THE WORLD BANK
IBRD • IDA | WORLD BANK GROUP

FOR OFFICIAL USE ONLY

Land Repurposing Methodology (LRM) at Amyntaio Mine

Wolfhart Pohl
Chrysanthos Steiakakis

FINAL

June 2020

Presented to:
The European Commission, Ministry of Environment and Energy, the Governor of Western Macedonia and the Coal Regions in Transition Working Group for Western Macedonia.

Contents

Table of Figures

1. Introduction

The Land Repurposing Methodology (LRM) was used to assess the Amyntaio mine, with the help of the GIS-based Land Use Repurposing Application (LURA). LURA incorporates the criteria developed and presented in detail in chapter 3.2 of the report "A Road Map for Managing the Coal Transition in Western Macedonia". The objective of the assessment was to pilot LURA on a section of mining lands planned for near future closure and repurposing, based on data provided by the Public Power Corporation (PPC) and to provide a best estimate of post mining land uses.

Based on the LRM LURA evaluates five distinct criteria which are considered to be the most important for post mining land use. These criteria cover physical, chemical, environmental, socio-economic and financial conditions of the land at the time of projected closure to characterize the possible repurposing potential. A key aspect of the methodology is to characterize the available mine lands, based on the actual conditions, and to produce optimum post mine land utilization with the minimum cost implications for reclamation and repurposing.

The five criteria used in LURA to assess the post mining land uses are (i) location and redevelopment potential; (ii) environmental risks / liabilities; (iii) geotechnical stability; (iv) topography and hydrography and (v) development potential and financial risks. Each criterion is further subdivided to capture the full extent of the land conditions in a simple and objective way. Each subcategory uses a five-scale rating procedure, ranging from the value "1" indicating the least favorable condition to "5" which is considered as the most favorable condition for the particular sub-criterion. An average score is calculated based on the sub-criteria rating for the main criterion. A net differential algorithm automatically evaluates the actual values for each criterion against the index value describing the most appropriate post mining land utilization, and matches the actual values for the five criteria with the best fitting optimum land use scenario.

To enable the application of LURA the mine is subdivided in segments / pixels with a user defined length and width to produce a land matrix. The length and width selected is based on the level of detailed needed for a particular assessment and the granularity and quality of available data. If a very detailed assessment is needed and a large amount of data are available for the different criteria used, then a high resolution matrix can be defined and populated with individual ratings. Once the rating of each segment is completed, the algorithm automatically produces the optimal post mining land use and presents it in a map with a color-coding per segment for each land utilization option. Additionally, the score of all possible land uses is calculated and shown, to provide additional information on other possible utilization scenarios, which may – for a variety of reasons – be considered, even if this would mean accepting higher costs for land reclamation, conditioning and development.

A final map of the mine area with colored clusters with post mine land use is created with additional information for the user such as the actual land area rated[1], the number of clusters (segments), the length and width of the cluster utilized. Furthermore for each post mining land use the actual land typology and area are presented in the resulting map. The system is robust so that different users with the same data are likely to produce very similar outcomes in terms of utilization scenarios. Also, the conditions that define a post land use type can be easily modified to better reflect local conditions if needed (e.g. for deployment and application of LURA in other regions / countries, or for other mining types, such as underground hard coal mining).

The evaluation of Amyntaio Mine with the use of LURA was executed in order to refine the methodology and to evaluate the possible optimum post mining land use. The outcome of the assessment should be considered as indicative of the least effort needed for repurposing to achieve the optimum land use based on the current land conditions. Of course land utilization options different from the optimum scenarios suggested by LURA can be chosen by future developers; in such cases LURA

[1] There may be areas with existing constraints that preclude the application od the LRS / LURA; e.g. areas that will be submerged after mine closure, or for which firm redevelopment scenarios have already been defined.

can be used to get rough estimates of the additional effort in time, funding and technology to put land in a condition that does not correlate with its designated optimum use.

It is important to note that the classification of post mine land use with LURA is not prescriptive. LURA proposes one of four broad potential utilization categories, ranging from low intensity, low value use to development with high added values: (i) forest and natural habitats; (ii) agriculture; (iii) industry and energy production; and (iv) business park developments, recreation and tourism. Additional areas that are consider as single use only are assigned in the matrix such as land restricted due to archeological findings, future inundation by groundwater rebound, or areas that have been characterized as forests by the Forest Authority and cannot be de-characterized.

2. Available data

The repurposing assessment executed with the use of LURA is based on actual available data. Generally, the minimum data required to produce a meaningful classification of a land should include:

(i) up-to-date electronic topographic maps of 1:5,000 scale or larger;

(ii) maps of same scale, depicting surface topography during past mining operations in 2 to 5-year intervals;

(iii) geological maps in same scale, with several representative cross sections in different directions and comments down to which geological layer / material excavation reached;

(iv) geotechnical conditions for slope stability such as detailed calculations of factors of safety in static and in seismic conditions, erosion potential of the slopes and possible liquefaction evaluation in fills or other materials located under the water table. Provision of specific deposition zones segregated by type of material;

(v) hydrogeological data and information; priority would be current groundwater elevation as well as during past mining stages. Ideally the original groundwater table before mining started would be available, as well as the future projection of the ground water table after all closure activities are completed, groundwater pumping has stopped and a full groundwater rebound achieved; surface hydrological information of low land areas that may accumulate water, areas that are considered to be preferential water pathways such as small seasonal streams, more permeant streams etc.;

(vi) environmental data of the two areas which should include test results for key pollutants at specific areas or locations; key parameters would be: Soil –> pH; organic content; sulfur; As, Cd, Cr, Cu, Ni, Pb, Zn; aliphatic, aromatic, polycyclic hydrocarbons. Groundwater -> same parameters, plus: dissolved oxygen, total oxygen demand (TOD), total organic content (TOC), hardness, conductivity, nitrate, ammonium;

The granularity / resolution of the above data, combined with a smaller segmentation / pixel size will produce a more accurate classification and utilization scenarios. . A large amount of data will produce a very clear and detailed vision of post mining land utilization scenarios, accounting for minimum reclamation efforts; a rich data set can also provide data for different legacies of the rated area that can be used for future evaluation of the most appropriate reclamation effort towards increased development opportunities.

