Use Of Impact Mapping For Planning The Infrastructure In Tourist Caves - Case Study: Maquiné Cave, Brazil

National Cave and Karst Research Institute

USE OF IMPACT MAPPING FOR PLANNING THE INFRASTRUCTURE IN TOURIST CAVES - CASE STUDY: MAQUINÉ CAVE, BRAZIL

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Abstract
The main objective of this article is to show how mapping and environmental impact analysis can be used to support the management decisions in tourist caves, such as infrastructure planning and monitoring efforts.

Introduction
The Maquiné Cave has great historical, scientific and speleological value in the Brazilian context. Located in the central portion of Minas Gerais, Brazil (Figure 1), this limestone cave has chambers with significant volume, speleothems of great beauty, is home for rare troglobites, and hosts an archaeological site in the entrance zone.

Since 1908, a large area of the cave has been used for tourism; being the first Brazilian cave to receive artificial lighting, in 1967. In that same year, a pathway system was installed (with stairs, walkways, flooring) and around the cave entrance, was implanted parking areas, gardens and restaurants. In 1999 a new lighting system was installed. With some interference, these infrastructures remain today in the cave. In 2005 the Peter Lund Natural State Monument was created. It was an important step to protect the cave and its surrounding area. The management of the area is shared by the State Institute of Forestry from Minas Gerais and the City Hall of Cordisburgo, through Maquinetur Foundation.

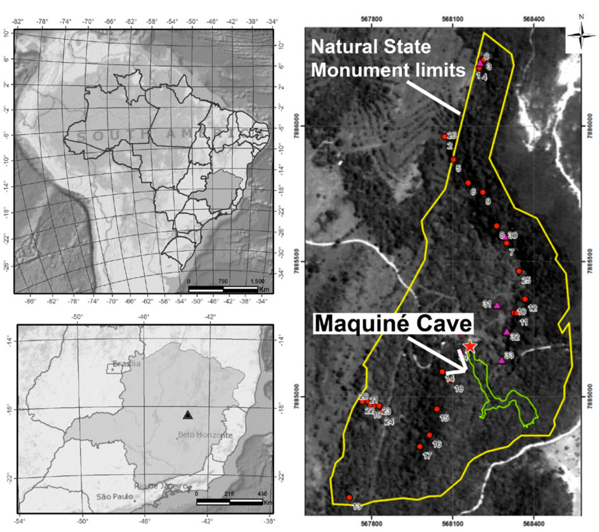


Figure 1. *Location map.*

In the first half of the nineteenth century the cave was studied and mapped by the Danish scientist and naturalist Peter Lund and his team, which revealed to the world the importance of this cave and its exceptional sedimentary deposits, where he found several specimens of extinct megafauna. Before that the saltpeter was explored in the cave. Today, about 50,000 people per year visit the cave, which has a significant socio-economic importance for the municipality of Cordisburgo, where it is located. In 2009 and 2010 was carried out the cave management plan, an important step towards the protection and control of environmental impacts.

The Peter Lund Natural State Monument is inserted in the Cerrado biome, one of 34 "Biodiversity Hotspots" on the global scale. The climate is mesothermal with dry mild summer (Cwb), with annual pluviometric average index of 1271.4 mm, characterized by a rainy season from October to March, and a dry season from April to September (IEF, 2010).

This article presents a summary of the impact assessment, briefly addressing the main anthropogenic interventions that cause environmental impacts, real and potential, inside and outside of Maquiné Cave. This assessment enabled the planning of management and monitoring actions in order to control, minimize and remediate the pressures on the cave, enhance existing assets and add quality to the cave tour.

The results presented below are part of a wider diagnostic, composed in different steps of speleological prospection; topographic and thematic mapping of Maquiné Cave,

establishment of Speleological Zoning, cave load capacity, management programs, and recommendations for emergency measures. This Diagnosis, in its turn, is part of an even broader set of environmental studies that includes the Management Plan for the Peter Lund Natural State Monument and the participation of a multidisciplinary team.

Methodology

The detailed topographic map of Maquiné Cave was the basis for the impact map (Figure 2). The topographic map was made using compass and sight clinometer (KB14 and PM5/ Suunto) and laser meter (DLE 50/ Bosch). This map was based on a highly detailed sketch, which used many topographic bases to delineate the deposits and internal features of the cave. The central axis of the topographic map was checked with a total station. In UIS classification, the work is between grades 5-4 and X-B-4-C. This map shows accuracy in galleries contour, and a faithful representation of chemical and clastic deposits.

Impact mapping was carried out throughout the cave by carefully observing surfaces, and recording the impacts identified in a map and by using photography, inspired in *Visitor impact point mapping* described in Bodenhamer (2006). Additionally, the lighting system and the water introduction system were mapped. Thus the electric cables and water piping, the position and orientation of the spotlights, the type of lamp used, and the location of pass and control boxes were mapped. The map of these systems was overlaid on the impact map in AutoCAD software, allowing correlation; for example, where the growth of lamp flora is observed and the type of lamp used.

The impact map is part of the thematic maps included in the management plan for Maquiné Cave. In this context, the cave attractions, weaknesses, conservation state, visitors flow, and risks to visitors were also mapped. The integrated analysis of thematic maps allowed the establishment of the Speleological Zoning.

