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Guidelines for cerrado establishment on open pit mine sites – Paracatu, Brazil

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Abstract

Too often, open pit mine reclamation is typified by minimal revegetation efforts and monocultures of grass species. This is most evident in developing nations where ongoing remediation may not be government mandated during the extraction process, and where native habitat tends to be valued more for its production or real estate potential, rather than its inherent ecosystem services. The Brazilian cerrado biome is one such region, regardless of its high proportion of endemic plant species and diversity, which is second only to the neighbouring Amazon rainforest. Deforestation rates in this tropical savannah are amongst the highest in the world, partially due to rapidly growing mining and agricultural practices, despite having naturally poor, toxic soil.

Through an in-depth literature review, landscape inventory and analysis, and synthesis of results, this research sought to determine if post-mining landscapes in the cerrado could serve as islands of native habitat. Preliminary results and guidelines were critiqued by specialists in the fields of mine reclamation and cerrado ecology. The research showed that cerrado soils and post-mining soils are remarkably similar both chemically and physically, which results in an overlap of vegetation that thrive in (and in some cases, remediate) these toxic environments. The two landscapes also share similar landforms, including plateau and cliff topography, suggesting that they may have comparable microclimates that support inhabitation by selective plant and animal species. The finalised guidelines for cerrado establishment on open pit mine sites have been graphically applied to a gold mine in Paracatu, Brazil, in order to demonstrate how these guidelines, when paired with appropriate land use planning, can contribute to safe and effective contaminant remediation, revenue generation, and renewal of ecosystem services to this region.

1 Introduction

The purpose of this research was to determine if mine sites located in the cerrado region of Brazil have the potential for restoration of native vegetation for conservation purposes. In order to do this, cerrado and mine site characteristics as well as current mine reclamation approaches needed to be understood.

The world's tropical savannas are located within 20 degrees latitude of the equator in both the northern and southern hemispheres. The Brazilian wet tropical savannah, or cerrado, is one of the more threatened biomes in the world, and has been identified as a priority for biodiversity conservation due to its high proportion of endemic species. This landscape is extreme in many senses: it has the second highest plant diversity of any ecosystem in the world, soils are very poor and acidic with high aluminium concentrations, and the climate ranges from very dry to wet depending on the season. The cerrado is a highly specialised environment of global importance; however, deforestation rates are high, ranging up to 30,000 km^2 per year in some areas. Surface mines contribute to this destruction; however, mine reclamation plans and practices in the developing world vary greatly, depending on the political territory and the mining corporation, amongst other things.

Through an extensive literature review of cerrado biome characteristics and mine reclamation, it was found that the conditions of these two landscapes can be remarkably similar. Combined with established landscape ecology principles, guidelines were developed in order to enable the establishment of large patches of cerrado on exhausted mine landscapes. By using a landscape architectural approach, which will be elaborated upon in the following pages, these guidelines were theoretically applied to a site, creating a demonstration plan.

2 Methodology

A methodology was structured around an extensive literature review of mine reclamation practices, cerrado characteristics, and landscape ecology principles. Requirements and characteristics were extracted, and a synthesis of the findings was then completed by assessing the relative compatibility of the characteristics to each other. The member validation method was used to qualify the results via external evaluation by leaders in the respective fields of interest. Evaluators were chosen based on their comparative experience in their field and their familiarity with current research and practices. This external evaluation of the results was completed via a descriptive, written questionnaire in order to reduce possible bias introduced by the researcher. Once this process was complete, comments provided by the evaluators were addressed and the guidelines were finalised.

Since reclamation planning is best performed on an individual site basis (Freberg and Gizikoff, 1999), the resulting guidelines from the literature have been documented as broadly as possible in order to extract as much useful information as possible without limiting applicability to a range of sites. Contaminant details and related remediation of contaminants were out of the scope of this research in order to maintain this broad applicability.

In order to test the applicability of the guidelines in a practical way, they were applied to an actual open pit mine site, located within the cerrado. The inventory and analysis process prior to design, or application of guidelines, is a thorough process generally completed at multiple scales. This is done in order to gain an understanding of those outside factors influencing the site, and the site factors affecting off-site areas at multiple levels.