The data related to Amyntaio mine, provided by PPC, and used to populate LURA and execute a first pilot land use classification of the mine are the following:

Data provided on 05/13/20:

1. Topographic map of the Amyntaio mine and outside overburden of current conditions in 2020, scale 1:10,000;

2. Six (6) Cross sections related to the excavating and dumping mining areas. Three cross sections in the southern part of the exterior dumping area and three cross sections in the mined area. The cross sections inside the mine have geological information as well;

3. Areas of archeological sites. The archeological areas of interest are located in the north part of the Amyntaio mine and around Lakkia mine;

4. Areas of future PV parks. The areas that PPC has proposed to install PV parks that have permitting is requested;

5. Areas that are considered as forest based on the forest authority assessment. This map depicts areas that have been forested and also areas in the South west part of the outside dump site which have been characterized as forest areas by the Greek Forest Authority;

6. Environmental Impact assessment (EIA), Water management plan, Water quality data 2018, Data of soil and water chemical analysis as well as a related study for Amyntaio Power Plant. These reports provides chemical analysis data in different areas of the mine and the TPP and the classification of the mine dump materials. Also a hydrogeological evaluation of the mine dewatering is provided with limited information for future water elevation in the mine;

7. Road network in the mining area is provided. The roads are considered secondary and provide local access to different mine areas;

8. Electricity transition network. This map provides the electricity distribution network around the mine area and also the medium voltage network around the mine;

9. Additional data regarding original ground surface and mine positions prior to mining activities.

Data provided on 05/08/20:

10. Amyntaio mine – reclaimed land, December 2018

11. Amyntaio mine – recent topographic elevation 2020

12. Amyntaio mine – post mining land uses, expropriation and other information

3. Classification and rating methodology

The GIS-based LURA application was utilized to rate the Amyntaio mine area based on the data provided by PPC. Based on the aerial view of the mine, a total area of 40 km^2 was selected and subdivided in 616 clusters with a length and width of 0.3km each. For this pilot study and the available information, the cluster dimensions were considered appropriate in order to produce an accurate representation of the post mining land uses. Further refinement of the model could be executed with smaller cluster dimensions and more detailed data, if more planning detail were needed.

The steps used to produce the classification and to rate each cluster of the map are the following:

STEP 1:

Locate the areas that have been considered as "areas of archeological interest" by the Greek Archeological Authority and areas that have been considered as "Forest areas" by the Greek Forest Authority. The areas considered as "areas of archeological interest" are located mostly on the North part of the Amyntaio Mine and around Lakkia mine as can be seen in figure 3.1.

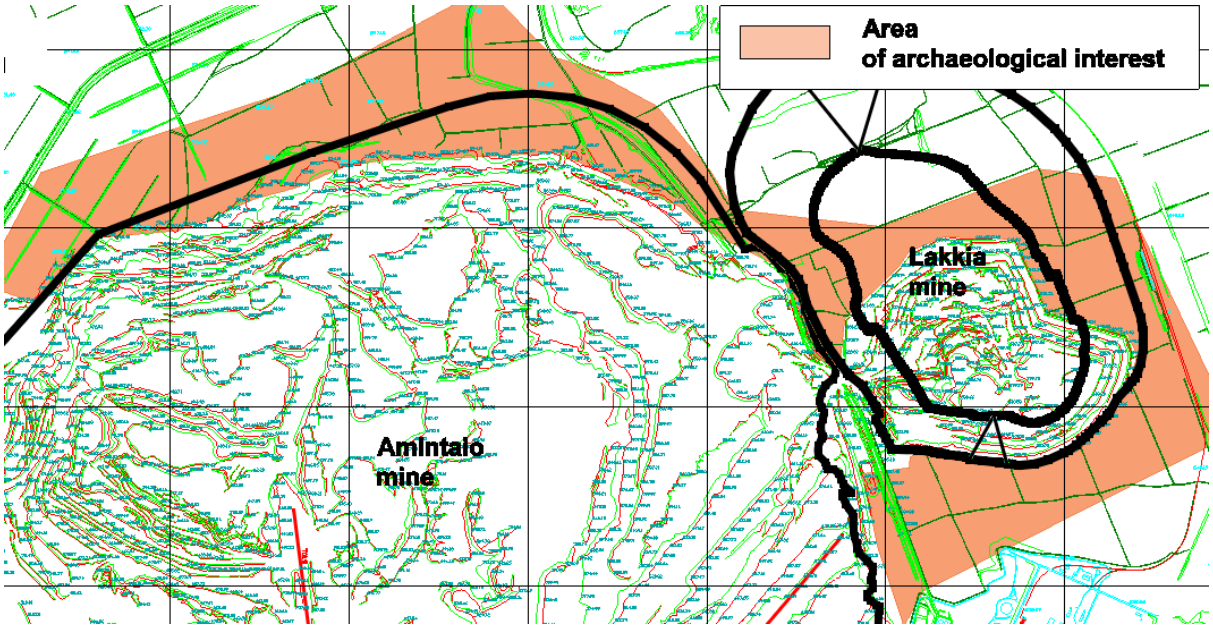


Figure 3.1: Area of Archeological interest in the North Part of Amyntaio mine based on [3]

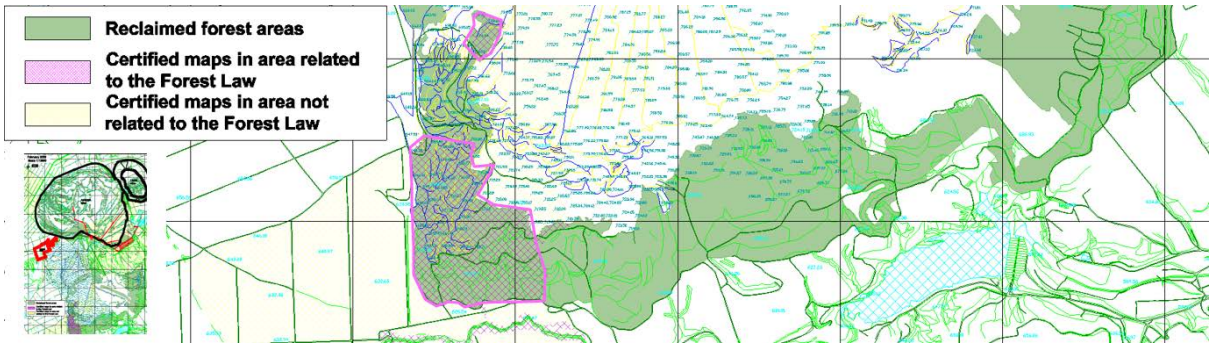


Figure 3.2: Forest area in the Southeast Part of Amyntaio mine based on [5]

These areas where assigned as "area segment is unusable" (meaning unavailable for redevelopment) and given the description of (i) *Archeological interest areas* for areas of archeological interest and (ii) *Forest authority areas* for areas characterized as forest (certified maps in the forest

law). These lands are considered to have only one single potential land use which cannot be changed due to Greek legal restrictions.

STEP 2:

The **Location criterion** has been rated for all other clusters (segments) of the map. The two subcategories used were:

- Distance to infrastructure and utilities
- Distance to human settlements

The rating selection from 1 to 5 based on location proximity is presented in the following figure, indicatively for cluster number 38.

Figure 3.3: Indicative rating of cluster 38 for location based on 1 to 5 scale and criteria

The distance between infrastructure such as roads and human settlements were measured either in the topographic map [1] provided, or Google Earth application and the appropriate rating was assigned based on the scale presented in the figure.

STEP 3:

The **Geotechnical Stability criterion** has been rated for all segments of the map not falling under legal restrictions as defined under Step 1. This criterion has three subcriteria which evaluate the possible expected residual settlements of fill, the slope stability of cut or backfilled slopes and sloping areas, and impact of ground water rise due to mine closure.

Based on the topographic map [1], the six cross sections [2] and the different data regarding original ground surface and mine positions [9], an estimate of fill overburden which is the height of fill placed on top of the natural or excavated ground surface was used to rate in a scale 1 to 5 the possible residual settlements as presented in the following figure. Fills that are of low height or have been placed a very long time ago are considered to produce lower residual settlements, than higher fills placed more recently.