It is noteworthy that the impact evaluation is focused on activities that arise directly or indirectly from tourist use. However, some impacts observed in the cave are due to events that occurred over the past 200 years, when large areas were excavated to extract saltpeter or fossils, causing permanent and irreversible impacts to the cave deposits. These impacts may currently be considered as historical remains and must be addressed during the cave tour.

Results and discussion

Caves are complex and fragile environments, with low resilience due to the presence of sensitive chemical and clastic deposits, endemic fauna, and aspects such as the absence of light, the limited resources supply and spatial confinement. On the other hand, caves provide educational, recreational and scientific opportunities for visitors and researchers. However, these uses, if not handled properly, can cause severe impact or even destroy the features that provide such opportunities (Pate, 2006).

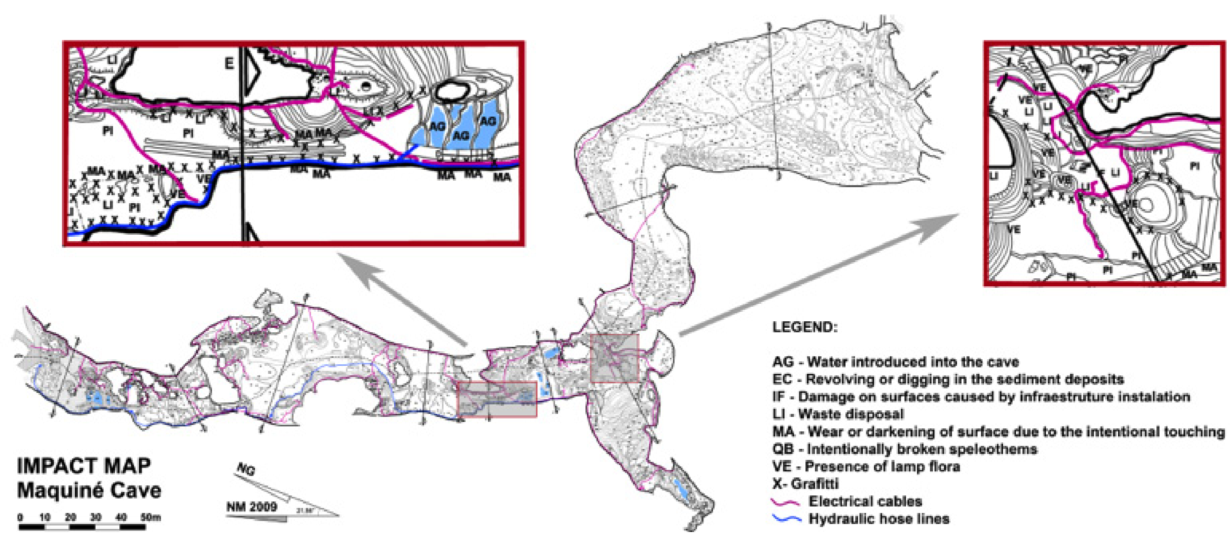


Figure 2. *Impact map*
Synthesis of the impacts and problems of the lighting system.

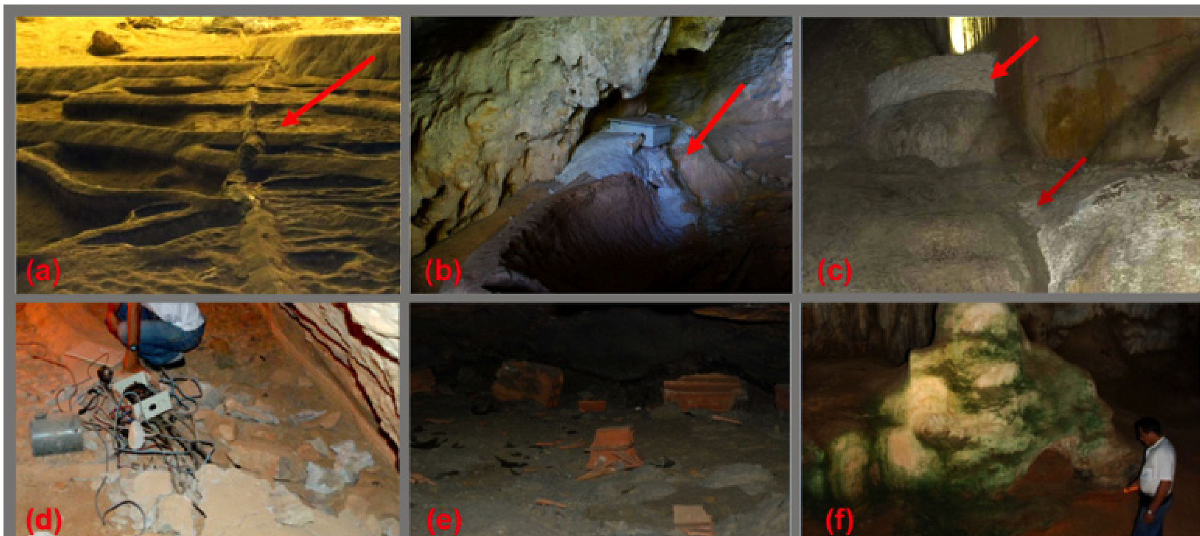
Among the main impacts noted in Maquiné Cave that stand out are serious damage to speleothems, sediments and rock surfaces, and possible impacts on fauna and microclimate. These impacts are the direct or indirect consequence of the installation, maintenance and operation of the existing infrastructure, as well as arising from problems of visitor flow management. As the caves are fragile and low resilience environments, the impactful activities, past and present, form a set of cumulative changes that must be mitigated and monitored.

