



Risk Assessment and Capacity Development in Costa Rica

Exposure and Vulnerability Models

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Risk Assessment and Capacity Development in Costa Rica

Exposure and Vulnerability Models

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1 INTRODUCTION

The Global Risk Modelling Alliance (GRMA) program, sponsored by the InsuResilience Solutions Fund (ISF), has the primary objective of strengthening the capacity of countries and cities in climate and disaster risk analysis for financial purposes. This initiative seeks to fill critical gaps in models and data, enhancing climate and disaster risk assessments at the national and subnational levels.

In the case of Costa Rica, GRMA identified and co-defined, together with local partners, the specific needs of the country in order to offer open tools for risk management, as well as data and access to operational expertise in risk financing.

Exposure and vulnerability reflect the socioeconomic conditions of an environment that may be impacted when hazardous events occur. The presence of exposed elements in areas where such events might take place, along with their susceptibility to damage, largely determines the occurrence of disasters—often more than the hazardous events themselves.

In general, an exposed element refers to any object, asset, or good that is susceptible to damage or loss due to the occurrence of a hazardous event. Exposed elements are therefore essential in risk assessment, as they form the basis for quantifying modeled losses.

Exposed elements can be categorized according to the type of inventory or exposure to which they belong, such as buildings, infrastructure, crops, or livestock, among others. These groups of exposed elements have distinct characteristics that differentiate them both in terms of the modeling approaches required to represent them and their susceptibility to each specific hazard under consideration.

In this study, the impact on buildings is measured in terms of direct damage to the asset or structure itself, the contents within, and the loss of income due to service disruption. Buildings are often organized into portfolios, depending on the stakeholder for whom the modeled losses are relevant. This approach enables the simulation of impacts across broad groups of exposed elements.

Infrastructure systems represent a particularly complex category of exposed elements to model. These systems are composed of individual components that are interconnected, forming nodes and links through which specific services are delivered. As a result, there is a degree of interdependence among system components. The impact involves both direct damage to individual elements and the resulting changes in service provision due to such damage. This study focuses on the direct impacts sustained by the components of infrastructure systems.

In the case of agricultural and livestock production, the exposed element can be understood as a unit of cultivated or productive land. This unit encompasses multiple factors, such as the type of crop or production system in place, the production cycle, the seasonality of that cycle, soil type, among others. The impact primarily manifests as a reduction in crop yields or variations in the grazing capacity of pastures, resulting in production losses. Unlike damage to buildings and infrastructure, these losses represent an economic flow rather than the loss of a tangible asset.

Vulnerability, therefore, must be assessed differently for each type of hazard being considered. This makes the study of the vulnerability of buildings, infrastructure, crops, and livestock a complex process and a field of knowledge that continues to be the subject of extensive research and academic work.

In catastrophic risk modeling, losses are treated as random variables. This approach allows the inherent uncertainty in the magnitude of losses caused by different hazardous events to be explicitly accounted for in the calculations. Vulnerability is defined on an element-by-element basis within the portfolio of exposed elements, meaning that the referenced loss pertains to an individual exposed element.

In general terms, loss can be defined as a variable ranging between 0% and 100% of the value of the exposed element (e.g., the replacement cost of a building, the annual production value of a cultivated area, etc.). Therefore, when referring to vulnerability throughout this document, loss is understood as a relative loss corresponding to the degree of damage—that is, as a fraction of the exposed value.

This document corresponds to deliverables **4a, 4b, 4c, 4d, 4e, 5a, 6a, 7a, 8a, and 8b** of the Terms of Reference, which provide a detailed description of the models of exposed elements and vulnerability curves that will be used for risk modeling in each of the projects included in this study.

This report is organized into several sections, as outlined below:

Section 1. Introduction

Section 2. Exposure and Vulnerability Models for the Strategic Project: Demonstration of Risk Assessment Methods for Critical Infrastructure in Heredia

Section 3. Exposure and Vulnerability Models for Operational Project 1: Disaster and Climate Risk Assessment for Road Infrastructure – National Route 2, Pan-American Highway (RN2)

Section 4. Exposure and Vulnerability Models for Operational Project 2: Flood and Drought Risk for Small and Medium-Sized Agricultural Producers

Section 5. Exposure and Vulnerability Models for Operational Project 3: Exposure and Risk Assessment of Small and Medium Hotels and Hostels under the Fu-turismo Program

Section 6. Summary of the Training Program Content on Vulnerability and Exposure, including statistics on the participation of representatives from Costa Rican institutions and the current progress status

1.1 Limitations To the Use and Development of Vulnerability Models

This report references a substantial number of vulnerability models required to support the risk assessments conducted across the different projects (see Annex A.5). Some of these models are drawn from existing scientific and technical literature, which is generally not specific to Costa Rica, while others were developed by the consultant specifically for this assignment. In all cases, the selection and matching of exposed elements to appropriate vulnerability models are based on the consultant's professional

judgment and experience, as there is virtually no locally developed vulnerability data or models specific to Costa Rica.¹

Whether existing models are applied or new ones are developed, there is insufficient data to support a formal validation process. A robust statistical validation would require, for each construction type, infrastructure asset, crop, or other exposed element, detailed loss information across a wide range of hazard intensities, with an adequate number of observations at each intensity level to reliably estimate the statistical properties of loss. This would, in turn, require comprehensive historical datasets from past events, including detailed records of damage to individual exposed elements, their specific characteristics, and the exact hazard intensities experienced at each location. Such datasets do not exist, either in Costa Rica or elsewhere.

The development of vulnerability models is inherently complex and typically relies on detailed analyses of how exposed elements respond to hazard intensities. This work is most commonly based on numerical and dynamic simulations rather than on empirical statistical data from historical events. Accordingly, the main international sources of vulnerability data (such as HAZUS, for example) rely extensively on scientific literature grounded in simulation-based approaches.

Consequently, within the scope of this assignment, it is not feasible to develop or apply a formal validation procedure for the vulnerability models presented herein. These models have therefore been selected or developed based on the consultant's expertise. While this introduces an additional source of uncertainty, it represents a reasonable and widely accepted approach that enables the implementation of the modeling framework and the generation of the project outcomes.

These considerations are further elaborated in Annex A.6.

¹ Previous studies like the CAPRA project, or the GRAF, for example, make use of previously existing models from international sources. No new models were developed in those studies.