For the slope stability subcriterion the presence of slopes either cut or fill, the foundation of fills on sloping ground and the previous landslide conditions were evaluated to rate the cluster conditions. Areas with high slopes and sloping ground or previous landslide conditions have been given a lower rate between 1 and 2 in relation to areas that are flat, with no significant fill slopes or sloping grounds

which are given higher ratings between 3 to 5 based on the available data. The rating considers the land "as is" and not as it can be transformed after additional land reclamation.

The impact of ground water was considered based on the elevation that the water table could rise in the future in relation to fill placement or excavated areas.

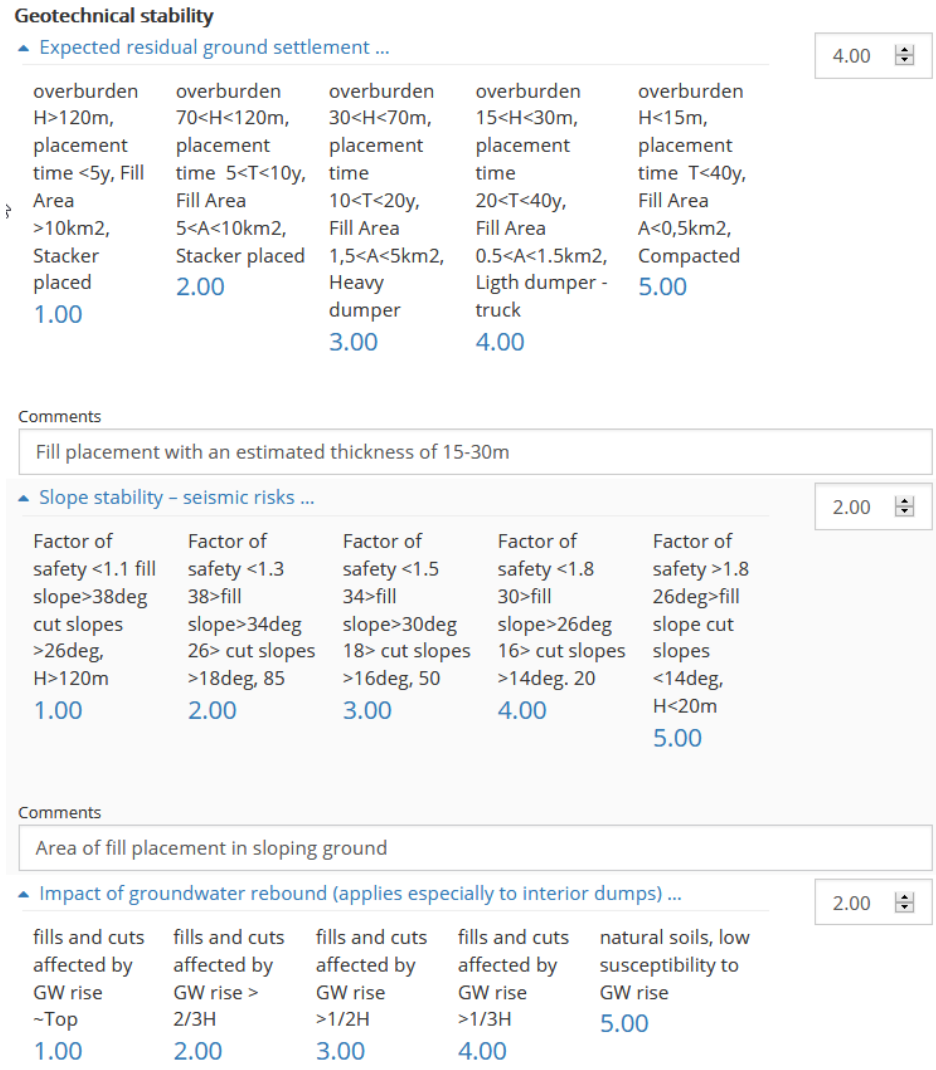


Figure 3.4: Indicative rating of cluster 38 for Geotechnical stability criterion

Based on [6] which provides a thorough groundwater evaluation of the mine area and [12] a ground water table rise inside the mine of +540m was considered. This elevation is the maximum lake elevation proposed by PPC predicted after mine closure. Reference [6] provides current ground water information, which is illustrated in the following figure but does not provide a future evaluation of the groundwater rise. The report finds a negative balance of ground water recharge mostly due to agricultural irrigation of the neighboring fields which will affect the actual groundwater rebound level once the mine drainage is stopped.

As can be seen from the following current ground water elevation, in the north of the mine and outside the dewatering boreholes, a ground water elevation of +540m is found. Near the mine the mine the water table drops to about +510m. Thus the estimation of a ground water rise to +540m is considered to be valid based on the available data.

It is of interest that the ground water elevation in the southeast part of the mine, is located between +590 to +600m. For this ground water elevation, there is no information of how it will affect areas of

the mined land bellow that elevation. In general the +600m elevation in the outside dump area is considered to be most of the time below the foundation elevation of the fills. Nevertheless capillary action and downward percolation of water cannot be excluded from the outer dump fills.

The impact of ground water is given the lowest value of 1 in areas bellow +540m and for areas that are above ground water elevation higher values are assigned based on engineering judgment due to the lack of more detailed hydrogeological modeling.

