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LANDSCAPE INTEGRATION IN ROAD DESIGN, CASE: BAHUICHIVO - CEROCAHUI IN CHIHUAHUA, MEXICO

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ABSTRACT

The design of roads must be considered as an element of the landscape. The construction of a road brings affectations to the fragility and quality of the landscape. For this reason, it is necessary to study the concept of the landscape to integrate it into the planning and development of road projects. Designing roads that integrate the landscape in the state of Chihuahua will lead to harmonize with the environment. The objective of this research was to develop a methodology to integrate roads to the landscape. The methodology of landscaping design begins with selecting the route that is integrated into the landscape through cartographic, photogrammetric and satellite image analysis. After selecting the route, evaluations were made of the type of terrain and natural elements at the preliminary project level, and finally, the design recommendations for horizontal, vertical alignment and cross sections in the executive project of the road are included. This methodology was applied to a case study: Bahuichivo-Cerocahui road from km 5 + 000 to 17 + 000, in the state of Chihuahua. The results obtained from this research lead to a change in the methodology used in the Road Geometric Design Manual of the Ministry of Communications and Transportation.

***KEYWORDS**: Biodiversity, Roads, Landscape Design in Roads, Landscape*

Article History

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INTRODUCTION

The design of roads must be considered as an element of the landscape. The development of road projects that lack methodologies that seek to harmonize with the environment leads to the reduction of environmental services in a region. This is relevant in all countries, since, if environmental damage continues, the ecosystems involved in road routes will no longer be able to provide goods and services (Oropeza, 2015).

The Sustainable approach in road construction must respect the production of goods and the provision of environmental services of an ecosystem such as the landscape, a key element of ecosystems nowadays is to understand and accept that they are not infinite natural capitals but rather otherwise they are finite and scarce.

Commonly the road projects are considered infrastructures that bring a social and economic benefit to the regions, but like any infrastructure work causes negative effects on the environment; Among the most significant can be listed: fragmentation of ecosystems, dispersion of species and population decline, alteration of the hydrological cycle, climate change and contamination of water and soil (Arroyave, et al., 2006).

The qualities of a road due to its territorial presence and its scenic capacity make these infrastructures have a high landscape capacity. It is derived from this that the road can provide services to scenic type users for better comfort and safety when traveling through them.

The challenge for specialists in this area has been to integrate transport infrastructure into the ecosystem in a sustainable manner, allowing communication in a secure way between communities, without impacting the environment and ensuring its technical and economic feasibility (Mendoza, 2014).

However, until today there is no methodology in Mexico that includes landscaping design in each of the road project phases. The current environmental impact assessments are limited in anticipating the damage and promoting mitigation measures when executing road infrastructure works. Therefore, an integrating approach is required that allows harmonizing the natural and the constructed (Otero, 2006).design of roads must be considered as an element of the landscape. The development of road projects without methodologies that seek to harmonize with the environment leads to the reduction of environmental services in a region. This is relevant in all the countries of the world, since, if damage continues, these ecosystems will no longer be able to provide an infinity of goods and services (Oropeza, 2015).

Materials and Equipment Used

Commonly the analysis of landscape patterns uses data such as aerial photographs, satellite images, censuses, and published data. In order to carry out this investigation, data was taken from the information gathered by the study of land use change from forest to the road. From the Bahuichivo-Cerocahui road of section km 5 + 000 to 17 + 000 made by Fernando Rafael Astorga Bustillos (Astorga, 2013). This includes land use charts, a cartography of bodies of water, the topography of the study site, mapping of landscaping units, basin of environmental services, vegetation and existing fauna, presence of endangered species. In addition, the information is completed with the information collected in the field.

Figure 1: View of Km. 10 + 000 Back View

Source: Astorga, F. (2013)

After collecting the data, all the information was integrated into a map. To do this, geographic information software (GIS) was used, called Global Mapper. Which facilitated the representation of a land area to analyze different data simultaneously.

METHODOLOGY

The methodology carried out in this investigation consists of 4 phases, which are illustrated in Figure 2.

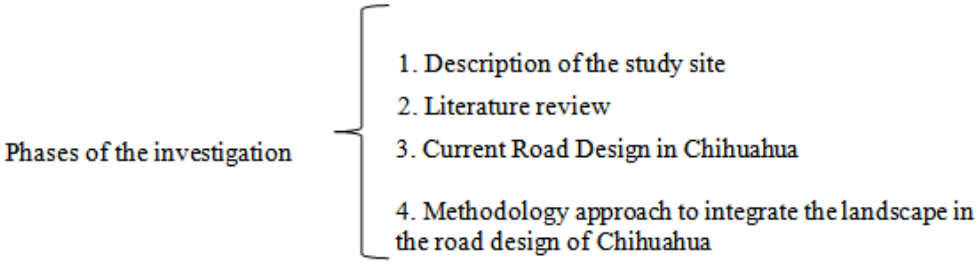


Figure 2: Phases of the Investigation

Source: **Self-Made**

In Phase 1, the most representative information about the place of study was investigated. Based on the study of land use change and the fieldwork carried out.

Continuing with Phase 2, a review of the literature most representative of the research topic was conducted.

For the location of bibliographic documents, a search was made in the Science Direct, Google Scholar, Google Books sites; In the search we used Phrases "Landscape" (Landscape), "Landscape Highway" (Landscape Road), "Integration Highway Landscape" (Integration Highway Landscape); In addition, important works from the United States were consulted, such as "Aesthetics & amp; Landscape Architecture "," Landscape and Aesthetics Design Manual "that study the integration of road elements in landscape design.

Many are the countries and states that have their own recommendations for the landscape design of their roads. Here are some examples:

UK

- Design manual for roads and bridges. Environmental design and management. Landscape Management. Including landscape in road design, construction, and mitigation (The country Agency, 2006)
- Design manual for roads and bridges. New Roads Landform and Alignments. Vol. 10 (Highways Agency, Scottish Executive, 1992)

The united States, examples prepared by some states:

- Florida: Florida Highway Landscape (Florida Department of Transportation, 1995).
- Pennsylvania: A Guide for Transportation Landscape and Environmental Design, (AASTO, 1991).
- Texas: Landscape and Aesthetics Design Manual (Texas Department of Transportation, 2017).

Australia (Queensland)

- Road Lanscape Manual (Department of transportation and Main Roads, 2013)

New Zealand

- Guidelines for highway Landscaping, (Transit, 2014)

Spain

- Technical recommendations for the design and execution of road systems in sensitive media (Junta de Andalucía, 2006).
- The road in the landscape. Criteria for planning, layout and project Ministry of Public Works and Transport (Español, 2008).

In Phase 3In Phase 3, it was determined that any road design should be subject to the Manual of Geometric Road Projects (SCT, 2018) and to the current regulations of the Mexican Transportation Institute (IMT). In the first one, there are geometric design parameters considering the type of terrain and the level of service. In the second is the procedures and regulations to carry out the projects, construction, conservation and quality control of the road.

From the manual, we obtain the following scheme (Figure 3) that shows the general stages to carry out a road project in Mexico.

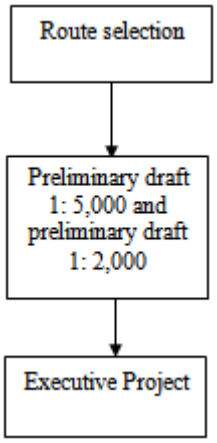


Figure 3: Development Scheme for Road Projects in Mexico

Source: Self-Made

Each of the mentioned steps is particularly described in Figures 4, 5 and 6.