2 STRATEGIC PROJECT: DEMONSTRATION OF RISK ASSESSMENT METHODS FOR CRITICAL INFRASTRUCTURE IN HEREDIA

The objective of this strategic project is to perform multi-sector infrastructure modeling in the canton of Heredia². The project involves the assessment of seismic and flood risk across portfolios of buildings and infrastructure, based on the available information for the canton of Heredia.

2.1 Building Exposure Model

The building exposure model for the canton of Heredia includes all buildings within its administrative boundaries, covering multiple use types or sectors, including residential, commercial, education, healthcare, law enforcement, Red Cross, fire stations, heritage buildings, and shelters. Building exposure is modeled using georeferenced information layers, where each element in the portfolio has a spatial geometric representation and a set of attributes that characterize it—such as geographic location, economic value, occupancy, and vulnerability type or classification.

The case of the canton of Heredia is particularly noteworthy due to the high availability of information on exposed elements. Since this level of detail is not necessarily available in other cantons of Costa Rica, Annex 1 (A.1) provides alternative data sources to those used for Heredia's model. This aims to serve as a reference for future replication efforts in other cantons where detailed local information may be lacking, offering general guidance on potential information sources for similar purposes.

2.1.1 Geographic Location of Buildings

The georeferencing of buildings is based on cadastral information provided by the Municipality of Heredia. The following data layers were consulted for this purpose:

- *Cadastral Map*: Contains the location, identification, and graphical representation of parcel boundaries.
- *Vertical Properties*: Provides information on the horizontal and vertical location of property units, as well as their identification and graphical delimitation within vertical condominiums.
- *Building Footprints*: Contains the georeferenced locations of building roof footprints. While the cadastral map outlines parcel boundaries, this footprint layer offers a more accurate approximation of the actual built-up areas within each parcel.

Figure 1 presents a general graphical representation of the aforementioned data layers.

² It refers to critical infrastructure located within the canton, in accordance with the definitions established in Decree No. 42465 of MOPT–MINAE–MIVAH.

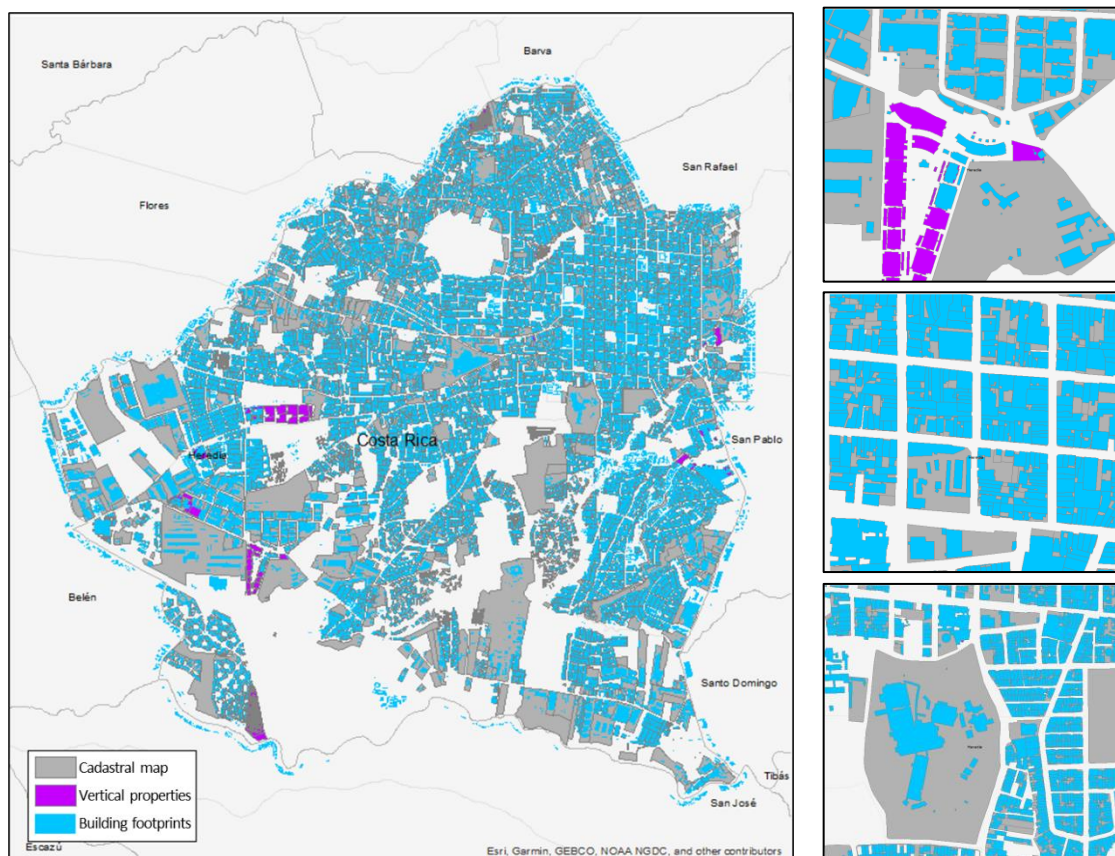


Figure 1. Cadastral map – Vertical properties – Building footprints.

2.1.2 Sector-based Location

Once the geographic location model of buildings was established—based on the cadastral map in the case of the canton of Heredia—public buildings that are required to ensure continuity of critical services following a disaster were identified within this model. To achieve this, various information sources were consulted, which are detailed below according to the respective use sector.

2.1.2.1 Health Sector

To identify buildings belonging to the health sector, the cadastral map and the general emergency plans for the health areas, provided by the municipality of Heredia, were consulted. These documents indicate that the health sector in the canton consists of the Heredia Cubujuquí Health Area (ASHC), the Heredia Virilla Health Area (ASHV), the San Vicente de Paul Hospital, and supporting clinics.

This information was cross-referenced and complemented with the health sector exposure model developed as part of the implementation of the first GRAF pilot in Costa Rica (2024), which was built using data provided by the Costa Rican Social Security Fund (Caja Costarricense de Seguro Social).

Figure 2 shows the location of health facilities within the canton of Heredia.

2.1.2.2 Emergency Response

Among the emergency response facilities, buildings belonging to the Red Cross, fire stations, and police (Fuerza Pública) facilities were identified. These were located using the descriptive attributes of the public areas data layer provided by the Municipality of Heredia.

Figure 2 illustrates the location of the emergency response facilities within the canton.