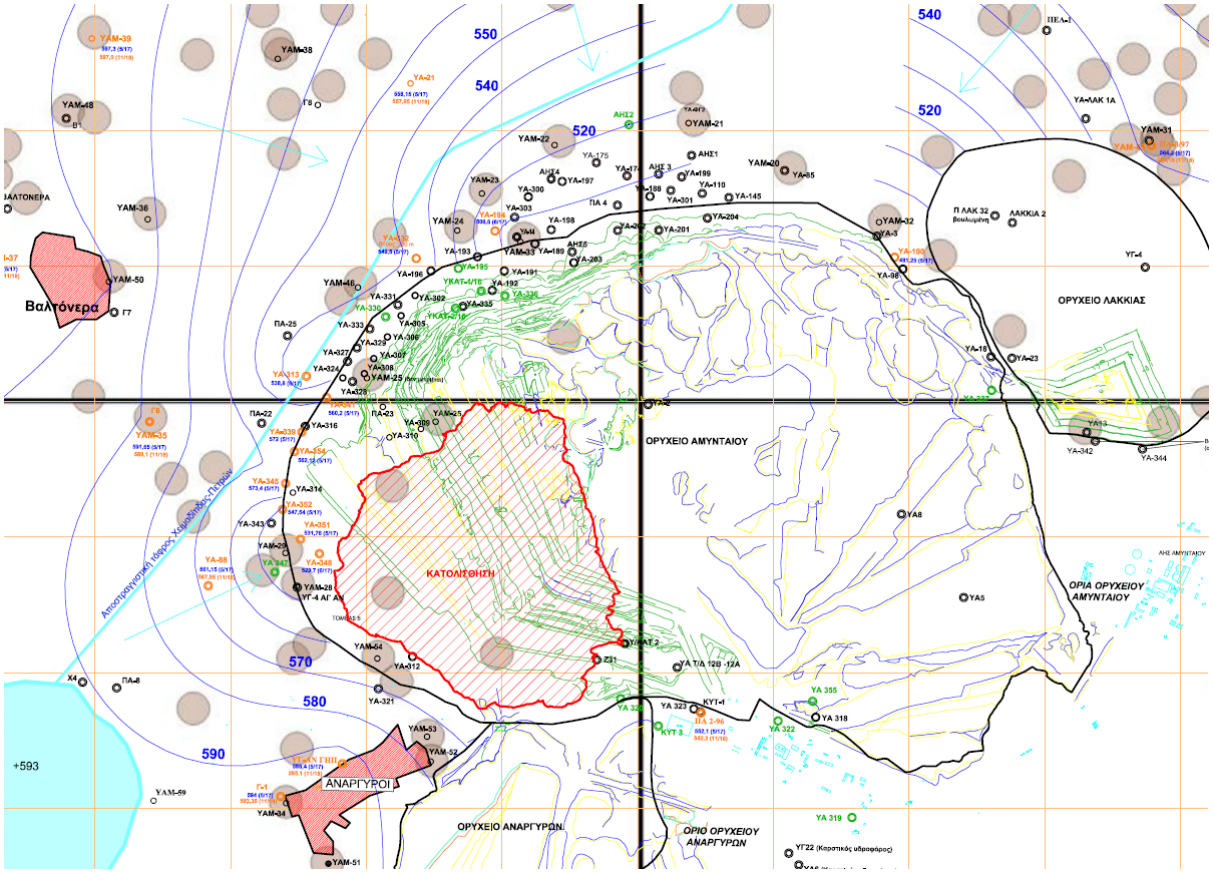


Figure 3.5: Current ground water elevation outside the mine boundaries due to dewatering from [6]. The area hatched in red depicts a large landslide that occurred in 2017.

STEP 4:

The **Topography and Hydrography criterion** has been evaluated based on three sub-criteria, describing the surface gradient and relief based on the current topographic mapping [1] of the land. Low scores are assigned to steeply sloping areas that are easily erodible and higher rating values are assigned to areas of mild inclination or flat areas.

Surface drainage is also evaluated based on the topographic maps [1] and land surface forms provided by satellite imagery. Areas that have been filled with spoil material with a stacker are considered to be uneven with local heights and depressions and are assigned lower rating values. Flat areas or areas with shallow gradients that can remove percolating and accumulating water are rated higher.

It was not possible to evaluate the hydrological risks due to extreme precipitation events with confidence due to the absence of a flood analysis and design of the mine area. Instead a constant rating of 4 was used in all clusters which defines an area susceptible to 50-100 year flooding. Only if an area

provided with a depression in a possible drainage root, a lower value was considered. This sub criterion could be further evaluated in the future if additional data in the form of a flood susceptibility analysis was prepared based on current topographic data and the updated Greek precipitation curves.

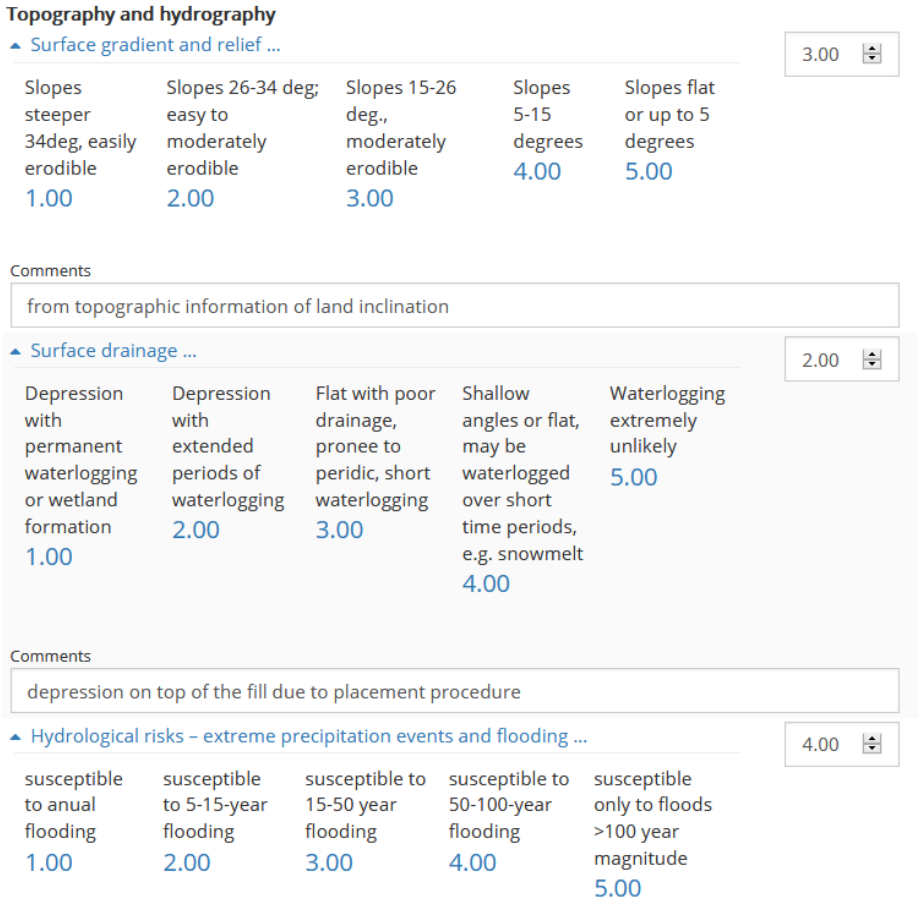


Figure 3.6: Indicative rating of cluster 38 for Topography and hydrography criterion

It must be noted that when both the surface drainage subcriterion and impact of ground water table receive a rating of one (1) then the area is considered to be permanently water logged and is assigned a "*Possible Water Body*" land use. This would preclude mot types of reutilization, with few exceptions (e.g. use of pond as water reservoir and / or for floating PV installations).

STEP 5:

The **Environmental Risk criterion** has been evaluated based on three sub-criteria which are used to assess the presence of contamination in dumped fill materials, the environmental burden placed by ongoing lignite production and related dust, emissions, noise and vibration and its proximity to an operating TPP, which may also be repurposed in the future.

Based on [6] and specifically the EIA "*most of the soils of PPC's deposits do not differ from the rest of the agricultural lands of N. Kozani*". And additionally the EIA report states "*Most of the lands of PPC's deposits, in terms of their extractable (assimilable from plants) concentrations in heavy metals, do not differ from the agricultural lands of N. Kozani*". The outside overburden was found to have a pH of 7,6 - 8,24 and in general the fill materials have been characterized as "inert waste". As

such the sub-criterion for contamination of dumped material was given a rating of 4 which is appropriate for no evidence of contaminations or presence of hazardous materials.

The subcriterion for current / manifested environmental impacts of ongoing lignite production was assigned for all clusters a value of 4 which is due to the decommissioning of the TPP and the limited operations of lignite production and reclamation that are taking place and will continue for the near future.

