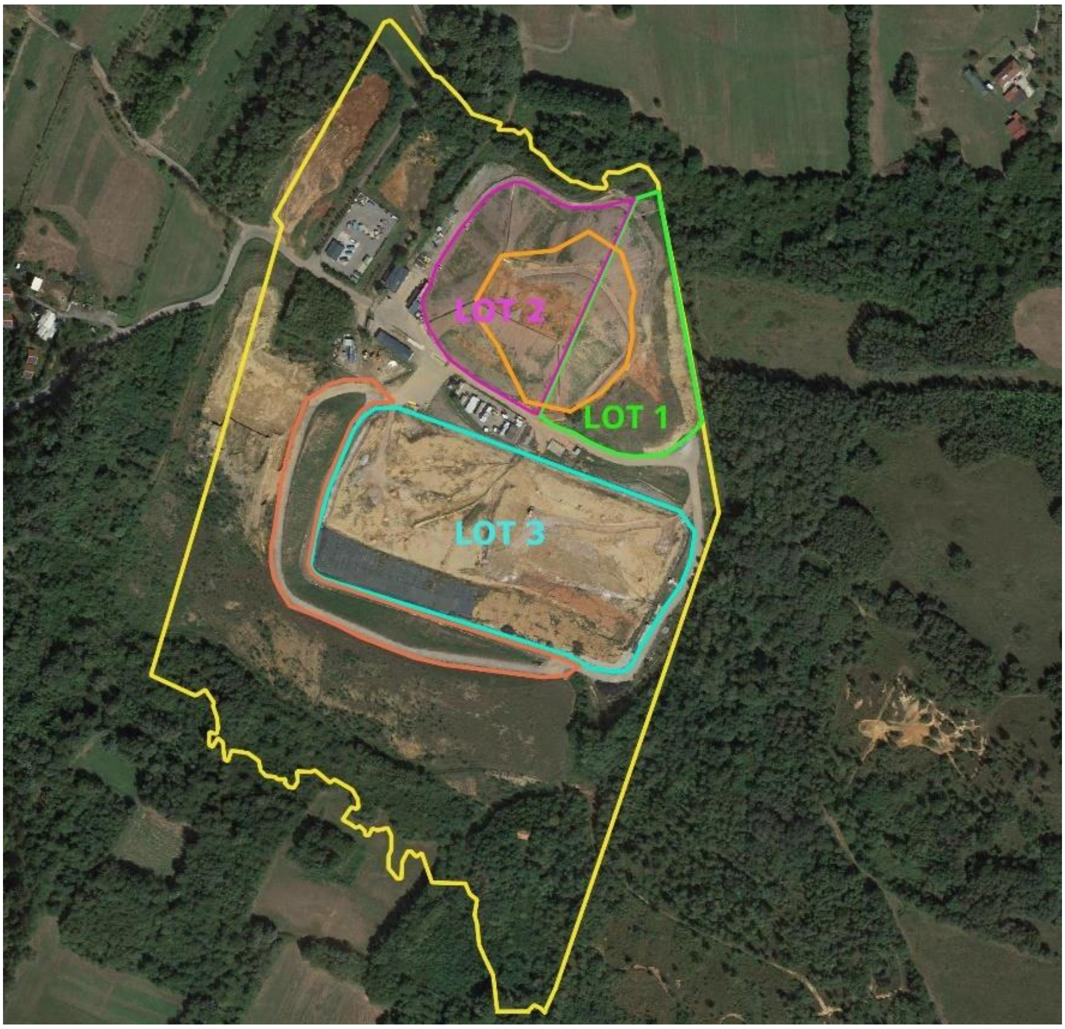

Figure 18: Expansion of lot 3 in dark orange line.

The consequence is an elevation of this lot and the capacity increase of 370,000 m^3 (260,000 t). The executive project of the third lot was in 2018 with an authorized volume of 821,800 m^3.

1.3 Spatial planning constraints.

The town plan (PRGC) for the municipality of Grosso was developed in 1977 with the regional law 56, it was approved in 2011 with the Regional Council Resolution, n. 41 – 2685. Figure 19 is an extract of table b 1:5000, use of soil, with a scale of 1:700.

The area of the landfill is bordered with the pink line in the Figure 19. The geomorphological reorganization of the zone in the west side was made with the last version of PRGC in 2014 with the resolution n°8.

An extract of the last version of the new PRGC is in Figure 20. With the expansion of the F zone is possible to enlarge the landfill with a new lot in the west side of the property (blue line in Figure 20).

The zone of the landfill belongs to Grosso, but the nearest municipality is Nole and the distance of the new centre from the nearest settlement is more or less equal to the distance from the other lots.

The landfill belongs to F zone, "Consortium plant for solid waste disposal".

Some constraints are hereby analysed:

- landscape constraint: the landfill is not in a protect area according with D. Lgs. 22. The zone is outside the buffer zone of 150 m from the left bank of the Fisca river. Furthermore, the landfill is not in a forested area.
- hydrogeological constraint: a buffer zone of 5 m has to be considered in the north boundary of the landfill for the presence of a brook (Chapter 1.1).
- Floodplain Buffer zones: the site is not in the zone A (band of flood flow) or B (area of flooding) of the local rivers (t. Stura di Lanzo e t. Malone)
- Protected areas: near the landfill there is the SIC-7-IT 1110005 "Vauda". The final design has to be correlated with the Valutazione di Impatto Ambientale (VIA) and with the Valutazione di Incidenza Ecologica

At the same time a waste pre-treatment plant will be implemented to have a preliminary selection of the waste. In this way the bulky waste can be sorted and sent to other destinations.

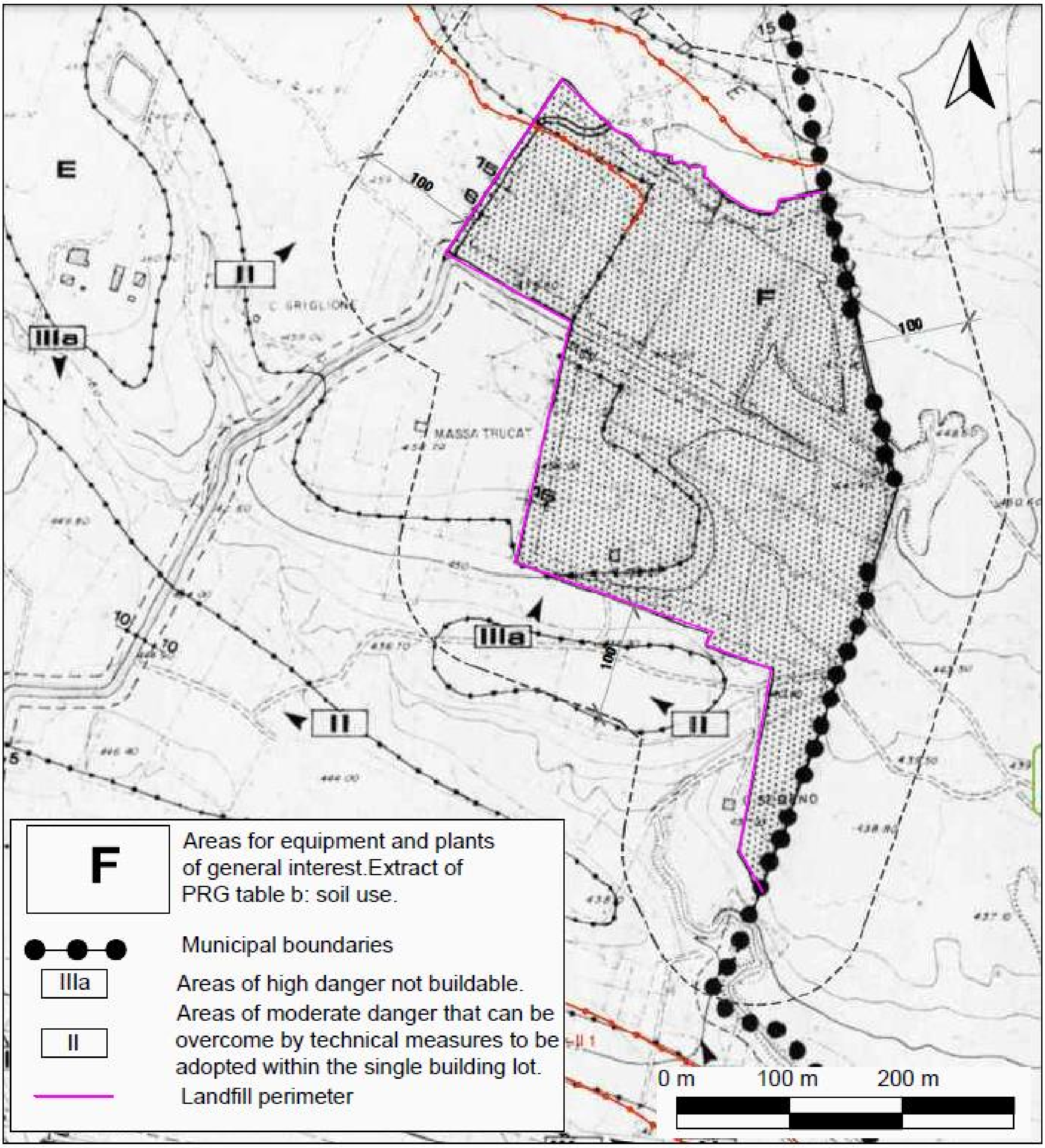

Figure 19: Extract of the table b of PRGC, Grosso. The boundary of the landfill is in pink line.

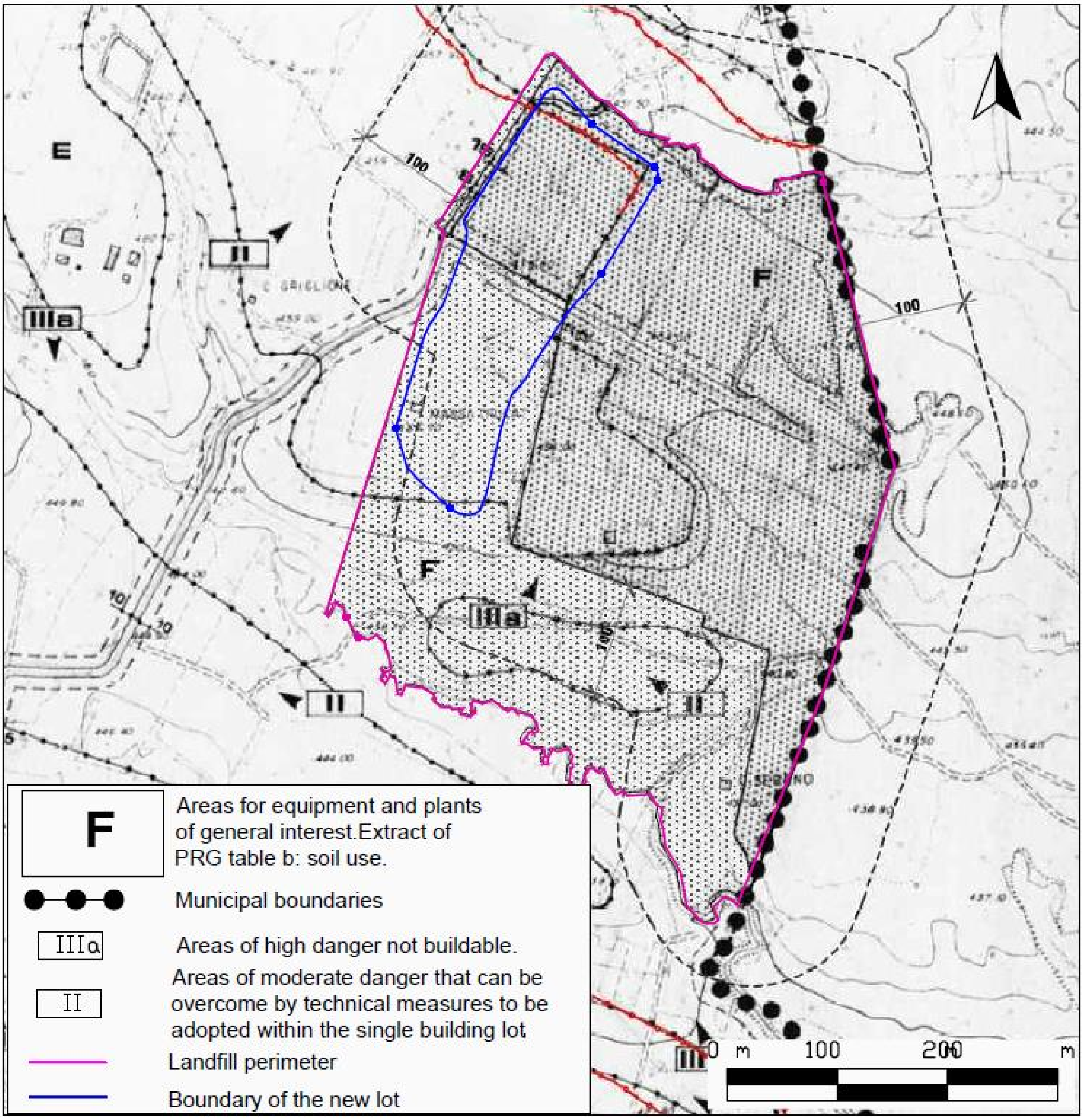

Figure 20: Extract of the new version of the PRGC. The new boundary of the landfill is in pink line, instead a possible option for the new lot is in blue.

2 METHODS

2.1 Data acquisition and processing.

Before working out solutions, a key need is to have an accurate 3D model of the terrain and an accurate representation of the current plan footprints of lots and of plants, along with spatial constraints given by, inter alia, the town masterplan. In this subchapter, some insights are given on the derivation of the Digital Terrain Model (DTM) (Chapter 2.1.1) and on the processing of georeferenced data with GIS and CAD software (Chapter 2.1.2).

2.1.1 Digital Terrain Model.

The Digital Terrain Model is obtained by drone flight, a kind of drone used for the plano-altimetric surveys, is in Figure 21: Example of droneFigure 21.

Figure 21: Example of drone.

The photogrammetry with the drone allows to have metric information of the land starting from the processing of photographs taken from different points of view. It is a real digital photography technique, in this case with a drone, that can be processed using professional software. Such software using aerial shots with drone can detect common points (called homologues) between all the images that are inserted, on which the cloud of the points will be built. Indeed, it is a group of points with the characteristic of being positioned by coordinates with precise values associated with the homologue points.

The photos and the topographic measurements of G.C.P. (Ground Control Points) are imported and a three-dimensional scaled and georeferenced model is generated, using special calculation algorithms. The result is the D.T.M. (Digital Terrestrial Model).

The digital model can be easily imported into the CAD and GIS environment to support the design. The level curves are generated by digital models of the terrain, i.e., they are formed by the union of points with the same altitude, and they represent the elevation of the terrain. They are the result of the photo matching process. These are a valuable tool to analyse the orography of the terrain and the trend of slopes. At each point of the cloud is associated its own position in a coordinate system and a value that characterizes the colour. For absolute accuracy the values range from one to two times the GSD, Ground Sample Distance (it is defined as the distance between the central points of two consecutive pixels of an image, measured on real ground. In essence, GSD is the "amount of land" contained in a pixel of orthophotos. The parameter is measured in meters on pixels, for horizontal measurements and one to three times the GSD for vertical measurements.

The DTM of the landfill of Grosso is in Figure 22.

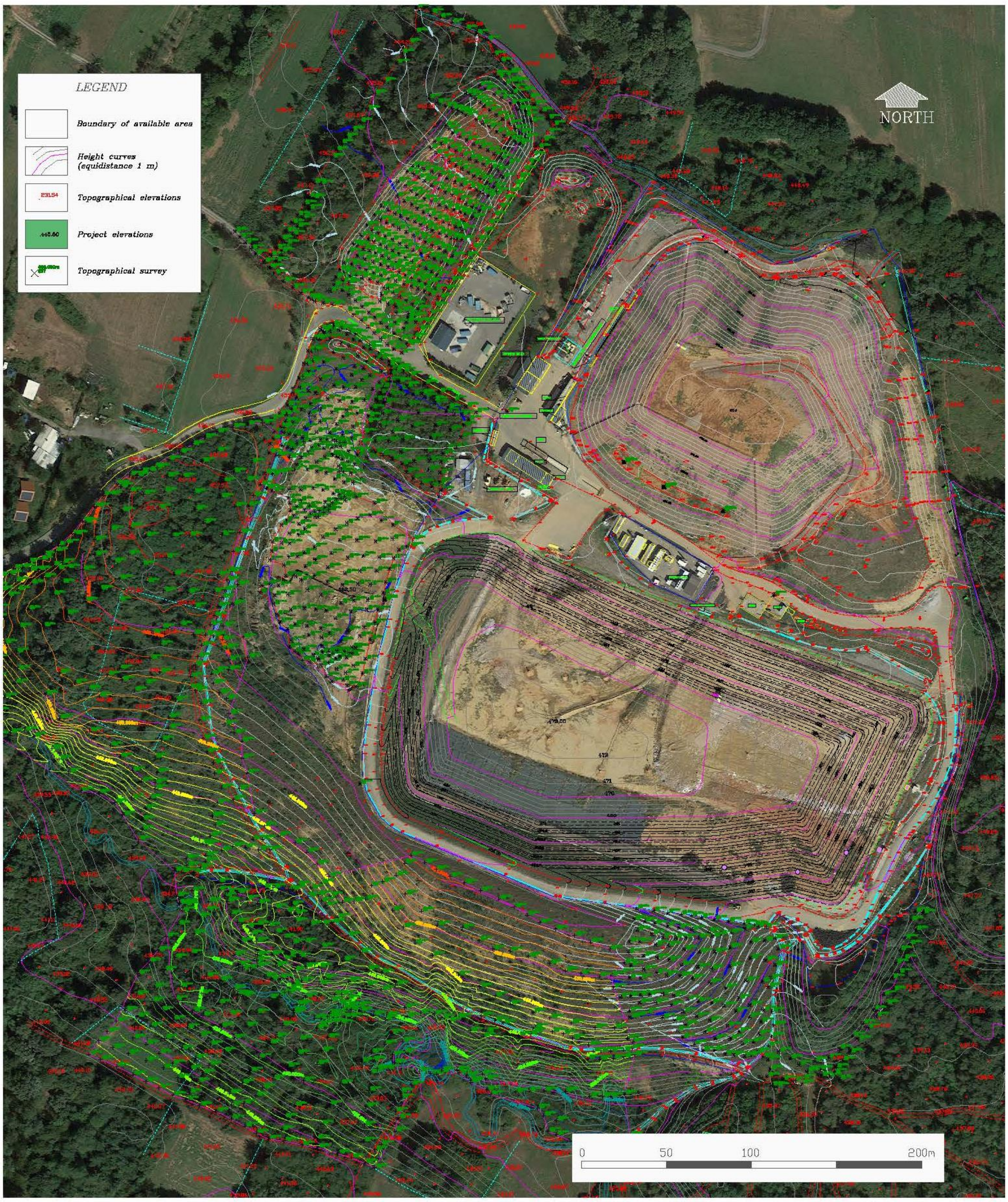

Figure 22: DTM of the area ah the landfill. The level curve are in pink lines and the dark crosses are the point of the topographic survey.

2.1.2 GIS and CAD input data processing

The Q-Gis program is used in this work to obtain a clear knowledge of the present situation. The preliminary part of this work is the creation of a model using the shape files that have been downloaded from the Geo-portal of Piedmont Region**.**

The base map of the model is in Figure 23 and it's a Google satellite image with the shape file of the municipal boundary. The piezometry, orography and the bottom of the aquifer are important information to understand the position of the groundwater and to protect it from leachate. The previous information are in Figure 24.

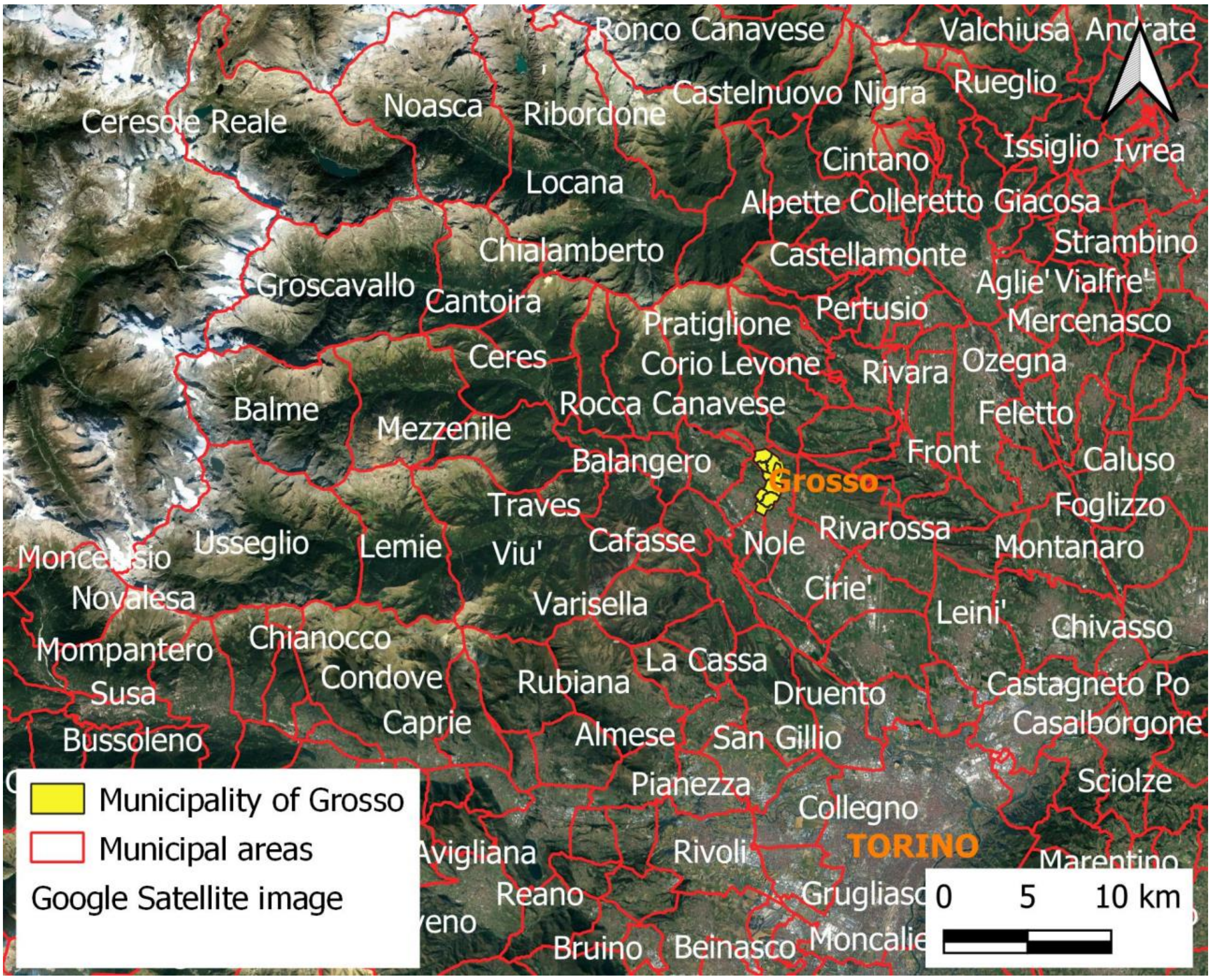

Figure 23: Base map of the Q-Gis model.