In 2009 there were 115 active spotlights in Maquiné Cave, using 9 different types of lamps. Most of them have low efficiency, high power (500W) and high-energy consumption, such as halogen, metal halide, sodium vapor, mercury-vapor and mixed vapor lamps. The lighting system could be powered up in sequence, however, in days of great visitor flow, it was turned on about 8 straight hours. The use of high power lamps can cause microclimatic changes, such as temperature increase and relative humidity decrease, especially in caves of low energy flow such as Maquiné (Cabrol, 1997).

Through the Impact Map (Figure 2) it was found that the development of lamp flora occurred more intensively near high power lamps (halogen, metal halide and mixed vapor). In addition to the aesthetic impact of color change the presence of lamp flora (Figure 3-f) can induce surface corrosion in speleothems by biochemical and biophysical processes (Pulido-Bosch et al., 1997). The lamp flora represent an additional introduction of nutrients into the cave, which can affect the ecosystem dynamics.

Spotlights located near speleothems cause glare, make them unattractive and cause large variations in surface temperature and humidity, which contributes to the deterioration of speleothems (Veni, 1997). Furthermore, heterogeneous and insufficient lighting of the floor generates risk to visitors and contributes to the widespread stepping on speleothems.

The main cabling of the lighting system runs in one side of the cave, interspersed with passage boxes, from which are derived the secondary wiring to spotlights and control boxes. To hide the wiring cement mortar was applied over speleothems, sediment or rock surfaces and in some places the cabling was buried. To hide the spotlight low walls of masonry were built (Figure 3-a,b,c). At some points, it is clear that the speleothems were intentionally broken for the installation of the electrical system. Burying the cables disturbs the original sediment stratigraphy. Such changes are potentially harmful in archaeological or paleontological sites. The techniques used to hide wires and spotlights are also impactant, as the adhesion of the cement mortar can produce physical and chemical changes in speleothems and rock surfaces, besides volumetric changes that generate large visual impact, compromising the attractions.



Changes in speleothems caused by addition of building materials (cement mortar and sand, clay bricks and other) for passing electrical cables (A), installation of passage box (B), shields to hide spotlights (C). Photos (D) and (E) solid waste (broken lamps, mortar, masonry) generated in the installation and maintenance of the lighting system. Photo (F) Growth of Lamp flora over sediment and speleothem. Photos: L. Alt

Figure 3. *Examples of the impacts and problems of the lighting system.*

The lighting system demanded frequent maintenance, either for bulb replacement, revisions in the cabling and electrical contacts. The use of cement mortar cords made the maintenance process difficult or impossible (Figure 3-d). In some locations the installation of new mortar strings over the existing exceeds 30 cm in height, increasing the visual impact. In addition, the constant maintenance on the system causes stepping of fragile speleothems. Unfortunately, much waste from this activity was improperly abandoned in the cave (Figure 3-e). Some of these wastes, such as electric bulb fragments, represent an imminent environmental risk, apart from being sharp they may contain toxic heavy metals.

At several points there are electrical cable splices without proper connectors and tangled cables without support with friction points to speleothems and rocks. This disorganization offers risks for the electrical system and for the maintenance agents and visitors, since these points can create contacts with energized elements. Furthermore, when the lighting system is switched on, it generates constant noise and electromagnetic fields, which can potentially interfere with bat dynamics.

Synthesis of impacts and problems related to pathway system

The pathway system installed in 1967 in Maquiné Cave consists of flooring, walkways and stairways. This system was not deployed the whole way through the cave, so the visitor sometimes walks on built infrastructure, and sometimes directly on speleothems and sediment surfaces. There are no physical structures to control or to delimit the visitors' flow, stopping places and the room for groups to pass each other.

The lack of infrastructure associated with visitation control generates a large area of alteration, by trampling, that stretches for almost the entire cave. This causes soil compaction, loss of individuals due to crushing, speleothem damage, and waste spread in large areas (Figure 4-d). According to Ferreira and Souza (2012) the fauna were attracted to artificial food sources within the visiting area, causing ecosystem changes in Maquiné Cave. In other words, the irregularity of the natural surfaces causes discomfort and risk to the visitor. Trampling also causes the suspension of fine particulate material, which may in the long term, affect the guides health and lead to loss of attractiveness of speleothems by deposition of the particulate material. According to oral reports, in the past, several speleothems were washed with a high-pressure water system applying large volumes of water to remove dust and lamp flora.

The existing infrastructure was installed using different techniques and materials: (I) by removing materials - partial or total breaking of speleothems and sediment

Figure 4. *Examples of impacts related to installation and operation of the pathway system.*

removal, (II) by adding materials (stone and cement mortar) over speleothems or sediment; (III) by the combination of these two techniques (Figure 4- a, b, c). These techniques in many instances caused irreversible damage, such as speleothem breakage, physical and chemical surface changes, visual impacts and the potential loss of visitors.

Stairways and walkways have irregular and/or slippery flooring which together with the lack of handrails and guardrails generates discomfort, walking difficulty, and imminent risk of falls and injuries to visitors. The risk increases when groups cross to each other in narrow walkways and stairways beside abrupt drops. Lack of handrails and guardrails induces the visitor to touch speleothems and other surfaces, causing darkening and in some cases surface wear (Figure 4-e).