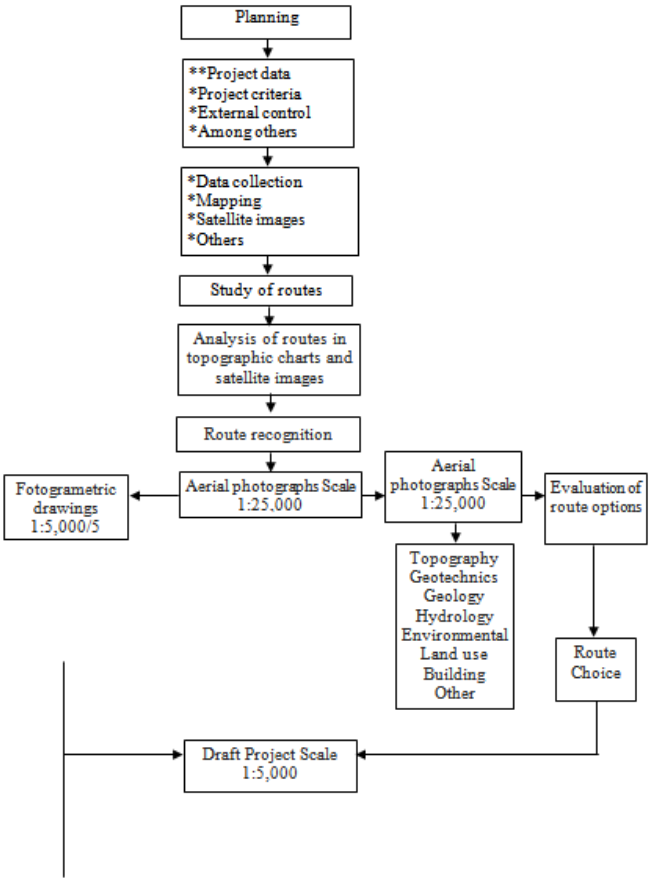


Figure 4: Route Selection Process. Source: SCT (2018)

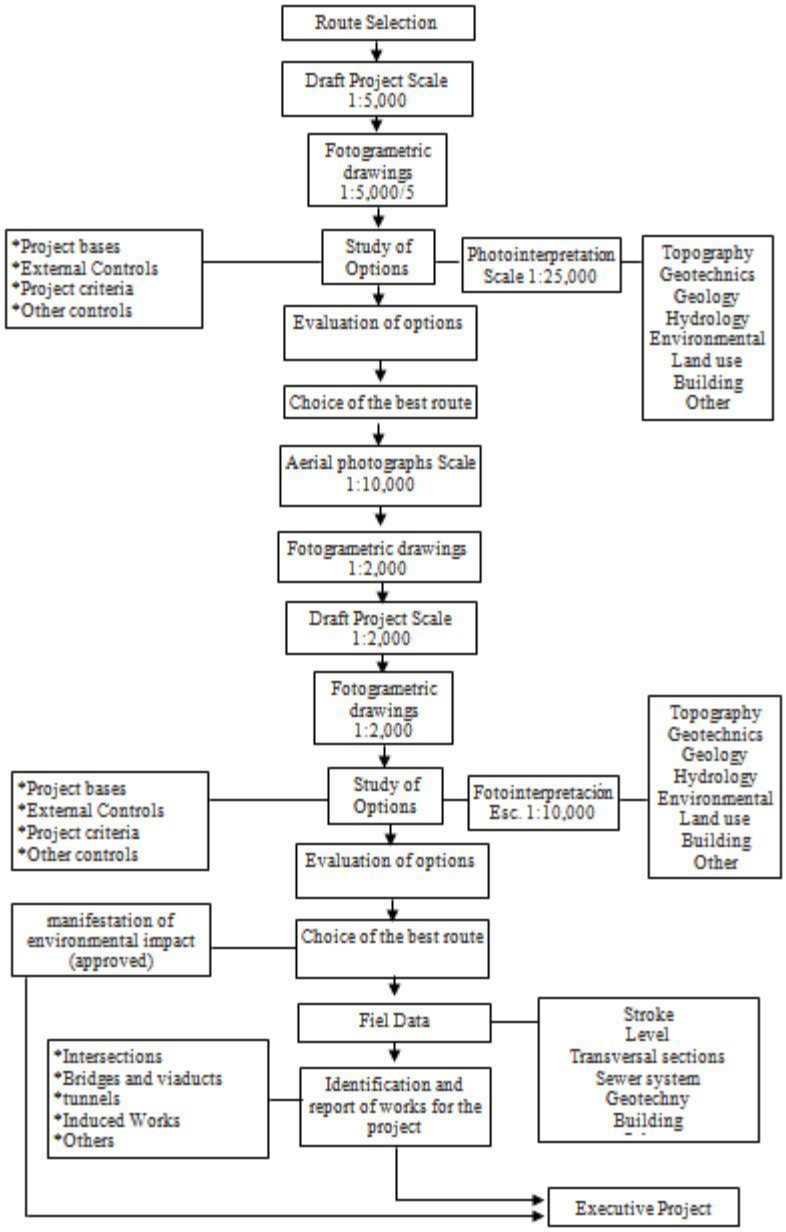


Figure 5: Process for Preliminary Project Scale 1: 5,000 and 1: 2,000. Source: SCT (2018)

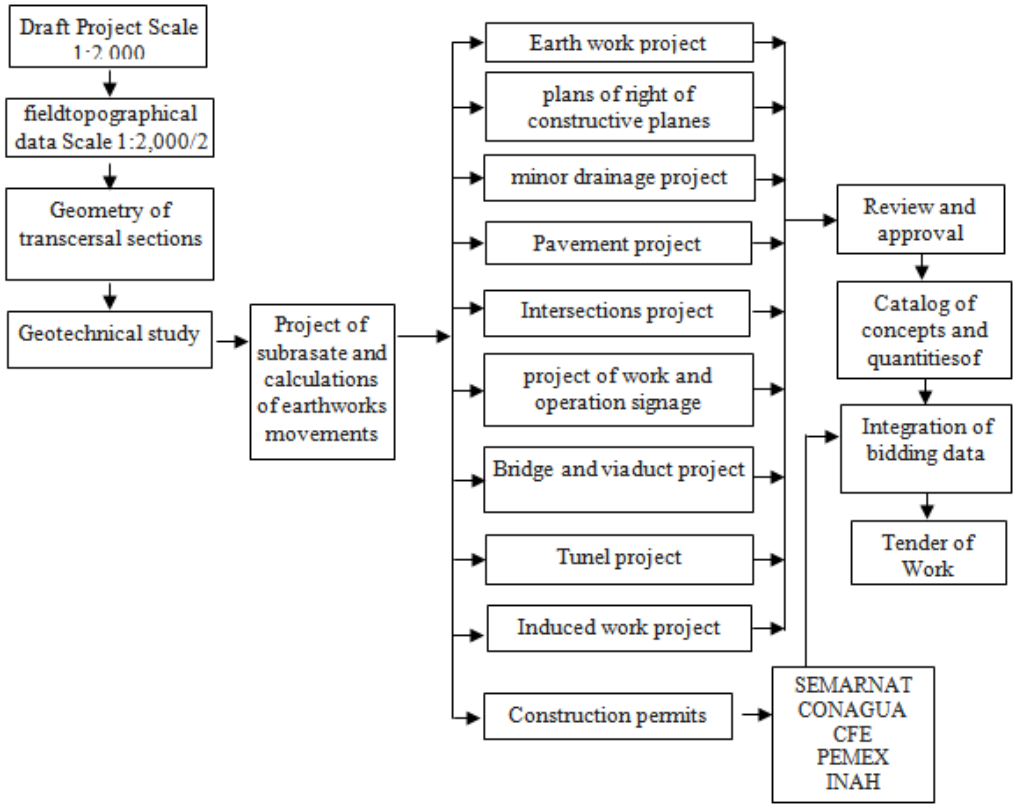


Figure 6: Process for Executive Project

Source**:** SCT (2018)

In the final phase, a methodology was proposed to integrate the landscape in the design of roads in Chihuahua. During the implementation of the previous phases, the methodology was sought to include the landscape as an integral element of the road design within the three stages of the Road project mentioned in phase 3.

DISCUSSIONS AND RESULTS

This work provides recommendations and guidelines to integrate the landscape in the geometric design of a road, photographs and illustrations are used for their simplicity to clarify the concepts addressed. Many of the recommendations are based on international guidelines.

The structuring of the results is divided into 2 sections:

Landscape considerations to trace the route (route selection phase)

Landscape integration methodology (preliminary project phase and executive project)

The approach of route layout alternatives is important to obtain a good final project. Although project costs are higher than estimates, it will always be better than an alternative based on arbitrary or preconceived criteria.

The main aspects to take into account when drawing a route are:

- Recognition of the wildlife trails that communicate niches (bodies of water, forests, grass lands, among others)

that give life to the ecosystem. You should look for the route that harmonizes with those vital areas.

- To choose the route that least damages the landscape, it will be the one that best respects the existing natural terrain and does not cause the modification of strong topographic elements.
- Finally, in the non-discarded alternatives, those sections or points that present connectivity problems should be identified to implement corrective measures (wildlife crossings, oversizing of drainage works, viaducts, among others).