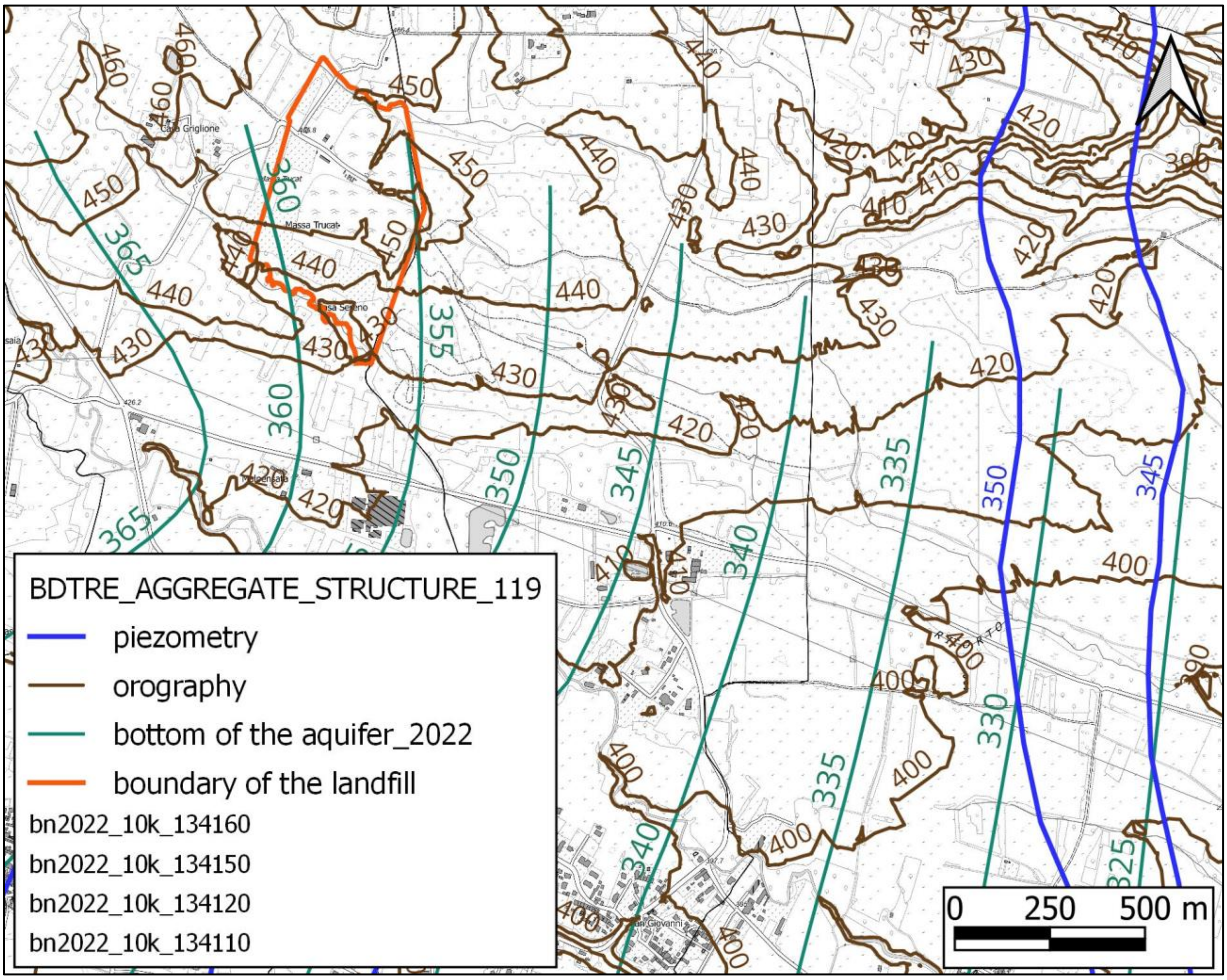

Figure 24: Position of the groundwater: in blue line the piezometry, in brown line the orography and in green line the bottom of the aquifer. The base map is a map layout of reference (BDTRE) and the orange line is the position of the landfill.

The design of the solutions is based on the digital terrain model (Chapter 2.1.1). The project of the excavation is developed on Autocad by drawing the elevation curve of the slopes. The result is the planimetry of the landfill.

The next step is to measure on cad the area of each elevation curve and then the volume between two curves is calculated as the average area of two elevation curve multiplied by 1 m. The sum of each single volume is the total volume of excavation. This is the most important information that determines the best solution (please refer to Table 9, Table 12, Table 14, Table 18).

The elevation of the waste is evaluated as before, the elevation curves are designed with a certain distance according to the slope (please refer to Table 10, Table 13, Table 15, Table 19).

2.2 Proposed solutions.

Three main solutions were hypothesized for the new parcel of the landfill and are hereby described. Solution 1 (Chapter 2.2.1) foresees the realization of the new lot on the western side, i.e., before the current entrance of the landfill. Since this solution would require a major change of the access road, a variant was developed (Solution 2, Chapter 2.2.2), in which the lot is divided into two sub-lots separated by the current access road. Since Solutions 1 and 2 would require the occupation of additional land surface, Solution 3 was developed (Chapter 2.2.3), in which the lot is realized exploiting the slopes of existing Lots 2-3.

In the first two solutions the position of the lot is the same instead for the third solution the new lot is between the second one and the third one.

For this last solution the slope of the excavation is 22° because it has a small depth of more or less 5 m. On the other hand, the slope for the other position is considered 34°. A higher slope results in a larger volume available for waste dumping, but the realization is more complex because come concrete must be added to the clay to improve its geotechnical properties.

2.2.1 Solution 1: one lot on the western side.

This solution involved the west side of the existing landfill with a merged lot from the north to the south part of the area and so the entrance road cannot be conserved. An issue is that the aqueduct line and the electric line, that pass through the entrance rode, must be shifted. As a result, also the weighbridge is placed along the space between the new lot and the second one.

The new N-W lot occupies the space of the eco-station, transport deposit and of the tank of second lot.

Another point of the project is the realization of a pre-treatment plant that can be in an area near the west boundary of the landfill (Chapter 2.3.7).

This preliminary study maximizes the amount of waste disposable and so the slope of the excavation is 34°.

2.2.2 Solution 2: two separated lots on the western side.

This solution also involved the west side of the existing landfill. The difference to the previous one is that there are two small lots, separated by the existing entrance road.

With this solution the aqueduct line and the electric line are kept, and the position of the weighbridge is not changed.

The interference of eco-station, pre-treatment plant and the tank of lot 2 is the same of the first solution.

Also in this case, the slope of the excavation is 34°.

2.2.3 Solution 3: new lot lying on existing ones.

The aim of this solution is to use the inner space of the landfill between the second and the third lots, the new lot is lying on the existing one.

This solution allows to conserve the entrance road and so the electric and hydraulic lines, and the position of the eco-station.

The advantage of this solution is that the expropriation of parcels is not necessary, i.e., the pre-treatment plant can be placed on the south side of the eco-station.

On the other hand, this solution interferes with the weighbridge and with the Asja plant that is placed near the pre-treatment plant.

2.3 Evaluation criteria.

The three solutions of Chapter 2.2 are now evaluated in detail according to the criteria described below.

2.3.1 Earthworks.

The main technical choice for earthworks affects the inclination of the excavated slopes. Two angles are considered (Figure 25):

- An angle of 22° that would result in 2.5 m of horizontal distance per every meter of elevation.
- An angle of 34° that would result in 1.5 m of horizontal distance per every meter of elevation.

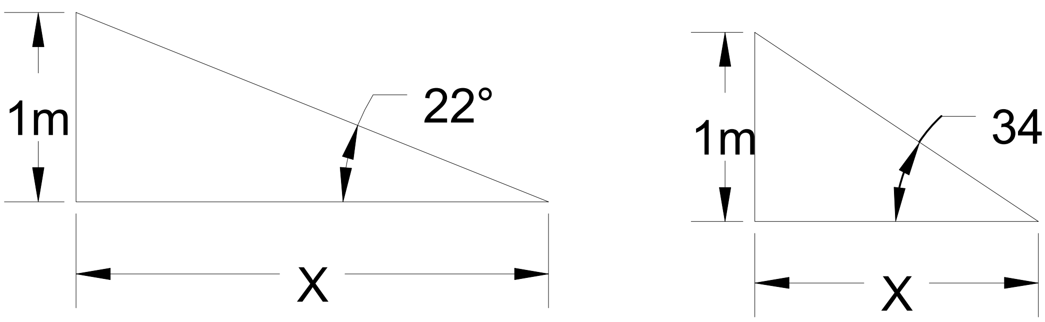

Figure 25: Slope angles considered: 22°(left) and 34° (right).

The solution with a slope of 34° is the best to have a greater available volume but is more difficult to construct. The stability of the isolation on the slopes is guaranteed with the use of a mix of clay and concrete and so the construction is more difficult.

On the other hand, the slope of the landfill above ground is always 22°.

The reference legislation is the D.Lgs. 13rd January 2003, n°36 that was updated with the D.Lgs 3rd September 2020, no. 121 (in particular, Annex 1-point 2 Stacks for non-hazardous and hazardous waste- point 2.4 protection of soil, subsoil and water-point 2.4.2. bottom and shore barriers).

The volume of collected wastes is an important evaluation criteria. At this scope the volume is calculated as the sum of the averages of the areas of two consecutive level curves.

2.3.2 Interference with existing installations.

The choice is also based on the interference with the existing installations. There are many possible configurations for the infrastructure.

The infrastructure that are involved in the construction of the new lot are (Figure 26):

1. Leachate tank of the second lot
2. Office fabricate (2a) and transport deposit (2b)
3. Asja cogeneration plant
4. Eco-station
5. Weighbridge

A further element to be considered is the possible interference with the road used by local inhabitants and show in grey in Figure 27.

Figure 26: Current situation, aerial photo.

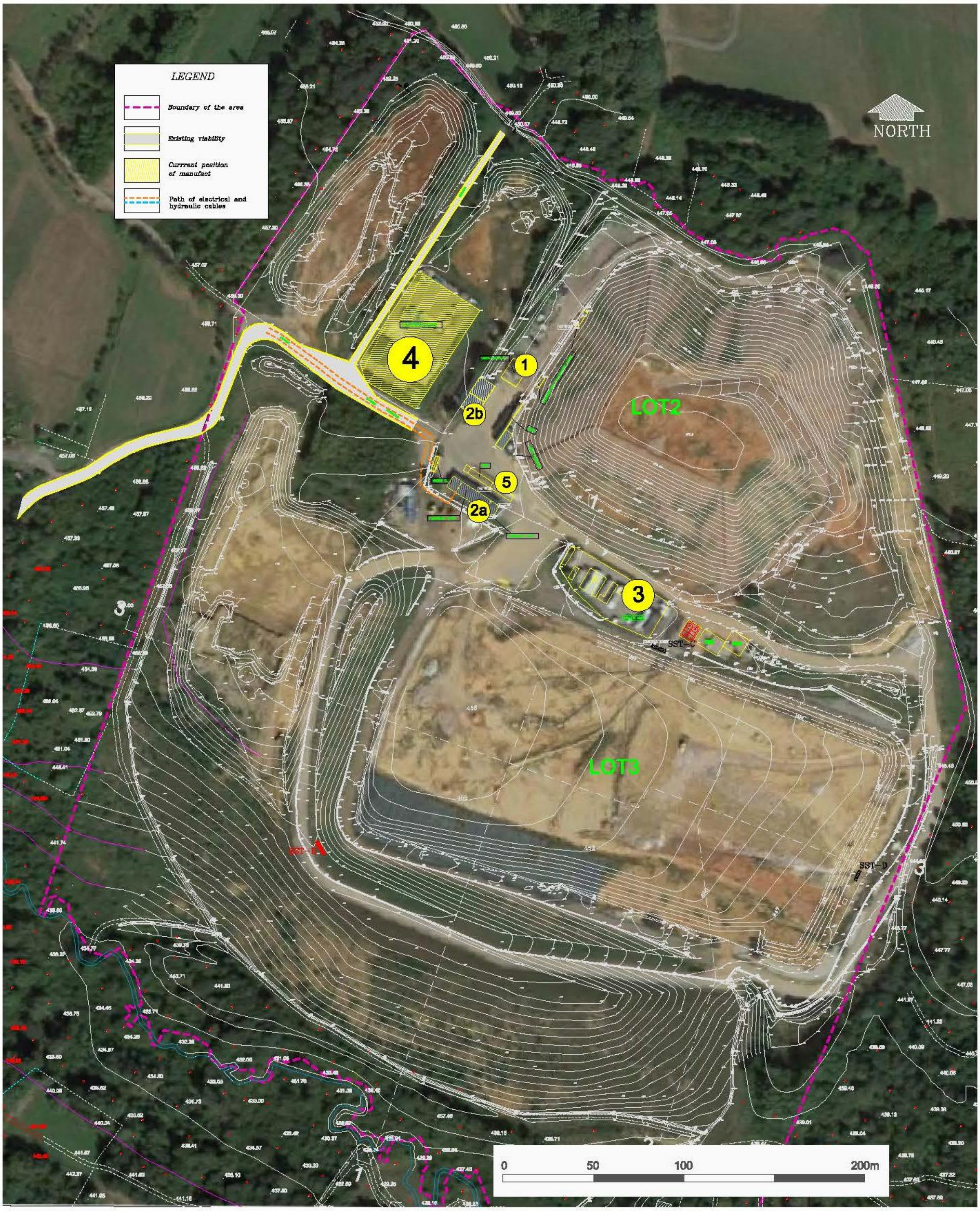

Figure 27: Elements of the landfill that can interfere with the new lot: 1) Leachate tank of the second lot; 2) Office fabricate and transport deposit; 3) Asja cogeneration plant; 4) Eco-station; 5) Weighbridge; the road used by local inhabitants (in yellow).

1

The leachate is collected in underground tanks as showed in Figure 28. The tank of the second lot must be dismantled for each solution to guarantee a passage around the new lot and the alternative viability for the lorry.

Figure 28: Current situation: photo of second lot tank.

2.

The office building must be change only in the third solution because the western boundary of the new excavation occupies this area. This infrastructure is prefabricated and so is not difficult to move. The only issue is the connection with the *Enel* cabin and with the cables of the aqueduct (Figure 29).

Figure 29: Current situation: photo of the office building.

3.

Between the existing lots there is the cogeneration plant of *Asja Ambiente Italia S.p.A.* This plant uses the biogas (it is composed by 50% of methane) generated by waste in order to produce electric energy. The electrical power of the power-generating module is 834 kW_e and it covers the needs of more than 1,760 families with four components each one.

The electrical energy is fed in the Enel's distribution network.

The interference with Asja plant is only in the third solution. This plant is only linked to the wells of biogas of lot 3 by three collectors respectively linked to three biogas pressure regulating stations. The biogas wells are divided in three zones linked to the three regulating substations (SST-C, SST-D, SST-E in Figure 30).

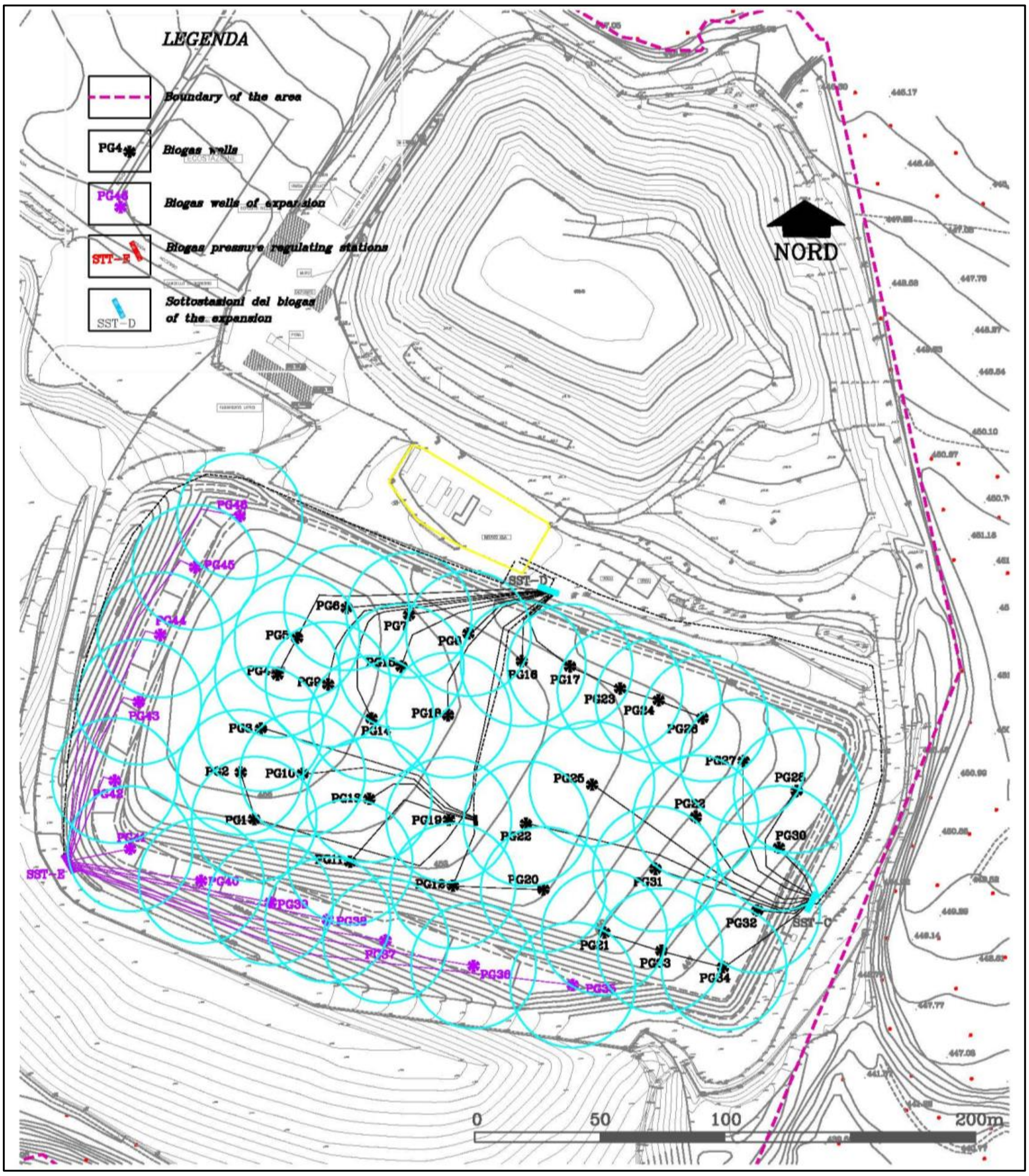

Figure 30: Current situation: connection of the biogas wells with Asja plant.

The biogas wells of the first two lots are not connected because there is no more biogas production. In the third solution the issue is to shift the plant near the west edge of the third lot and to change the path of the collectors.

However, the new lot, for each of the three solutions, needs other regulating substation and other connections to the cogeneration plant.

4.

The existing eco-station occupies the area on the west side of the second lot, it is visible in Figure 31. Therefore, it is dismissed only in solution one and two.

One of the principal goals of the third solution is to maintain the current position of the eco-station nonetheless, there is the idea of shift the eco-station nearer to the first houses as in Figure 32.

Figure 31: Current situation: photo of the Eco-station.

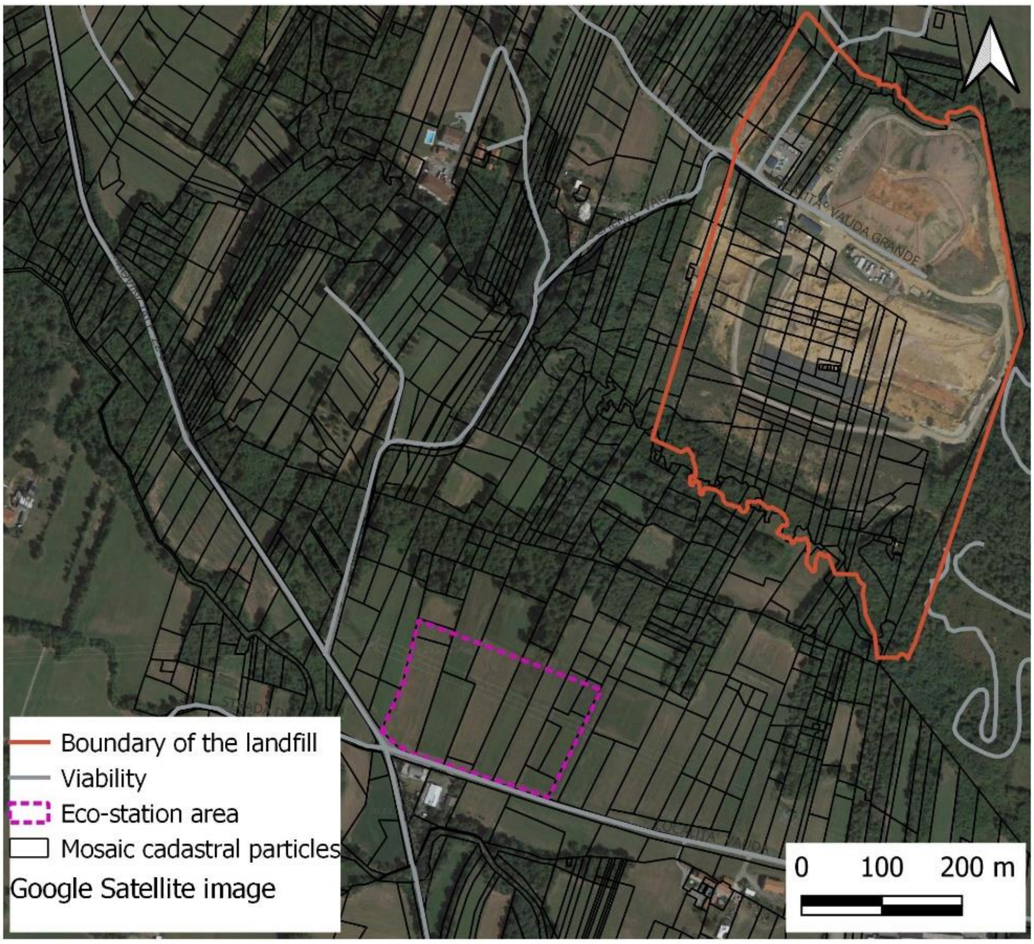

Figure 32: Individuation of the zone for the Eco-station.