2.1.2.3 Heritage

To identify and locate properties belonging to the cultural or historical heritage of the canton, the platform provided by the Ministry of Culture and Youth for querying designated heritage assets or sites of cultural interest was consulted. This platform includes information at the national level (see Figure 2).

2.1.2.4 Shelters

The UBICA platform of the Municipality of Heredia provides a data layer labeled "Shelters," which contains the locations of sites proposed as shelters in case of an emergency. This information was supplied by the Heredia Municipal Emergency Committee (see Figure 2).

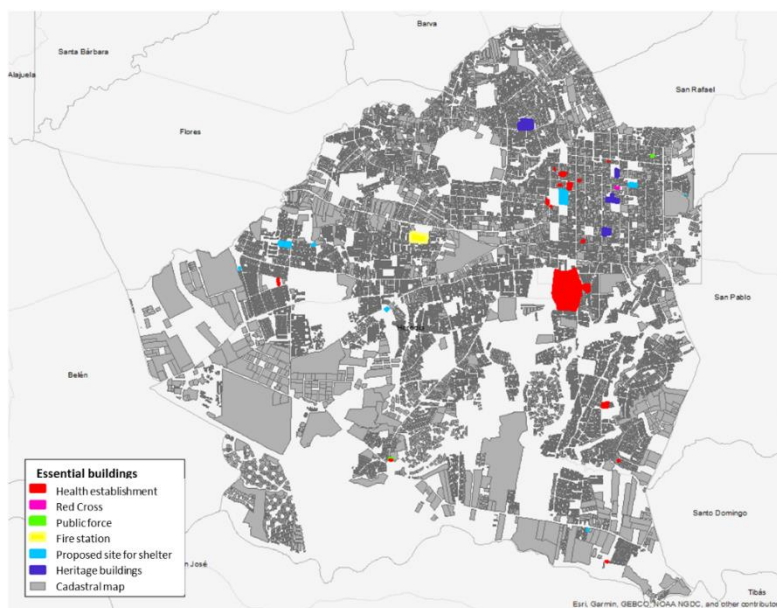


Figure 2. Critical buildings – Heredia canton.

2.1.2.5 Educational Facilities

The Geographic Information System of the Ministry of Public Education (SIGMEP) provides an open data layer with the spatial location (latitude and longitude) and identification of public and private educational institutions in Costa Rica. This information was spatially joined with the cadastral map to complement the data on educational facilities already identified in that layer.

Figure 3 shows the location of educational institutions resulting from the combination of these two data sources (SIGMEP and the cadastral map).

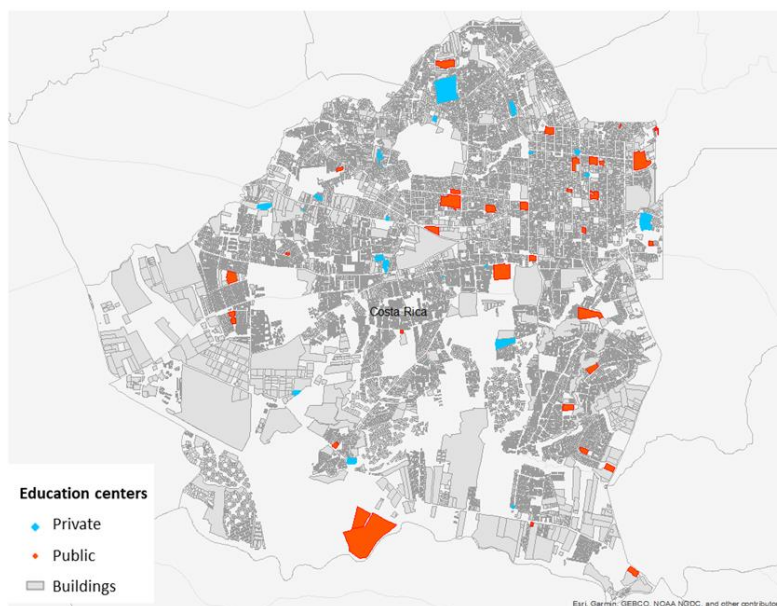


Figure 3. Educational facilities Heredia canton- SIGMEP.

2.1.3 Economic Valuation

To estimate the economic value of buildings, information was sourced from different datasets depending on the availability by use sector and the specific characteristics of the buildings.

2.1.3.1 Cadastral Value of Constructions

The economic valuation of buildings was primarily based on the cadastral value of the construction within each parcel. This information was provided by the municipality of Heredia as part of the descriptive attributes of the cadastral map. For properties within vertical condominiums, the cadastral value was calculated as the sum of the individual property values grouped by building.

2.1.3.2 Map of Homogenous Value per Square Meter

For buildings without cadastral value data —mainly public or government buildings that are exempt from tax payments— the economic valuation was estimated by calculating the built area (defined as the footprint area multiplied by the number of floors) and applying the value per square meter according to the corresponding homogeneous value zone. The map of homogeneous value zones per square meter was provided by the municipality of Heredia and is shown in Figure 4.

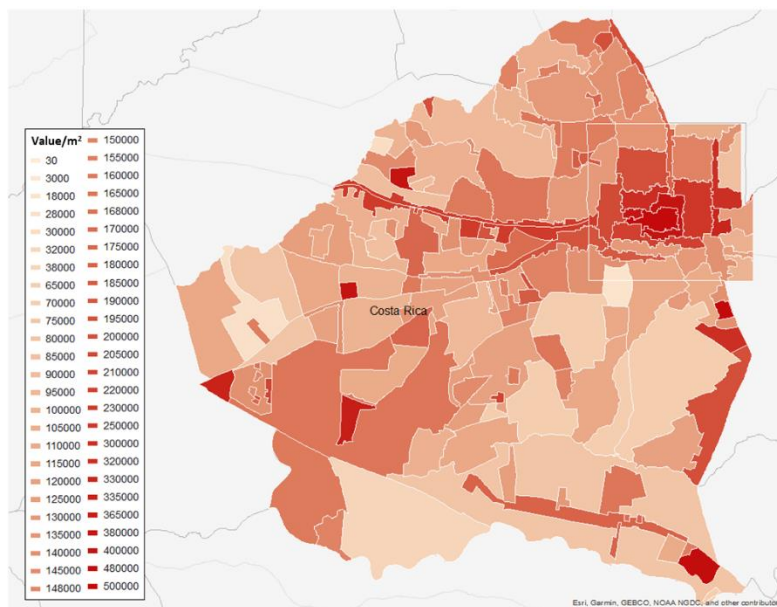


Figure 4. Map of Homogenous Value per Square Meter.