To increase the adherence of stairs and walkways surfaces, a cement mortar mixed with sediment taken from inside the cave was applied. This practice causes sediment removal in sites with paleontological potential and can potentially destroy microhabitats for invertebrate fauna. Another practice commonly used is floor washing, which may cause changes in the fauna, relative humidity, and can stain speleothems and other surfaces (Figure 4-c).

In some areas of the cave, as in the entrance zone, there is an excess of infrastructure (wide sidewalk area, shop desks, turnstiles, gate) (Figure 4-c). However, this hall houses a prehistoric archaeological site. Flooring installation caused changes in sediment, possibly disrupting their original stratigraphy, which can cause irreversible damage to archaeological sites. The entrance flooring also changed the runoff water dynamics, probable causing suppression of vegetation and microhabitats to the epigeal fauna, which, according to Ferreira and Souza (2012), may have influenced the delicate ecosystem dynamics in the cave. This wide sidewalk area induces a dispersed flow of visitors, encouraging touch and interference on existing rock art panels.

Careful planning of the pathway system is decisive in a tourist cave and may reduce the diverse impacts in a cave, enhance visitors security, and help to protect sensitive or fragile resources (Hildreth-Werker et al, 2006). However poor planning of this may compromise the attractiveness of the cave. The Maquiné Cave is in a stage where a good review of the infrastructure (pathway and lighting system) and proper management of visitors, along with programs of restoration, conservation and monitoring, could mitigate many damages observed and promote a high quality tour.

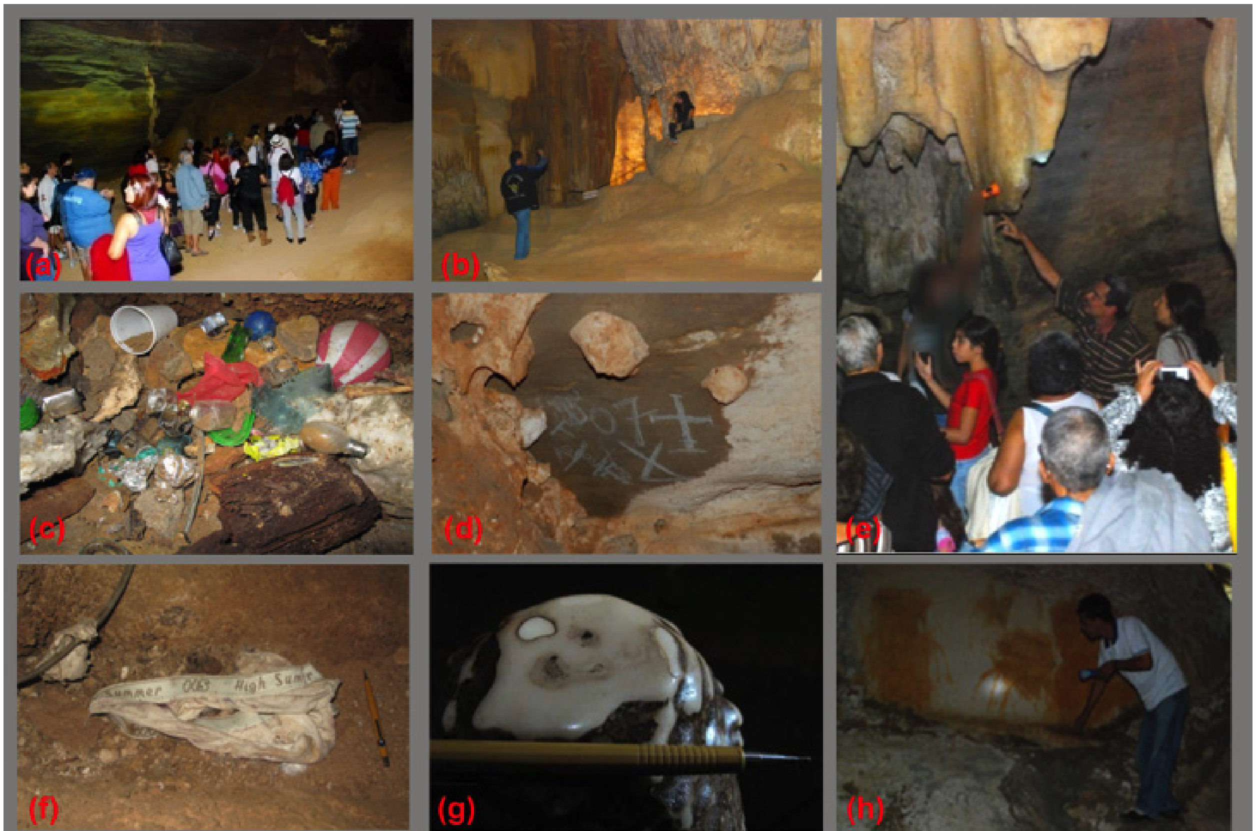
Synthesis of the impacts and issues related to water introduction system

Most of the year, Maquiné Cave is dry; only in the rainy season some travertine dams fill naturally. In order to increase cave scenic beauty to attract more visitors, and to reduce the suspended particulate material in the air, a hydraulic system was installed to moisten the floor and fill some of the travertine dams. This system is comprised of plastic hoses, Polyvinyl Chloride tubes (PVC), and passage boxes. The system was deployed along one side of the cavern, which is opposed to the lighting system. For the installation of the system, components were buried in sediment or covered by mortar cords. The valves were installed in passage boxes, which were built of masonry over sediments, speleothems or rocks. The installation and maintenance of this system resulted in numerous impacts, similar to those identified for implementation and maintenance of the lighting system, due to the similarity of the techniques used.