5.

The presence of weighbridge is required by the Legislative Degree 152/2006 (alias "Testo Unico Ambientale"). The amount of waste that enter in the destination site must be weighted in order to verify the information in the FIR (Formulario Identificativo dei Rifiuti).

The lorries need a straight section of the road before the weighbridge so as to they can adjust their direction.

The weighbridge of the landfill addressed in this work is in Figure 33.

Figure 33: Current situation: photo of the weighbridge.

In the first solution the current entrance road is closed by the new lot and so the weighbridge is shifted along the new road. The third solution also require the previous intervention because, in this case, the new lot occupy a part of the area of the weighbridge.

2.3.3 Interference with existing pipelines and cable conduits.

The two cable conduits that feed the landfill are: the electrical one and the aqueduct one.

The paths of both pipelines are not clear. In this work the position of the cables is supposed to be along the existing entrance road (Figure 34) but in the future the surveys are necessaries to verify the situation.

The main difference between the first and the second solution is the conservation of the entrance road and so of the existing pipelines.

As a result, the solutions two and three are better than the second one from the point of view of this interference.

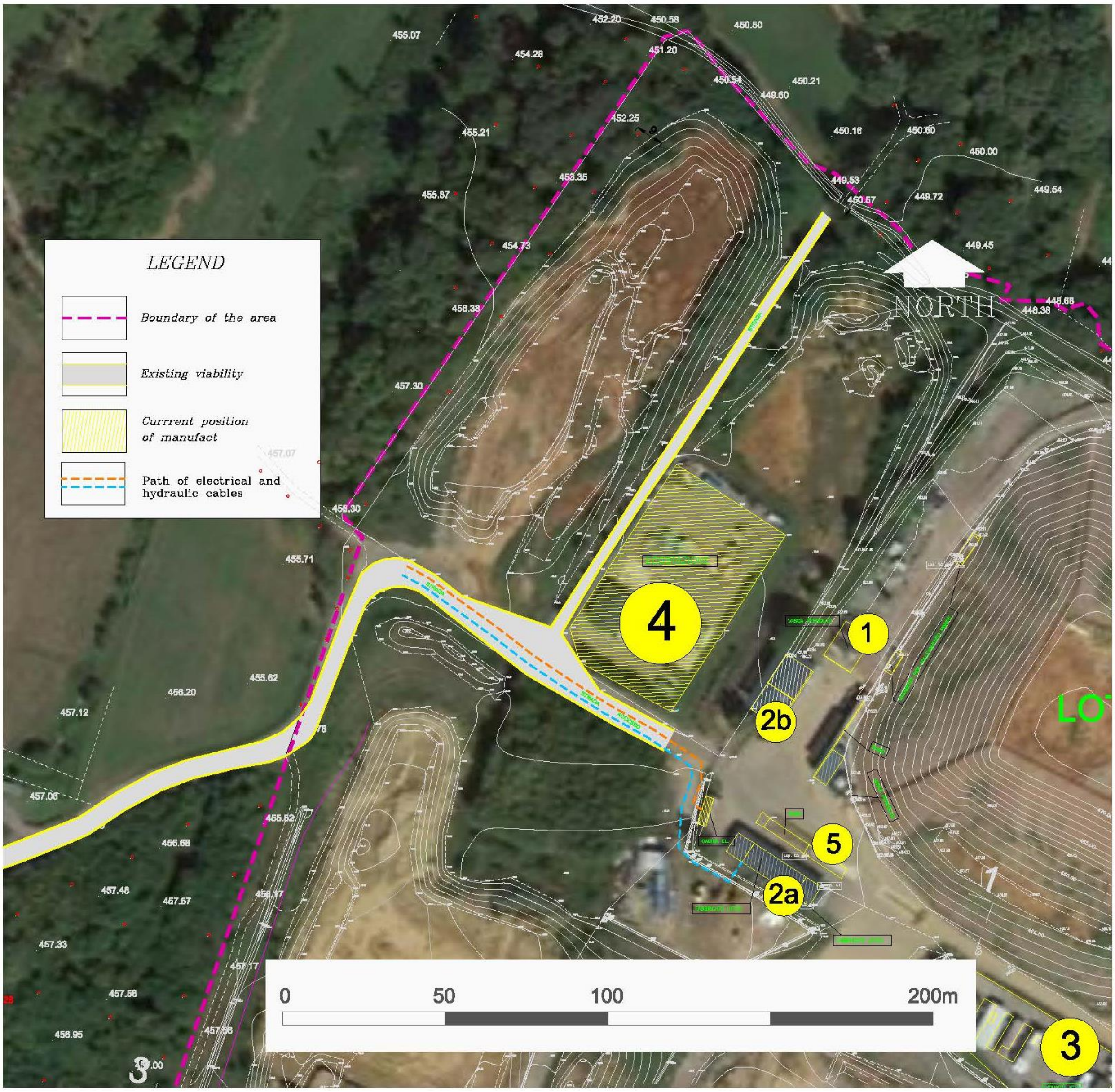

Figure 34: Approximate paths of the aqueduct pipelines (light blue) and of the electrical cable conduits (orange).

2.3.4 Impermeabilization of the bottom of the excavation.

The impermeabilization is made by different layers according to the D.lgs. 121/2020. The natural geological barrier is the deeper one and it must be at last 1.5 m above a confined aquifer and 2 m above the maximum hight of the top of the unconfined aquifer. If there is not the geological barrier a clay layer of 0,5 m must be use sometimes with geosynthetic. The thickness of 0.5 m can be reduced in the slopes. Over this natural barrier there is the artificial waterproofing made by clay (otherwise called impermeabilizzazione mineraria) of 1 m. The clay is spread and compacted each 0,25 m. For a non-hazardous waste landfill, the geological barrier has a hydraulic conductivity of 10^{-9}

m/s and a thickness of 1 m. Over the clay level there is the impermeable geomembrane in HDPE (high level polyethylene) with a thickness of 2.5 mm. The last layer is 0.5 m of a draining material. Figure 35 is a scheme of the impermeabilization of the bottom of the excavation.

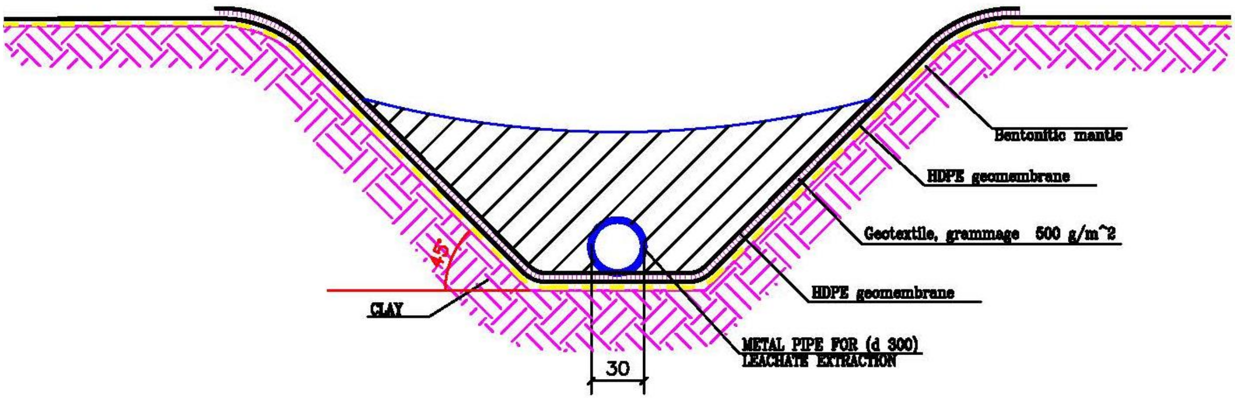

Figure 35: Stratigraphy of the bottom liner of the landfill.

The impermeabilization surface is:

- 41,813 m^2 for the first solution.
- 42,477 m^2 for the second solution.
- 22,030 m^2 for the third solution.

The surface that must be waterproofed is more or less the same for solution one and two. The difference is the operational difficulty. In the second case the clay can be applied in a single time instead in solution one there are two different excavations.

Another point is the fixation of the impermeable geomembrane in HDPE with a thickness of 2.5 mm. For this reason, a trapezoidal hole is performed all along the edge of the excavation ("trincea di zavorramento") The hole has a depth of 80 cm and an amplitude of 1 m. The ends of bentonitic mantle and the geomembrane are rolled out inside the hole that is filled with compacted natural soil. Therefore, is better to have a unique excavation, in fact, in solution two there is not the middle holes at both the side of the road.

The third solution, instead, presents the issue of the retention of the leachate. A part of waste of the new lot will be over the previous one and so the rain that falls over is not contained by an excavation. The solution is the construction of a small embankment of clay along the edge of the waste above the previous lots.

2.3.5 Final capping.

The capping keeps the waste isolated from the outdoor environment, in order to:

- minimize the infiltration of the water and so the quantity of leachate.
- reduce the maintenance.

- reduce the erosive phenomena.
- improve the impact between the landfill and the landscape.

The coverage is a multilayer structure. From the bottom to the top there are (Figure 36):

- Adjustment layer made by drainage material.
- Compacted mining layer with a thickness of at last 0.5 m and a hydraulic conductivity $K \leq 10^{-8}$ m/s. It can be substituted by geosynthetic.
- Drainage layer of granular material with a thickness of at least 0.5 m and a hydraulic conductivity $K > 10^{-5}$ m/s
- Natural filter that retains the finest material of the upper layer.
- the shallow layer with a thickness of at least 1 m has to ensure the growth of the plant species. These perform the environmental restoration and protect the underlying layers from erosion and from thermal excursions.

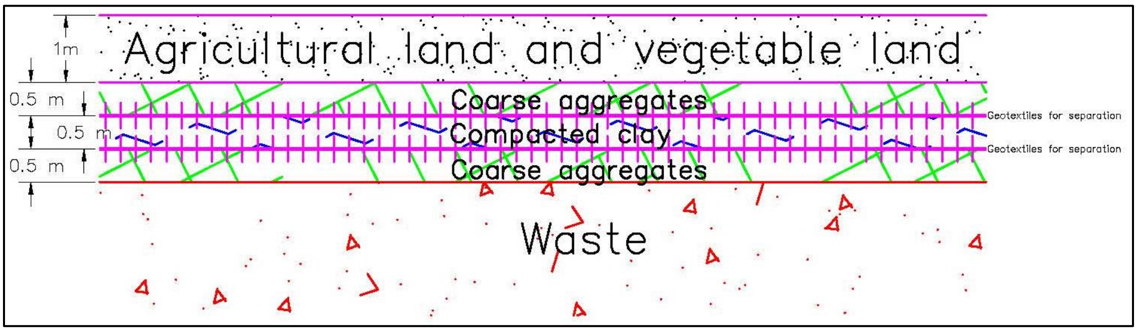

Figure 36: Stratigraphy of the final capping.

The final capping is performed when the lot is depleted. The solution one allows to have a unique hill and is easier to assign a more uniform slope in respect to the solution one.

From this point of view the best solution is the third one because the space between lot two and lot three is filled and the result is a unique landfill on the east part of the site.

2.3.6 Biogas and leachate wells.

The radius of influence of the biogas wells is 25 m and they have to cover the entire surface occupied by waste. A step in the middle of the lot's slope is necessary in order to ensure the stability of the biogas wells but in this feasibility study is not present and the design is just to figure out the number of the wells. In Table 3 there is the estimated price for one biogas well based on the Price List of Piedmont Region 2022. The price of a biogas well is more or less 20,000 €.

The same evaluation is made for the leachate wells that are placed at the end of each pipe on the bottom of the excavation. The pipes run along the basis of the excavation to catch the leachate. At least two pipes are placed for each excavation to prevent the stop of the system in the case of clogging or maintenance of one line.

The length of the pipe for a single well in Table 2 is an average value and the price for the realization of a leachate well is more or less 45,000 €.

Table 2: Estimated cost for a leachate well.

	SIZE	U.M.	n°	UNIT PRICE [€]	TOT [€]
Supply and installation of hdpe pipes for drainage, produced with virgin granule of 1 quality, smooth surface standards uni 7611 76 type 312. - diameter 160 mm pn12,5 with 3 perpendicular slots at the axis for the 2/3 of the alternate circumference between them, slot width 4/8 mm Leachate drainage on tank bottom	70	m	1	23.14	1619.8
Realization of extraction system of the leachate as planned, including oblique well on the slope and relative concrete base, pump and connection with the drainage manifold, delivery pipe, and everything else needed to give the work perfectly executed to rule of art.		cad	1	40 000	40 000
TOT					41 620

Table 3: Estimated cost for a biogas well.

	SIZE	U.M.	n°	UNIT PRICE	TOT €
Supply and installation of pipe base element fissured drainage for vertical wells of biogas, including junction sleeve and stainless steel fixing screws			1	90	90
Formation of drainage or wasps close to masonry with the use of pebbles provided by the firm, for quantities exceeding m^3 0. 10 (machined, including service worker's)	1.5	m^3	1	27.7	41.55
HDPE well head with flange Inspection, testing and valve butterfly interception.		cad	1	900	900

	SIZE	U.M.	n°	UNIT PRICE	TOT €
Supply of polyethylene pipes a. D. Compliant standard ISO 4437 and recognised by the s5 series iip mark for pipelines underground for the distribution of gas fuels prepared for butt welding for polyfusion. De 90 (3") sp. 8,2 mm Biogas connection from wells to substations	133	m	1	5.44	723.52
Laying of polyethylene pipes series s5 by welding by polyfusion including head or electrofusion, and offset in the price the supply and the insertion of special pieces and any other burden to give the finished work to perfection. De 110 Biogas connection from wells to substations	133	m	1	8.59	1142.47
Condensate separators, made of hdpe, to be inserted on the biogas supply lines		cad	1	900	900
Flow valve for the regulation of depression on the individual wells		cad	1	130	130
Construction of new substation complete for the biogas		cad	1	15 000	15000
Supply of polyethylene pipes a. D. Compliant standard ISO 4437 and recognised by the s5 series iip mark for pipelines underground for the distribution of gas fuels prepared for butt welding for polyfusion. De 200 (8") sp. 18,2 mm Connection from substations to the system of suction and energy recovery	16	m	1	27	432
Laying of polyethylene pipes series s5 by welding by polyfusion including head or electrofusion, and offset in the price the supply and the insertion of special pieces and any other burden to give the finished work to perfection. De 200 Connection from substations to the system of suction and energy recovery	16	m	1	13.13	210.08
TOT					19 570
					20 000

2.3.7 Expropriation of new land.

The third solution does not require the expropriation because all the fabricates are in the area of SIA S.r.l.. Instead, in the first two solution, SIA S.r.l. must obtain other lands for the pre-treatment plant.

A preliminary assumption is to use the land along the west side of the landfill, the green area in Figure 37.

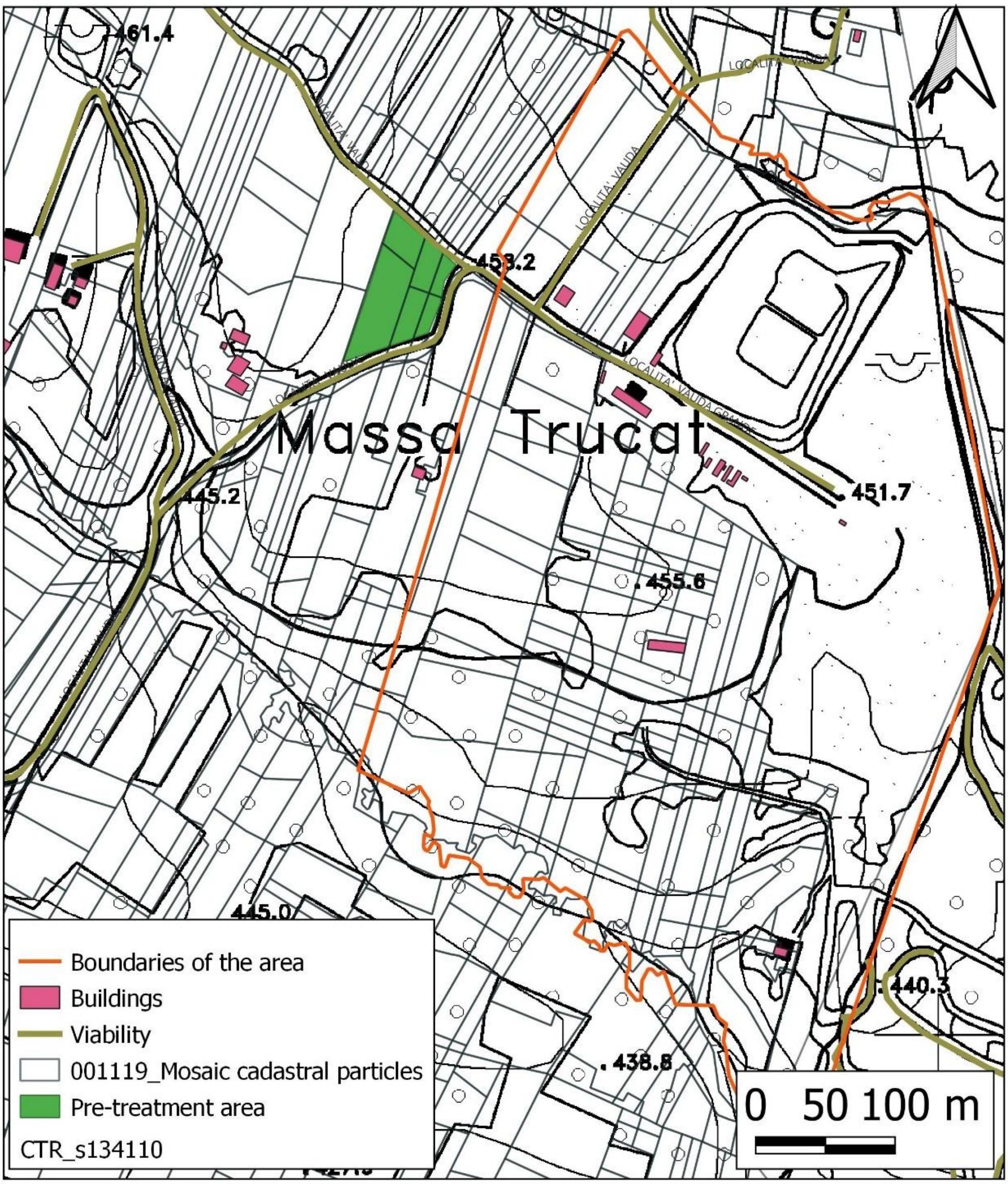

Figure 37: Position of the area for pre-treatment plant (green area).

2.3.8 Estimation of costs.

The excavation, impermeabilization and final capping have a great influence in the installation cost. The first thing is the evaluation of the volume of excavation, including the impermeabilization. In particular, according to D.lgs. 121/2020, the thickness of the impermeabilization is 1.5 m at the bottom and 1 m along the slopes.

In Table 4, Table 5, Table 6, taking into account the price list of Piedmont Region 2022 (Prezzario Regione Piemonte 2022 [3]), there are the evaluation of the cost for the excavation for the three solutions.

Table 4: Solution one, cost of excavation.

Section	Code	Description	Size	U.M.	Unit price[€]	€
01	**01.A01.A10**	General excavation, stripping or open section excavation, in loose or compact soils up to 4 m deep, carried out by mechanical means, excluding mine rock but including rock and masonry blocks up to 0,50 m³, measured in actual section, including loading on trucks, transport and accommodation within the yard area				
01	01.A01.A10.010	Even in the presence of water up to a maximum swing of 20 cm	153 493	m³	4.12	632 391
01	**01.A01.A15**	General excavation, stripping or open section excavation, in loose or compact soils, more than 4 m deep, carried out by mechanical means, excluding mine rock but including rock and masonry blocks up to 0,50 m³, measured in actual section, including loading on trucks, transport and accommodation within the yard area				
01	01.A01.A15.010	Even in the presence of water up to a maximum swing of 20 cm, only for the part exceeding 4 m	503 942	m³	5.40	2 721 288
TOT						3 353 679

Table 5: Solution two, cost of excavation.

Section	Code	Description	Size	U.M.	Unit price[€]	€
01	**01.A01.A10**	General excavation, stripping or open section excavation, in loose or compact soils up to 4 m deep, carried out by mechanical means, excluding mine rock but including rock and masonry blocks up to 0,50 m^3, measured in actual section, including loading on trucks, transport and accommodation within the yard area				
01	01.A01.A10.010	Even in the presence of water up to a maximum swing of 20 cm	156 693	m^3	4.12	645 575
01	**01.A01.A15**	General excavation, stripping or open section excavation, in loose or compact soils, more than 4 m deep, carried out by mechanical means, excluding mine rock but including rock and masonry blocks up to 0,50 m^3, measured in actual section, including loading on trucks, transport and accommodation within the yard area				
01	01.A01.A15.010	Even in the presence of water up to a maximum swing of 20 cm, only for the part exceeding 4 m	401 520	m^3	5.40	2 168 209
TOT						2 813 784

Table 6: Solution three, cost of excavation.