These considerations can be included in the current scheme of the Ministry of Communications and Transportation, as follows:

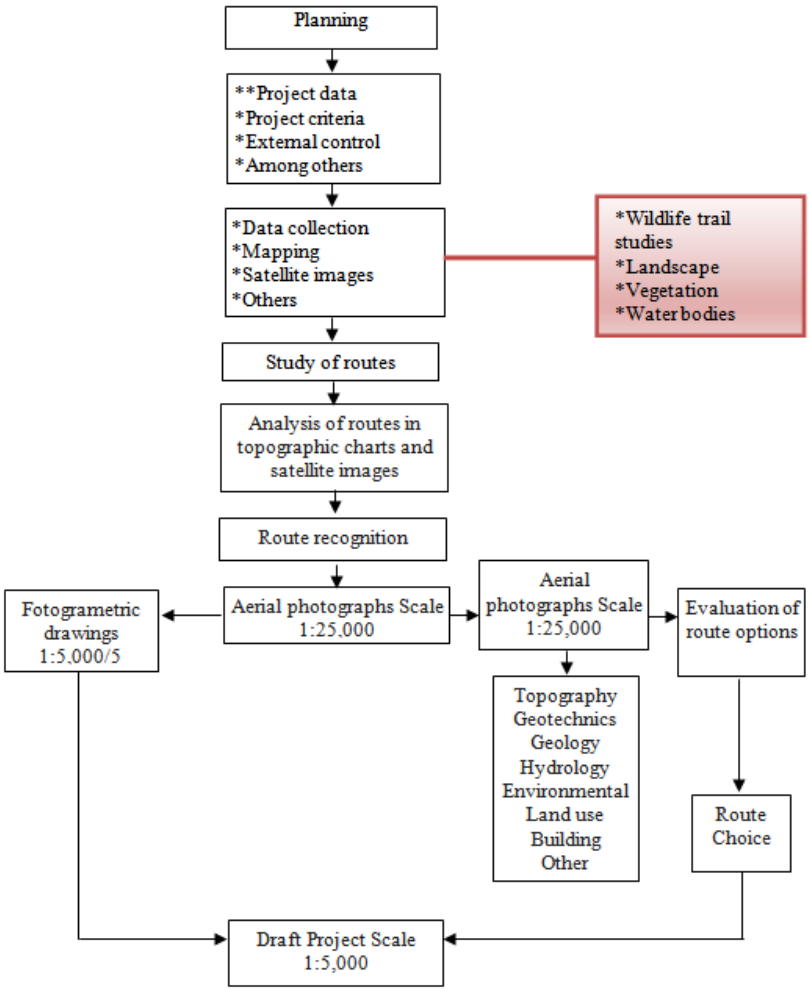


Figure 7: Route Selection Process. Source: Own Elaboration from SCT (2018)

Continuing with section 2 of the results It is important to keep in mind that the methodology proposed below depends on having a selected road route, considering the guidelines mentioned in section 1. The guidelines of the methodology are presented in the logical order of the design of the One Way.

First, the definition of the type of terrain refers to the slopes and the cross-section. They reflect the effect on the cost of operating vehicles (SCT, 1991).

Second, the recognition of the landscape elements of the place where it crosses, the conservation of soil, bodies of water, preservation of historical places, topography, potential uses of the soil, improvement of visual perception, adequate reforestation, reduce maintenance is sought of lateral areas, among others (AASHTO, 1991).

Third considerations of landscape design for horizontal, vertical alignment, cross sections and finally restoration measures. The process is shown in figure 8.

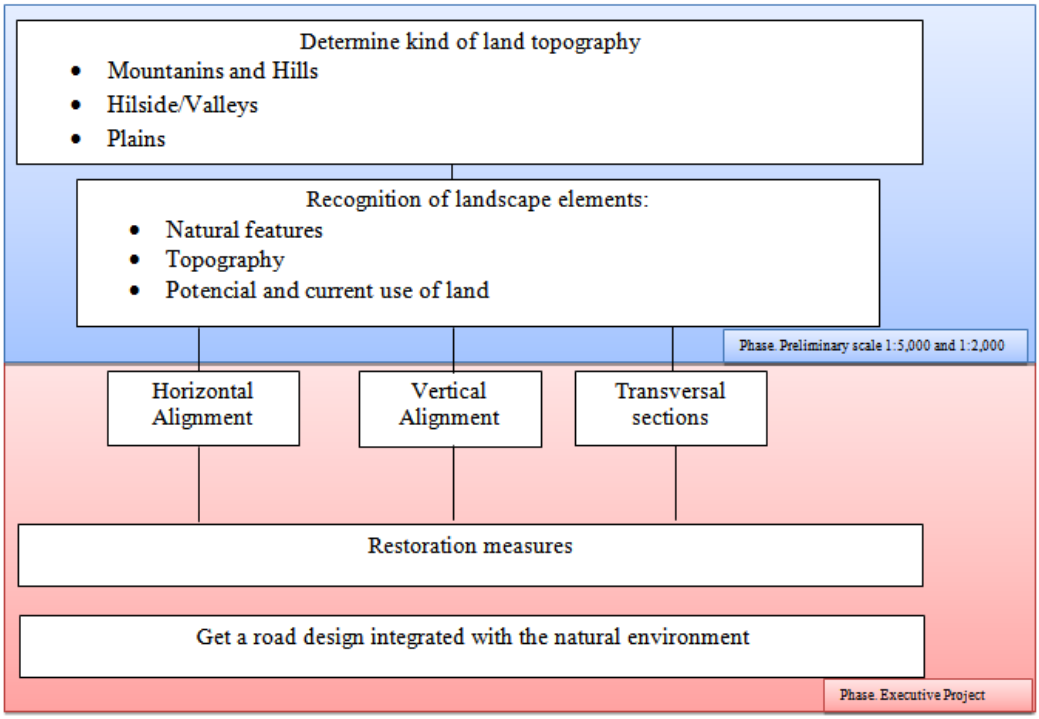


Figure 8: Outline of the Investigation

Source: Self-Made

Definition of the Type of Terrain

The road section under study is located in the state of Chihuahua, Mexico (Figures 9 and 10). The objective of this research was to provide a landscape design methodology on roads for Mexico and it was decided to exemplify this technique on the Bahuichivo - Cerocahui road section from Km 5 + 000 to Km 17 + 000. Which is in a land type lomerío. Next, the characteristics of the project are mentioned.

- Total length: 9.0 km.
- Type of road: "C"
- Type of terrain: Hillside
- Transit (TDPA): 500 to 1,500 vehicles / day
- Project speed: 80 km / hr
- Degree of maximum curvature: 11 °
- Governor's pending: 7%

- Maximum slope: 9%
- Road width: 7.0 m
- Crown width: 7.0 m
- Type of folder: Watering two stamps
- Right-of-way width: 40 m

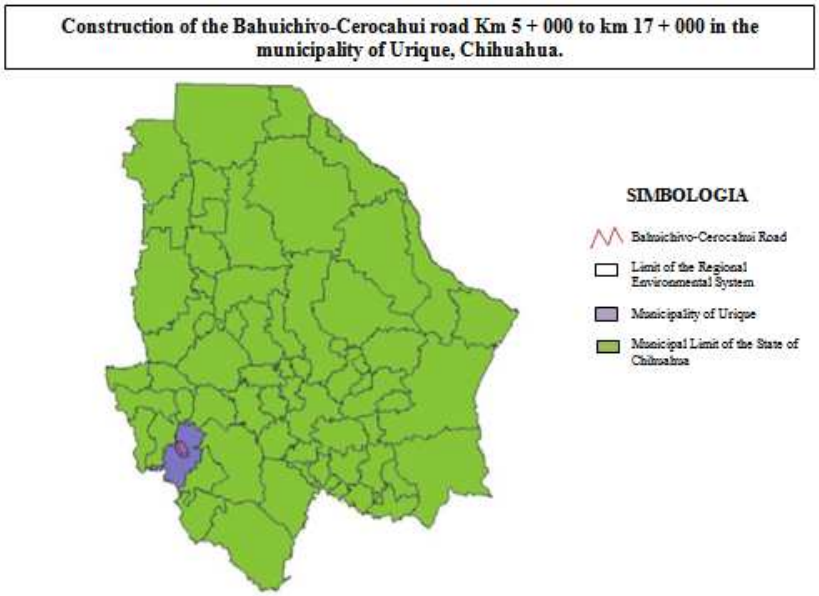


Figure 9: Location of the Project at the Regional Level

Source: Astorga, F. (2013).