Criteria for the inventory were developed using a comprehensive set of physical, biological and cultural attributes (LaGro, 2008) both on and surrounding the site, as they will all influence end use design. These attributes were documented from a variety of sources, including GIS maps created with data from NASA's Warehouse Inventory Search Tool (WIST) and the United States Geological Survey's Hydro1k data sets. Satellite images from Google Earth, maps from Instituto Brasileiro de Heografia e Estatistica (IBGE), and a site visit were also used. The resulting inventory was then analysed with respect to its implications for reclamation, re-development, and restoration of cerrado. This procedure is essential in the design process, clarifying opportunities and constraints of the site so that the design is responsive to the local and regional context.

Inventory and analysis outcomes were combined with the guidelines in order to design the site so that it is left safe and stable. The mine reclamation guidelines were considered most important to ensure the site would be safe for people and animals. The second step was to apply the landscape analysis information, resulting in a master plan of the site. The third step was to apply the landscape ecology principles, where the analysis permitted, by blocking in patterns of vegetation. Lastly, cerrado characteristics were applied, dictating the type of vegetation that could be placed in each location. The design was then fine-tuned in areas to ensure smooth transitions.

3 Data

This research evaluates mine reclamation in the cerrado, a wet tropical savannah in central Brazil. The cerrado once occupied 23% of Brazil, extending 2 million km^2 from the border of Venezuela, down into Paraguay and Bolivia (Bieras and Gracas Sajo, 2009). Although wet tropical savannas occur in other parts of the world, the cerrado is unique for its high diversity of plant species which is second in the world to the neighbouring Amazon rainforest (Felfili and da Silva Jr., 1993; Klink and Machado, 2005; Ratter et al., 1997; Woodward, 2003). The cerrado provides ecosystem services to surroundings areas and to the region, such as: mitigation of flooding and droughts, moderate climate, stream and river protection and improving water availability by raising the groundwater table. The cerrado also provides a variety of renewable non-wood products such as pharmaceuticals, insecticides and food (Wantzen et al., 2006). These benefits are being lost at an astounding rate, i.e. roughly 22,000 to 30,000 km^2/year. Post-mining rehabilitation could play a role in their return (Klink and Machado, 2005; Ratter et al., 1997).

With the development of government legislation, advanced research, increased corporate social responsibility and the Superfund, mine reclamation practices in developed nations have improved drastically over the last 50 years. Nonetheless, in developing countries and countries without formal legislation, landscapes, ecosystems, and communities continue to be negatively impacted by these extraction practices. In these cases, it is important that reclamation be inexpensive and effective so that this important step is taken. Further incentives for reclamation can be provided through the potential for revenue generation on the site after closure, as a result of insightful programming. In order to understand how this is possible, it is important to understand necessary practices in mine reclamation as well as the characteristics of the landscape.

A finalised list of guidelines for each relevant topic area were developed for the re-establishment of cerrado on mined land in central Brazil, as presented in the following sections.

3.1 Mine reclamation guidelines

- Salvage topsoil prior to mining for use in restoration, or use amended subsoil in cases where topsoil is unavailable or unsuitable.
- Minimise soil degradation during restoration or reclamation construction.
- Locate contaminated water (in tailings ponds) and soils away from clean water.
- Ensure containment ponds have sufficient capacity to accommodate high intensity storms.
- Control overland water flow and maximise infiltration in non-polluted areas.
- Minimise sediment load in water runoff.
- Stabilise and remediate solid tailings using phytostabilisation.
- Use the hydrological basin as a design unit for topographic re-design, if possible.
- Minimise the height of aboveground fill, length and steepness of slopes.
- Use a combination of erosion control methods to trap sediment on site.
- Restore for ecosystem management and functions to achieve a broad range of goals.
- Implement near-natural plant establishment techniques.
- Stabilise steep slopes through stabilisation aids and alternative planting techniques.
- Introduce target species following primary plant establishment.
- Monitor the site following plant establishment.

3.2 Landscape ecology principles

- Large patches are preferable to small patches.
- Small patches can act as stepping stones to larger habitat areas.
- More patches are preferable to fewer, regardless of size.
- Patches should ideally have a rounded core with curvilinear edges and elongated offshoots.
- Elongated patches should be oriented perpendicular to the direction of dispersal.
- The presence of species at risk should be considered when selecting patches for conservation.
- Edges should be vertically and horizontally variable.
- Edges are curvilinear, complex and gentle, and include tiny patches in larger coves.
- Edges should be wider on the side facing prevailing wind or sun exposure.
- Similar vegetative structure and species should exist in corridors between large patches.