2.1.3.3 Unit Base Value Manual by Construction Typology

For specific buildings such as healthcare facilities or educational centers (e.g., schools, universities), economic valuation was estimated by multiplying the built area by the unit value corresponding to the construction typology, as defined in the *Unit Base Value Manual by Construction Typology*. This tool was developed by the Technical Standardization Body of the Ministry of Finance³.

This manual is designed to determine the replacement cost of constructions and provides detailed descriptions for each construction type, including:

- Cabins
- Chalets
- Apartment Buildings
- Retirement Homes
- Commercial Premises
- Commercial Buildings
- Shopping Centers
- Office Buildings
- Educational Buildings
- Hospitals
- Religious Buildings
- Restaurants
- Lodges
- Hotels
- Cinemas
- Theaters
- Gyms
- Warehouses
- Industrial Sheds
- Clubhouses
- Concrete Housing
- Glass Housing
- Drywall Housing
- Container Housing
- Prefabricated Housing
- Loft Housing
- Pyramid Housing
- Plastic Housing
- Wooden Housing
- Bamboo Housing
- Adobe Housing
- Bahareque Housing
- Large Sheds
- Warehouses

³ <https://www.hacienda.go.cr/docs/ManualdeValoresBaseUnitariosporTipologiaConstructiva.pdf>

This manual constitutes a standardized and official tool that enables detailed economic valuation of buildings based on their typology when official data sources, such as cadastral records, are not available. In these cases, the built areas (e.g., building footprints multiplied by the number of floors) must be estimated and then multiplied by the corresponding unit values to approximate the construction value.

Figure 5 shows the distribution of the final exposed value obtained for the buildings in Heredia.

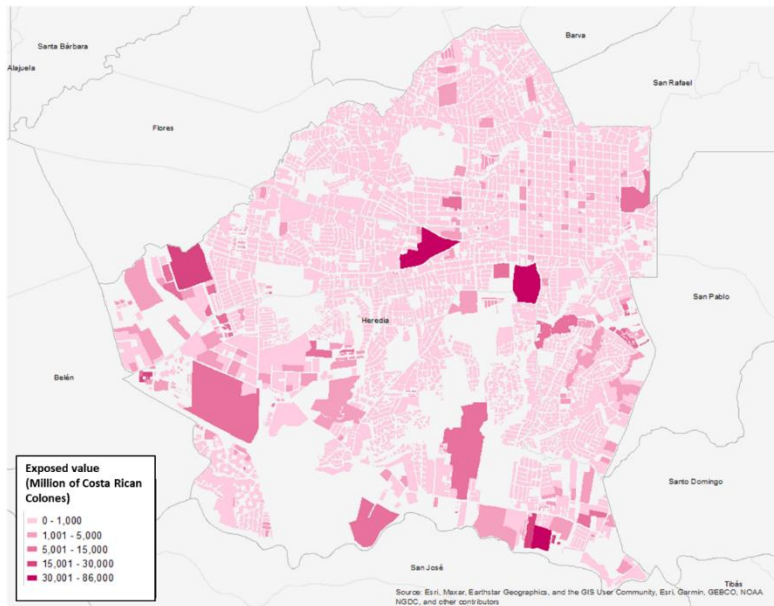


Figure 5. Exposed value.

2.1.4 Number of Stories

To determine the number of floors in buildings within the canton of Heredia, the descriptive attribute “PLANTAS” from the cadastral map was used. For properties within vertical condominiums, the maximum number of floors recorded in the “Vertical Properties” layer was assigned to the group of properties belonging to the same building.

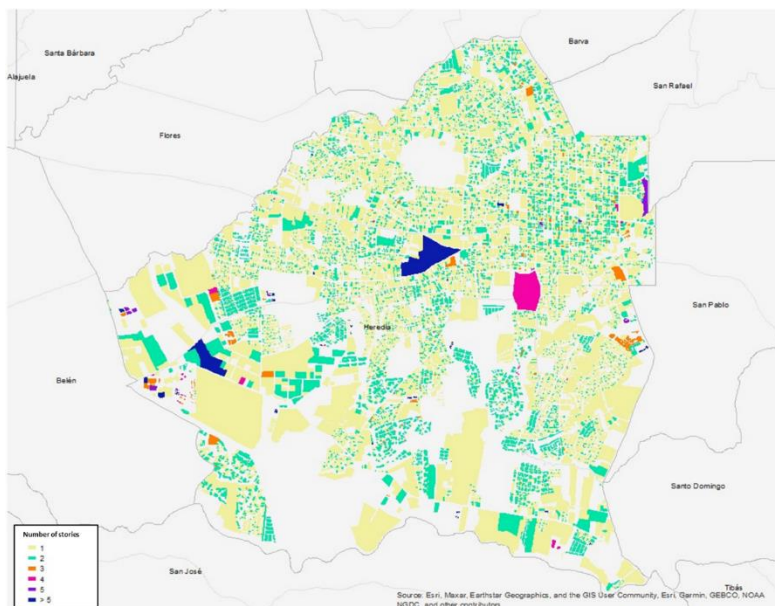


Figure 6. Number of stories.

2.1.5 People at Risk

According to population projections from the National Institute of Statistics and Census (INEC), the estimated population of the canton of Heredia for the year 2025 is 149,930 inhabitants⁴. Additionally, the UBICA platform of the Municipality of Heredia provides a data layer with population figures from the 2011 national census. This information is detailed at the level of Minimum Geostatistical Units (UGM), which are composed of polygons that encompass urban blocks or irregular areas bounded by road networks, rivers and streams, or other cultural infrastructure elements.

To estimate the population within the buildings of the canton of Heredia, the canton-level population projection was disaggregated across buildings according to the distribution defined by the 2011 census minimum geostatistical units.

Figure 7 shows the population distribution, expressed as the number of inhabitants per parcel, based on the available INEC data.