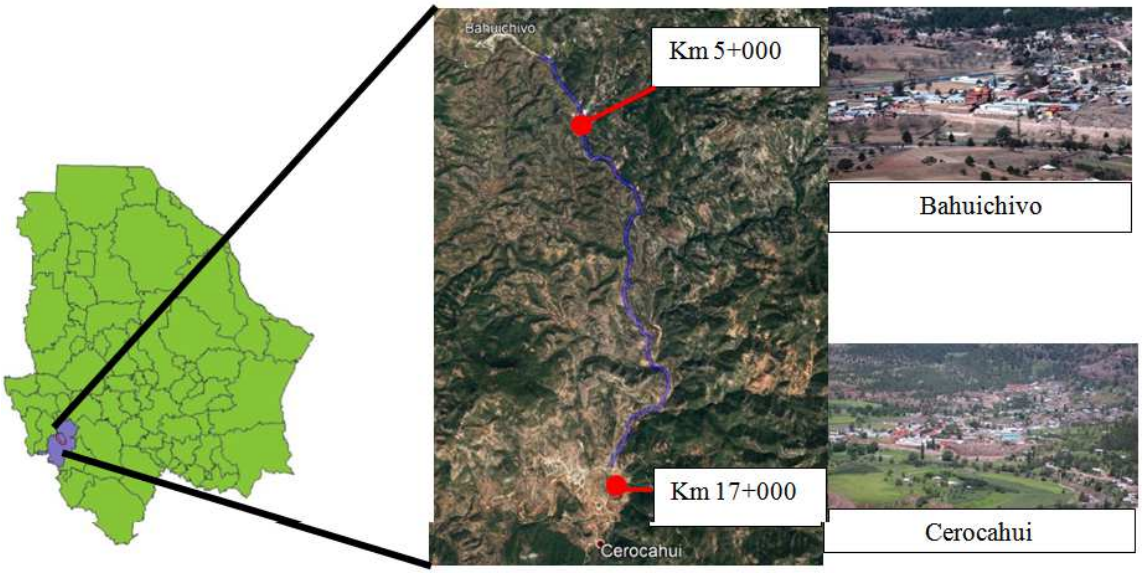


Figure 10: Location of the Bahuichivo - Cerocahui Road

Source: Google (s.f.)

Recognition of Natural Elements

The spatial impact of a road can be achieved through a regional environmental system (SAR). To delimit the SAR, the water part of each micro-basin, type of vegetation, current use of areas of interest is considered. To achieve the above, the geographic information system is used, thematic letters generated by the National Institute of Statistics and Geographical Information (INEGI).

Land use and Vegetation of the Case Study

In Figure 11 you can see the use of soil and vegetation of the SAR, information from INEGI.

- Desert wilderness micropyle
- Pine-oak forest
- Natural grassland
- Oak forest
- Pine forest
- Deciduous forest

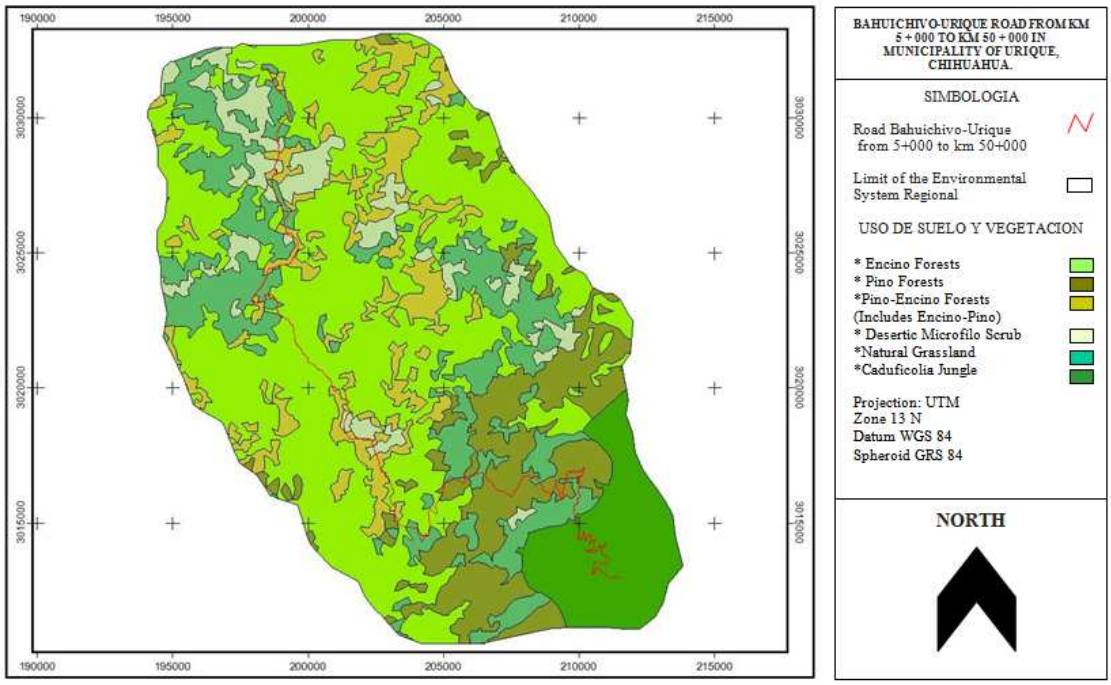


Figure 11: Letter of Land use and Vegetation

Source: Astorga, F. (2013)

Species Threatened or Endangered

It is necessary to point out that in the place where the project will be carried out, there is no type of fauna that is considered to be in a special status according to the Official Mexican Standard NOM-059-SEMARNAT-2010. The road section will continue in parts of the existing road, so there are areas that had previously been impacted by anthropogenic,

agricultural, livestock and by the opening of the existing road several years ago. This activity brought as a consequence that the wildlife that inhabited the region of the municipality and surrounding areas moved to other areas where the original vegetation is still preserved, in search of new refuges, food or for its reproduction.

Landscape Quality

This study includes aspects such as landscape units, fragility and visual sensitivity. Taking this into account, it was concluded that the location of the project in an area that does not have anthropogenic structures or structures, has high conservation status since approximately 95% of the area is covered by natural vegetation. Based on the previous evaluation, this landscape allows contrasts caused by construction, but they should not be evident. The contrasts are visible, but should not be striking.

Characteristic Natural Elements

The line of the road continues through the tunnel built with chisel and marro by the inhabitants of the town of Cerocahui and is considered an emblematic structure. See Figure 12.

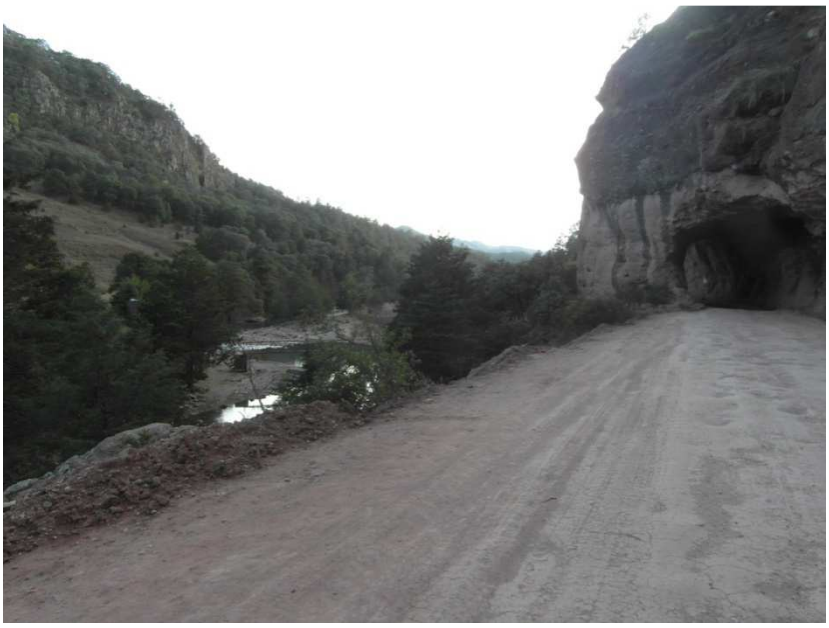


Figure 12: Trace of the Road with Tunnel before the Modernization

Source: Astorga, F. (2013).

The modernization option for this section included the integration of the tunnel with the new line as shown in Figure 13.

Figure 13: Modernization Option Conserving Tunnel

Source: Astorga, F. (2013)

Another element of the landscape is a rock formation that represents a Bear as can be seen in Figure 13. The trace of the path was made so that travelers pass near this natural configuration and can enjoy this pleasant landscape.

Figure 14: Rock Formation of a Bear at km 12 + 000

Source: Astorga, F. (2013)

The road is designed to conserve the quantity and quality of the water, the bodies of water are elements of the landscape to be admired by road users. The bodies of water provide sustenance for the species of the place. See Figure 15.

Figure 15: Body of Water of the Bahuichivo-Cerocahui Road

Source: Astorga, F. (2013)

The landscape criteria that involve the definition of the terrain and the recognition of the landscape elements should be considered in the stage of preliminary draft scale 1: 5000 and 1: 2,000 of SCT as shown in Figure 16.