- A corridor or cluster of smaller patches should be provided between two large patches.
- Habitat should be maintained on both sides of streams as buffers.
- Fragmentation should be avoided.
- Buffers should be used to protect habitat from invasive plants and animals.
- A mixture of adjoining habitat combinations encourages varying species.
- Provide alternative routes to the same destination.
- Large mesh-size networks are better than small networks.
- Network intersections should be protected via strategic location and buffering.

3.3 Brazilian cerrado characteristics

- The majority of soils are deep, porous, well-drained, and strongly weathered.
- Soils are generally poor, with high levels of aluminium.
- The landscape is composed of plateaus and valleys.
- Vegetation subformations differ according to elevation, soil fertility, water availability, and fire frequency.
- Some plant species are common throughout the cerrado.
- Vegetation is diverse in form and function.
- For conservation or restoration, native vegetation should be planted.
- When restoring cerrado, vegetation functions should be organised in alternating patches.
- A natural fire regime should be used to preserve animal diversity.
- Plant species should overlap.
- Buffer zones between hill slopes and agricultural areas should be created.
- Larger rivers have legally preserved narrow, continuous forest margins.
- Preserve the network of streams and rivers.
- ‘Legal Reserves’ should be established.

3.4 Landscape inventory and analysis

The study site, an open pit gold mine called Morro do Ouro, is located in Paracatu, Minas Gerais, Brazil, which is centrally located within the country, about 230 km southeast of the Brazilian capital, Brasilia. The area has been actively mined by artisanal miners since 1722; however, the Morro do Ouro Mine has only been operational since 1984. The mine is now owned and operated by Rio Paracatu Mineração (RPM), a subsidiary of Kinross Gold Corporation of Canada. The grade of gold is currently averaging 0.45 grams per tonne, which is relatively poor low but still profitable (Kinross Corporation Annual Report, 2010).

In 1997, Paracatu was named a priority area for conservation at the Cerrado Priority-Setting Workshop, organised by NGO’s and universities, and funded by the Brazilian Ministry for the Environment. The region was chosen for several reasons; most important were: 1) a high level of presence of rare, threatened, or migratory species, 2) the presence of economic or cultural value, 3) high species richness, and 4) landscape features that were important in conserving biodiversity (Cavalcanti and Joly, 2002). Notwithstanding, it appears there has been little progress in terms of conservation; however, the guidelines previously developed indicate that this open pit mine environment may provide an opportunity for restoration.

The inventory described the existing conditions, while the analysis interpreted how the site and areas around the site would be affected by reclamation, outlining opportunities and constraints. These items will be discussed.

3.4.1 Regional scale

Soils in the Paracatu region are mainly latisols, also referred to as oxisols in the American Soil Taxonomy Classification System. This means that the soils are mineral-rich, and typically either have an oxic horizon within 150 cm of the surface, or they have greater than 40% clay by weight in the upper 18 cm. This contributes to a high proportion of plinthites as noted in the literature review, but also adds stability to the soil, making it more structurally sound for uses such as tailing impoundment dams or roads.

Native vegetation is sparse in the region is sparse, as the landscape is dominated by agricultural fields for pasture. According to federal conservation laws, 20% of this land must be preserved as native cerrado; however, this 20% is widely dispersed in small patches and contributes little to conservation efforts as a result.

The mine site and the city of Paracatu are located at the upper portion of a valley system. These areas can be hydrologically important as they are typically groundwater recharge areas. Consequently, extreme care is required to ensure that seepage of contaminants into the groundwater does not occur.

3.4.2 Local land use and circulation

The mine is framed by two major highways to the east and west, and on the south by the city of Paracatu. The actual extraction site is currently at the south end of the site, bordering the city and with residential dwellings less than 100 m away from the pit wall. In total, the site contains: one large tailings impoundment pond, one large processing plant and one small processing plant with three mills, the extraction site, and a large parcel of land currently being prepared for conversion into a second tailings impoundment pond. This second pond will make landscape connectivity more difficult for animals, while any infrastructure will need to be cleaned and made safe for public access, or removed from the site.

Circulation to the immediate south of the site, in Paracatu, includes heavy pedestrian traffic and a narrow road network. Access to the mine is through a small residential street. The mine site has its own network of dirt roads that change often depending on the location and type of work being done.