Section	Code	Description	Size	U.M.	Unit price[€]	€
01	**01.A01.A10**	General excavation, stripping or open section excavation, in loose or compact soils up to 4 m deep, carried out by mechanical means, excluding mine rock but including rock and masonry blocks up to 0,50 m³, measured in actual section, including loading on trucks, transport and accommodation within the yard area				
01	01.A01.A10.010	Even in the presence of water up to a maximum swing of 20 cm	20 996	m³	4.12	86 504
01	**01.A01.A15**	General excavation, stripping or open section excavation, in loose or compact soils, more than 4 m deep, carried out by mechanical means, excluding mine rock but including rock and masonry blocks up to 0,50 m³, measured in actual section, including loading on trucks, transport and accommodation within the yard area				
01	01.A01.A15.010	Even in the presence of water up to a maximum swing of 20 cm, only for the part exceeding 4 m	1 762	m³	5.40	9 515
TOT			22 758			96 018

The excavation of the third solution is very small in respert to the previous ones and so the price is more or less € 100,000. On the other hand, solution one and two are comparable, the difference is only the portion of excavation below the current entrance road.

The cost for the impermeabilization and the final capping are the other two main voice of the economic balance.

The economic evaluation addresed in this work considers two average price , i.e., 85 €/m^2 for the waterproofing package and 75 €/m^2 for the final capping. In Table 7 there are the value respectively for the three solutions.

Table 7: Price for the impermeabilization and the final capping.

SOLUTION ONE					
Section	**Description**	**Size**	**U.M.**	**Unit price[€]**	**€**
Waterproofing	Landfill waterproofing package. HDPE clay, bentonite and geomembrane mattress	28 996	m^2	85	2 464 660.00
Capping and recovery	75 € per square meter are considered	27 552	m^2	75	2 066 365.25
SOLUTION TWO					
Section	**Description**	**Size**	**U.M.**	**Unit price[€]**	**€**
Waterproofing	Landfill waterproofing package. HDPE clay, bentonite and geomembrane mattress	32 337	m^2	85	2 748 645.00
Capping and recovery	75 € per square meter are considered	30 239.64	m^2	75	2 267 973.00
SOLUTION THREE					
Section	**Description**	**Size**	**U.M.**	**Unit price[€]**	**€**
Waterproofing	Landfill waterproofing package. HDPE clay, bentonite and geomembrane mattress	22 039	m^2	85	1 873 315.00
Capping and recovery	75 € per square meter are considered	23 646.00	m^2	75	1 773 450.00

The total cost for excavation, impermeabilization and final capping is in Table 8.

The comparison is based on the economic indicator: the ratio between the total cost of the new lot and the cubic meter of waste that can be disposed.

The cost of the third solution is three times the cost of the other two. The option with the new lot ling on the existing one is abandoned in favour of the other two. However, it will be reconsidered when the new lot, addressed in this work, will be depleted in order to complete the landfill of Grosso.

Table 8: Evaluation of cost of excavation, impermeabilization and capping.

	SOLUTION ONE	**SOLUTION TWO**	**SOLUTION THREE**
Excavation [€]	3 353 679	2 813 784	96 018
Waterproofing [€]	2 464 660	2 748 645	1 873 315
Capping and recovery [€]	2 066 365	2 267 973	1 773 450
TOT [€]	7 884 704	7 830 402	5 626 225
TOTAL VOLUME [m^3]	770 000	701 000	110 000
Economic indicator [€/m^3]	10.24	11.17	34.03

3 RESULTS

3.1 Analysis of Solution 1.

3.1.1 Earthworks.

The solution one considers the construction of a unique lot in the west side of the area, the expansion reservoir has a roughly rectangular shape, with a 37,500 m^2.

The design slope of this lot is in Figure 38, the angle of excavation is 34° (1/1.5) and the elevation slope 22° (1/2.5). The excavation goes from 454 m a.s.l. to 436 m a.s.l. The greater angle is used in the excavation in order to maximize the amount of disposable waste.

In Table 9 and in Table 10, the total volume is calculated measuring the areas subtended by the level curves.

Table 9: Volume of excavation for solution 1.

Excavation		
Level curves	m2	m3
436	13834	
437	14890	14362
438	15967	15428.5
439	17063	16515
440	18181	17622
441	19318	18749.5
442	20476	19897
443	21654	21065
444	22853	22253.5
445	24071	23462
446	25308	24689.5
447	26562	25935
448	27832	27197
449	29119	28475.5
450	30421	29770
451	31478	30949.5
452	32367	31922.5
453	33128	32747.5
454	33653	33390.5
455	33542	33597.5
456	33206	33374
457	31868	32537
458	30133	31000.5
459	28313	29223
460	26404	27358.5
TOT		621 522

Table 10: Volume of elevation for solution 1.

Elevation		
Level curves	m2	m3
460	26 404	
461	24 407	25 405.5
462	22 461	23 434.0
463	20 561	21 511.0
464	18 700	19 630.5
465	16 894	17 797.0
466	15 142	16 018.0
467	13 441	6 720.5
468	11 793	12 617.0
469	3 009	7 401.0
470	-	1 504.5
TOT		152 039.0

The excavated volume that can be used for the waste is 621,522 m^3 and the excavated volume for the impermeabilization is 35,913 m^3. The total volume that must be excavated for the first solution is 657,435 m^3.

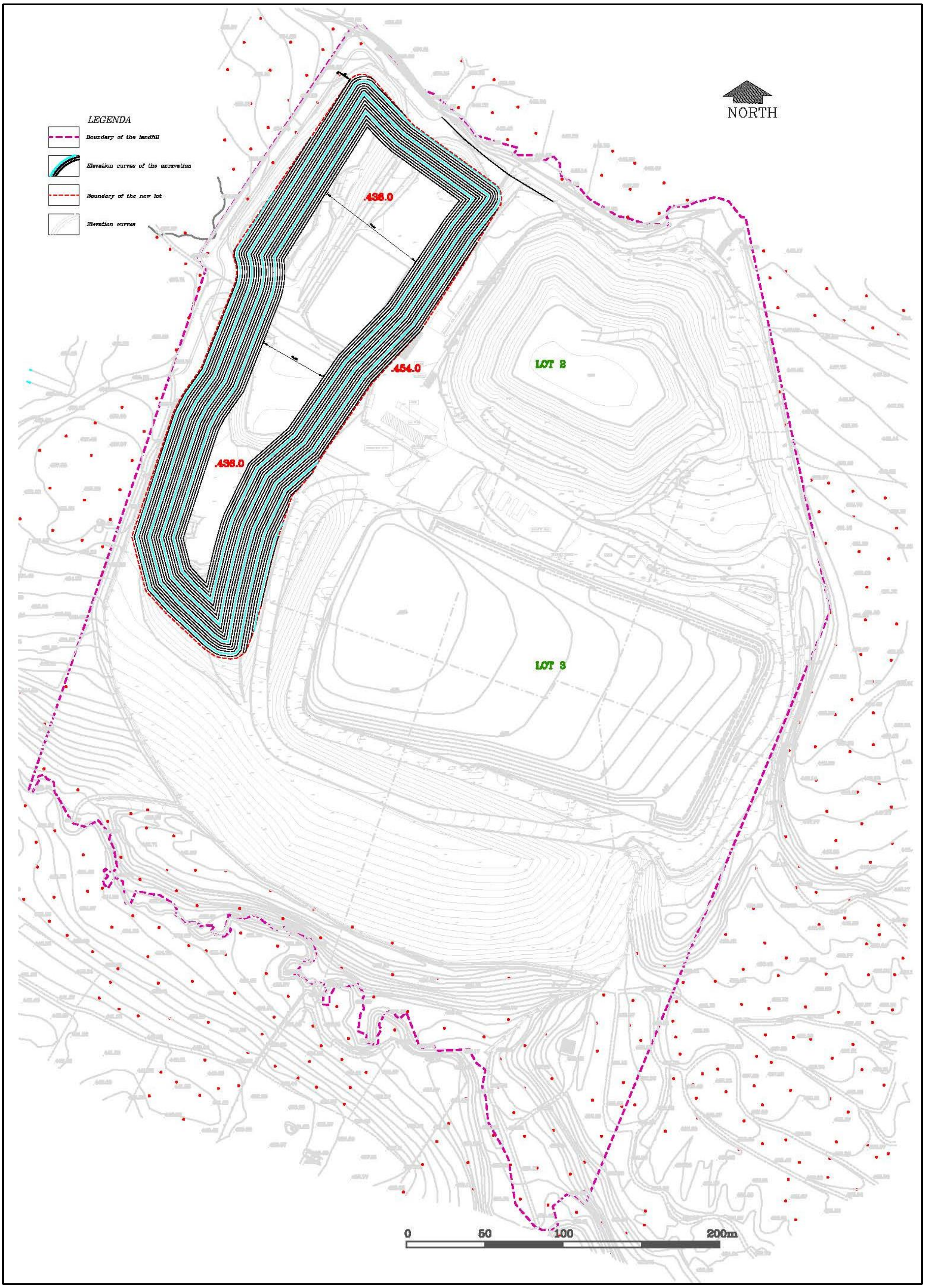

Figure 38: Excavation of the first solution.

3.1.2 Interference with existing installations and expropriation of new lands.

The new lot occupies all the west portion of the SIA's area and so it interferes with current entrance road. The new entrance road passes along the outermost perimeter of the new lot, and the entrance of the landfill is on the north side of the area between lot two and the new one.

A direct consequence is that the weighbridge is rotated of 90° and it is located along the west side of the second lot because the lorry of waste needs a straight before the weighbridge.

The leachate tank of the second lot is also in the zone between the current eco-station and the second lot. It can be reconstructed at the end of the leachate wells that are along the west side of the second lot and its volume can be smaller than the current one because the second lot is old, and it doesn't produce big amount of leachate

The new lot occupies the zone of eco-station and of the transport deposit. The eco-station is moved in a land closest to the first house (Chapter 2.3.2) and moreover, the land on the west side of the new lot is acquired by the SIA s.r.l. in order to construct a pre-treatment plant (Chapter 2.3.7). Moreover, this is a zone II in the PRGC of Grosso, in particular is defined as an area of modest hazard, which could be overcome through technical measures to be implemented in the lot to be developed (in the original document: "area di moderata pericolosità superabile mediante accorgimenti tecnici da attuare nell'ambito del singolo lotto da edificare").

The pre-treatment-plant has the entrance at south on the road that bring to provincial road 22 and the exit on the road that bring to the new entrance of the landfill.

Currently, the zone behind the office is occupied by old and unused container. This area can be redeveloped and used as car park, transport deposit and equipment storage.

The situation of the first solution is well explained in Figure 39.

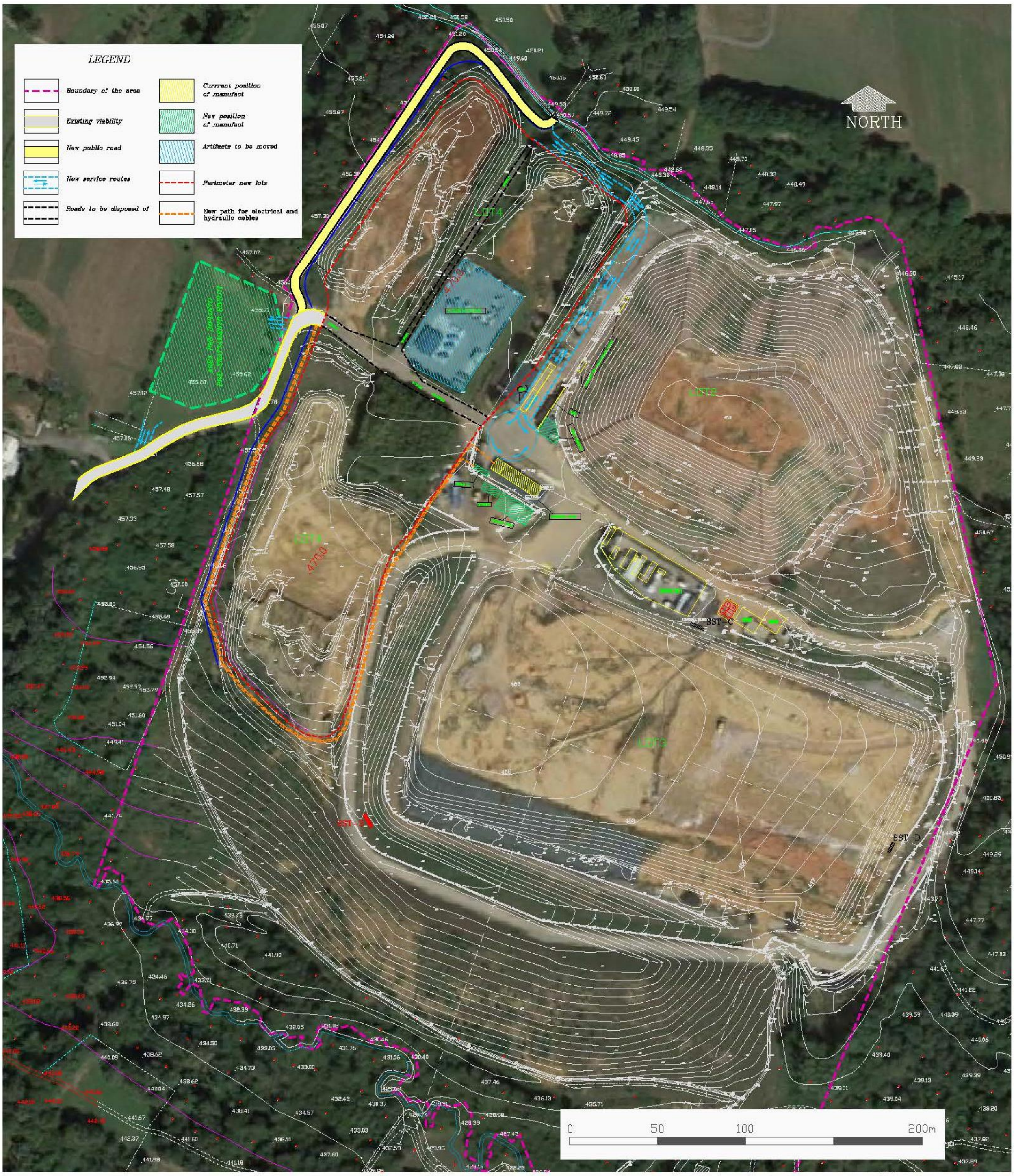

Figure 39: Plan view of the first solution.

3.1.3 Interference with existing pipelines and cable conduits.

The existing pathway of the electric cable is along the entrance road. The cables are used for the office and for the forecourt lighting and they arrived at the *Enel*'s cabin that is in front of the office. The new pathway could pass along the terrain at south of the new lot of the landfill (orange line in Figure 39).

At the same time the aqueduct cable that pass through the entrance road has to be moved along the south boundary of the new lot in order to arrive to the office (orange line in Figure 39).

3.1.4 Biogas wells and leachate wells.

The biogas wells for this solution are represented in Figure 40 (pink circle). The solution one requires 32 biogas wells to cover the entire surface of the new lot.

This solution has a unique big lot and so with the embankments (dashed dark line in Figure 41) the landfill tank can be filled in different steps. The leachate wells have to be constructed at the end of the pick-up line (dashed orange line in Figure 41) and in this case there are 8 wells.

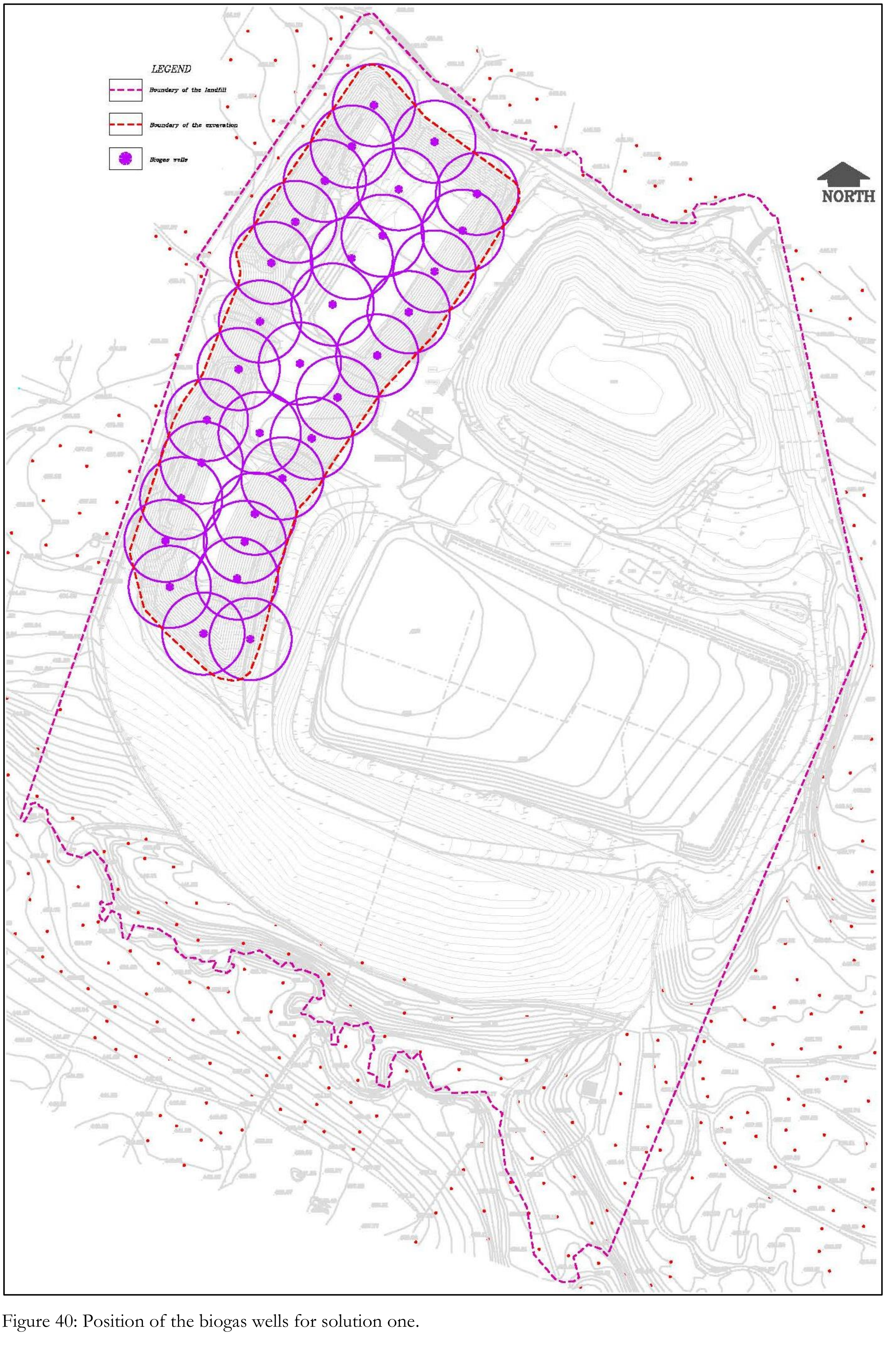

Figure 40: Position of the biogas wells for solution one.

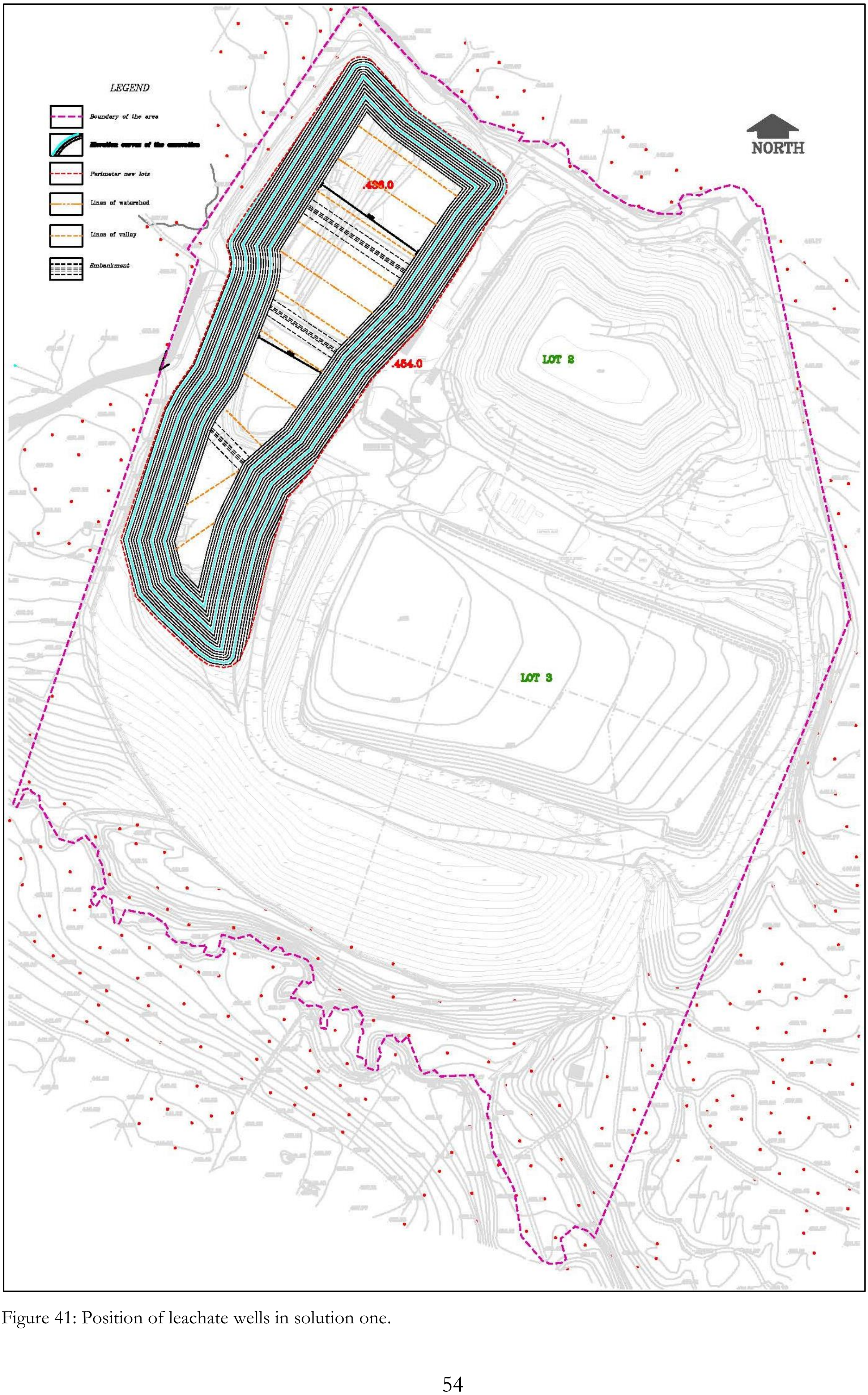

Figure 41: Position of leachate wells in solution one.