⁴ <https://services.inec.go.cr/proyeccionpoblacion/frmproyec.aspx>

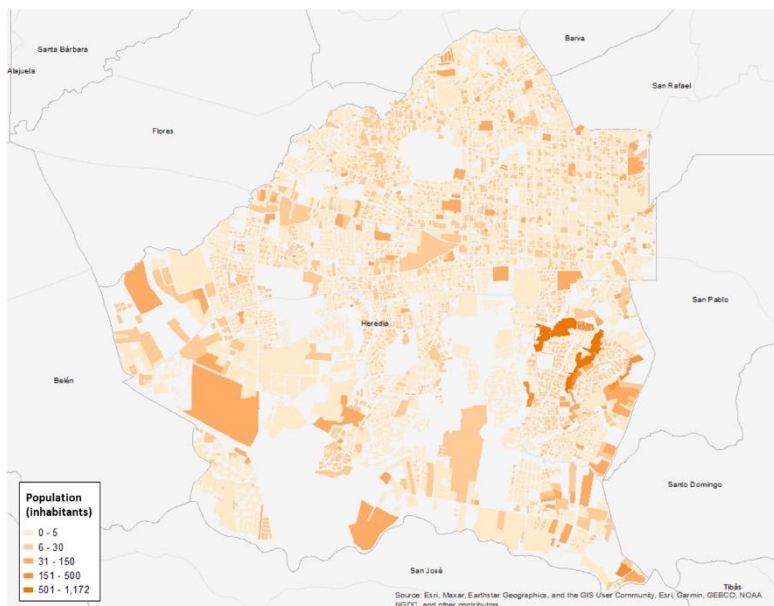


Figure 7. Population per parcel.

2.1.6 Use Sector

To determine the use sector, the cadastral map data includes the descriptive attributes “USO” (use) and “OBSERVACION” (observation), which enable the differentiation of use sectors for each parcel. These attributes help identify sectors not previously addressed in the sections above, such as the residential, commercial, and industrial sectors. Figure 8 shows the distribution of use sectors across the canton, grouped into general categories.

The USO and OBSERVACION fields were used in a complementary manner. Specifically, the OBSERVACION field was employed when the USO field was empty. In addition, OBSERVACION was used to achieve a higher level of detail than that provided by USO, which is inherently more general. For instance, the OBSERVACION field enabled the identification and differentiation of critical facilities (such as historical buildings, police stations, fire stations, and Red Cross facilities) which are explicitly described in this field, whereas in the USO field they are aggregated under a single institutional-use category.

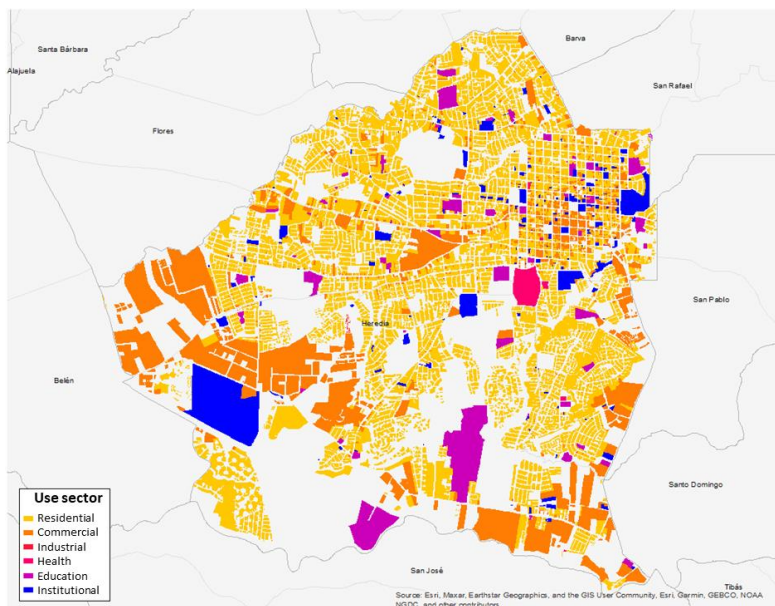


Figure 8. General use sector.

2.1.7 Summary of Building Exposure in Heredia

Given the very large number of elements that make up the building portfolio of the canton of Heredia, this section presents a general summary with the total estimated replacement value and the total number of individual elements that comprise each sector considered.

Table 1. Economic valuation and elements of building exposure in the Canton of Heredia

Sector	Economic valuation (€)	Elements
Residential	1,212,441,346,781	33,569 housing units 10 informal settlements
Institutional	91,228,748,233	1 Red Cross stations 1 fire station 3 public security buildings 7 heritage buildings 10 proposed shelter sites 178 institutional buildings (churches, public buildings)
Health	59,871,830,316	1 hospital 2 main offices 2 alternate offices 8 EBAIS clinics (primary care centers) 3 supporting clinics
Education	81,162,415,616	37 public educational institutions 32 private educational institutes
Commercial	774,847,802,307	2,086 commercial buildings
Industrial	383,471,866	182 industrial buildings

2.2 Building Vulnerability Models

The assessment of the physical vulnerability of built elements is a central component of the risk model developed in this study. While the exposure model defines the location, physical characteristics, and replacement value of assets, the vulnerability model estimates how these elements may sustain physical damage when exposed to natural hazards, and the extent to which such damage translates into economic loss.

Each building element is classified under a representative typology, to which a vulnerability function is assigned. This function is defined as a mathematical relationship between the intensity of a hazard (e.g., seismic acceleration or flood depth) and the expected percentage of direct loss for the element. These functions enable the estimation of the probability of physical damage and the quantification of relative economic loss based on the event parameters.

For the canton of Heredia, a typological classification of all buildings is available, providing a detailed description of their construction and structural characteristics⁵. This information is sufficient for risk modeling across all sectors involved in this study. However, a specialized archetype model was developed specifically for the health sector, given the highly specialized nature of the contents and functions of healthcare buildings.

Therefore, this section presents general vulnerability models based on construction typologies, along with specialized vulnerability models for healthcare building archetypes.

2.2.1 General Building Typologies

To classify building typologies, the Heredia cadastral database includes descriptive attributes for most buildings, such as structural material, wall and roof materials, construction age, conservation condition, among other variables.

One of the most informative attributes for typology classification is the “DESTINO” field, as it characterizes the construction typology by encompassing the previously mentioned attributes while also providing general information about the potential contents of these structures.

Figure 9 shows the distribution of construction typologies within the canton of Heredia. In the case of seismic vulnerability, no new vulnerability functions were developed. The derivation of earthquake vulnerability functions represents a substantial effort that is well beyond the scope of this assignment. Instead, the existing library of seismic vulnerability functions from the CAPRA project was used. This library provides ready-to-use functions covering all structural construction types considered in this assessment.