There are intact patches of cerrado vegetation to the south-east, along the bordering highway. To the north and west, land is being used by local farmers for pasture; minimal cerrado vegetation exists on these portions. The remnants of cerrado will be important seed sources for revegetation of the site.

3.4.3 Local vegetation, soils, and hydrology

The vegetation subformation in Paracatu is primarily cerrado sensu stricto, ranging from grasslands at higher elevations on site, to dense forest and grasses at lower elevations and near water sources. The most common plant species, in terms of abundance are: *Dilleniaceae, Leguminosae, Compositae, Vochysiaceae, and Malpighiaceae* (Felfili and da Silva Jr., 1993). The transition in vegetation as you move throughout the site coincides roughly with a transition from red latisols at higher elevations, to yellow and finally brown-grey latisols at lower elevations.

Watercourses are abundant on the site, including seasonal creeks and a few rivers. RPM has permits to take water from three of the watercourses: the Sao Domingo River and the Santa Rita Rivers, which traverse the site, and the Sao Pedro River, which is located in the eastern-most plot of land where RPM’s exploration concessions exist. Rico Creek, located in the south-west portion of the site, is contaminated with mercury from historic artisanal mining, and will need to be remediated. Soils and vegetation should be replaced to match pre-existing conditions as much as possible. Watercourses will be disrupted by the second tailings pond and the continuation of mining, making a new site-grading plan necessary.

3.4.4 Local topographic features and views

Topography elevations on the site ranges from less than 500 to over 825 m above sea level; the mine infrastructure is located at a high point on the site making it visible from a distance, providing good views out of the site. Furthermore, the main highway into Paracatu runs along the west side of the mine, at the top of a ridge, making the large tailings pond and extraction site the primary view as one approaches the city. At present these are an eyesore; however, an opportunity exists to create a positive impression for people entering the city.

3.4.5 Opportunities and constraints

The site analysis has been divided into opportunities and constraints, and graphically represented in Figures 1 and 2. This analysis identifies the implications of the existing site characteristics as they relate to the potential for reclamation and revegetation of the Morro do Ouro Mine in Paracatu.

Opportunities are as follows:

- High to low elevations, wet and dry areas, and slopes from less than 5% to over 50% will provide a variety of environments for cerrado subformations.
- A large existing patch of cerrado vegetation neighbours the site and may act as a seed bank for vegetation.
- The neighbouring vegetation patch also provides connectivity for local fauna to colonise the site.
- The main access highway to Paracatu, and the south-western edge of the site, provides good views of the entire site, acting as an introduction to the city. This provides an opportunity to draw people into the site.
- The southern edge of the site borders a residential area with low traffic levels, which will help buffer the site from city activities.
- The southern edge of the site may be useful as a public conservation area, doubling as a buffer from the city.
- The highway west of the residential area may provide a good entry point onto the site for the public.
- Large tailings ponds may have potential for floating phytoremediation plantings that would also reduce evaporation (necessary to keep pollutants from being exposed in the dry season) and would help to clean the water.
- Location of tailings ponds allows for loops of vegetation, acting as corridors, and providing a choice of pathways for fauna species.
- Existing infrastructure may provide educational or art opportunities once cleaned.
- The high point of the site provides excellent views of surrounding areas, and has potential for any necessary built structures.