Getting water inside a cave that possesses a small single entrance, low air circulation and low energy inputs, as Maquiné Cave, constitutes a risk of changing the original relative humidity level. Furthermore exogenous organism and chemical products, suspended or dissolved in the water, can be introduced. The water quality analysis performed by IEF (2010) identified the presence of cyanobacteria in the water. According to Cabrol (1997) the artificial introduction of water, in many cases, is not compatible with the cave environment and may erode, dissolve or degrade speleothems. Some guides reported that, before the water is introduced into the cavern, chlorine is added to it. This element is potentially harmful to cave fauna, due to its known biocide action, and may increase the corrosive power of water.

Synthesis of the impacts and issues related to visitor flow management

The visit to Maquiné Cave is guided, and the visitor does the same route to enter and leave the cave. One of the main problems observed in the cave are very large groups, sometimes with more than 50 visitors per guide



Part of a very large group, with more than 50 visitors per guide (A), Unsupervised visitation (B), Waste disposal (C), Graffiti (D), Attraction created by the interaction of guides with the cave (E), Some visitors uses the cave as a toilet (F), Wear and darkening of speleothems due to continuos touch over years (G), Unsuccessfully attempts to camouflage or remove existing graffiti (H). Photos: L. Alt.

Figure 5. *Examples of impacts and issues related to visitors flow management.*

(Figure 5-a), making it impossible to control the whole group, especially in the narrow section between the big chambers. In these places, where the guide loses visual contact with the group, there are large concentrations of graffiti over speleothems and rock surfaces.

Some attractions are created by the interaction of guides with the cave, when they beat speleothems, in order to produce sound, or jump hard on the floor, to show that the floor is "hollow" (Figure 5-e). This kind of action does not have educational value and encourages visitors to touch the speleothems - causing darkening and introduction of surface corrosion - and jump over several parts of the route - which generates sediment compaction, damage to speleothems and possible impacts on the cave fauna.

Another problem is that some guides complete their tours in the last visited chamber, allowing visitors to return unsupervised to the entrance of the cave (Figure 5-b). This favors the occurrence of many impacts like graffiti, broken speleothems, stepping or touching fragile features, using the cave as a toilet, and improper disposal of waste.

A significant portion of the more delicate speleothems in Maquiné Cave, like straws, draperies, stalactites, stalagmites or pearls were partially broken or removed. Many of these breakages seem to have happened in the distant past. It is noticeable today, in a small area of the cave, that some speleothems are beginning to grow over the broken ones, in a very slow process of natural regeneration.

A large part of the rock surfaces, including speleothems and rock art panels in Maquiné Cave, located within reach, have some graffiti, with dates ranging from 1887 to the year that the work was done (Figure 5-d). In some places the graffiti exist in high density, in others occur isolated. Some graffiti was made with material removal, by incisions, and others with the addition of various materials such as graphite, carbon, acrylic paint, clay, lipstick, among other things.

Numerous unsuccessful attempts to camouflage or remove existing graffiti by applying cement, artificial pigments, clay, sanding, and other techniques were observed. The use of these techniques caused even greater visual impact and physicochemical changes on cave surfaces (Figure 5-h).

Another potential problem is the amount of visitors per day in the cave, which is currently controlled by the guides. Long lasting microclimatic and CO_2 concentration monitoring was not performed in the cave. Therefore, it cannot be determined what the percentage of change in temperature and relative humidity is caused by visitors and/or by the existing lighting system. Changes in these parameters due to visitors or lighting system are widely described in the literature, especially in low energy caves, as Maquiné, since they generate impacts in speleothems and cave fauna (Villar, 1984; Cigna & Forti, 1988).

Synthesis of the impact assessment

The installation, maintenance and operation of the infrastructure (lighting, pathway, and water introduction systems) and the management of visitor flow generates impacts inside the cave, in their chemical and clastic deposits, on rock surfaces, fauna, microclimate, in paleontological and archaeological heritage. The interference conducted near the cave entrance for installation, maintenance and operation of the external infrastructure (parking areas, buildings and gardens), caused impacts on the karst landscape, vegetation, fauna, and soil. These changes, in their turn, can potentially result in impacts inside the cave, mainly in fauna dynamics and visual impact. The relationship between these impacts is summarized in Figure 6 below.