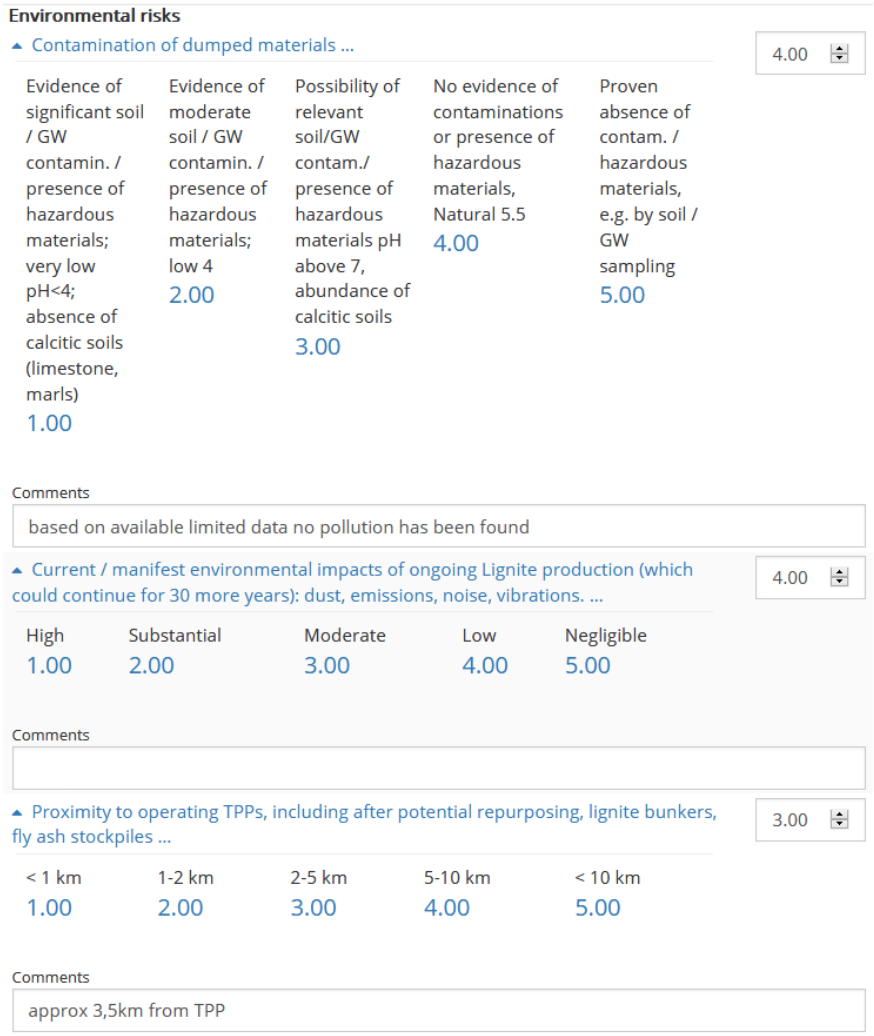


Figure 3.7: Indicative rating of cluster 38 for Environmental risks criterion

The sub-criterion for proximity to operating TPP which include possible repurposing and proximity to fly ash stockpiles and lignite bunkers was directly measured from the topographic map [1] and google earth and appropriate rating was assigned.

STEP 6:

The **Development Opportunities criterion** has been evaluated based on the general assessment of the area in relation to all other criteria. If a cluster had moderate to high rating for the other criteria it was considered as an area with higher potential added value, which would encourage future high value development with expected high returns (hence, this is a reinforcing criterion). Conversely, if a cluster has low rankings in other criteria then lower development opportunities with lower potential added value generation will prevail.

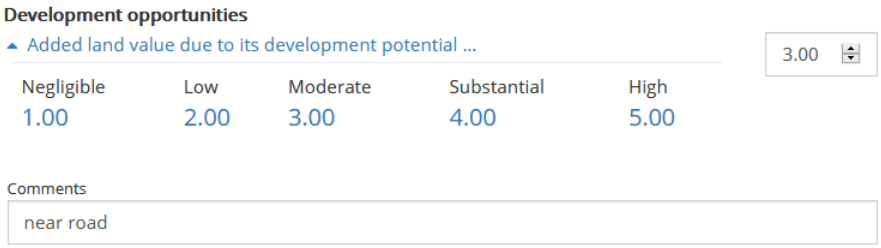


Figure 3.8: Indicative rating of cluster 38 for Development opportunities

4. Classification and rating results

Based on the methodology previously described, a pilot test was executed with LURA for Amyntaio mine. Each cluster (segment) was individually rated with the available data as presented in chapter 2. In total 616 different segment ratings were executed in order to produce the outcome presented in this report. The detailed evaluation of each segment is presented in Appendix I of the report.

After the rating for each criterion is completed for each segment, LURA's algorithm executes the calculations to determine and match utilization scenarios, assigns the appropriate signature in the map and presents the results for each segment as follows below:

- Figure 4.1 figure depicts an individual segment and its color which defines the optimal land use determined by LURA, and illustrates the average ratings for the five evaluated criteria in a pentagram chart;
- Figure 4.2 presents the average score per criteria in tabular form, as well as the net differences between the determined optimum utilization scenario and the five available land use. The lowest value for a typology indicates the optimal land use and is the one depicted in the map with the appropriate color.

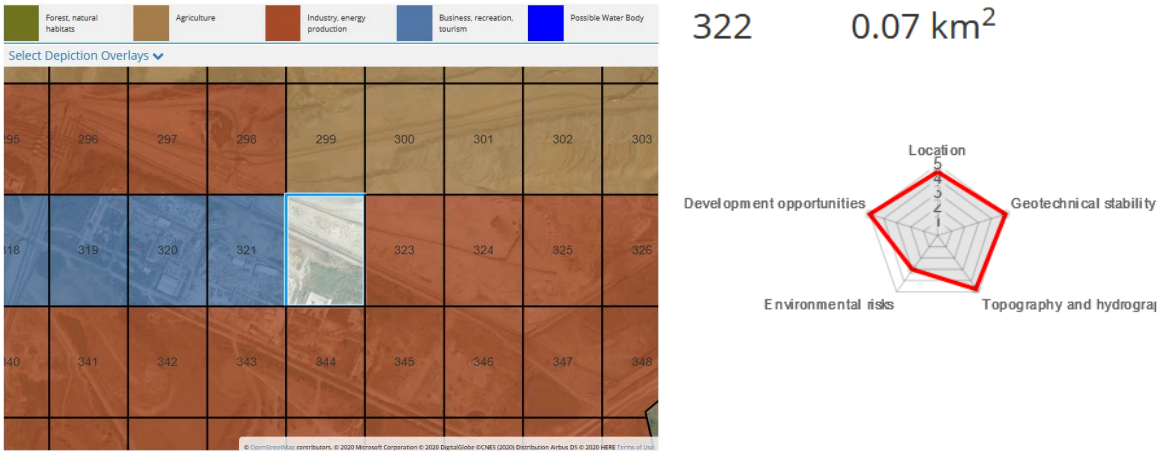


Figure 4.1: Indicative output map and chart with rating for cluster 322

Theme	Average Score
Location	4.50
Geotechnical stability	5.00
Topography and hydrography	4.67
Environmental risks	3.00
Development opportunities	5.00

Land Use Segment Rating	
Forest, natural habitats	38.00
Agriculture	24.00
Industry, energy production	11.00
Business, recreation, tourism	10.00
Possible Water Body	40.00
Coordinates	

Figure 4.2: Indicative output of average score and optimal land use calculation for cluster 322

The table providing the net difference values from optimal land use per typology, is very important to evaluate, since different land uses can have very similar results. For example as can be seen for segment 322, the lowest differential – meaning most favorably rated typology - is business, recreation, and tourism. However, there is a marginal difference of only 1 point to the next-best typology, industry and energy production. This means that the optimal use of this segment could be both a business park and equally an industrial development area.