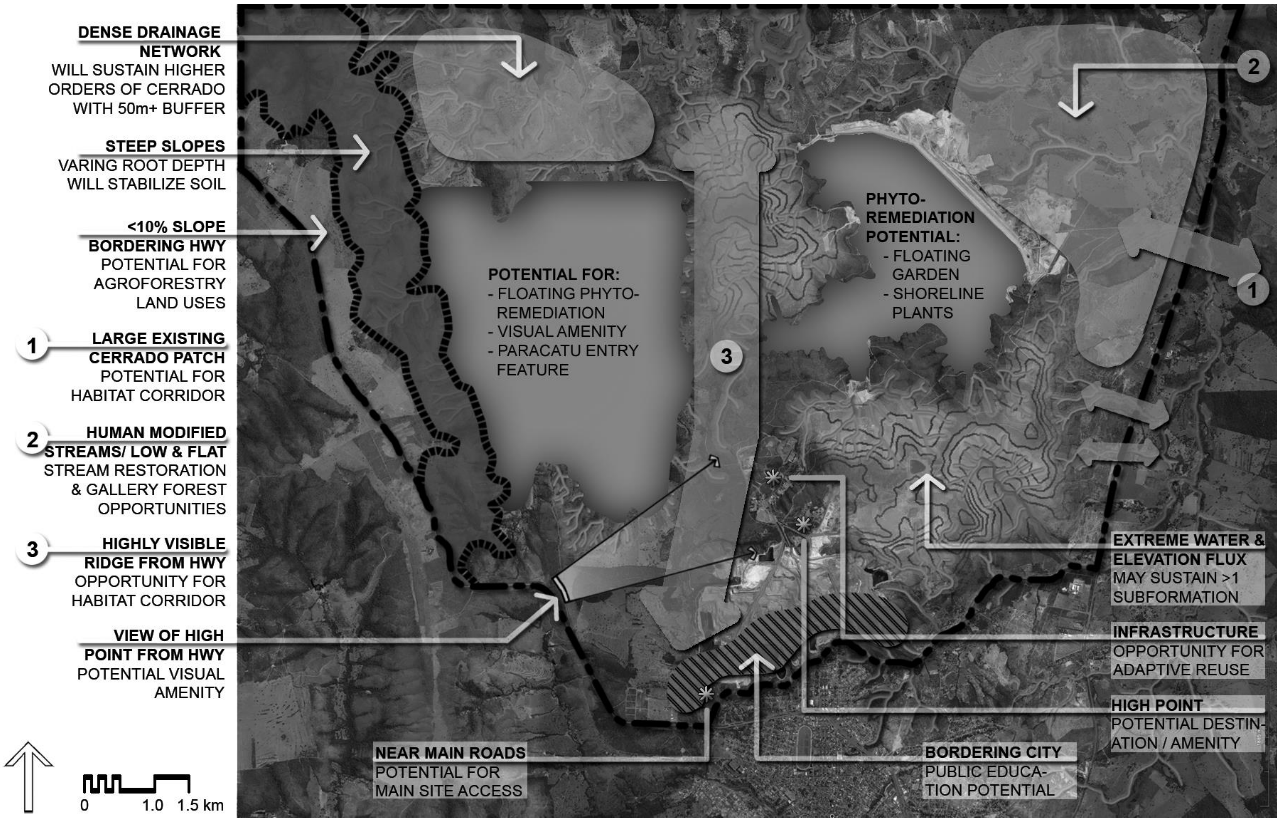

Figure 1 Opportunities for mine reclamation and cerrado establishment at Morro do Ouro

Constraints are as follows:

- Tailings impoundments will require monitoring, making vehicular access to them necessary.
- Slopes in excess of 30% may require physical slope stabilisation.
- Barriers or diversion structure will be required at roads where animal crossing is likely to occur.
- Highly altered drainage patterns will require extensive restoration.
- Toxic materials in tailings ponds may need to remain submerged under water to inhibit oxidation from taking place. Tailings ponds can be unsightly and fragment the landscape.
- Narrow gaps between tailings ponds will require infill in order to keep ponds separate from each other. This soil will have different properties than the surrounding soil.
- View of entire site is good from the south-west edge of the site; however, the site is currently visually unappealing, making the transformation or shielding of mining activities necessary.
- Current view of site from residential units to the south is unattractive and requires shielding or transformation.
- Exposed bedrock allows for oxidation of sulphate minerals to occur, creating a toxic landscape. Further oxidation should be inhibited.
- Some current infrastructure may require removal; mineral extraction infrastructure may require removal or extensive cleaning.
- Extensive existing and restored stream networks may be required to be buffered at a minimum of 50 m on each side.