Throughout Maquiné Cave damage on speleothems and rock surfaces were observed that are caused by: (I) intentional breakage due to: installation and maintenance

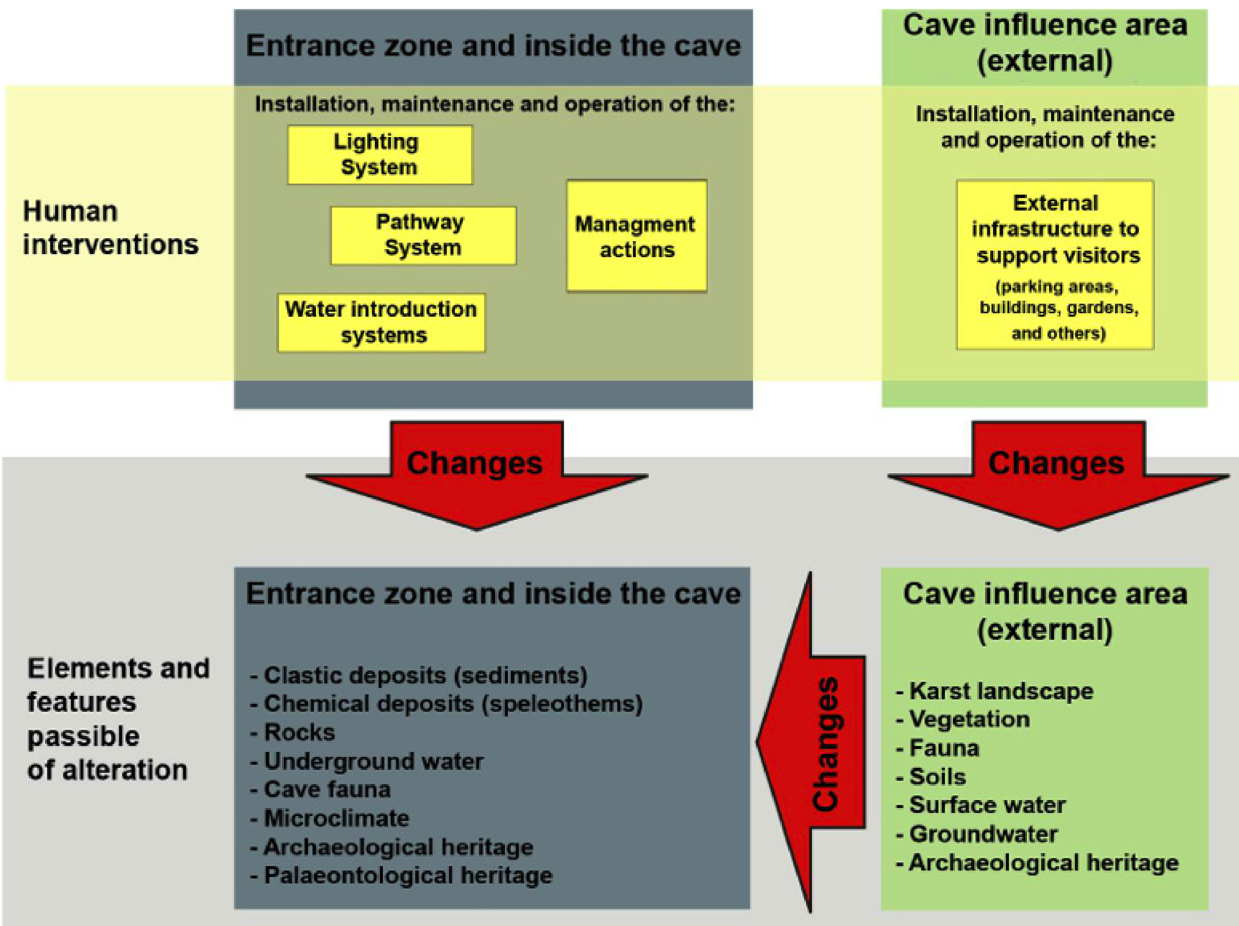


Figure 6. *Scheme of interaction between human interventions and cave environment in Maquiné Cave.*

of existing infrastructure, actions of vandalism, extraction of calcite, saltpeter or fossils; (II) speleothem surface wear due to trampling and intentional touching, (III) physical and physicochemical changes by adding building materials, by graffiti, by mistaken restoration attempts; (IV) possible biochemical and biophysical surfaces due to lamp flora growth; (V) ecosystem changes due to artificial introduction of nutrients and preventing bats entry (Use of gate with wire mesh for many years. This mesh was partially removed in 2009, allowing bats to return). Several of these damages are harmful to tourism activities.

Most of the damage to clastic deposits in the cave is caused by: (I) removal or revolving sediments for installation and maintenance of existing infrastructure, by historical activities such as the old digs for saltpeter or fossils extraction, (II) compaction, impermeabilization and modification of surface drainage due to trampling or the addition of materials.

Disperse waste can be observed throughout the cave, especially in spots that are not visible from local intensive visitors flow, such as high levels, low ceilings, or narrow passages between speleothems. The presence of two distinct types of waste can be clearly noted: those left by visitors - candies, chewing gum, batteries, flash bulbs, toys, toothpicks, matches, and others - and those from the installation and maintenance of existing infrastructure - such as scraps of building material (brick, cement, mortar, wood), remains of electrical material (wires, connectors, broken electric bulbs, electric bulb packs, damaged spotlights), and remains of hydraulic equipment . The table 1 below correlates the observed impacts with different impactant activities.

Synthesis of mitigation measures

We are defining programs and management recommendations to mitigate the impacts observed in Maquiné Cave. Each program has clear strategies to achieve its objectives and indicators that point to its effectiveness. For each management program there is an action plan, which includes: beginning and ending date for proposed actions, expected results, investment value, and who is responsible for implementation. Table 1 below shows the correlation between the main observed impacts and the main management programs that seek to mitigate these impacts. Below is a brief description of the proposed management programs and the recommendations they proposed.