3.1.5 Estimated costs.

This chapter analyses in detail the cost of the first solution.

The cost of excavation is evaluated with the price voice in section 1 of the Price List of Piedmont Region 2022. The evaluation is divided in two voices according to the depth reached.

The other voices of Table 11 are mainly based on the metric calculation of the other lots of the landfill addressed in this work, for example, the impermeabilization and the drainage are instead evaluated with a mean price for m^2.

According to Table 11 the price for this solution is more or less € 10,800,000 with a capacity of 770,000 m^3 of disposable waste.

The final economic indicator is calculated in the equation below:

$$Economic\ indicator = \frac{total\ cost}{volume\ of\ waste} = \frac{10800000}{770000} = 14.05\,\frac{€}{m^3} \qquad \text{Eq. 1}$$

Table 11: Estimated cost for the first solution.

Section	Code	Description	Size	U.M.	Unit price[€]	€
01	**01.A01.A10**	General excavation, stripping or open section excavation, in loose or compact soils up to 4 m deep, carried out by mechanical means, excluding mine rock but including rock and masonry blocks up to 0,50 m³, measured in actual section, including loading on trucks, transport and accommodation within the yard area				
01	01.A01.A10.010	Even in the presence of water up to a maximum swing of 20 cm	153 493	m³	4.12	632 391
01	**01.A01.A15**	General excavation, stripping or open section excavation, in loose or compact soils, more than 4 m deep, carried out by mechanical means, excluding mine rock but including rock and masonry blocks up to 0,50 m³, measured in actual section, including loading on trucks, transport and accommodation within the yard area				
01	01.A01.A15.010	Even in the presence of water up to a maximum swing of 20 cm, only for the part exceeding 4 m	503 942	m³	5.40	2 721 288
TOT						3 353 679
Waterproofing		Landfill waterproofing package. HDPE clay, bentonite and geomembrane mattress	28 996	m^2	85	2 464 673.57
Capping and recovery		75 € per square meter are considered	27 551	m^2	75	2 066 360.33
Drains		0.5 m layer thickness, considering only the bottom and not the escarpments	6917	m^3	26	179842
Leachate storage		Tanks of 50 m^3 each	1	cad	50 000	350 000
Leachate wells			8	cad	45 000	360 000
Biogas wells			32	cad	20 000	640 000
Moving municipal road			1400	m^2	100	140 000
Eco-station shift						500 000
Enclosure			920	m	60	55 200
Electricity network						100 000
Water supply and sewerage						150 000
New access track with roundabout			2800	m^2	100	280 000
Redevelopment of the area			1800	m^2	100	180 000
TOT						**10 819 755**
Economic indicator						**14.05**

3.2 Analysis of Solution 2.

3.2.1 Earthworks.

The second solution has the same design of the first one, but the new lot is divided in two sub-lots by the current entrance road: the first one in the area on the north of the entrance road and the second in the area on the south of the entrance road.

The expansion reservoir is composed by two roughly rectangular holes, with a total surface of 36,486 m^2.

As in the previous solution, the design slope of this lot is 34° (1/1.5) for the excavation that goes from 454 m a.s.l. to 436 a.s.l. and 22° (1/2.5) for the elevation.

The design of the excavation is in Figure 42.

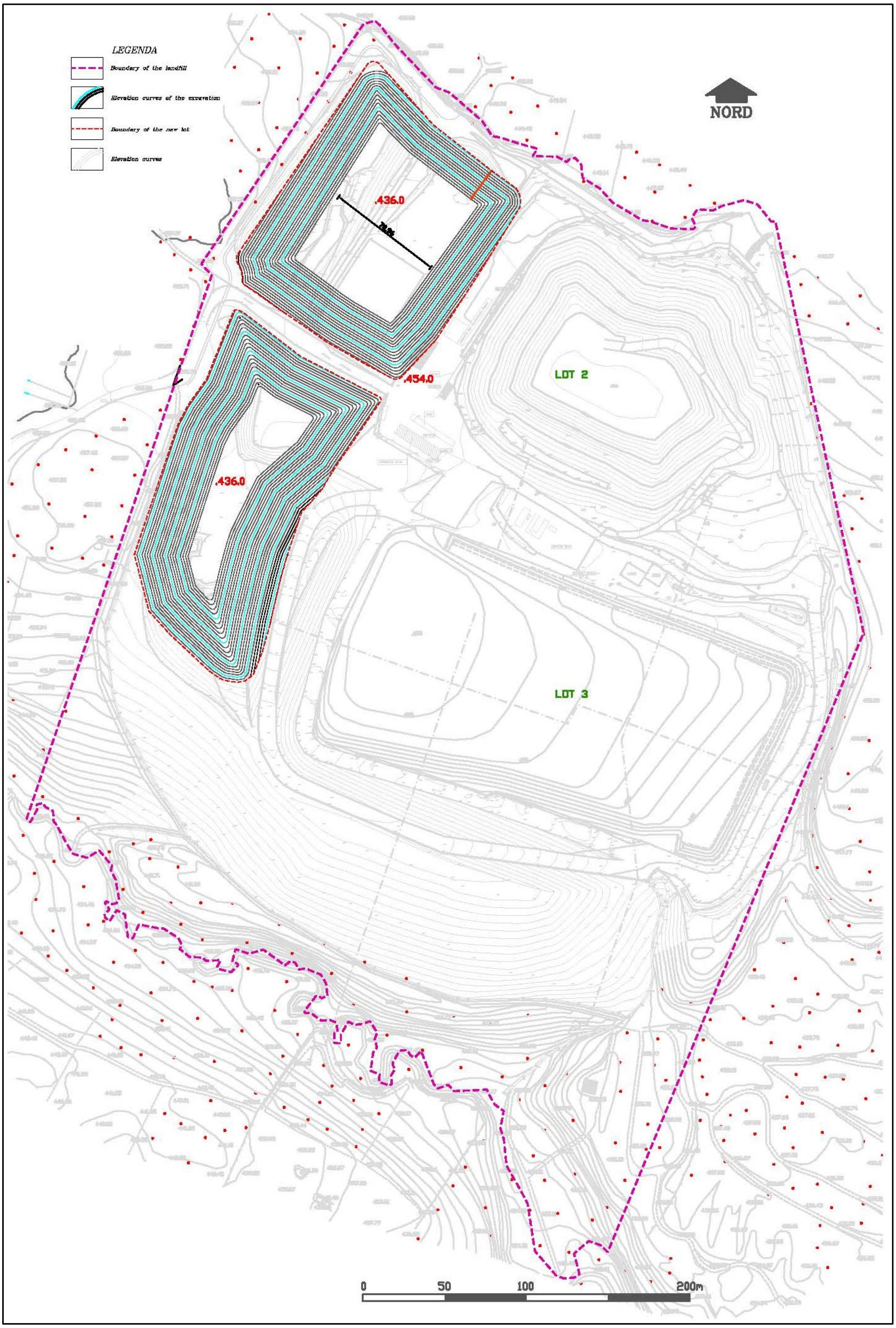

Figure 42: Excavation of the second solution.

In Table 12 and Table 13 there are the values of the N-W part of the new lot and in Table 14 and Table 15 the volume of the S-W part of the new lot.

Table 12: Volume of excavation of solution two, N-W lot.

N-W Excavation		
Contour lines	m^2	m^3
436	7 100	
437	7 600	7 350
438	8 100	7 850
439	8 700	8 400
440	9 290	8 995
441	9 880	9 585
442	10 490	10 185
443	11 120	10 805
444	11 760	11 440
445	12 420	12 090
446	13 090	12 755
447	13 780	13 435
448	14 490	14 135
449	15 200	14 845
450	15 940	15 570
451	16 454	16 197
452	16 717	16 586
453	16 826	16 772
454	16 696	16 761
455	16 297	16 497
456	15 651	15 974
457	15 651	15 651
TOT		271 876.50

Table 13: Volume of elevation of solution two, N-W lot.

N-W Elevation		
contour lines	m2	m3
457	15 651.0	
458	13 405.0	14 528.0
459	12 290.0	12 847.5
460	11 198.0	11 744.0
461	10 153.0	10 675.5
462	9 156.0	9 654.5
463	8 209.0	8 682.5
464	7 313.0	7 761.0
465	6 468.0	6 890.5
466	5 673.0	6 070.5
467	4 931.0	5 302.0
468	4 242.0	4 586.5
469	3 606.0	3 924.0
470	-	1 803.0
TOT		104 469.5

Table 14: Volume of excavation of solution two, S-W lot.

S-W Excavation		
Contour lines	m^2	m^3
436	3 339.0	
437	3 830.0	3 584.5
438	4 342.0	4 086.0
439	4 874.0	4 608.0
440	5 428.0	5 151.0
441	6 002.0	5 715.0
442	6 597.0	6 299.5
443	7 212.0	6 904.5
444	7 848.0	7 530.0
445	8 505.0	8 176.5
446	9 182.0	8 843.5
447	9 880.0	9 531.0
448	10 598.0	10 239.0
449	11 335.0	10 966.5
450	12 090.0	11 712.5
451	12 863.0	12 476.5
452	13 654.0	13 258.5
453	14 460.0	14 057.0
454	15 287.0	14 873.5
455	16 170.0	15 728.5
456	16 195.0	16 182.5
457	15 650.0	15 922.5
458	14 774.0	15 212.0
459	13 864.0	14 319.0
460	12 942.0	13 403.0
TOT		248 780.50

Table 15: Volume of elevation of solution two, S-W lot.

S-W Elevation		
Contour lines	m^2	m^3
460	12 942.0	
461	11 972.0	12 457.0
462	10 790.0	11 381.0
463	9 677.0	10 233.5
464	8 612.0	9 144.5
465	7 596.0	8 104.0
466	6 627.0	7 111.5
467	5 706.0	6 166.5
468	4 837.0	5 271.5
469	4 020.0	4 428.5
470	-	2 010.0
TOT		76 308

The total volume of the new parcel of the landfill, in Table 16, is the sum of the volume of the excavation and the elevation of the single lots.

Table 16: Total volume for the second solution.

	Volume (m^3)
TOT , N-W lot	376346
TOT, S-W lot	325088.5
TOT	701434.5

The total volume that can be used for the waste is 520,657 m^3 and the total volume of excavation for the impermeabilization is 37,556 m^3. Finally, the total volume that has to be excavated for the second solution is 558,213 m^3.

3.2.2 Interference with existing installations and expropriation of new lands.

The new lot occupies the portion of land of the eco-station, as in the previous solution, that is shifted near the first houses.

In the second solution the access road for the lorry is not changed but the N-W part of the new landfill is bigger than in the first solutions and so the tank of the second lot is shifted to allow the passage between the new lot and the second one. The new tank is smaller than the current one and is situated at the west boundary of the second lot, near the leachate wells.

Even in this case, the area behind the office is used as parking area and as a deposit and the pre-treatment plant is in the same position of solution one.

The situation is clarified in Figure 43.

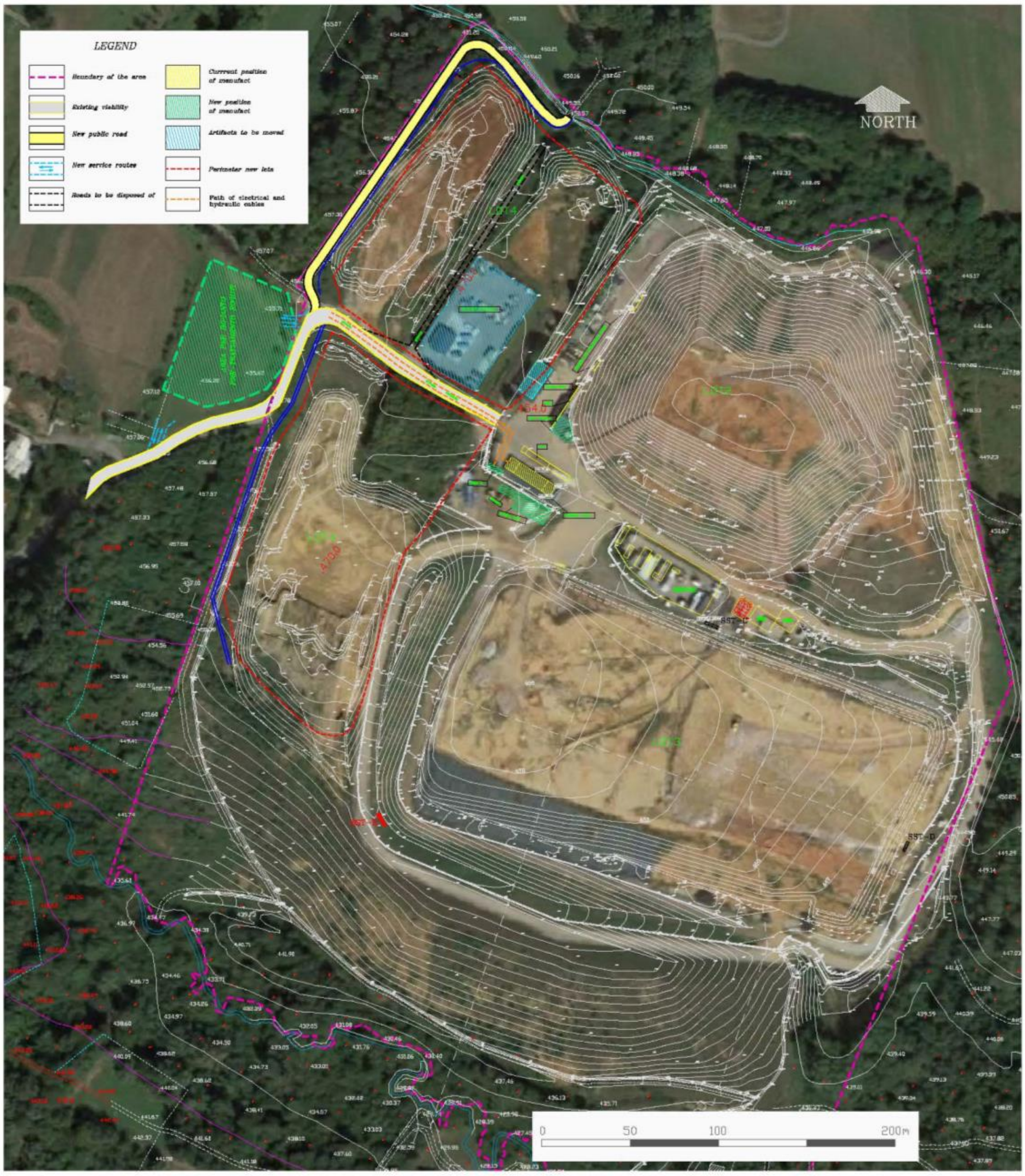

Figure 43: Planimetry of the second solution.

3.2.3 Biogas wells and leachate wells.

The biogas wells for this solution are represented in Figure 44 (pink circle). The solution two requires 31 biogas wells to cover the entire surface of the new lot.

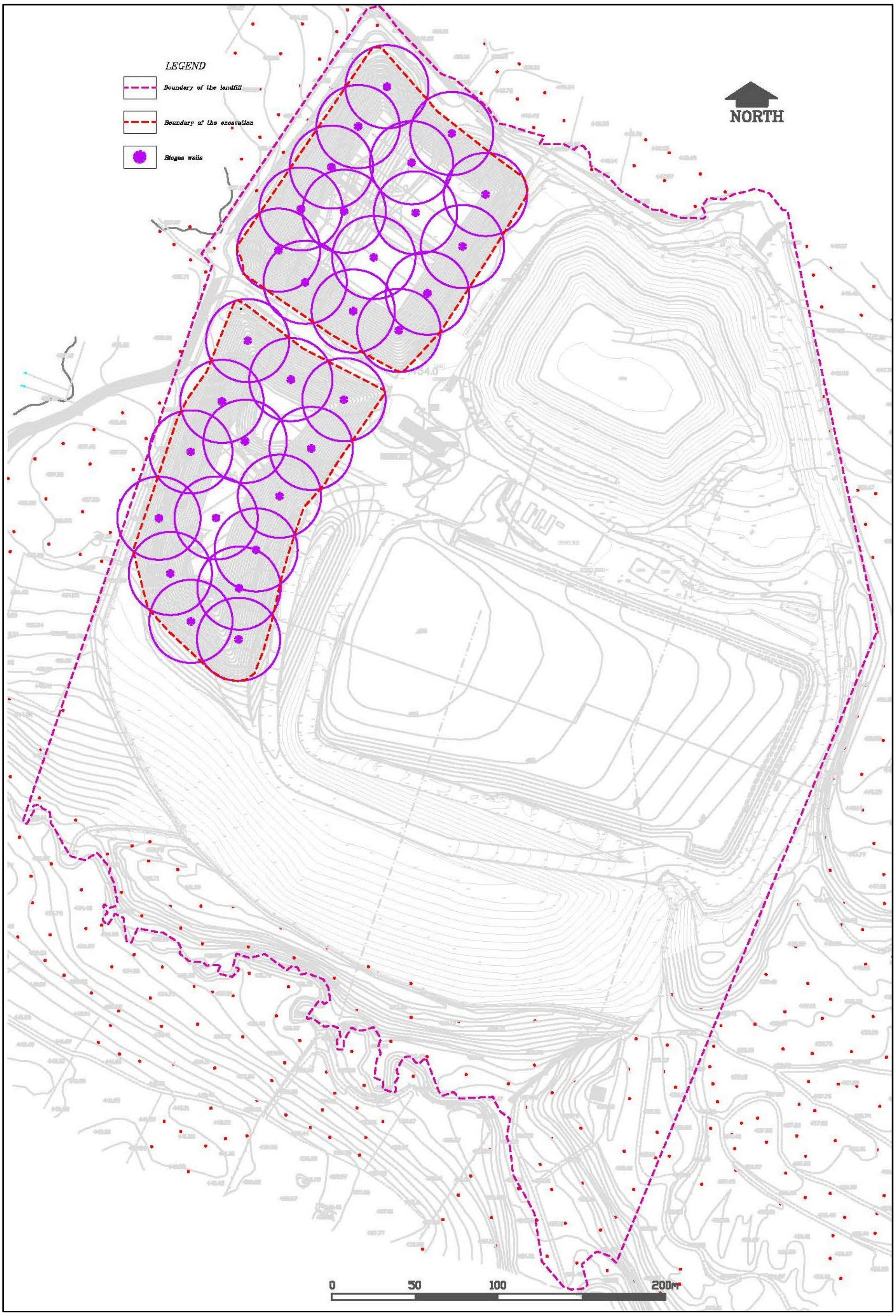

Figure 44: Position of biogas wells in solution two.

In this solution there are two embankments for each one of the two sub-lots to allow the step filling (dashed dark line in Figure 45). Also in this case, the number of leachate wells is 8 (dashed orange line in Figure 45).

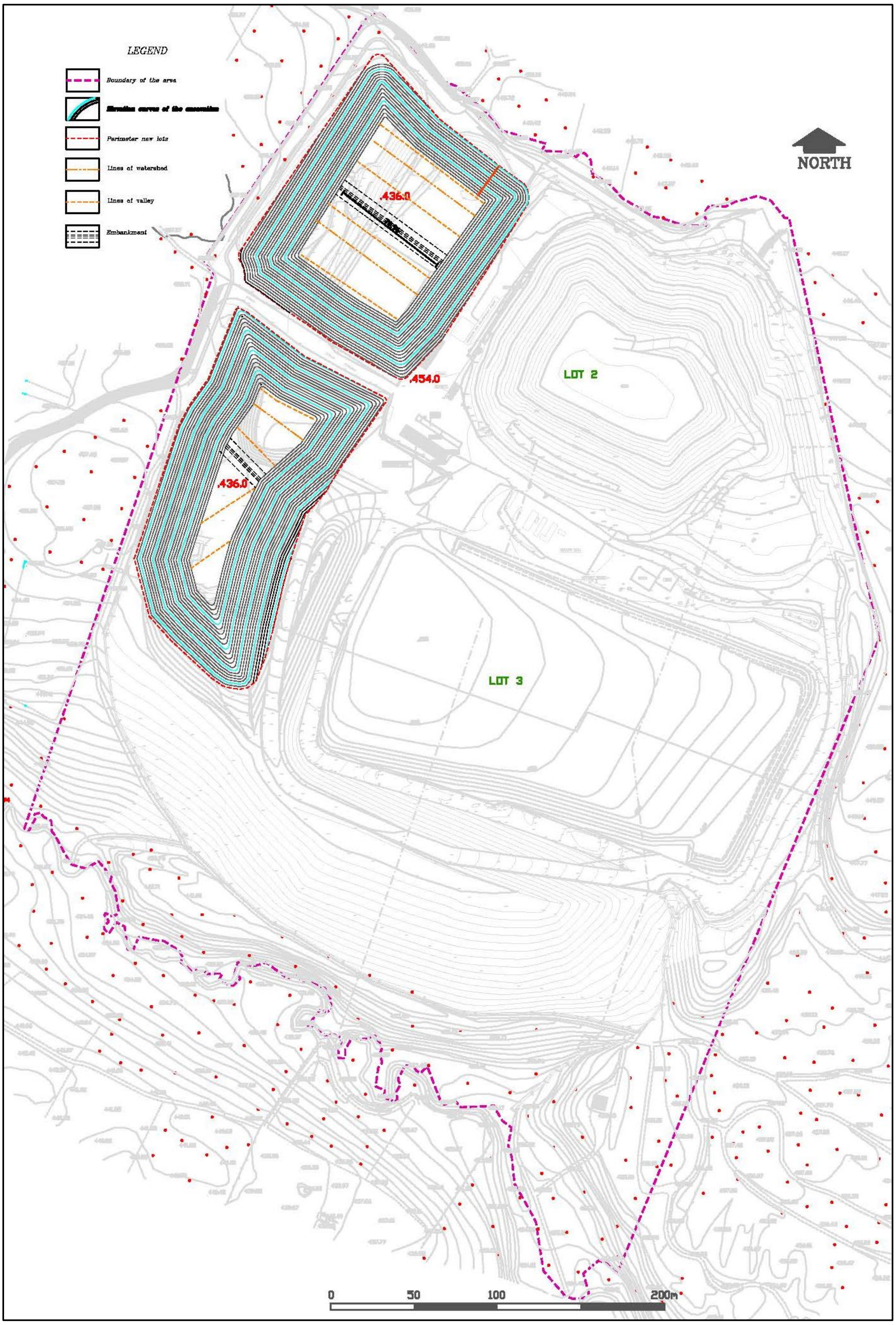

Figure 45: Position of leachate wells in solution two.