⁵ The cadastral dataset includes a construction typology code assigned on a building-by-building basis. This code directly corresponds to the typologies defined by the Costa Rican Ministry of Finance in the document Manual of Unit Base Values by Construction Typology (“Manual de valores base unitarios por tipología constructiva”).

For flood vulnerability, the archetype-based modeling approach presented in the Inception Report (Section 9) enabled the combination of damage functions for individual building components and contents, resulting in the development of new vulnerability functions tailored specifically to this assignment.

Table 1 provides a detailed description of each typology identified in Heredia.

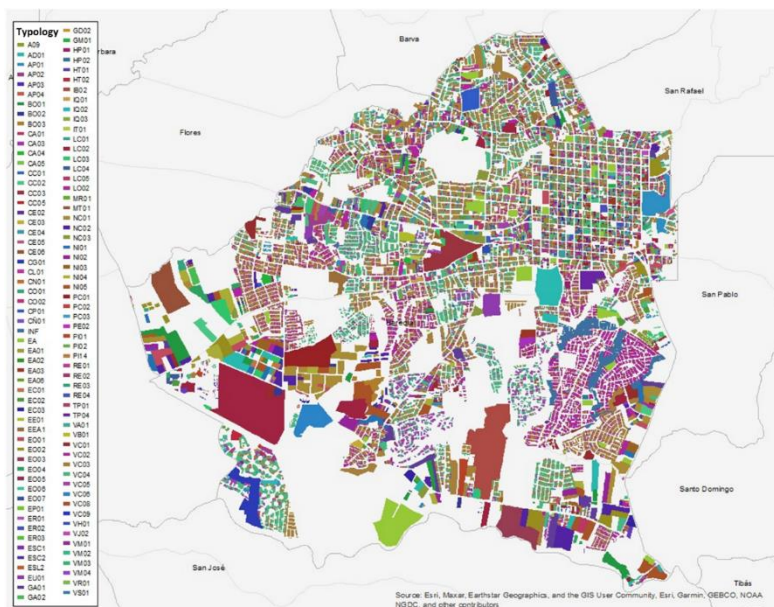


Figure 9. Structural typologies.

For the various structural types included in the available typology descriptions (see In the case of seismic vulnerability, no new vulnerability functions were developed. The derivation of earthquake vulnerability functions represents a substantial effort that is well beyond the scope of this assignment. Instead, the existing library of seismic vulnerability functions from the CAPRA project was used. This library provides ready-to-use functions covering all structural construction types considered in this assessment.

For flood vulnerability, the archetype-based modeling approach presented in the Inception Report (Section 9) enabled the combination of damage functions for individual building components and contents, resulting in the development of new vulnerability functions tailored specifically to this assignment.

Table 1), specific vulnerability functions are defined for each hazard considered. It is important to note that vulnerability functions are not provided for landslides, as vulnerability in this case is treated as a binary condition (either no impact or total loss; see Section 9.1.3 of the Inception Report).

In the case of seismic vulnerability, no new vulnerability functions were developed. The derivation of earthquake vulnerability functions represents a substantial effort that is well beyond the scope of this assignment. Instead, the existing library of seismic vulnerability functions from the CAPRA project was used. This library provides ready-to-use functions covering all structural construction types considered in this assessment.

For flood vulnerability, the archetype-based modeling approach presented in the Inception Report (Section 9) enabled the combination of damage functions for individual building components and contents, resulting in the development of new vulnerability functions tailored specifically to this assignment.

Table 1. Structural Description of Construction Typologies in Heredia.

ID	Description
Concrete Housing	
VC01	Integral masonry, prefabricated
VC02	Concrete, integral masonry, prefabricated or metal profiles
VC03	Concrete, integral masonry, prefabricated or metal profiles
VC04	Concrete, integral masonry, prefabricated, structural panels with polystyrene, or metal profiles
VC05	Concrete, integral masonry, prefabricated, structural panels with polystyrene, or metal profiles
VC06	Reinforced concrete columns and beams, cast in place, structural panels with polystyrene, or metal profiles
VC07	Reinforced concrete columns and beams, cast in place, structural panels with polystyrene, or metal profiles
VC08	Reinforced concrete columns and beams, cast in place or metal profiles
VC09	Reinforced concrete columns and beams, cast in place or metal profiles
VC10	Large dimension columns, beams and walls in reinforced concrete, cast in place or metal profiles
Glass Housing	
VV01	Reinforced concrete columns and beams, cast in place or metal profiles
Drywall Housing	
VS01	Galvanized steel profiles fastened with galvanized steel screws at the base, beams, and horizontal and vertical elements
VS02	Galvanized steel profiles fastened with galvanized steel screws at the base, beams, and horizontal and vertical elements
Container Housing	
VR01	Recycled steel or aluminum containers and plywood, anchored on raised concrete foundations. May have concrete subfloors on which the container rests
VR02	Recycled steel or aluminum containers and plywood, anchored on raised concrete foundations. May have concrete subfloors on which the container rests
Prefabricated Housing	
VE01	Steel pieces designed by computerized process for modular assembly
Loft Housing	
VL01	Reinforced concrete columns and beams, cast in place, structural panels with polystyrene or metal profiles
Pyramid Housing	
VI01	Square tube metal frames, secondary structure of 7.20 cm x 7.20 cm, both welded or articulated. Continuous reinforced concrete slab.
Plastic Housing	
VP01	Self-leveling of fixed system composed of galvanized steel elements grade 16 and insulated plates as concrete pedestal foundations, with anchors, leveling pedestal, cord, and foundation profiles. Galvanized steel columns, gauges 14, 16, and 18 according to design, spaced every 1.22 m
VP02	Metal frame system with square profile of 7.62 cm x 7.62 cm or 10,16 cm x 10,16 cm, welded or articulated. Reinforced concrete insulated plates.
Wood Housing	
VM01	Concrete block base, generally cedar wood columns, ties, and wall plates of 5 cm x 7.5 cm
VM02	Generally cedar wood columns, ties, and wall plates of 10 cm x 15 cm
VM03	Generally cedar wood columns, ties, and wall plates of 10 cm x 15 cm
VM04	Generally cedar wood columns, ties, and wall plates of 15 cm x 20 cm
Bamboo Housing	
VB01	Bamboo, concrete block base, bamboo lattice with 10 cm x 15 cm wooden structure
Adobe Housing	
VA01	Generally cedar wood columns or posts, ties or floors, and wall plates or beams. Cyclopean stone foundations and carved stone bases of 10 cm x 15 cm
Bahareque Housing	