Evaluating an area for optimal land use means that for each segment, the smallest effort and resources would be required to transform the land from its current conditions to the defined optimal land use. Additional efforts for reclamation and repurposing or other development strategies may be required to repurpose an area for a land use diverging from the one suggested by LURA.

Also further refinement of the segment subdivision and the use of more complete or more detailed data sets, can produce a different optimal use for given area than the one produced in this evaluation. Hence, the outputs of this pilot study should be considered as an indication of optimal land repurposing and utilization, but neither as exhaustive and definitive assessment (which is outside the scope of this pilot exercise), nor as a stringent recommendation without any flexibility.

Figure 4.4 presents the optimal land use map for Amyntaio mine from this pilot run of LURA based on the available information. As can be seen from the map five land use typologies have been produced based on actual rating and two on restrictive land use. The typologies produced by rating are the following (i) Forest and natural habitats, (ii) Agricultural use, (iii) Industry and energy production, (iv) Business park – recreation – tourism and (v) Possible water body – artificial lake. The percent and area that each land use type covers in the total area of about 40km^2 is shown in the following figure.

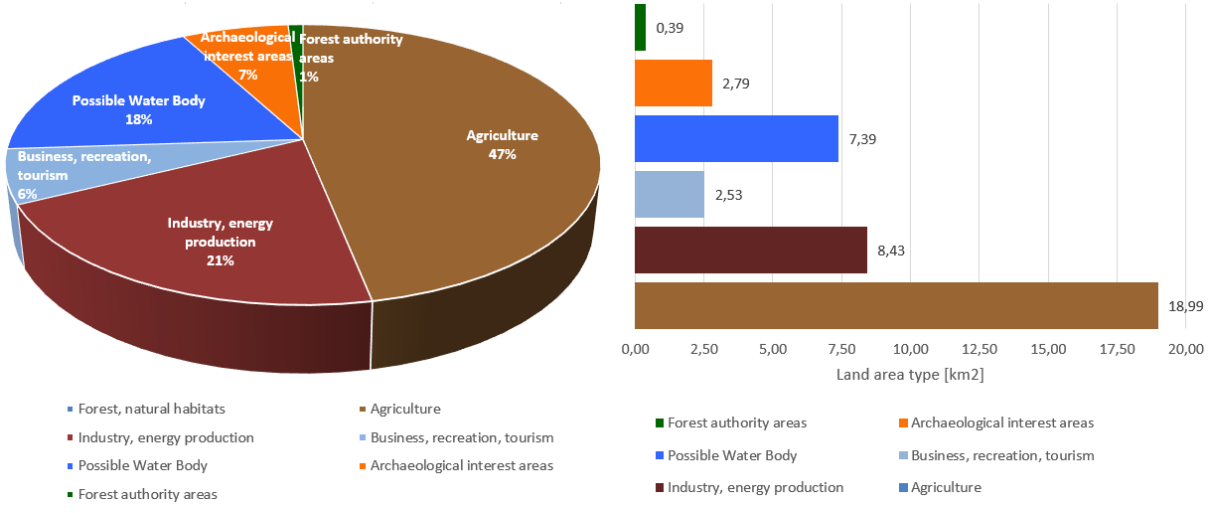


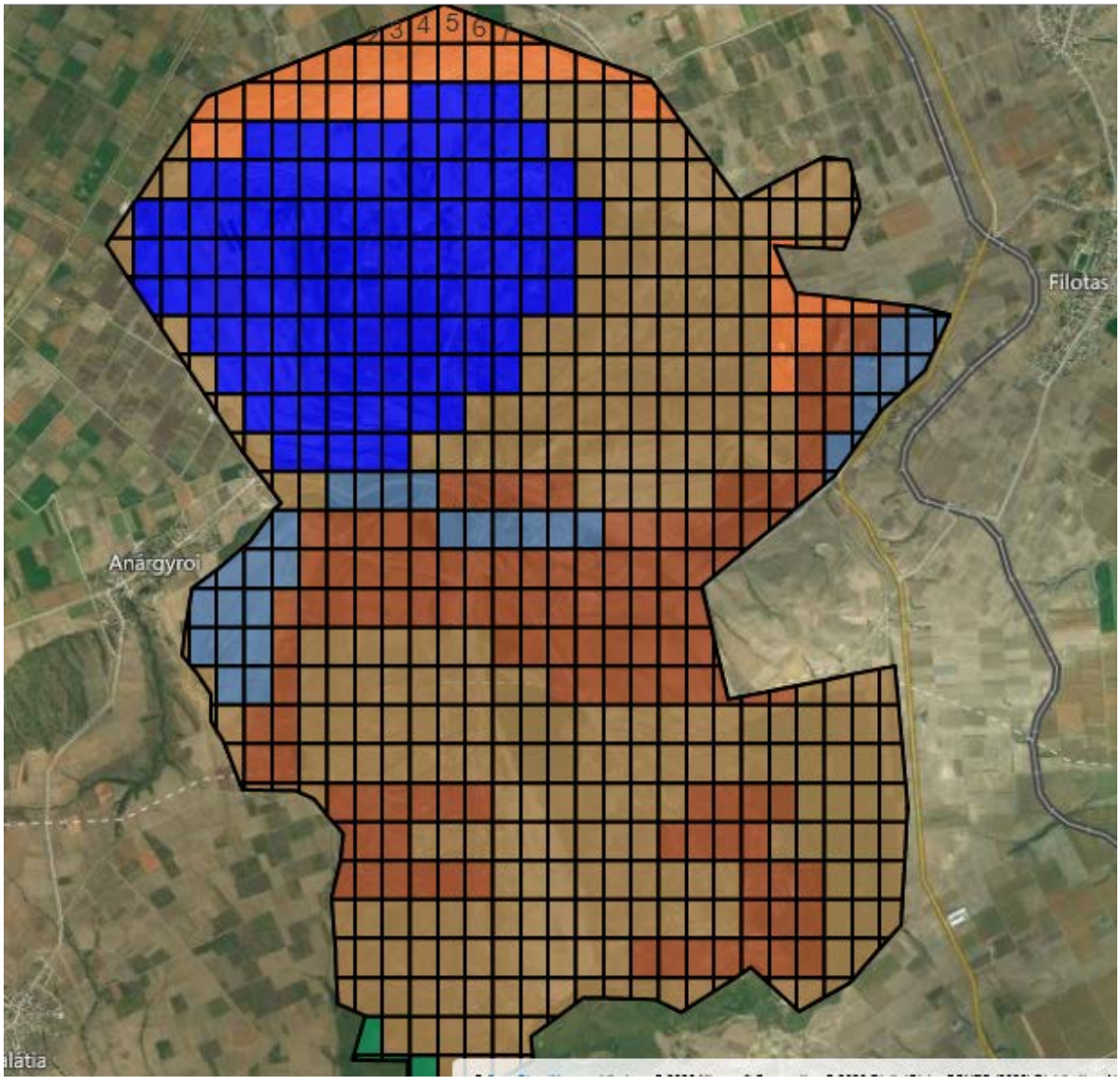
Figure 4.3: Amyntaio mine land use rating map

As can be seen from the charts of figure 4.3 and the map in figure 4.4, the predominant optimal land utilization has been found to be agriculture. This is based on the proximity of the area to infrastructure and transport network, the geotechnical liabilities such as long-term settlements and slope instabilities' and the favorable environmental conditions without pollution of soil and groundwater.