3.2.4 Estimated costs.

This chapter analyses in detail the cost of the second solution.

As in Chapter 3.1.4, the cost of excavation is evaluated with the price voice in section 1 of the Price List of Piedmont Region 2022 instead the other voices of Table 17 are mainly based on the metric calculation of the other lots of the landfill addressed in this work.

According to Table 17 the price for this solution is more or less € 10,100,000 with a capacity of 701,000 m^3 of disposable waste.

The final economic indicator is calculated in the equation below:

$$Economic\ indicator = \frac{total\ cost}{volume\ of\ waste} = \frac{10100000}{701000} = 14.51\frac{€}{m^3} \quad \text{Eq. 2}$$

The result is more or less the same of the previous solution (Chapter 3.1.4).

Table 17: Estimation cost of the second solution.

Section	Code	Description	Size	U.M.	Unit price[€]	€
01	**01.A01.A10**	General excavation, stripping or open section excavation, in loose or compact soils up to 4 m deep, carried out by mechanical means, excluding mine rock but including rock and masonry blocks up to 0,50 m³, measured in actual section, including loading on trucks, transport and accommodation within the yard area				
01	01.A01.A10.010	Even in the presence of water up to a maximum swing of 20 cm	156 693	m³	4.12	645 575
01	**01.A01.A15**	General excavation, stripping or open section excavation, in loose or compact soils, more than 4 m deep, carried out by mechanical means, excluding mine rock but including rock and masonry blocks up to 0,50 m³, measured in actual section, including loading on trucks, transport and accommodation within the yard area				
01	01.A01.A15.010	Even in the presence of water up to a maximum swing of 20 cm, only for the part exceeding 4 m	401 520	m³	5.40	2 168 209
TOT						2 813 784
Waterproofing		Landfill waterproofing package. HDPE clay, bentonite and geomembrane mattress	32 337	m²	85	2 748 617.85
Capping and recovery		75 € per square meter are considered	30 239.64	m²	75	2 267 972.85
Drains		0.5 m layer thickness, considering only the bottom and not the escarpments	5223	m³	26	135798
Leachate storage		Tanks of 50 m³ each	1	cad	50 000	350 000
Leachate wells			8	cad	45 000	360 000
Biogas wells			31	cad	20 000	620 000
Moving municipal road			1400	m²	100	140 000
Eco-station shift						500 000
Enclosure			920	m	60	55 200
Electricity network						-
Water supply and sewerage						-
New access track with roundabout						-
Redevelopment of the area			1800	m²	100	180 000
TOT						**10 171 373**
Economic indicator						**14.51**

3.3 Analysis of Solution 3.

3.3.1 Earthworks.

The excavation of this solution is the smallest one because on the right side there are two leachate wells that cannot be shifted. They are individuated by two orange circle in Figure 47.

The extension of the new lot goes from the west side of the third lot to the two leachate shells with a surface of 5,272 m^2.

The best aim of this solution is to connect the existing lots and to have a unique big landfill.

In this case the excavation is designed at 22° (1/2.5), the same of the elevation, because there is a small space and the bottom is only 7 m b.g.l., from 454 m a.s.l. to 445 m a.s.l.

The project of excavation is in Figure 47.

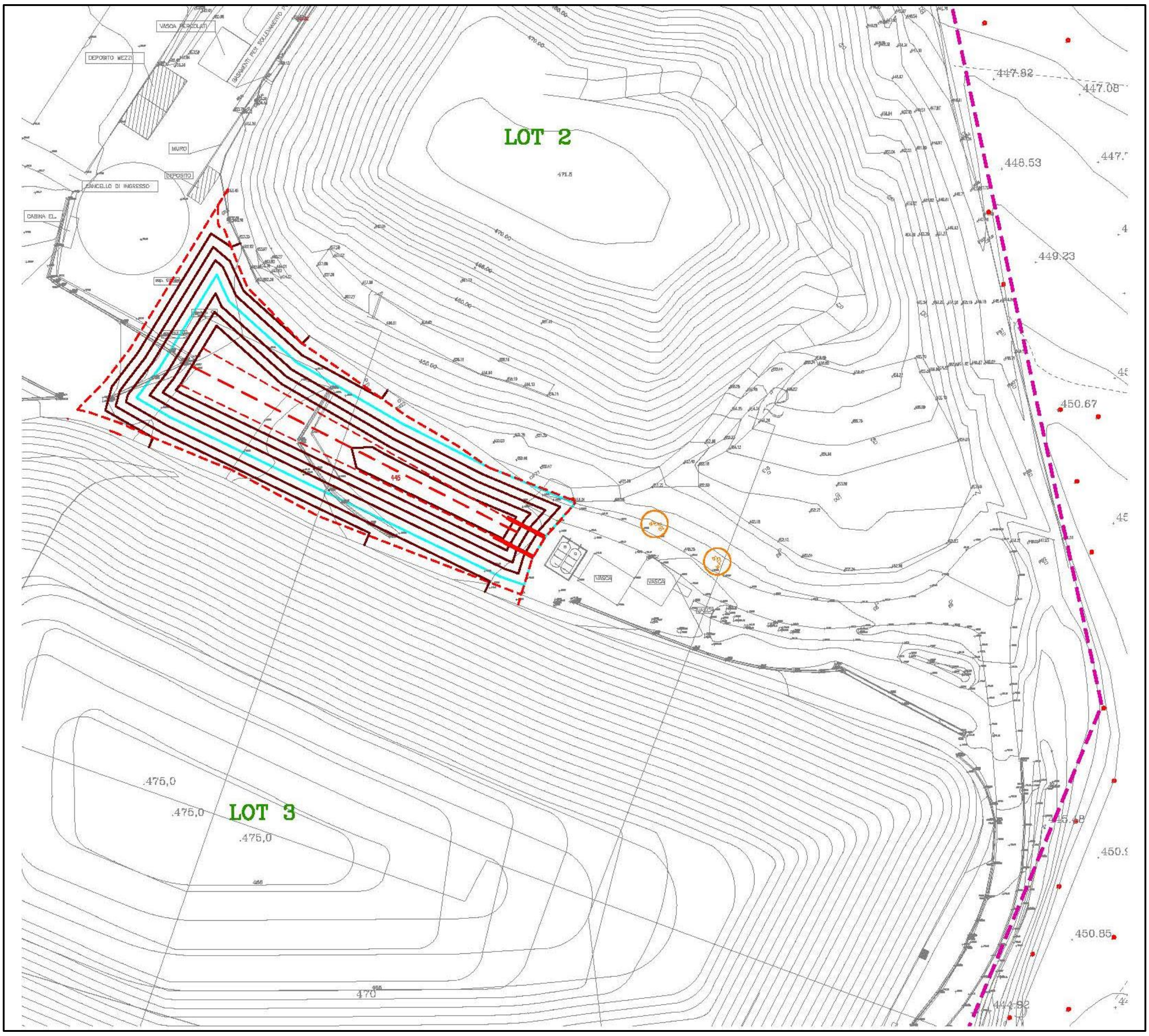

Figure 46: Detail of the excavation of the third solution.

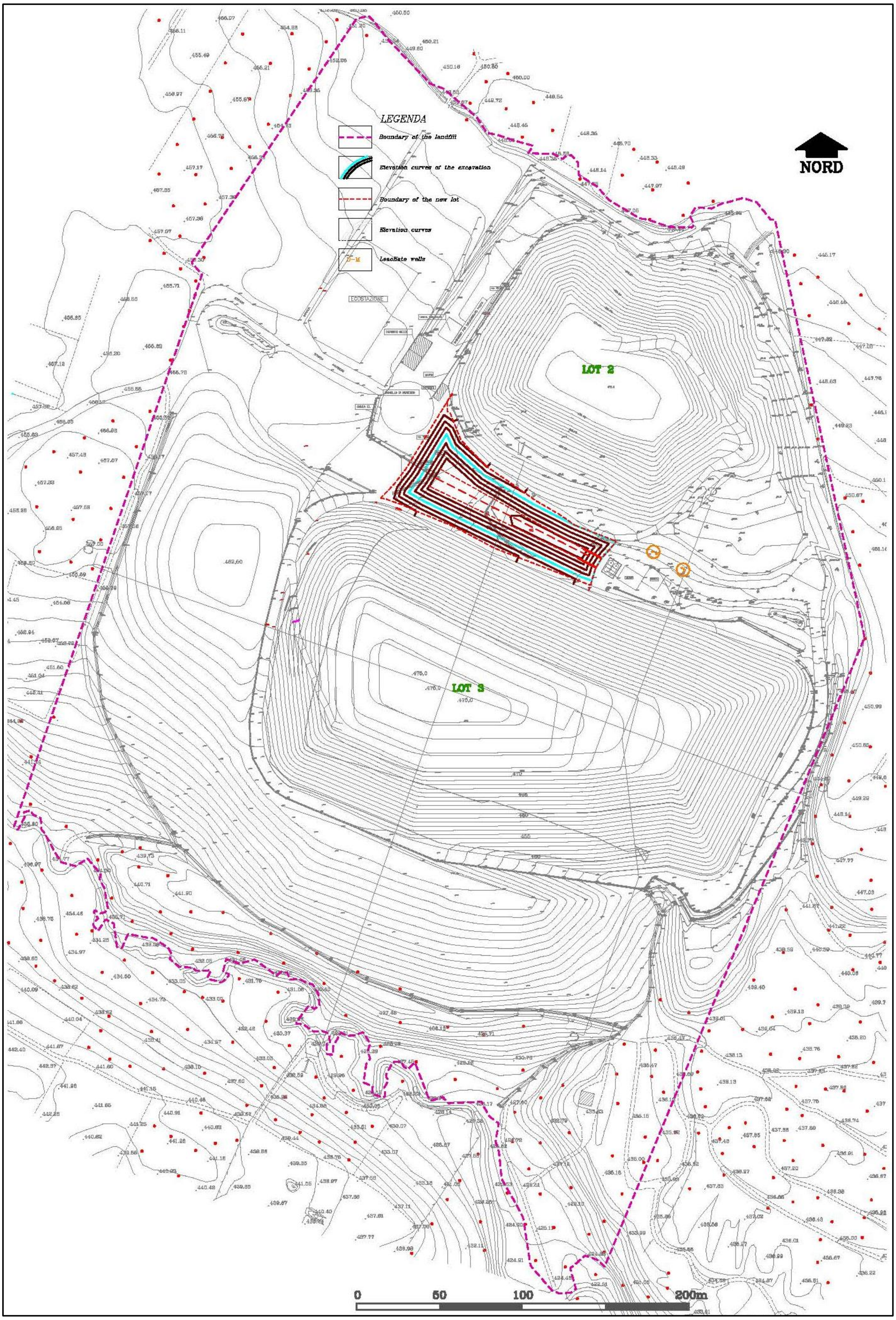

Figure 47: Excavation of the third solution.

In Table 18 and Table 19 there is the evaluation of the volume for this solution.

Table 18: Volume of excavation of solution three.

Excavation		
Contour lines	m^2	m^3
447	1 443.0	
448	2 080.0	1 761.5
449	2 776.0	2 428.0
450	3 532.0	3 154.0
451	4 683.0	4 107.5
452	5 635.0	5 159.0
453	6 660.0	6 147.5
TOT		22 757.5

Table 19: Volume of elevation of solution three.

Elevation		
Contour lines	m^2	m^3
453	6 660.0	
454	7 565.0	7 112.5
455	7 900.0	7 732.5
456	8 176.0	8 038.0
457	8 714.0	8 445.0
458	9 044.0	8 879.0
459	9 248.0	9 146.0
460	9 392.0	9 320.0
461	9 490.0	9 441.0
462	9 517.0	9 503.5
463	9 427.0	9 472.0
464	9 300.0	9 363.5
465	9 130.0	9 215.0
466	8 951.0	9 040.5
467	8 729.0	8 840.0
468	8 464.0	8 596.5
469	8 163.0	8 313.5
470	7 825.0	7 994.0
471	7 932.0	7 878.5
472	6 907.0	7 419.5
473	2 038.0	4 472.5
474	1 469.0	1 753.5
TOT		169 976.5

The total volume that can be used for the waste is 110,859 m^3 and the excavation volume, including the volume for the impermeabilization, is 22,758 m^3.

3.3.2 Interference with existing installations and expropriation of new lands.

The main interference is the Asja's cogeneration plant that is connected to the biogas wells of the third lot.

Along the perimeter of the third lot there are three biogas sub-station. In particular the SST-C substation is behind the two reservoirs for the leachate and it is not involved in the new excavation.

The positive aspect is that the biogas sub-stations positions have not to be changed and the only issue is the collector that arrive at the current cogeneration plant (Figure 30).

Moreover, new biogas sub-station has to be considered for the new lot and the new cogeneration plant is in the S-W part of the area.

In Figure 48 there is a possible pathway for the new biogas collector.

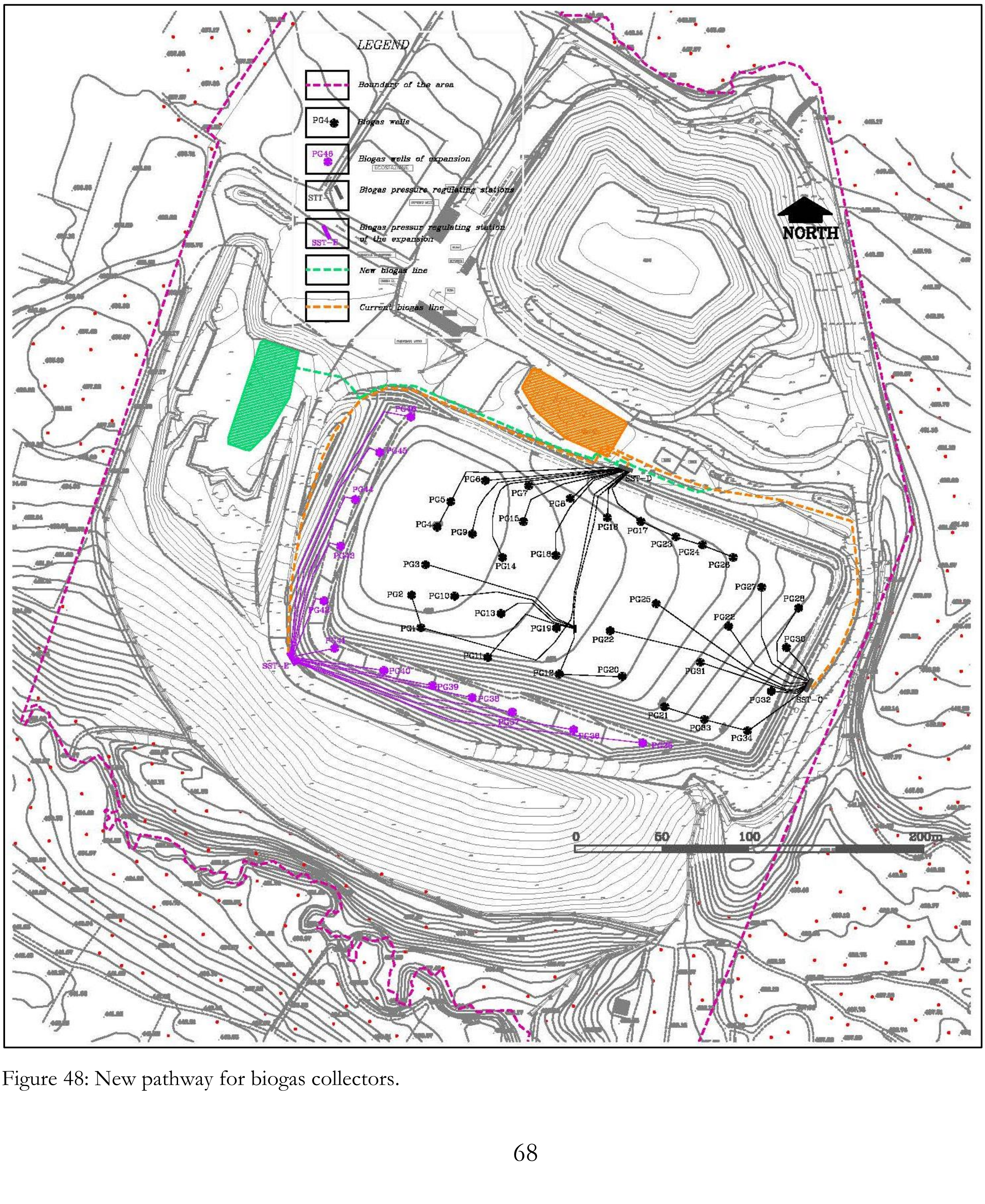

Figure 48: New pathway for biogas collectors.

The area behind the current office building is upgraded and it can be used for the new office and for the repository of vehicles.

Moreover, the new lot cover the area of the weighbridge and so the third solution require the construction of another entrance between the eco-station and the second lot. In this way the lorries enter from the north part and go out by the road between the eco-station and the pre-treatment plant. The leachate tank of the second lot is moved towards the eco-station in order to have a bigger passage between the second lot and the new one.

An advantage of this solution is that the expropriation is not necessary because the pre-treatment plant can be placed in the area at the west of the third lot, near the road that bring to the landfill. Figure 49 explain the situation.

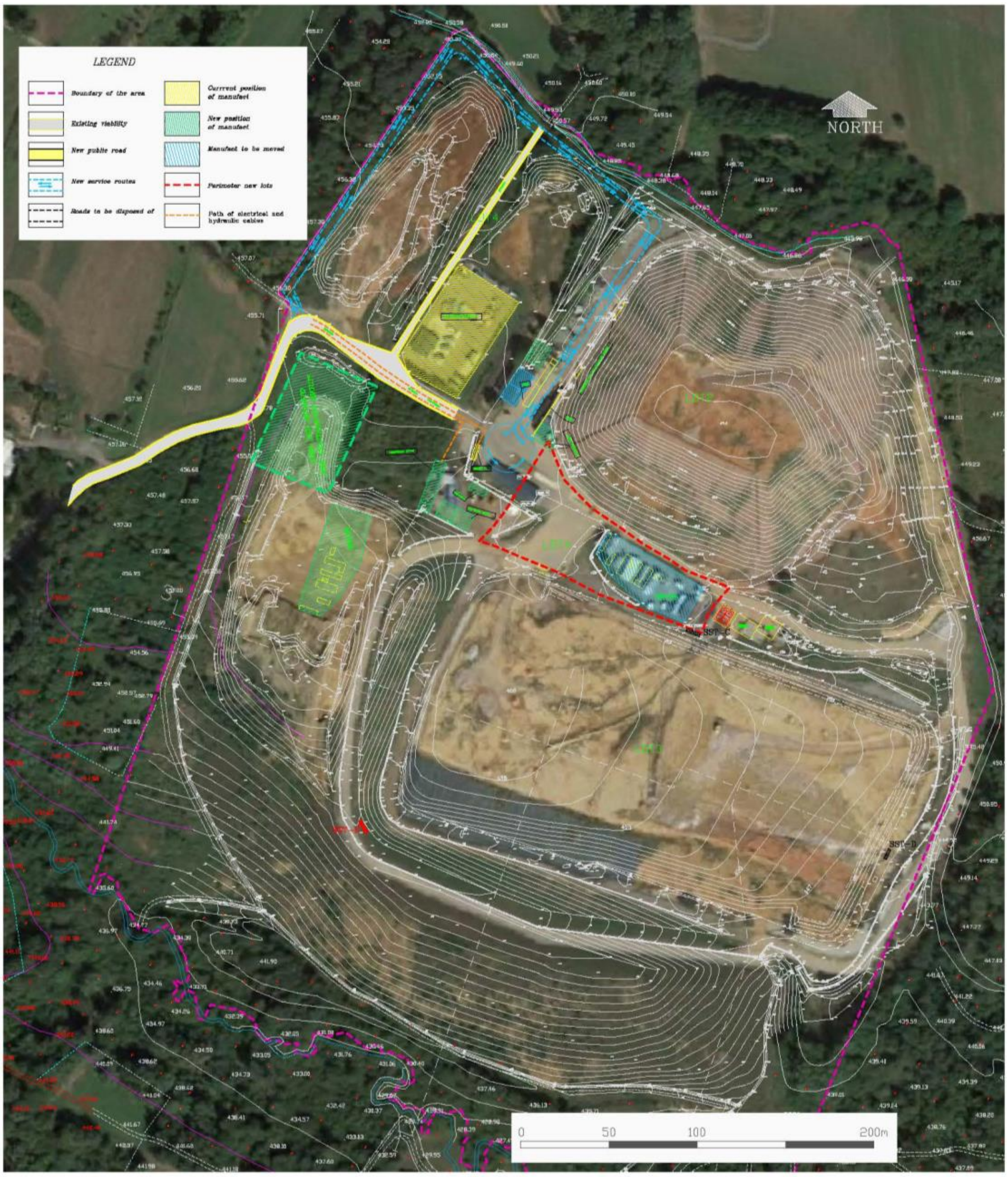

Figure 49: Planimetry of the third solution.