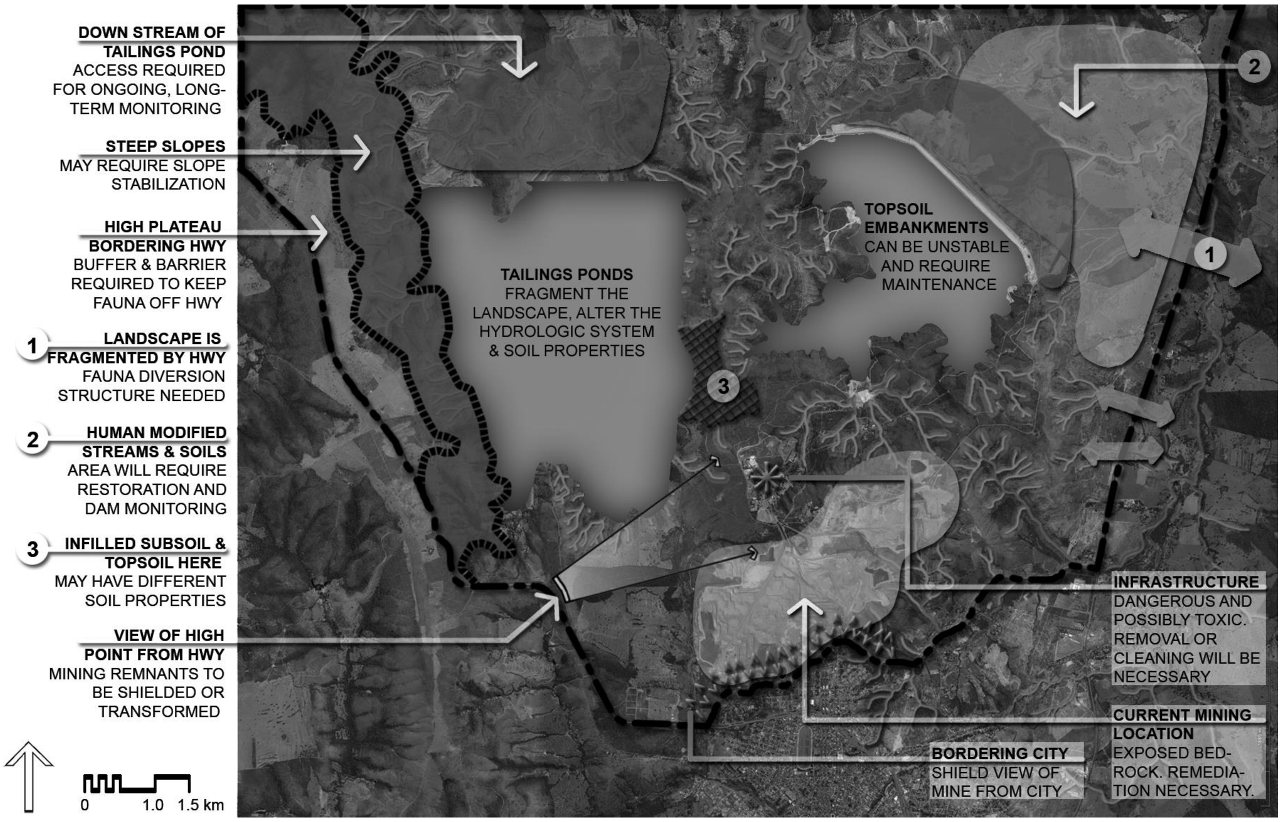

Figure 2 Constraints for mine reclamation and cerrado establishment at Morro do Ouro

4 Results

Many of the finalised guidelines are congruent, indicating that there is a large proportion of overlap in the landform, soils, and vegetation that is characteristic of both cerrado and post-mining landscapes. It follows that mining landscapes provide potential for the restoration of the cerrado habitat and isolation of contaminants while land is being remediated, especially when basic landscape ecology principles are implemented. At a time when the cerrado biome is being removed at an alarming rate, mainly for agricultural crops or pasture, expansive open pit mines across central Brazil provide an opportunity to create a network of habitat patches for cerrado restoration. Potential end land uses may encourage sustainable use of the natural resources and/or achieve revenue generation through land-use planning.

In the case of the Morro do Ouro Mine in Paracatu, Brazil, three hours south of Brasilia, a complete inventory and analysis was completed through a site visit, GIS, and previously mapped information. A design for the application of this research onto the site was completed showing where different vegetation subformations might be located and arranged to allow for, or to deter, animal migration where beneficial. The plan also proposes a number of different land-uses, revenue generation opportunities, and remediation techniques that the research showed were mutually beneficial to both cerrado habitats and mine reclamation. The demonstration plan is shown in Figure 3.