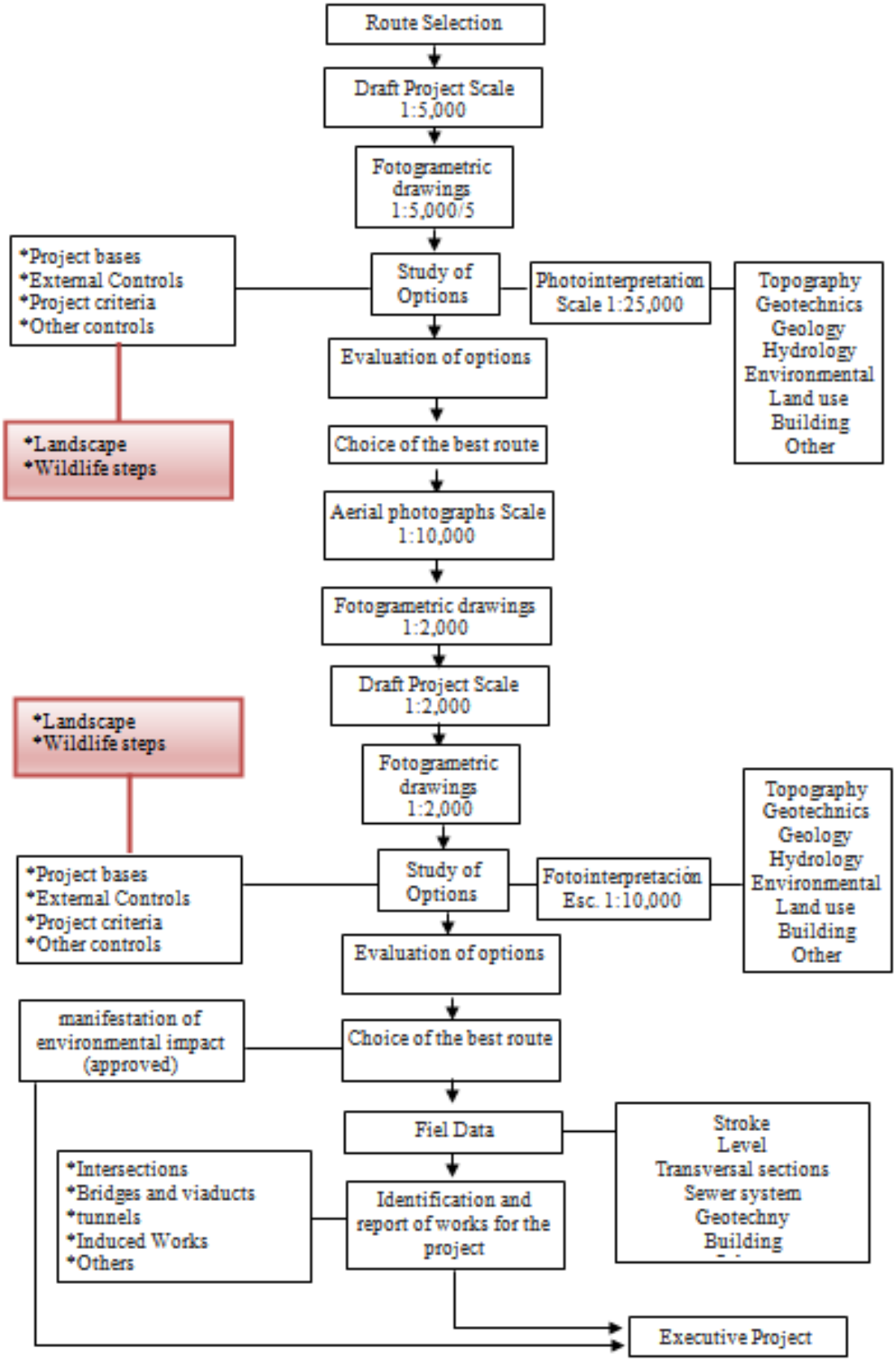


Figure 16: Process for Preliminary Project Scale 1: 5,000 and 1: 2,000

Source: Modified from SCT (2018)

Horizontal Alignment Integrated Into the Landscape

a) Adjustment to the topography

To check the adjustment of the trace to the topography, the alignment of the horizontal alignment was made on the Level curves, and later the road route was analyzed, as can be seen in Figure 17.

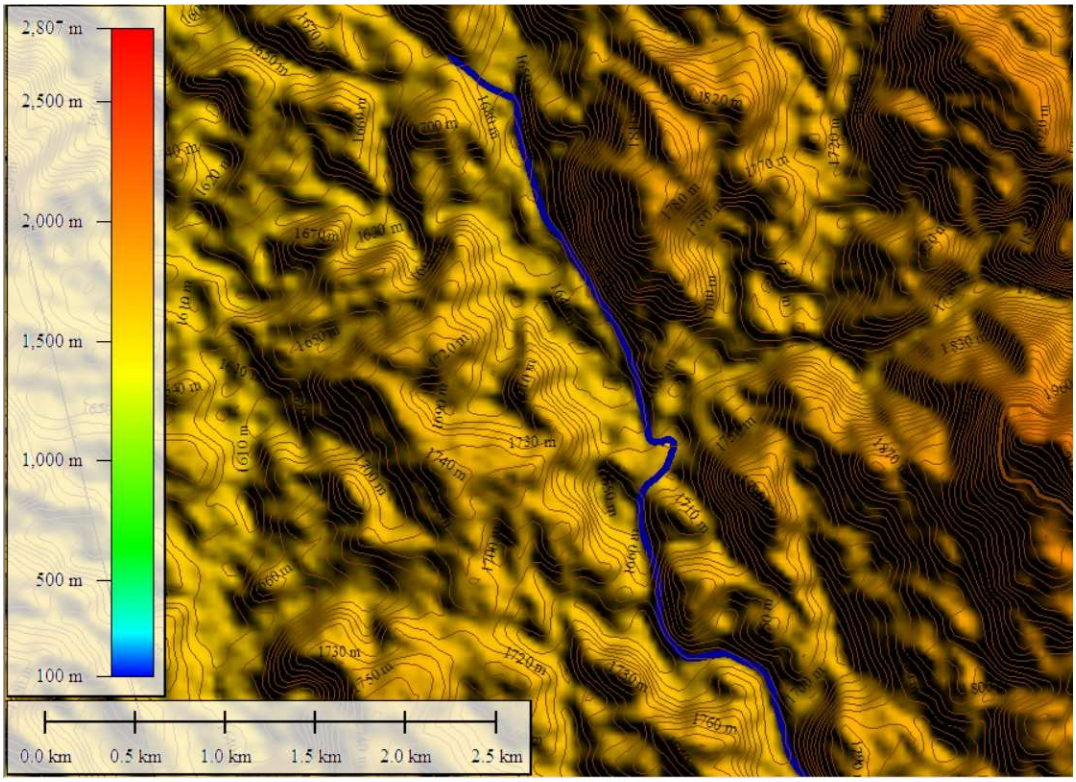


Figure 17: First 5 km of the Alignment where the Topography of the Place can be seen

Source: Self-Made

Based on this analysis, it can be determined that the road follows the topographic contours of the site, which concludes that the line is adjusted to the natural terrain. However, there are areas of opportunity to increase ecological connectivity which will be addressed in the vertical alignment.

Less Movement of Land

A project with less movement of lands causes less damage to the environment than a project with greater volume of earth moving, this is achieved with optimal use of the topography of the area where the road will be projected. For example, on the proposed viaduct at km 14 + 000.

Vertical Alignment Integrated into the Landscape

Elevation or Decrease of the Level of Elevation

The recommendation of the vertical alignment in flat areas is to increase the level of the grade to avoid the fragmentation of ecosystems and reduce the affectation of channels. By having drainage works and wildlife passages, the runoff of surface water and the movement of fauna are favored. At kilometer 14 + 000, a viaduct was proposed that will facilitate the drainage of surface water and the fauna will be able to move from one side of the road to the other. See

Figures 18, 19 and 20.