ID	Description
VH01	Generally cedar wood columns or posts, ties or floors, and wall plates or beams. Cyclopean stone foundations and carved stone bases of 10 cm x 15 cm
Cottages	
CÑ01	Posts or log structure of 12.70 cm, treated wood such as melina, cedar, laurel, or teak, and exterior and interior walls with 10 cm posts, on continuous or isolated slabs (pilings)
CÑ02	Posts or log structure of 12.70 cm, treated wood such as melina, cedar, laurel, or teak, and exterior and interior walls with 10 cm posts, on continuous or isolated slabs (pilings) with internal walls of treated wood measuring 4.10 cm x 4.10 cm
CÑ03	Posts or log structure of 12.70 cm, treated wood such as melina, cedar, laurel, or teak, and exterior and interior walls with 10 cm posts, on continuous or isolated slabs (pilings) with internal walls of treated wood measuring 4.10 cm x 4.10 cm
Chalets	
CH01	Treated cypress wood columns and beams on continuous or isolated slabs (pilings)
CH02	Concrete, integral masonry, prefabricated or metal profiles
Apartment Buildings	
AP01	Reinforced concrete columns and beams, prefabricated or metal profiles
AP02	Reinforced concrete columns and beams, prefabricated or metal profiles
AP03	Reinforced concrete columns and beams, prefabricated or metal profiles
AP04	Reinforced concrete columns and beams, prefabricated or metal profiles
AP05	Reinforced concrete columns and beams, prefabricated or metal profiles
AP06	Reinforced concrete columns and beams, prefabricated or metal profiles
Retirement Homes	
HR01	Reinforced concrete columns and beams, prefabricated
HR02	Reinforced concrete columns and beams, prefabricated or metal profiles
HR03	Reinforced concrete columns and beams, prefabricated or metal profiles
Commercial Premises	
LC01	Recycled steel or aluminum containers and plywood, anchored on raised concrete foundations
LC02	Integral masonry, prefabricated, and 5 cm x 7.5 cm wood
LC03	Integral masonry, prefabricated or metal profiles
LC04	Integral masonry, prefabricated or metal profiles
LC05	Reinforced concrete columns and beams, prefabricated or metal profiles
LC06	Reinforced concrete columns and beams, prefabricated or metal profiles
Commercial Buildings	
EC01	Reinforced concrete columns and beams, prefabricated or metal profiles
EC02	Reinforced concrete columns and beams, prefabricated or metal profiles
EC03	Reinforced concrete columns and beams, prefabricated or metal profiles
Shopping Centers	
CC01	Reinforced concrete columns and beams, prefabricated or metal profiles
CC02	Reinforced concrete columns and beams, prefabricated or metal profiles
CC03	Reinforced concrete columns and beams, prefabricated or full-web metal profiles
CC04	Reinforced concrete columns and beams, prefabricated or full-web metal profiles
CC05	Reinforced concrete columns and beams, prefabricated or full-web metal profiles
CC06	Reinforced concrete columns and beams, prefabricated or full-web metal profiles
Office Buildings	
EO01	Integral masonry or prefabricated
EO02	Reinforced concrete columns and beams, prefabricated or metal profiles
EO03	Reinforced concrete columns and beams, prefabricated or metal profiles
EO04	Reinforced concrete columns and beams, prefabricated or metal profiles
EO05	Reinforced concrete columns and beams, prefabricated or metal profiles
EO06	Reinforced concrete columns and beams, prefabricated or metal profiles
EO07	Reinforced concrete columns and beams, prefabricated or metal profiles
Educational Buildings	
EA01	Prefabricated columns and metal profile beams
EA02	Prefabricated columns and metal profile beams
EA03	Self-leveling or fixed system composed of galvanized steel elements and insulated plates with concrete pedestal foundations
EA04	Integral masonry or prefabricated and metal profile beams

ID	Description
EA05	Integral masonry or prefabricated and metal profile beams
EA06	Integral masonry or reinforced concrete
EA07	Prefabricated columns and metal profile beams
EA08	Reinforced concrete columns and beams, prefabricated or metal profiles
EA09	Reinforced concrete columns and beams or metal profiles
EB01	Prefabricated columns and metal profile beams
EB02	Reinforced concrete columns and beams, prefabricated or metal profiles
EL01	Reinforced concrete beams and columns, prefabricated or metal profiles
EU01	Reinforced concrete beams and columns, prefabricated or metal profiles
Hospitals	
HP01	Reinforced concrete columns and beams, prefabricated or metal profiles. Designed according to healthcare building standards
HP02	Reinforced concrete columns and beams, prefabricated or metal profiles. Designed according to healthcare building standards
HP03	Reinforced concrete columns and beams, prefabricated or metal profiles. Designed according to healthcare building standards
Religious Buildings	
CP01	Reinforced concrete columns and beams, prefabricated or metal profiles
ER01	Integral masonry or metal profiles
ER02	Reinforced concrete columns and beams, prefabricated or metal profiles
ER03	Reinforced concrete columns and beams, prefabricated or metal profiles
Restaurants	
RE01	Reinforced concrete columns and beams, prefabricated or metal profiles
RE02	Reinforced concrete columns and beams, prefabricated or metal profiles
RE03	Reinforced concrete columns and beams, prefabricated or metal profiles
RE04	Reinforced concrete columns and beams, prefabricated or metal profiles
Cabins	
CB01	Bamboo on bases and/or concrete plinths, bamboo lattice with wooden structure
CB02	Recycled steel or aluminum containers and plywood, anchored on raised concrete foundations. May have concrete subfloors
CB03	Recycled steel or aluminum containers and plywood, anchored on raised concrete foundations. May have concrete subfloors
CB04	Structures with steel rods, welded mesh, covered with mesh and shotcrete
CB05	Reinforced concrete pipes with steel reinforcement, no exterior or interior coating; diameter of 2.44 m. Without external loads
CB06	Integral masonry or prefabricated
CB07	Integral masonry or metal profiles
CB08	Integral masonry or metal profiles
CB09	Integral masonry and prefabricated, structural panels on concrete bases
CB10	Integral masonry
CB11	Reinforced concrete wall in raw or exposed concrete slab, no exterior or interior coating; concrete tiles
CB12	High-quality wood columns and beams. Generally pentagonal forms. Some are attached to tree trunks
CB13	High-quality wood columns and beams of large dimensions, and/or metal profiles. Various shapes such as hexagonal and rectangular
CB14	Various base types such as wooden platforms on concrete bases, or pilings, concrete slabs, all with necessary anchors for galvanized tube structures forming domes or geodesic domes
CB15	Combined metal and wood columns and beams, predominantly metal; on rectangular concrete bases of 50 cm x 50 cm, embedded, approximately 7.00 m or more above ground
CB16	Combined metal and wood columns and beams, predominantly metal; on concrete pilings embedded approximately 7.00 m or more above ground
Hotels	
HT01	Integral masonry, prefabricated or metal profiles
HT02	Reinforced concrete columns and beams, prefabricated and/or metal profiles
HT03	Reinforced concrete columns and beams, prefabricated and/or metal profiles
HT04	Reinforced concrete columns and beams, prefabricated and/or metal profiles
HT05	Reinforced concrete columns and beams, cast in place or prefabricated, and/or metal profiles