The optimum land utilization with the second higher frequency based on current conditions, has been found to be industrial development. This development can take place in areas that are geotechnically stable with minimum amount of expected long term settlements, are close to infrastructure and energy networks and far from villages.

A significant percentage of the lands will probably be submerged under water and an artificial lake will be created. This lake could be used for recreational purposes and as a natural habitat. A pumped water storage cannot be excluded but additional evaluation of the quantities of water and head need to be clarified.

A small but not insignificant land area has been found to be optimal for business parks or recreational usage.



Utilization	Total Segments	Total Area Size	%
Forest, natural habitats	0	0.00km^2	0.00
Agriculture	293	18.99km^2	47.56
Industry, energy production	130	8.43km^2	21.10
Business, recreation, tourism	39	2.53km^2	6.33
Possible Water Body	114	7.39km^2	18.51
Total	**576**	**37.34km^2**	**93.50**

Unusable Category	Total Segments	Total Area Size	%
Archaeological interest areas	43	2.79km^2	6.98
Forest authority areas	6	0.39km^2	0.97
Total	**49**	**3.18km^2**	**7.95**

Figure 4.4: Amyntaio mine land use rating map

An interesting outcome is that forestry - which would be expected for lands with the poorest conditions - has not been selected by LURA's automated rating procedure. This is because the entire mine area has added value based on the distance to human settlements, primary and secondary road proximity and very good environmental conditions (absence of pollution). It is seen from the ratings that for the Amyntaio mine forestry seems more of an environmental restoration approach, than a response to actual land conditions. Afforestation may be an option for e.g. marginally stable slopes, where forest cover could increase stability and reduce erosion and water runoff. Such conditions could be identified in a more granular, higher resolution run of the classification, which – however - is outside of the scope of this work.

5. Comparison of LURA output with PPC proposed future land use

The LURA output map of land uses has been compared with the proposed future land use types that PPC has produced [12]. In the following figure 5.1 the two maps have been overlapped and in figure 5.2 have been placed side by side.

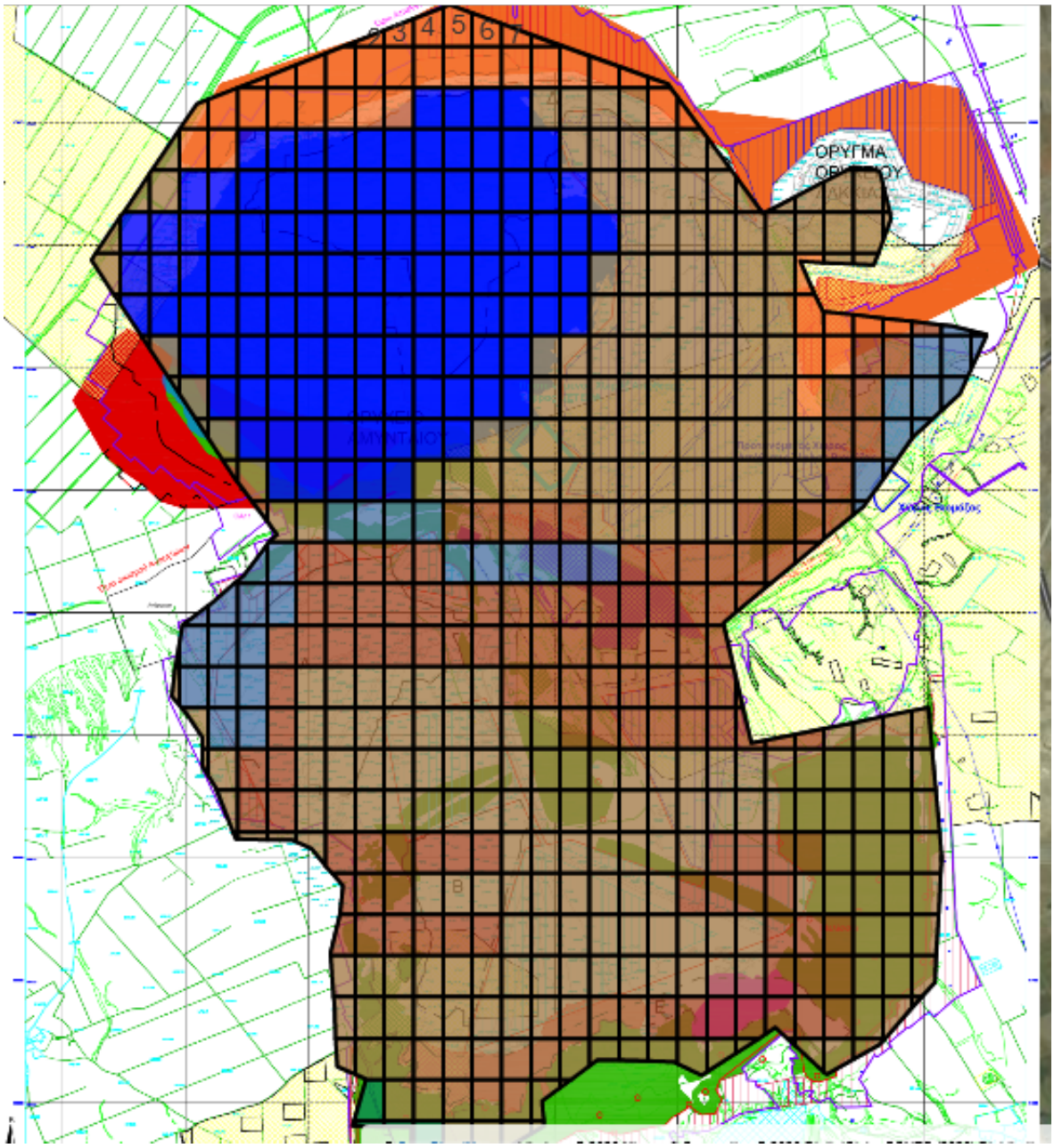


Figure 5.1: Amyntaio mine optimal land use map from LURA overlapped on PPC proposed land future land use

The maps look similar but have the following differences. Much of the agricultural use has been assigned for PV usage by PPC. The agricultural land typology does not preclude the installation of PVs but additional reclamation may be warranted to produce an appropriate land surface for PV installations.