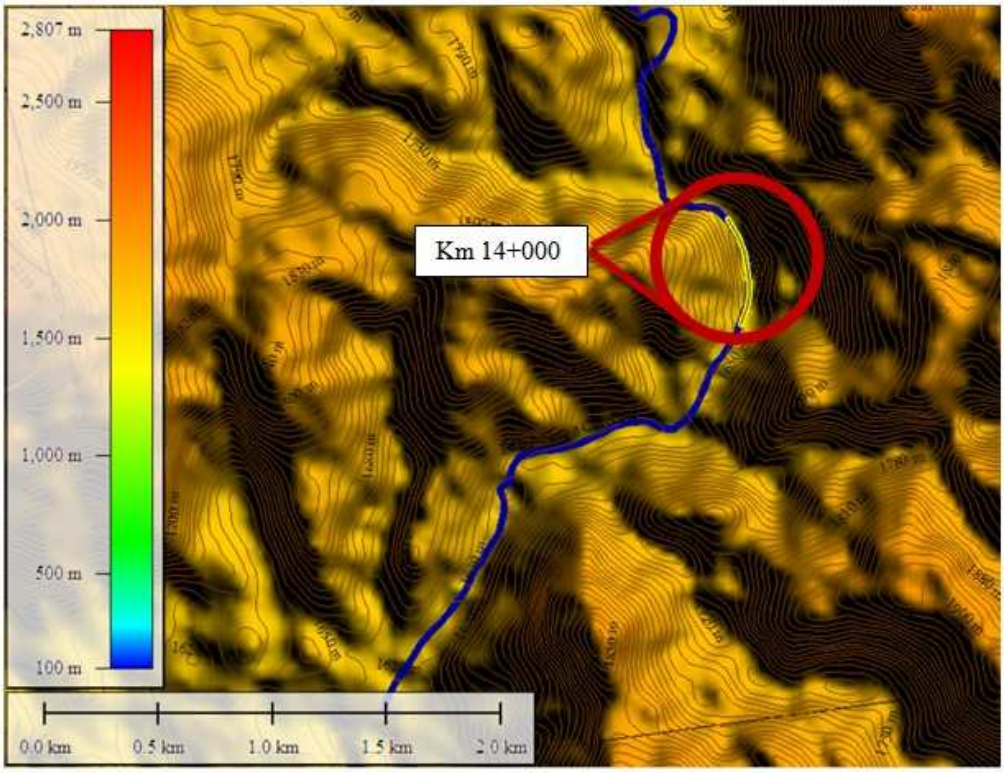


Figure 18: Viaduct at km 17 + 000, to Increase Ecological Connectivity

Source: Self –Made

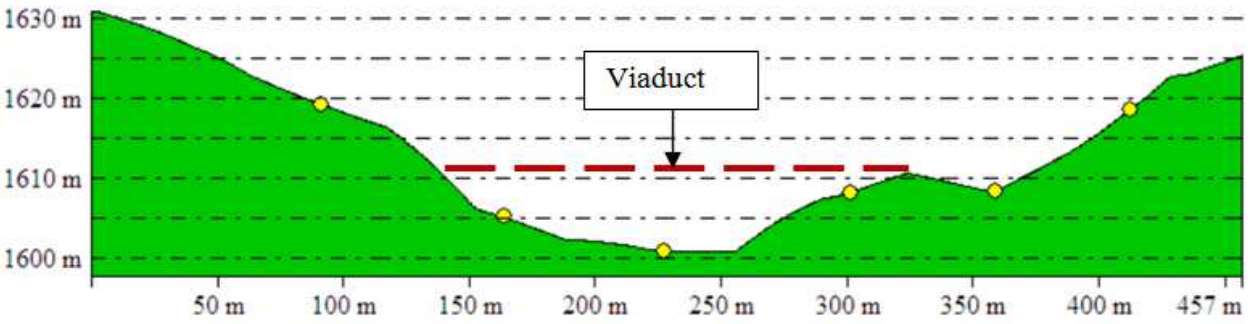


Figure 19: Profile of Viaduct km 14 + 000, Approximate Length of 180 Linear Meters

Source: Self -Made

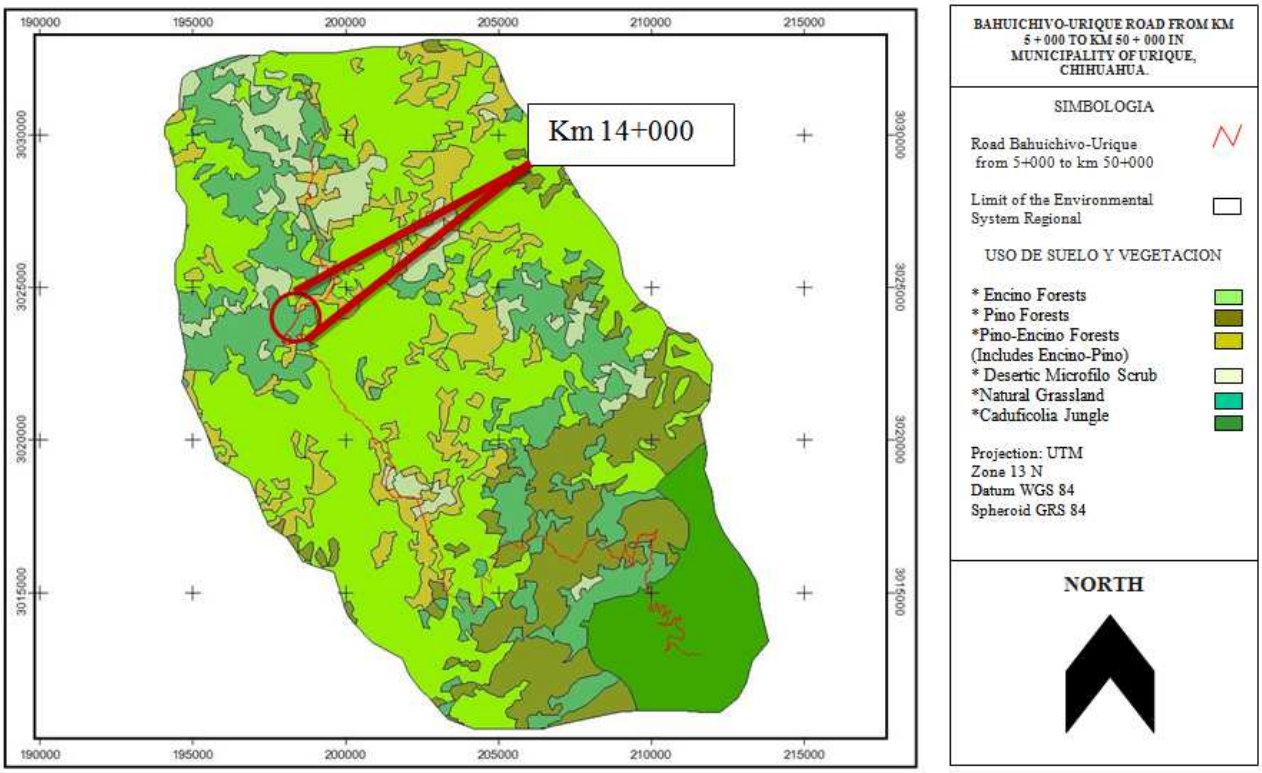


Figure 20: Landscape Unit at km 14 + 000, Pine-oak Forest

Source: Modified from Astorga, F. (2013)

This area is of great interest since it can be considered as a biological corridor and also a place of sustenance for the animals of the area. In this area, we can find frogs that go through periods of freezing and months after spring arrives they thaw and return to normal. See Figure 21

Figure 21: Pine-Oak and Amphibious Forest of the Region

Source: Modified from Astorga, F. (2013)

Inclusion of Tunnels

The tunnels are works of great landscape integration, allow the visibility of the character of the landscape, have very scenic scenic-landscape qualities and allow to maintain a corridor of connectivity within the ecosystem. A tunnel is proposed at km 13 + 000 to maintain connectivity in the area. See Figures 22 and 23.