3.3.3 Interference with existing pipelines and cable conduits

The entrance road and so the electric and hydraulic cables are conserved in this solution.

The office structure is rotated along the S-N direction and only the connection with the electric and hydraulic cables is changed as in Figure 49.

3.3.4 Biogas wells and leachate wells

The biogas wells for this solution are represented in Figure 50 (pink circle). This solution requires 19 biogas wells in order to cover the entire surface of the new lot.

This solution has a small tank and so a unique leachate well is sufficient but to avoid the stop of the drainage two pipes are placed along the north and south boundary of the excavation. The leachate wells have to be constructed at the end of the pick-up line (dashed orange line in Figure 51) and in this case there are 2 wells on the east side where there are already the tank of the third lot.

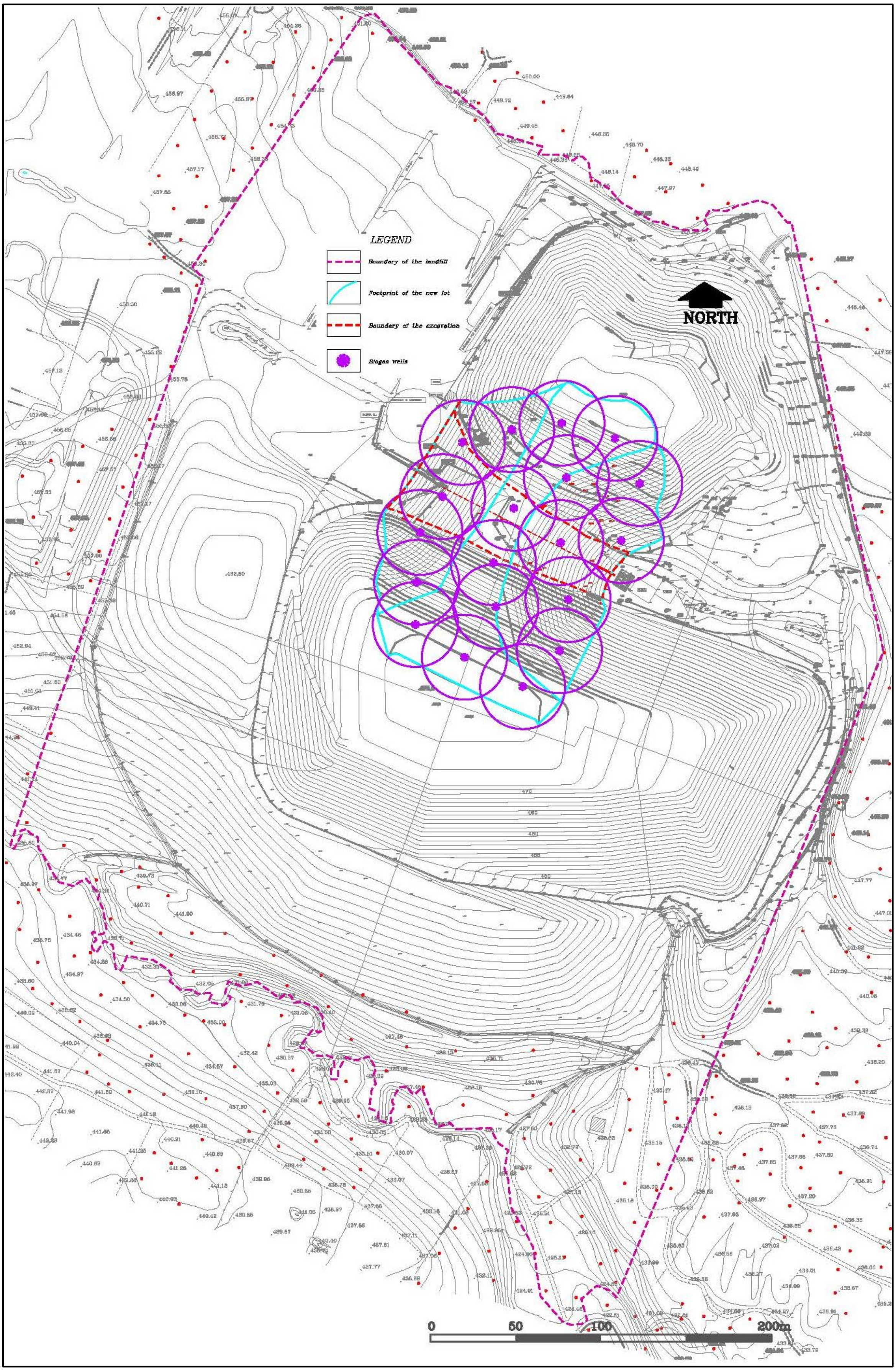

Figure 50: Position of biogas wells in solution three.

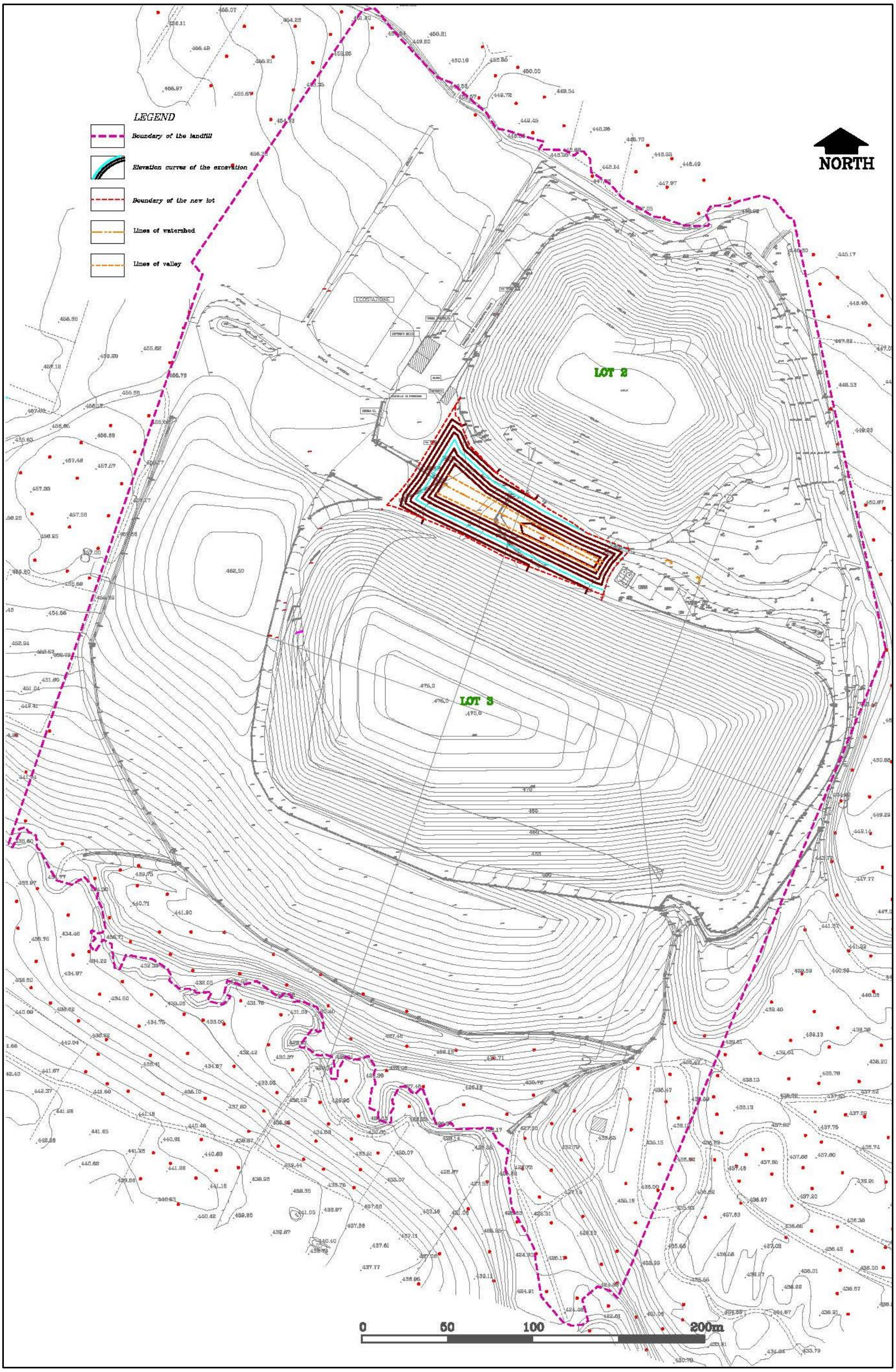

Figure 51: Position of leachate wells in solution three.

3.3.5 Estimated costs.

This chapter analyses in detail the cost of the third solution with the same criteria of the previous two solution. The final cost is in Table 20.

The price for this solution is more or less € 5,000,000 with a capacity of 110,000 m^3 of disposable waste.

The final economic indicator is calculated in the equation below:

$$Economic\ indicator = \frac{total\ cost}{volume\ of\ waste} = \frac{5000000}{110000} = 46.02\,\frac{€}{m^3} \qquad \text{Eq. 3}$$

The economic indicator of this solution is three times the indicator of the previous two solutions and so the third solution is not the best one. The possibility of a unique lot that link the other two will be considered when also the new lot presented in this work is exhausted.

Table 20: Evaluation cost of the third solution.

Section	Code	Description	Size	U.M.	Unit price[€]	€
01	**01.A01.A10**	General excavation, stripping or open section excavation, in loose or compact soils up to 4 m deep, carried out by mechanical means, excluding mine rock but including rock and masonry blocks up to 0,50 m³, measured in actual section, including loading on trucks, transport and accommodation within the yard area				
01	01.A01.A10.010	Even in the presence of water up to a maximum swing of 20 cm	20 996	m³	4.12	86 504
01	**01.A01.A15**	General excavation, stripping or open section excavation, in loose or compact soils, more than 4 m deep, carried out by mechanical means, excluding mine rock but including rock and masonry blocks up to 0,50 m³, measured in actual section, including loading on trucks, transport and accommodation within the yard area				
01	01.A01.A15.010	Even in the presence of water up to a maximum swing of 20 cm, only for the part exceeding 4 m	1 762	m³	5.40	9 515
TOT			22 758			96 018
Waterproofing		Pacchetto di impermeabilizzazione discarica. Argilla, materasso bentonitico e geomembrana in HDPE	22 039	m^2	85	1 873 306.50
Capping and recovery		Vengono considerati 75€ al mq forfettari	23 646	m^2	75	1 773 450
Drains		0.5 m di spessore dello strato, considerando solo il fondo e non le scarpate	720.5	m^3	26	
Leachate storage		Tanks of 50 m^3 each	1	cad	50 000	200 000
Leachate wells			2	cad	45 000	90 000
Biogas wells			19	cad	20 000	380 000
Moving municipal road				m^2		-
Eco-station shift						
Enclosure			322	m	60	19 320
Electricity network						-
Water supply and sewerage						-
New access track with roundabout			5000	m^2	100	500 000
Redevelopment of the area			1300	m^2	100	130000
TOT						**5 062 095**
Economic indicator						**46.02**

4 IDENTIFICATION OF THE BEST SOLUTION AND FINAL DETAILS

4.1 Discussion on the results of the analysis.

The feasibility study highlights that the first two solution are comparable instead the third one is too much smaller from the point of view of the capacity.

The volume of the lot lying on the existing one is six time smaller than the volume of the other possibility and the final cost of the third solution is only half of the cost of the other solutions.

According to the economic indicator the best solution is the first one. In particular it has a cost of € 65,000 more than the second solution but with 70,000 m^3 more.

A further problem is the destination of the earth and rock from excavation. The Chapter 4 explains the possible solutions.

4.2 Excavated rock and earth.

The aim of this chapter is to evaluate the problem of the destination of the excavated earth and rock in the best solution, i.e., the first one.

The management of the excavated earth and rocks is linked to the part four, "Rules on waste management and remediation of polluted sites", of the D.Lgs. 152 of 3 April 2006.

The easier way to solve the problem is to use the excavated material in the landfill in order to create an embankment useful for a future further expansion of this new lot.

SIA is inclined to acquire new lands that will be use as deposit for the excavated rock and earth, in particular the possible terrains are delimitated by the dark yellow line in Figure 52.

The area is wooded, as in the Q-Gis representation of Figure 53, and so there are many constraints according to the D.Lgs. n°42, 2004.

One of the most important is the landscape bond explained in Chapter two, article 142 letter g of the third pard of the legislative decree:

"They are however of landscape interest and are subject to provisions of this Title:

g) the territories covered by forests and woods, even though they are or damaged by fire, and those subject to constraints of reafforestation, as defined in D. L.gs. 03/04/2018 n. 34 - Testo unico in materia di foreste e filiere forestali (TUFF);"

In Figure 54 there is the design of the embankment with a slope of 22°. In this solution the public road (the yellow one in figure) has to be shifted along the west side of the embankment.

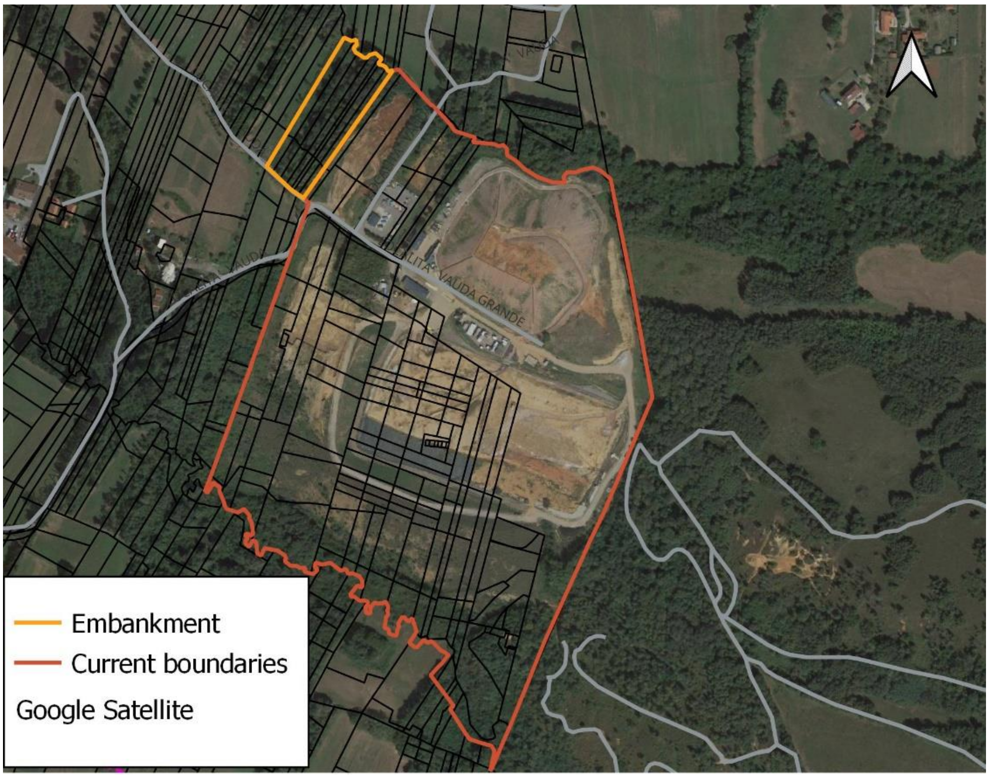

Figure 52: First solution, expansion for the embankment.

Figure 53: Wooded areas and parks.

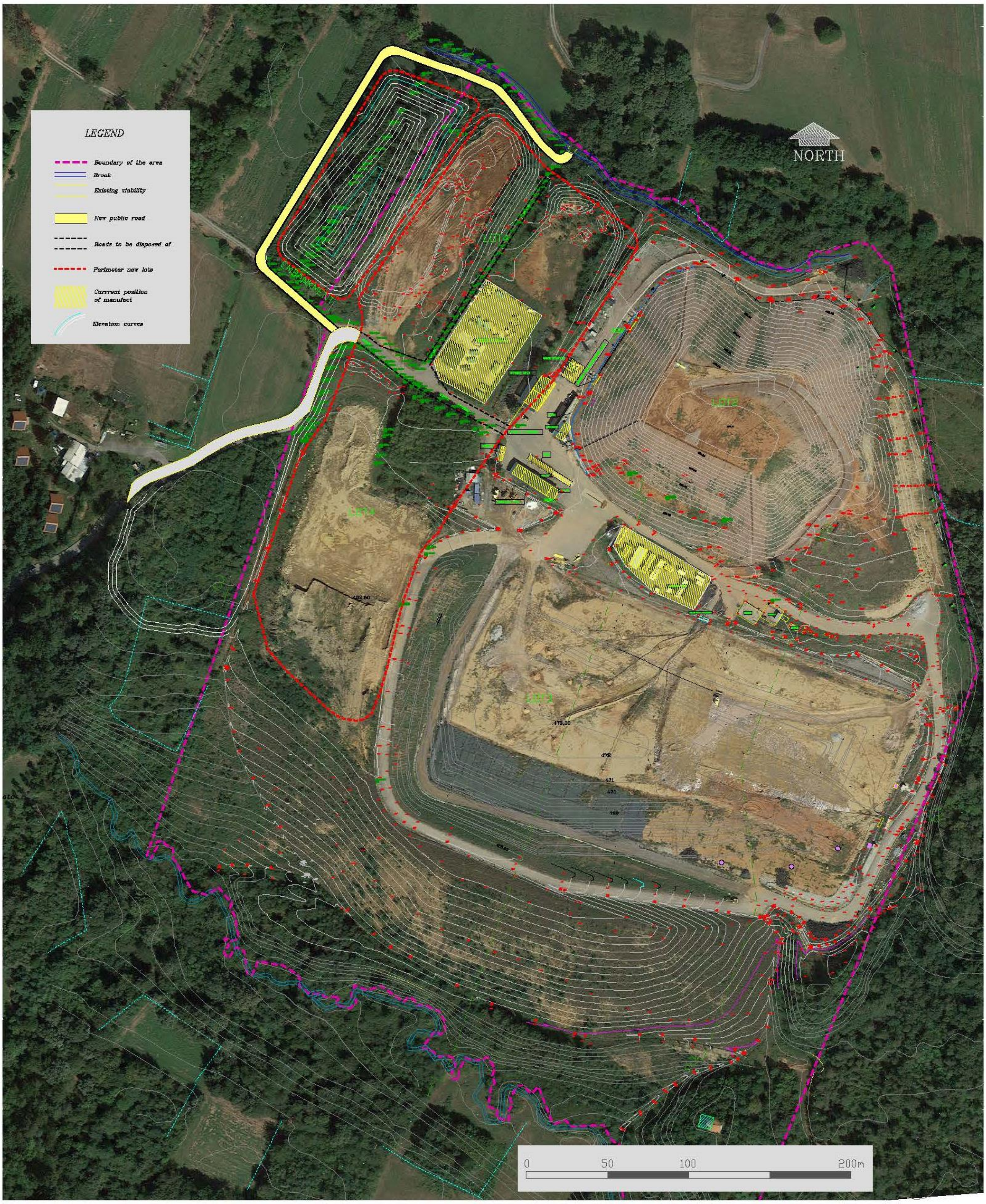

Figure 54: First option: design of the planimetry of the embankment.

The volume of material that can be accumulated in this area is in Table 21.

Table 21: Total volume of the embankment.

Level curves	m^2	m^3
452	8 219.0	
453	8 039.0	8 129.0
454	7 683.0	7 861.0
455	7 255.0	7 469.0
456	6 673.0	6 964.0
457	5 968.0	6 320.5
458	5 132.0	5 550.0
459	4 336.0	4 734.0
460	3 587.0	3 961.5
461	2 884.0	3 235.5
462	2 229.0	2 556.5
463	1 623.0	1 926.0
464	1 066.0	1 344.5
465	556.0	811.0
466	232.0	394.0
467	38.0	135.0
TOT		61 392

This volume is not sufficient because the excavated volume of the new lot is 657,435 m^3 instead the area of Figure 54can contain only 61,392 m^3.

The second possibility is to acquire a bigger area on the western side of the boundary as showed in Figure 55. In this case there are other S-W lands with wood as in Figure 56.

In Figure 57 there is the design of the embankment with a slope of 22°. In this solution the public road (the yellow one in figure) must be redesign in order to allow the connection with the houses on the north of the landfill.

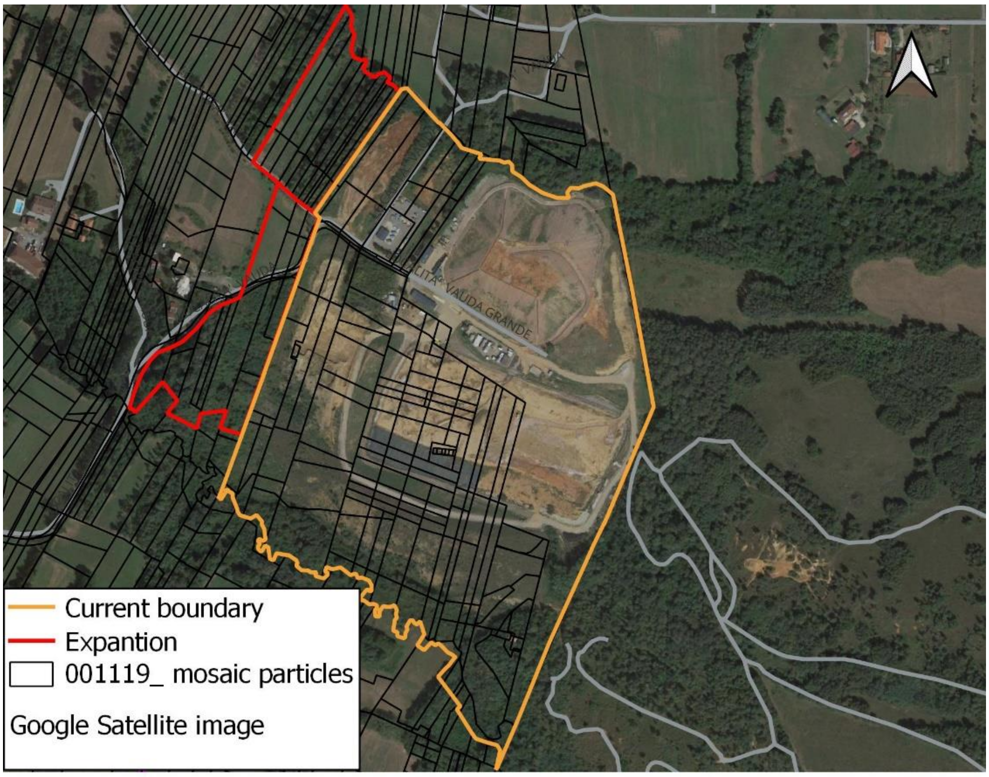

Figure 55: Second solution, expansion for the embankment.