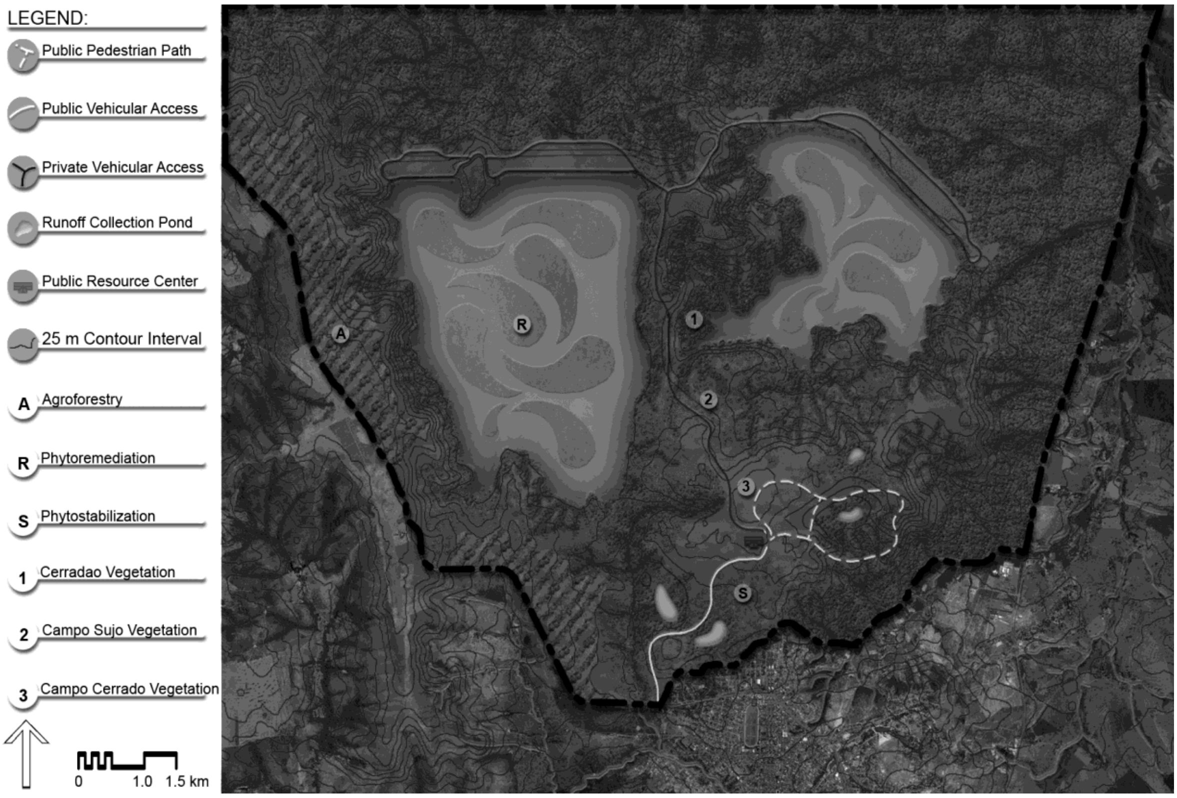

Figure 3 Demonstration plan for the Morro do Ouro Mine, Paracatu, Brazil

5 Conclusions

The inventory and analysis process has demonstrated that a variety of land uses and activities are possible on the Morro do Ouro site. Opportunities exist for transforming Paracatu from a mining city to one of regional interest for eco-tourism, environmental awareness, and adaptive reuse. Multiple land uses are preferable to single uses, especially given the large size of the site. Many of these potential land uses provide the benefit of revegetation as well - for instance: agroforestry, phytoremediation, phytostabilisation, phytomining (also known as phytoextraction), and sustainable harvesting, as indicated through the previously mentioned literature review. Economic gain from these resulting land uses is important, as it encourages this and future reclamation, and also helps to fund the maintenance of the site after closure.

It is important to note that the reclamation of these sites is not only likely to be beneficial in terms of financial and ecological terms. The improved aesthetics and improved health of the site can also contribute to the emotional and sociological health of the population and improve the city's recreational and tourism potential. The demonstration plan provided here is just one of many possible applications of the guidelines; it creates a grand entry into the city, with an improved view over whimsicle phytoremediation islands. These islands have the potential to change the image of the city for potential visitors, while potentially remediating contaminants (Mendez and Maier, 2008; Bradshaw, 2000) and re-establishing an important native plant community.

Acknowledgements

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