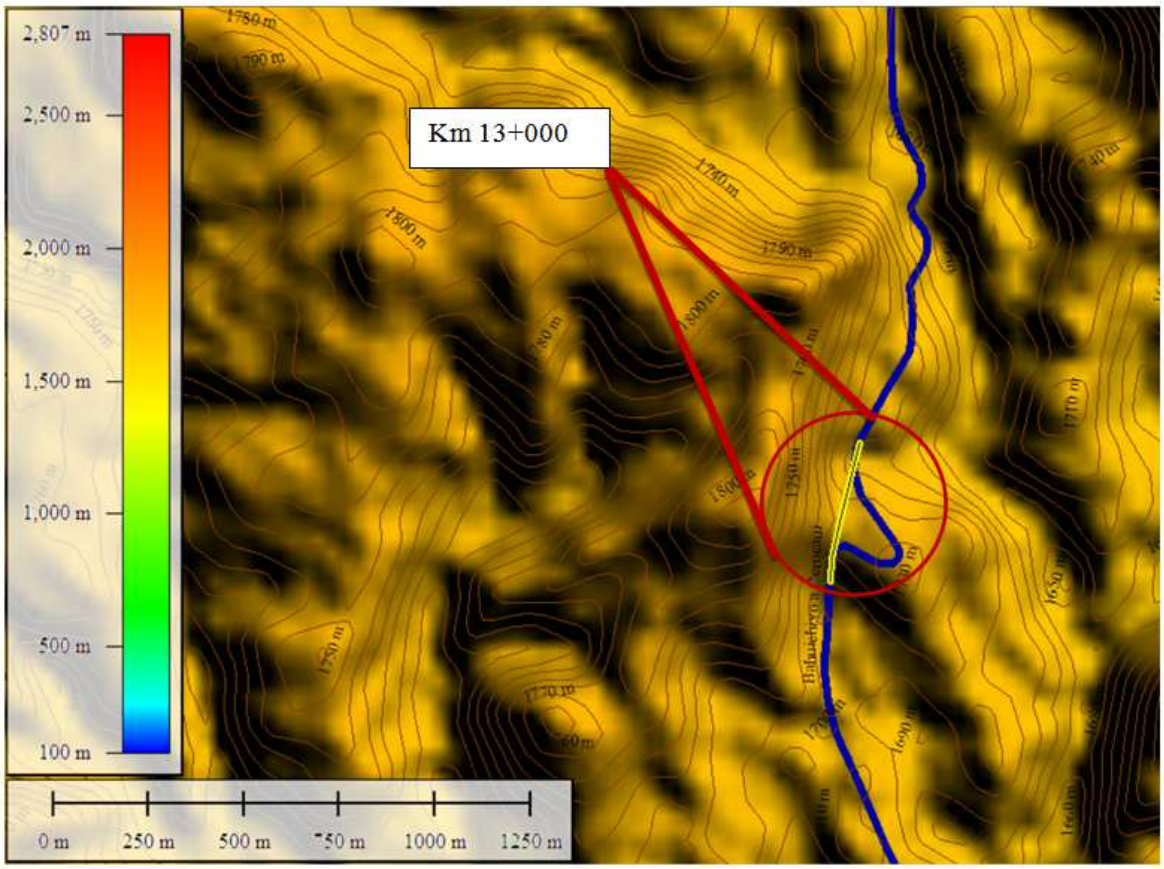


Figure 22: Alignment with the Inclusion of a Tunnel km 13 + 000

Source: Self -Made

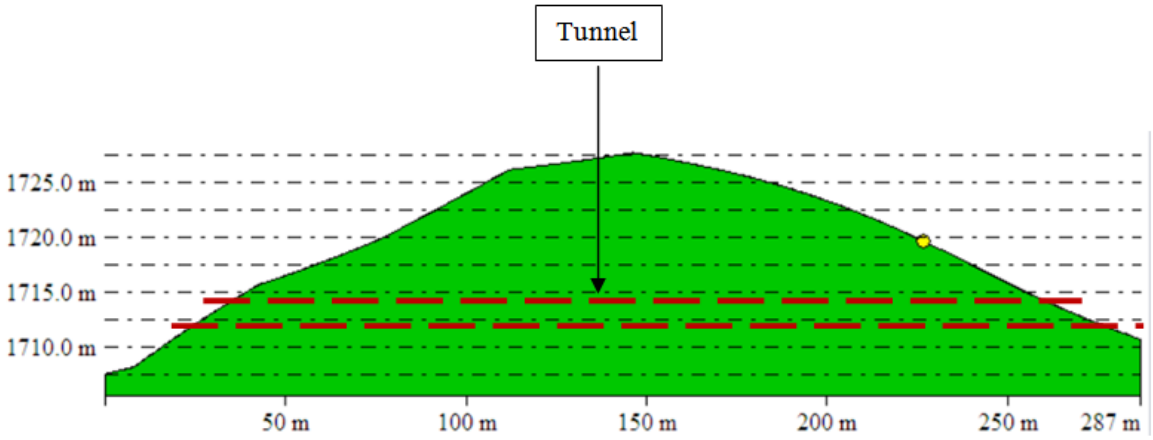


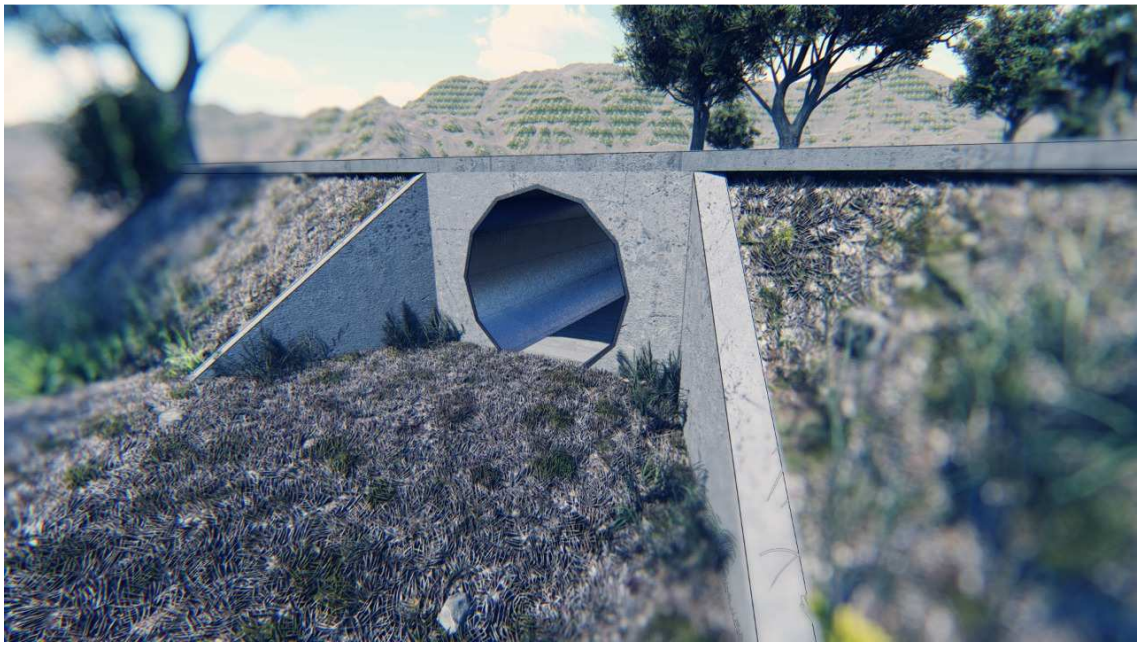
Figura 23: Tunnel Profile km 13 + 000, Approximate Length of 250 Linear Meters

Source: Self Made

Adaptation of Drainage Works

The drainage works must have adaptations of access for small animals in the area such as hares, skunks, ferrets, among others. These adaptations are simple and have the purpose of providing transversal access for small animals even in rainy weather. In Mexico, two types of transversal drainage works are used, slab-type and tube-type drainage. Figure 24 shows the adaptation for both cases.

(a)



(b)

Figure 24: Example of Adaptations for Crossing Terrestrial Animals. a) Slab type Drains Manufactured with Animal Corridors in Perennial Flow or Rainy Weather. b) Tube Type Drainage, with Concrete Coating on the Bottom

Source: Modified from Luell B. (2005)

Definición de la Sección Transversal Integrada al Paisaje

Adjustment of the Slopes of the Transversal section

The project contemplates the modernization of the current road carrying out works of earthworks, structures, drainage works and paving based on asphalt binder by the system of seal irrigation, with a width of 7.0 m to accommodate two traffic lanes, one in each direction. Figures 25 and 26 show the two type sections for the construction.