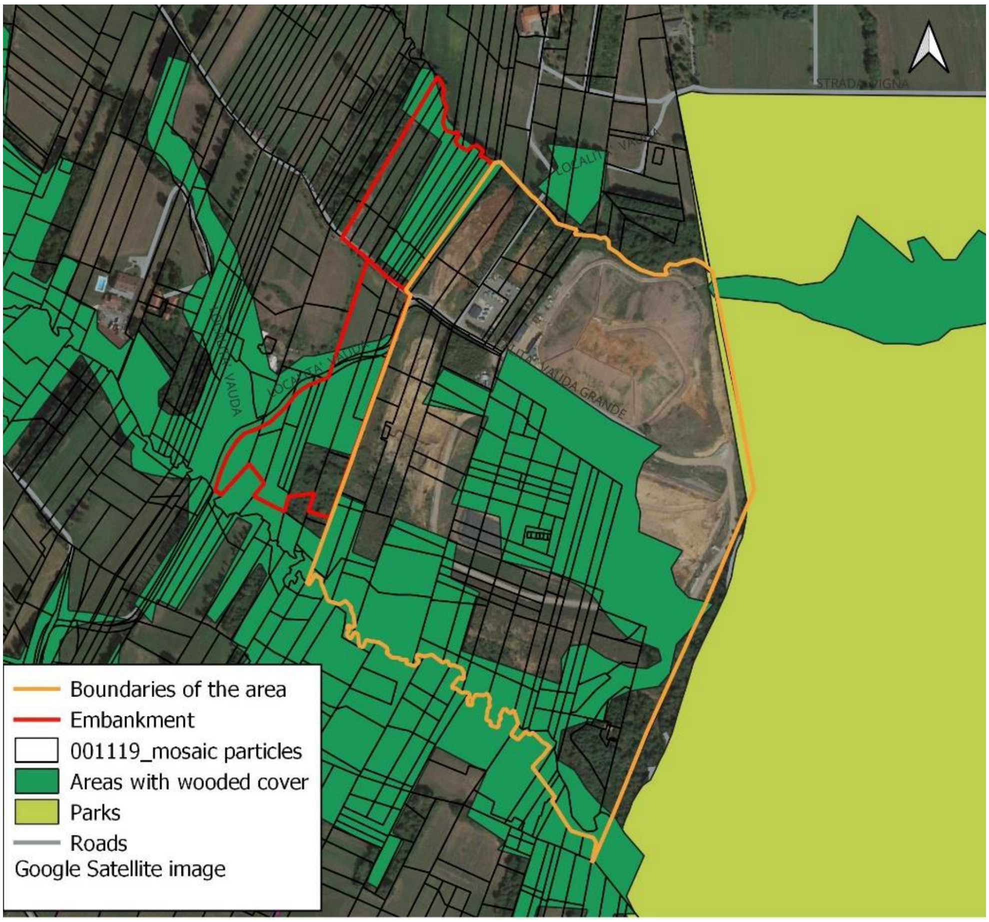

Figure 56: Wooded areas and parks.

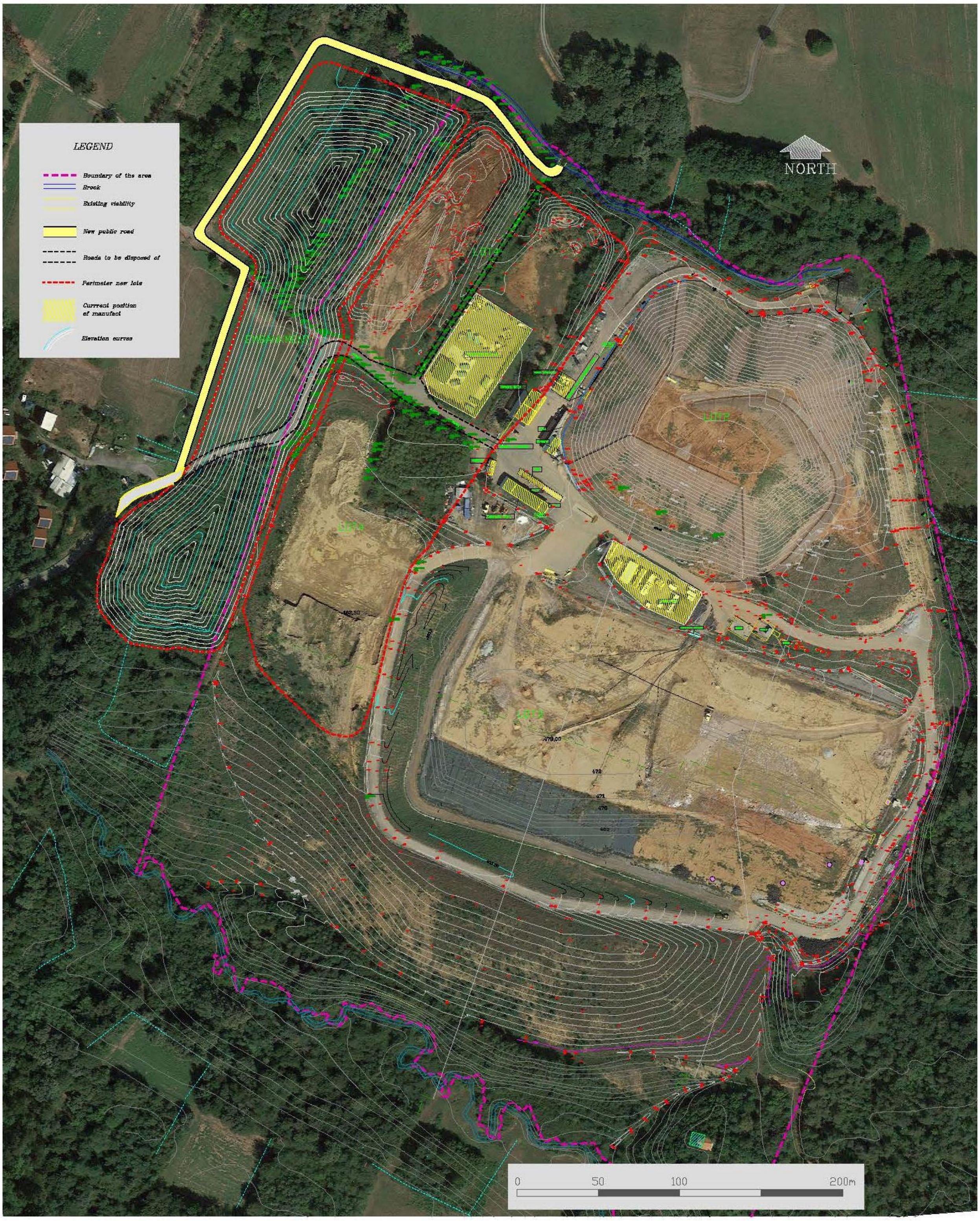

Figure 57: Second option: design of the planimetry of the embankment.

The volume of material that can be accumulated is in Table 22.

Table 22: Total volume of the embankment.

Level curves	m^2	m^3
452	28 627.0	
453	28 432.0	28 529.5
454	28 203.0	28 317.5
455	27 621.0	27 912.0
456	26 841.0	27 231.0
457	24 949.0	25 895.0
458	22 650.0	23 799.5
459	20 647.0	21 648.5
460	18 559.0	19 603.0
461	16 515.0	17 537.0
462	14 517.0	15 516.0
463	12 567.0	13 542.0
464	10 663.0	11 615.0
465	8 806.0	9 734.5
466	6 995.0	7 900.5
467	5 231.0	6 113.0
468	3 654.0	4 442.5
469	2 570.0	3 112.0
470	1 796.0	2 183.0
471	1 183.0	1 489.5
472	700.0	941.5
473	360.0	530.0
474	129.0	244.5
TOT		297 837

Also in this case, the volume is not enough for the accumulation of all the excavated material. The disponible volume is less than half of the excavated material of the first solution.

In conclusion one half of the excavated material takes place on the landfill site and the other half has to be transferred away.

Another important consideration is that the average cost for the use of a wooden area is 10,000 € per hectare and the wooden zone in this case covers more or less 19,000 m^2.

The price for the use of wooden area in this case is around 20,000 € and it has to be added to the price for the acquisition of the land.

4.3 Project details of the best solution.

The best solution identified in the previous chapter was further addressed from the point of view of excavations. First, the landfill needs ramps to reach the bottom of the excavation to deposit the waste, which brings to a reduction of the capacity of the lot (Table 9). The position of the ramp is strictly related to the position of the leachate wells because it makes the construction of the wells more difficult. In this case, there are eight leachate wells along the west side of the lot and so the position of the ramp is on the north side. The tilt angle of the ramp is 12% and it reach the bottom of the lot in the N-W corner with an altitude of 437 m. a.s.l.. With this slope of the ramp the lorries can reach the bottom of the north part of the excavation where they can unload the waste.

This new lot will be filled step by step from north to south. In particular the three embankments with a height of 2 m allow to fill the north sub-lot and consequently the lorries can reach the other sub-lots passing over the waste. Another important aspect is the slope of the bottom of the excavation.

The minimum value for the inclination of the bottom of the excavation is 2% in order to allow the leachate to reach the well. A smaller value of the angle brings to a bigger volume for the waste and so the slope of the bottom of the new lot is 2%.

Figure 58 is the detailed project of the excavation of the new lot.

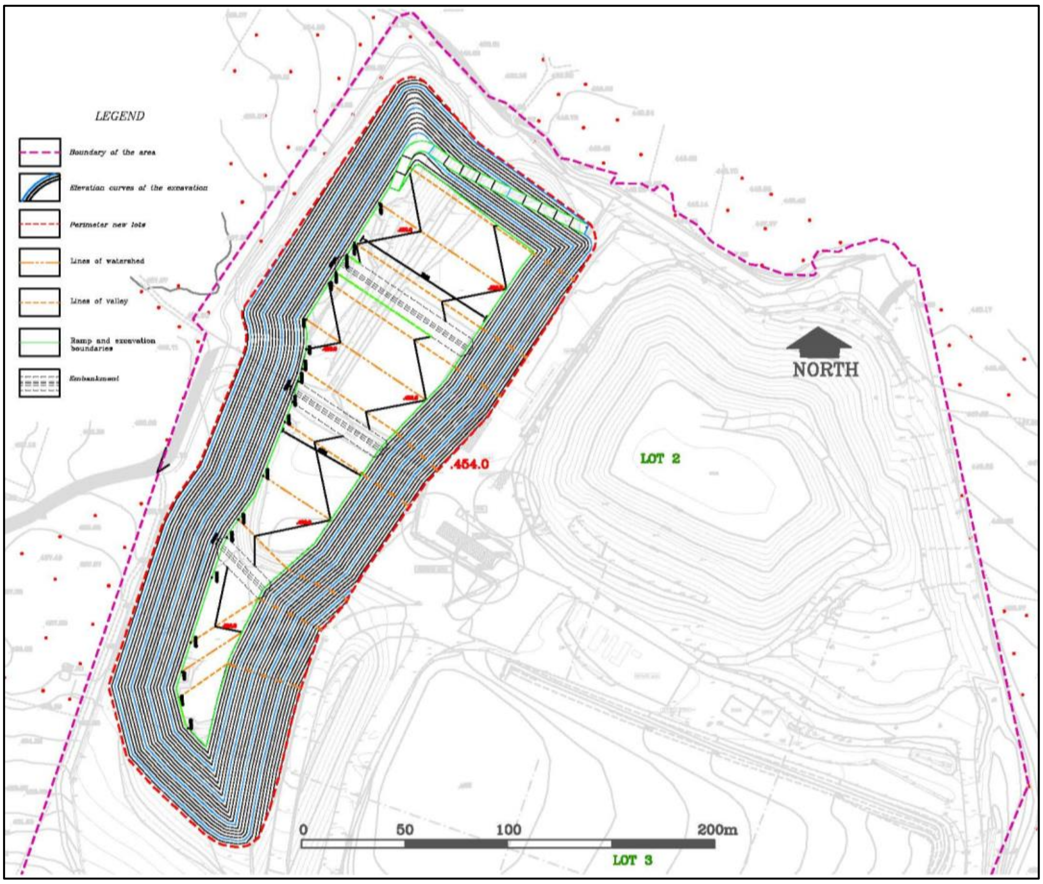

Figure 58: Final project of the excavation of the new lot.

4.4 Economic balance.

The economic balance is based on the cash flow method because the evaluation is complex, and it changes year by year. The beginning of the works is estimated for 2025 and the evaluation involve 35 years, from 2025 to 2060, 5 of which for the active management. In Table 23 there are the amount of income and expenses for each year and the resulting cash balance.

One of the outflows that involve all the year of passive management is the cost for the leachate management. The leachate infiltration is estimated as one third of the rainfall (1,256.6 mm/y), that is, 418 mm/y of leachate, thus leading to a production of 15713 m/y (see Equation 4):

$$Leachate = total\ surface * leachate\ \left(\frac{mm}{y\,m^2}\right) = 37592 m^2 * 0.418\ \frac{m}{y\,m^2} = 15713\,\frac{m^3}{y} \qquad \text{Eq. 4}$$

The price for the transport and disposal of the leachate is 25 €/m³.

The values of column seven of Table 23 are calculated according to the Equation 5.

$$Price_{Leachate} = leachate\ \left(\frac{m^3}{y}\right) * \frac{€_{leachate}}{m^3} = 15713\,\frac{m^3}{y} * 25\ \frac{€}{m^3} = 393735\,\frac{€}{m^3} \qquad \text{Eq. 5}$$

The revenue to be introduced into the economic balance of the landfill is derived from the disposal tariff of the waste. According to the report of SIA S.r.l. the landfill of Grosso has received 68,849 t of waste in 2021 divided in 41,461 t from January to June and 27,388 t from July to December. In this project it has been assumed a contribution of about 70,000 tons for the five years planned for the active management of the landfill. The annual revenue is the product between these quantities and the first assumption of the net disposal rate. The correct value of the rate is calculated using the net of cash values (Table 23). The net of cash of each year, added to the cash fund of the previous year and to the interest paid (or received) on it, provides the new cash situation, on which the interest receivable or payable are calculated.

The interest rate is 0,5 % for a positive net of cash and 3,5 % for a negative net of cash.

The result is the net of cash of the last year that is the profit or deficit of the entire investment.

The break-even net tariff of waste disposal, i.e. the one that leads the overall balance of the budget to a null value in the last year is estimated in 87.61 €/t.

The value obtained represents the net minimum "industrial cost", to which must be added the amounts relating to ecotaxes, compensatory charges for the Municipality and the general expenses and corporate profits of S.I.A. S.r.l.. The evaluation of these bonuses goes beyond the technical aspects concerning the design of the landfill and is therefore entrusted directly to S.I.A. S.r.l.

Table 23: Economic balance of the landfill, evaluation of the net disposal cost (yellow cell).

	Interest rate (%)	ATTIVO =	0.50%	PASSIVO=	3.50%				Disposal charges a (€/t)		87.61		

Year	Setting up (€)	Accessories costs of fitting out (€)	Costs of set-up management (€)	Capping and environmental recovery (€)	Accessories cost of environmental recovery (€)	Leachate cost (€)	Workers (€)	Costs (€)	Waste (t)	Profits (€)	Budget (€)	Cash found (€)	Annual interest (€)
2025	6 358 194.39	1 755 200	220 000.00			393 734.67	350 000.00	9 077 129.06	70 000.00	6 133 012.79	- 2 944 116.26	- 2 944 116.26	- 103 044.07
2026			220 000.00			393 734.67	350 000.00	963 734.67	70 000.00	6 133 012.79	5 169 278.13	2 122 117.80	10 610.59
2027			220 000.00			393 734.67	350 000.00	963 734.67	70 000.00	6 133 012.79	5 169 278.13	7 302 006.52	36 510.03
2028			220 000.00			393 734.67	350 000.00	963 734.67	70 000.00	6 133 012.79	5 169 278.13	12 507 794.68	62 538.97
2029			220 000.00			393 734.67	350 000.00	963 734.67	70 000.00	6 133 012.79	5 169 278.13	17 739 611.78	88 698.06
2030				2 706 360.33	580 700.00	393 734.67	350 000.00	4 030 795.00			- 4 030 795.00	13 797 514.84	68 987.57
2031						393 734.67	175 000.00	568 734.67			- 568 734.67	13 297 767.74	66 488.84
2032						393 734.67	100 000.00	493 734.67			- 493 734.67	12 870 521.92	64 352.61
2033						393 734.67	100 000.00	493 734.67			- 493 734.67	12 441 139.86	62 205.70
2034						393 734.67	100 000.00	493 734.67			- 493 734.67	12 009 610.89	60 048.05
2035						393 734.67	100 000.00	493 734.67			- 493 734.67	11 575 924.28	57 879.62
2036						393 734.67	100 000.00	493 734.67			- 493 734.67	11 140 069.23	55 700.35
2037						393 734.67	100 000.00	493 734.67			- 493 734.67	10 702 034.91	53 510.17
2038						393 734.67	100 000.00	493 734.67			- 493 734.67	10 261 810.42	51 309.05
2039						393 734.67	100 000.00	493 734.67			- 493 734.67	9 819 384.81	49 096.92
2040						393 734.67	100 000.00	493 734.67			- 493 734.67	9 374 747.06	46 873.74
2041						393 734.67	100 000.00	493 734.67			- 493 734.67	8 927 886.13	44 639.43
2042						393 734.67	100 000.00	493 734.67			- 493 734.67	8 478 790.90	42 393.95
2043						393 734.67	100 000.00	493 734.67			- 493 734.67	8 027 450.18	40 137.25
2044						393 734.67	100 000.00	493 734.67			- 493 734.67	7 573 852.77	37 869.26
2045						393 734.67	100 000.00	493 734.67			- 493 734.67	7 117 987.37	35 589.94
2046						393 734.67	100 000.00	493 734.67			- 493 734.67	6 659 842.64	33 299.21
2047						393 734.67	100 000.00	493 734.67			- 493 734.67	6 199 407.18	30 997.04
2048						393 734.67	100 000.00	493 734.67			- 493 734.67	5 736 669.55	28 683.35
2049						393 734.67	100 000.00	493 734.67			- 493 734.67	5 271 618.23	26 358.09
2050						393 734.67	100 000.00	493 734.67			- 493 734.67	4 804 241.66	24 021.21
2051						393 734.67	100 000.00	493 734.67			- 493 734.67	4 334 528.20	21 672.64
2052						393 734.67	100 000.00	493 734.67			- 493 734.67	3 862 466.17	19 312.33
2053						393 734.67	100 000.00	493 734.67			- 493 734.67	3 388 043.84	16 940.22
2054						393 734.67	100 000.00	493 734.67			- 493 734.67	2 911 249.39	14 556.25
2055						393 734.67	100 000.00	493 734.67			- 493 734.67	2 432 070.97	12 160.35
2056						393 734.67	100 000.00	493 734.67			- 493 734.67	1 950 496.66	9 752.48
2057						393 734.67	100 000.00	493 734.67			- 493 734.67	1 466 514.47	7 332.57
2058						393 734.67	100 000.00	493 734.67			- 493 734.67	980 112.38	4 900.56
2059						393 734.67	100 000.00	493 734.67			- 493 734.67	491 278.28	2 456.39
2060						393 734.67	100 000.00	493 734.67			- 493 734.67	0.00	0.00

5 CONCLUSIONS

This work presents the feasibility study of a new lot for a landfill of non-hazardous special waste in the municipality of Grosso, 30 km at N-W of Turin.

The landfill is located approximately 1600 m far from the main settlement of Grosso, 1400 m far from the hamlet of Madonna della Neve, 1300 m far from the hamlet Vauda di Rocca and 1100 m far from Vauda di Nole.

The site is in a plain bordered by the rivers Stura di Lanzo and Malone, and there are three main terraced areas. The geological composition is characterized by coarse alluvial deposits overlying different sandy gravel layers and pebble layers with a sandy matrix and a silty matrix.

The first lot of the landfill was exhausted in 1996 and then the second one was built on the western side of the previous one. The second lot was exhausted in 2008 and then the space between the two lots was used. The last lot is in use since 2012, but it is going to be exhausted within a few years. For this reason, the project of a new lot has become necessary.

The first step is the study of the territory with the use of GIS and the identification of possible positions for the new lot.

The three possibilities are i) one lot on the western side, ii) two separated lot on the western side, iii) new lot lying on the existing ones.

The evaluation of the solutions was based on different criteria, namely: earthworks, interference with existing installations and pipelines, the costs for the impermeabilization of the bottom of the excavation, the costs for the final capping, the number of biogas and leachate wells needed, the possible need for expropriation of new cadastral lots, the overall costs, and the costs per unit volume.

The solution one has the largest volume, but it requires the modification of the current entrance road. The most relevant advantage of the second solution, which is a modification of the first one (the new lot divided in two smaller lots), is that the current configuration of the infrastructures is almost unaltered.

The third solution, i.e., the new lot lying on existing ones, was worked out to avoid the expropriation of new cadastral lots and to have a unique landfill. However, the volume is only one sixth compared to the other two solutions, while the costs are only roughly halved. This leads to a triple value of the cost per unit volume, which is the main economic evaluation metric. According to this economic indicator, the best solution is the first one, with a cost of about 10.8 M€ and a volume of 770,000 m^3.

This work consisted in a multicriteria analysis of different solutions for the expansion of an existing landfill, and it could represent a reference for similar contexts, where the methods and criteria presented here could be adapted.

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