Program for review of lighting system

This program aims to reduce the negative environmental impacts of the old lighting system, enhance the existing attractions, and provide security for visitors, guides and maintenance staff. The main activities under this program are the development of an executive electrical and lighting design project for the new lighting system, implementation of the new system, realization of photographic documentation, temperature/ relative humidity monitoring (before and after the intervention) and maintenance staff training.

These executive projects of the new lighting system shall be performed in accordance with current best practices, providing: (I) reduction of hotspots by the replacement of high power lamps with Light Emitting Diode (L.E.D); (II) reduction of the development of photosynthetic organisms in the aphotic zone, by using an appropriate wavelength according to Olson (2006), (III) removal of mortar cords and low walls that cause visual impact in attractions, with consequent restoration of these surfaces, (IV) removal of all the lighting infrastructure that will be deactivated and waste from the old system, (V) reduction of speleothem trampling in maintenance through the use of safe, high durability and low maintenance materials (tinned copper cables, waterproof fittings and spotlights), (VI) reduction in alterations in sediment, speleothems and rock surfaces by using apparent wiring and spotlight installed over removable bases made of inert materials. These projects should be harmonized with the walkway project, so that the main wiring can be installed with the walkway.

The new lighting system shall enhance the existing attractions, through the proper placement of the spotlights, showing the natural speleothem colors. The system should be trigger sequenced, illuminating only the chamber with visitors. Spotlights should not be focused on Primitive zones. The use of techniques that cause irreversible impacts on the cave, such as drilling, breaking, applying cement mortar and other products over speleothems and other surfaces should be avoided. To increase the safety of visitors, guides and maintenance staff an emergency lighting system should be installed, and the pathway and the narrow places should be properly lighted.

Program for pathway system revision

This program aims to reduce the negative environmental impacts caused by the current pathway system and

Table 1. *Correlation between management programs, impacts and environmental effects identified in Maquiné Cave and its influence area.*

IMPACTANT ACTIVITIES: Lighting System – Installation and maintenance	Lighting System – Operation (Use)	Pathway System – Installation and maintenance	Pathway System – Operation (Use)	Water introduction systems – Installation and maintenance	Water introduction systems – Operation (Use)	Management actions – Operation (Use)	External Infrastructure – Installation	External Infrastructure – Maintenance and operation	ENVIRONMENTAL IMPACTS	MANAGEMENT PROGRAMS: Review of lighting infrastructure	Revision of pathway system	Guides continuous training	Revision of cave influence area	Conservation and restoration program	Monitoring program
									INTERNAL ENVIRONMENT AND CAVE ENTRANCE						
■		■		■		■			Intentional speleothems breakage		■	■		■	■
■		■		■					Physico-chemical changes in speleothems and other surfaces due to the introduction of building materials	■	■			■	■
■		■		■		■			Improper disposal of solid waste	■	■	■		■	■
■		■	■	■		■			Changes in speleothems by trampling	■	■	■		■	■
■		■	■	■		■			Sediment disturbance (compaction, revolving, removal)	■	■	■			■
	■								Change in speleothems and other surfaces due to lamp flora	■				■	■
	■				■	■			Potential change in the microclimate	■		■			■
						■			Potential change of the CO2 concentration			■			■
	■								Changes in surface temperature of speleothems and others	■					■
	■					■	■	■	Noise generation	■		■			■
	■					■			Generation of electromagnetic fields	■					■
	■								Introduction of light in aphotic zones	■					■
■			■			■			Change in speleothems and others due to intentional touch	■	■	■		■	■
■	■	■	■	■	■	■	■	■	Potential change in cave fauna dynamics	■	■	■	■	■	■
■	■	■		■			■		Landscape changes or visual impact	■	■		■	■	■
		■							Changes in drainage and runoff water		■				■
		■				■			Alterations in speleothems and other surfaces by graffiti, and use of inappropriate techniques for graffiti removal		■	■		■	■
									CAVE INFLUENCE AREA (EXTERNAL)	■	■	■	■	■	■
						■	■		Topographic changes and removal of original vegetation cover				■		
						■	■	■	Introduction of exotic plant species				■	■	■
						■	■		Changes to the permeability of soil				■		
						■	■		Changes in landscape or visual impact				■		
						■		■	Inappropriate disposal and treatment of wastewater				■	■	■
						■		■	Improper disposal of solid waste				■	■	■

to improve the conditions for public use and safety, providing accessibility to individuals with special needs, until the second room of the cave. The main activities under this program are the development of an Executive Project for the new pathway system; implementation thereof; conducting photographic documentation (before and after implementation); and maintenance staff training.

These executive projects should specify inert and safe materials for the cave environment, according to Werker (2006) and other references, with design and construction techniques that cause minimal visual and physical impact to the cave, which should be demonstrated through 3D modeling, sketches and / or photo inserts. The materials and techniques used must be highly durable, providing ease and low maintenance cost. The use of techniques that cause irreversible impacts on the cave should be avoided. Where possible, the old stairs should be removed and speleothems restored. This project shall comply with cave zoning and the places established for the pathway.

The delineation of the pathway will concentrate the impacts of visitation in a restricted area, reducing problems such as trampling over speleothems, sediments and fauna, graffiti, intentional touching or speleothems breaking and other impacts in the cave.