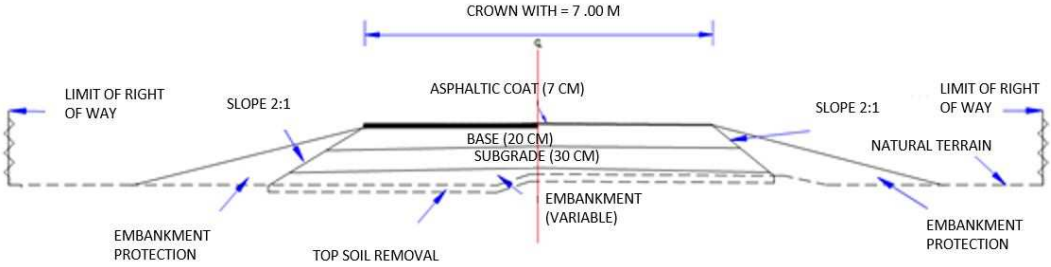


Figure 25: Type Section in the Embankment

Source: Astorga, F. (2013)

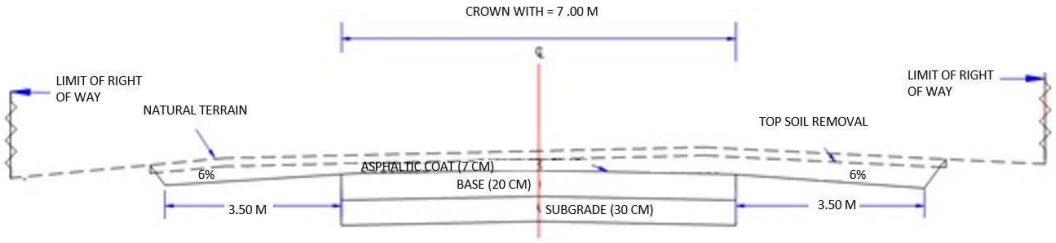


Figure 26: Type Section in Section

Source: Astorga, F. (2013)

The sections shown are those typical of construction, however, there are modifications to be made to integrate the cut and embankment slopes into the landscape. The slopes in sections of the cut must have a faded slope that does not obstruct the horizon and is integrated into the landscape (Figure 27).

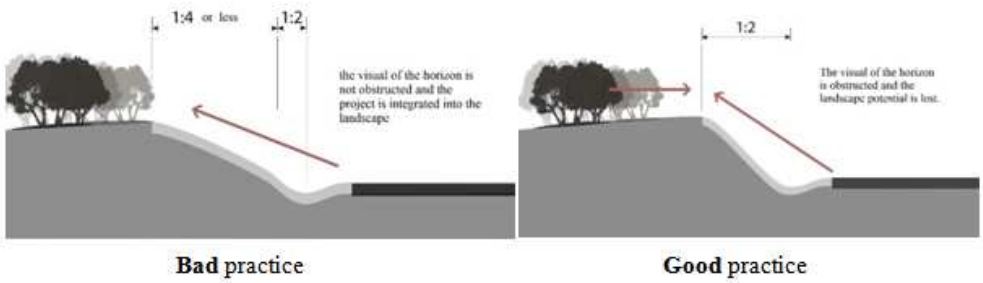


Figure 27: Transition of Slopes in a Section of the Cut. Source: Modified from Highways Agency (1991)

On embankments, the slope transition must be made to gently return it to the level of land use and decrease the appearance of the embankment in the landscape (Figure 28).

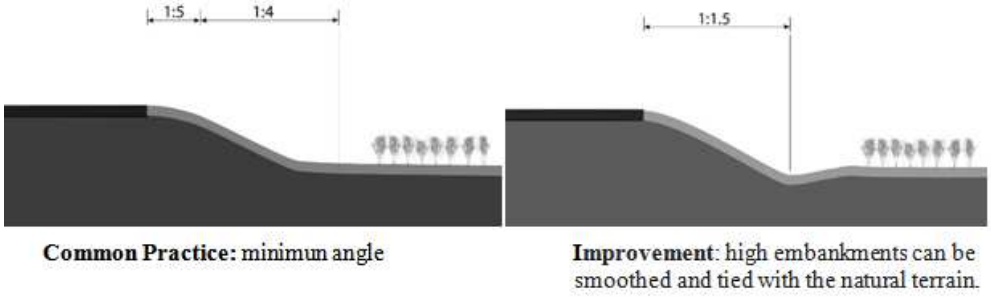


Figure 28: Transition of Slopes in Embankment Section Source: Modified from Highways Agency (1991)

Security Elements

Taking into account the classification of the treatment of this landscape as class 2, defenses with wooden roofs are proposed that do not stand out in the landscape and ditches made with materials from the region, Figure 29 shows how the contours of the road can be integrated into the landscape by means of defenses made with wood and ditches made with stone from the region, thus replacing the conventional concrete gutters.

Figure 29: Example of the Road with a Gutter of Regional Materials and Flexible Defense with Treated Wood, Road of Cerocaui. Chihuahua Source: Self -Made

The recommendations of the horizontal, vertical alignment and cross sections are included in the stage of the road executive project of the SCT as shown in Figure 30.

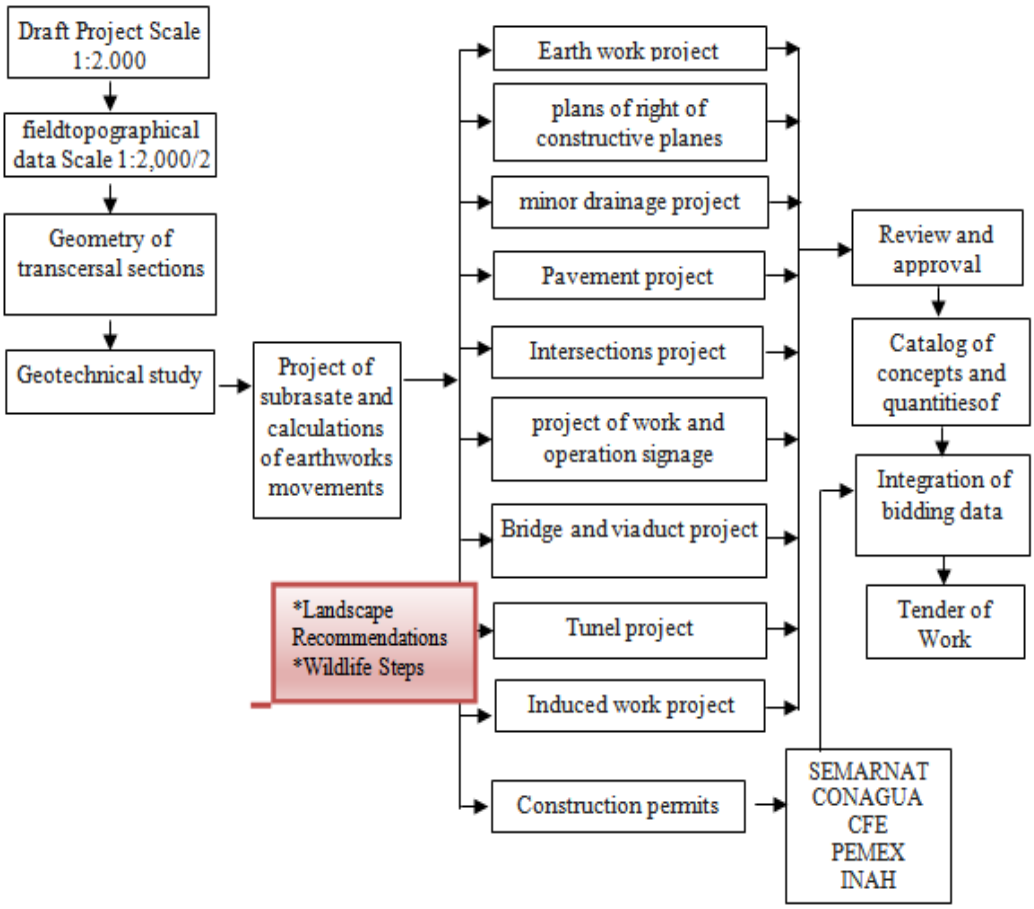


Figure 30: Process for the Executive Project

Source: Modified from SCT (2018)

Finally, the corrective measures or management of the infrastructure provide elements of visual improvement very precise, among which can be mentioned are: location of plant screens, planting of slopes, treatment of clearings, location of signaling and safety considerations.

CONCLUSIONS

- The process of evaluating the elements of the landscape should be done since it allows the environmental assessment of Strategies that allow the conservation of different types of habitats, disturbances of habitats, relevant landscape elements, presence of endangered species.
- The successful selection of the best alternative of horizontal alignment in the infrastructure planning phase is fundamental to avoid environmental impacts and will reduce the cost of the measures that are subsequently necessary to correct or compensate the impacts.
- Design the vertical alignments that reflect the local topography; the slopes should be similar to the slopes of the terrain. Technical solutions such as tunnels and bridges can be chosen for greater integration in mountain trails.
- Special care should be taken to design the cross section since its parameters have a great influence on the probability and severity of accidents. It must have an adequate dimension to provide sidewalks in the points of

interest.

- Sewer and bridge works that are used as crossings of fauna should be well connected with their environment, either through plantations that direct small animals or through corridors of suitable habitat for larger animals.
- The principle of landscape design of tunnels can be summarized as security, minimal environmental impact, Aesthetics, regionalism, integration with the environment that surrounds it and economic.
- It is important to mention that the security conditions of elements (defenses or walls) new such as those mentioned must be laboratory tested and standardized.

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