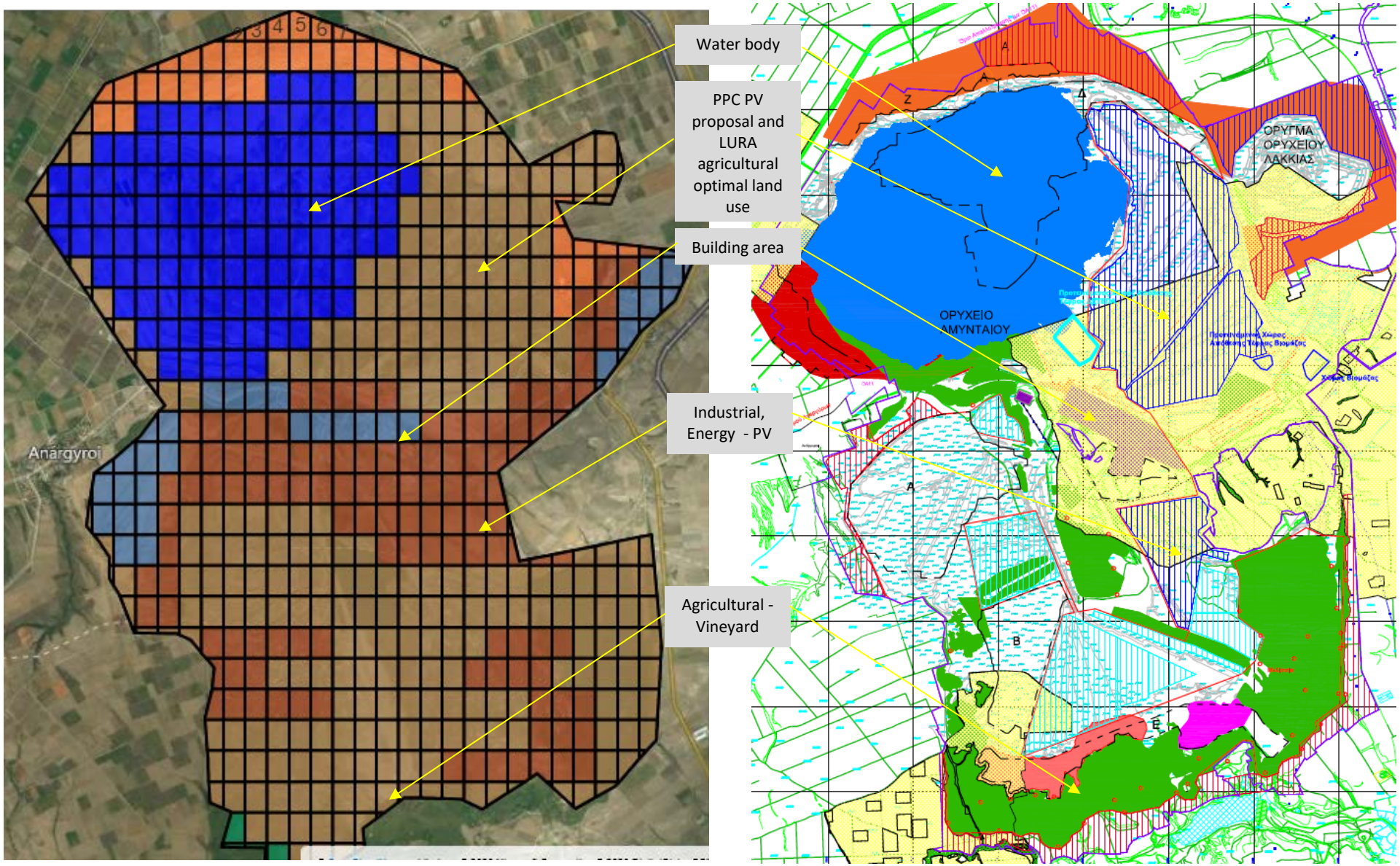


Figure 5.2: Amyntaio mine optimal land use map from LURA side by side to PPC proposed land future land use

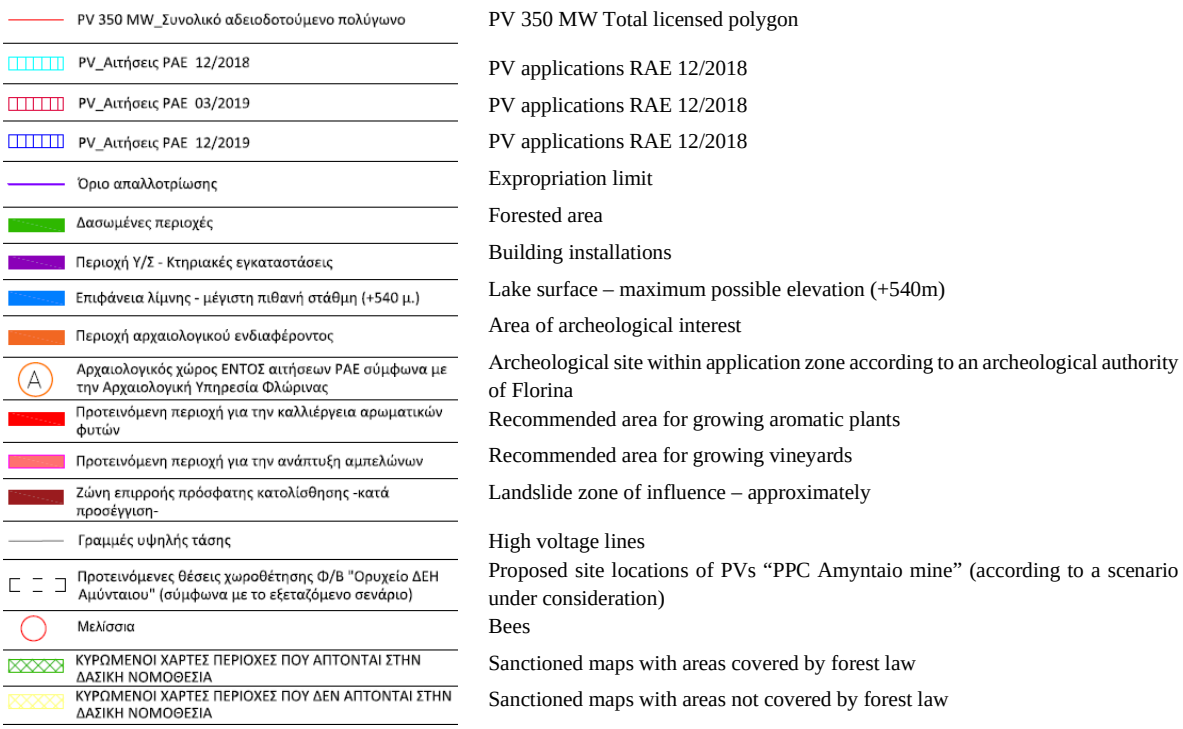


Figure 5.3: Amyntaio mine PPC future land use legend

The maps have identical water body locations, which is logical based on the topography and the expected ground water rise, once pumping for dewatering is discontinued. PPC’s land use map proposes a significant part of the land to be covered with forest, which is an approach that emphasizes environmentally friendly land use, regardless if this may not be the optimal land use (except for steep, marginally stable slopes).

Industrial land use has not been foreseen in PPC future land use, only in certain minor locations such as the area for biomass energy production. However, there are examples of a good overlap of LURA’s proposals with PPC’s planning: The area proposed for building development by PPC has been found for most part suitable land use by LURA. Areas proposed by PPC for vineyards are located in areas classified for agricultural use by LURA.

In conclusion, the pilot evaluation of repurposing scenarios for lands of the Amyntaio mine using LURA produced accurate representations of possible optimal land use for future development. PPC’s proposals are based on more detailed studies and assessments, which have taken much more time and resources to complete. They are similar in many aspects and have not been found to significantly contradict LURA’s proposals. This pilot project confirms that the LURA tool is highly useful and efficient as an assessment and planning tool for lands repurposing in the context of mine closure. Additional time and resources to collect and process data with higher resolution and granularity will further improve the quality of LURA’s outputs.