Program for guides continuous training

The objectives of this program are to train the guides continuously, seeking quality service to visitors, the quality and relevance of the information provided and the educational practices, awareness of the cave fragility, and the need to respect the established load capacity and the optimal number of visitants per group.

The main activities under this program are the revision of the programmatic content of the visit, realization of semester courses for instruction and training, and development of educational materials.

Conservation and restoration program

The objectives of this program are to reduce negative environmental impacts and effects on Maquiné Cave. The following brief descriptions are the main actions foreseen in the program.

Restoration of damaged surfaces including: (I) restoration of the main surfaces with graffiti, marks of trampling or unsuccessful attempts at camouflaging graffiti; (II) restoration of speleothems and other surfaces after removal of infrastructure such as stairs, bulkheads, and cement mortar cords.

Re-naturalization of the First Hall including: (I) removal of existing infrastructure (desks, tables, roulette wheels, grills, benches, low walls, paved floor, gate), (II) Compatibility with pathway system and lighting system revisions.

Project to deactivate and remove the water piping system. Implementation of waste removal project, coordinated by a biospeleologist, including the removal of the waste from the installation and maintenance of existing infrastructure and waste from visitation.

Program for monitoring changes in speleological heritage

This program aims to monitor, continuously, some environmental indicators in Maquiné Cave, generating subsidies for the dynamic adjustment in the load capacity, for future revisions for the Cave Management Plan, and to assess the effectiveness of the proposed actions. Monitoring lets you check whether the expected results are being achieved, and if not, lets you see where the problems are occurring, and act correctively, according to the logic of adaptive management.

The main activities of this program are:

1. Continuous visitor flow monitoring
2. Continuous climatic monitoring inside and outside Maquiné Cave, with temperature, relative humidity and CO_2 concentration measurement.
3. Photosynthetic organisms monitoring in the aphotic zone of the cave.
4. Biological communities dynamics Monitoring.
5. Graffiti monitoring around the pathway system.

Conclusions

It is important to think about the concept of visitation desirable for Maquiné Cave. The model applied in the 1970s does not work fully, and causes irreversible damage to the speleological heritage by not providing a proper appraisal of the historic, cultural, educational and scientific potential available.

There are few places in Maquiné Cave where human impacts are not noted. Among the main effects observed

are serious damage to speleothems, sediments and rock surfaces, fauna and possible impacts to microclimate. These were caused by an interaction of problems in managing the visitor flow, infrastructure located in the interior of the cave and in the cave influence area.

A cave adapted for mass tourism can serve as a tool for education and awareness about the importance and fragility of caves and karst environments; contributing to the protection of speleological heritage as a whole. The Maquiné Cave has significant natural attractions that have made it one of the most visited caves in Brazil. These can be valued appropriately by a new lighting system, a new pathway system, by the reformulation of the programmatic content of the visit, by guides training, among other issues. The impact mapping gave support to the management decisions in Maquiné Cave, guiding the intervention strategies needed to protect the cave and to reduce impacts on this fragile environment, helping to plan a sustainable and secure public use of the cave.

References

Bodenhamer, H. 2006, Visitor Impact Mapping in Caves, in Cave Conservation and Restoration, New Mexico: National Speleological Society, p. 193-292.

Cabrol, P., 1997, Protection of Speleothemes, in Hill, C. and Forti, P. Cave Minerals of the World. 2nd ed. Alabama: National Speleological Society, p. 294-300.

Cigna, A.A., and Forti, P., 1988, The environmental impact assessment of a tourist cave. In: UIS (Ed.) Cave Tourism International Symposium. Postojna: UIS, 1988, p. 29-38.

Ferrreira, R. L., and Souza, M. F. V., 2012, Notes on the behavior of the advanced troglobite Eukoenenia maquinensis Souza & Ferreira 2010 (Palpigradi: Eukoeneniidae) and its conservation status: Speleobiology Notes, v. 4, p. 17-23.

Hildreth-Werker, V., Goodbar, J. R., Werker, J. C., 2006, Trail Delineation and Signage in Caves: Reduce Visitor Impact in Cave Conservation and Restoration. New Mexico: National Speleological Society, p. 175-185.

IEF, 2010, State Forestry Institute Management, Plan for the Natural State Monument Peter Lund / Maquiné Cave / Booklet I, Belo Horizonte, Brasil. (In Portuguese)

Olson, R., 2006, Control of Lamp Flora in Developed Caves, in Cave Conservation and Restoration – 2006 Edition. New Mexico: National Speleological Society, p. 343 -348.

Pate, D. L., 2006, Management Tools for Supporting Conservation Ethics, in Cave Conservation and Restoration – 2006 Edition. New Mexico: National Speleological Society, p. 229 -236.

Pulido-Bosch, A., et al. (1997). Human impact in a tourist karstic cave (Aracena, Spain). Environmental Geology, 31(3/4), 142e149.

Veni, G., 1997, Speleothemes: Preservation, Display, and Restoration, in Hill, C. & Forti, P. Cave Minerals of the World. 2. ed. Alabama: National Speleological Society, 301-309p.

Villar, E., 1984, Ambient temperature variations in the Hall of Paintings of Altamira Cave due to the presence of visitors. Cave Science, v. 11. no. 2, p. 99-104.

Werker, J.C., 2006, Materials Considerations for Cave Installations, in Cave Conservation and Restoration. New Mexico: National Speleological Society, p. 167-174.