ID	Description
Motels	
MO01	Prefabricated and/or metal profiles
MO02	Integral masonry or prefabricated
MO03	Reinforced concrete columns and beams or metal beams
MO04	Reinforced concrete columns and beams or metal beams
Cinemas	
CI01	Reinforced concrete columns and beams
Theaters	
TE01	Concrete or integral masonry
TE02	Reinforced concrete columns and beams or metal profiles
Gyms	
GM01	Reinforced concrete columns and beams, prefabricated or metal profiles
GM02	Integral masonry or metal profiles
GM03	Reinforced concrete columns and beams, prefabricated or metal profiles
Sheds	
GA01	Round timber columns and beams
GA02	Metal columns and beams
GA03	Integral masonry or prefabricated
Warehouses	
BO01	Recycled steel or aluminum containers and plywood, anchored on raised concrete foundations. May have concrete subfloors
BO02	Reinforced concrete columns and beams or metal profiles
BO03	Metal profile columns and beams
Industrial Sheds	
NA01	Metal profile columns and beams or similar
NA02	Open-web or full-web metal profile columns and beams
NA03	Open-web or full-web metal profile columns and beams
NA04	Open-web or full-web metal profile columns and beams
NA05	Reinforced concrete columns and beams, prefabricated
Clubhouses	
CL01	Concrete or steel beams and columns
CL02	Reinforced concrete columns and beams, integral masonry or metal profiles
CL03	Reinforced concrete columns and beams, integral masonry or metal profiles
Parking Buildings	
EP01	Reinforced concrete columns and beams
EP02	Reinforced concrete columns and beams
EP03	Structural steel columns, beams, and carrier platform or tray measuring 1.80 m to 2.50 m wide and 5.00 m to 6.50 m long, with a height of 1.50 m to 2.20 m; thickness between 0.8 cm and 2.54 cm; welded joints and inclined hydraulic support
EP04	Structural steel columns, beams, and carrier platform or tray measuring 1.80 m to 2.80 m wide and 5.00 m to 6.50 m long, with a height of 1.50 m to 4.50 m; thickness between 0.8 cm and 2.54 cm; welded joints and vertical hydraulic support
EP05	Structural steel columns and beams measuring 1.80 m to 2.50 m wide, 5.00 m to 6.50 m long, and 1.60 m to 5.00 m high; thickness between 0.8 cm and 2.54 cm; welded joints and hydraulic system for independent vehicle retrieval
EP06	Structural steel columns and beams measuring 2.10 m to 3.50 m wide, 5.15 m to 6.50 m long, and 1.50 m to 2.20 m high; thickness between 0.8 cm and 2.54 cm; welded joints and vertical hydraulic support system at each pair of posts to reach the
EP07	Structural steel columns and beams measuring 2.10 m to 3.50 m wide, 5.15 m to 6.50 m long, and 1.50 m to 2.20 m high; thickness between 0.8 cm and 2.54 cm; welded joints and vertical hydraulic support system at each pair of posts to reach the
EP08	Structural steel columns and beams measuring 2.10 m to 3.50 m wide, 5.15 m to 6.50 m long, and individual heights of 1.50 m to 2.20 m; thickness between 0.8 cm and 2.54 cm; welded joints and hydraulic tray support system. The final height
EP09	Structural steel columns and beams measuring 2.10 m to 3.50 m wide, 6.00 m to 7.50 m long, and 1.50 m to 2.20 m high; thickness between 0.8 cm and 2.54 cm; welded joints and hydraulic support system for rotating platforms to position
EP10	Structural steel columns and beams measuring 2.10 m to 3.50 m wide, 6.00 m to 7.50 m long, and 1.50 m to 2.20 m high; thickness between 0.8 cm and 2.54 cm; welded joints and hydraulic support system; distribution via an elevator with

Figure 10 through Figure 13 present a collection of available vulnerability functions for different general structural systems, expressed in terms of flood depth relative to ground level. The vulnerability functions presented were obtained from the CAPRA vulnerability function library. These functions were originally based on HAZUS-MH and were modified by INGENIAR-CIMNE to adapt them to the construction typologies of Central America. For further details please refer to ERN-AL (2008).

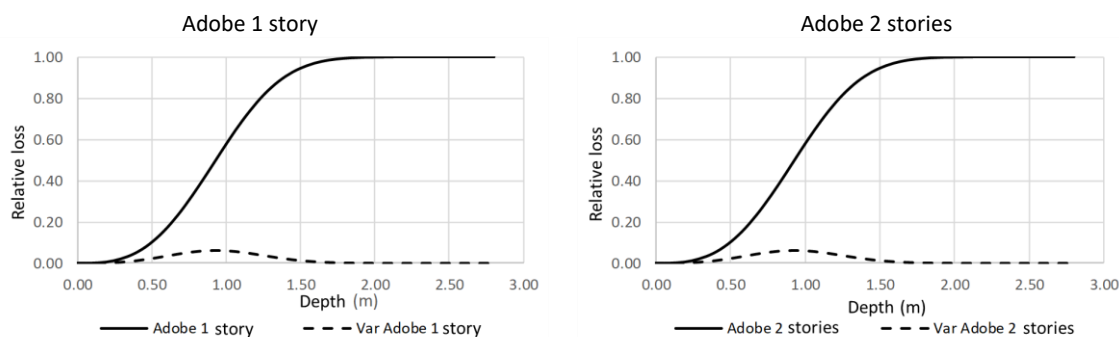


Figure 10. Flood Vulnerability Functions for Adobe Structures

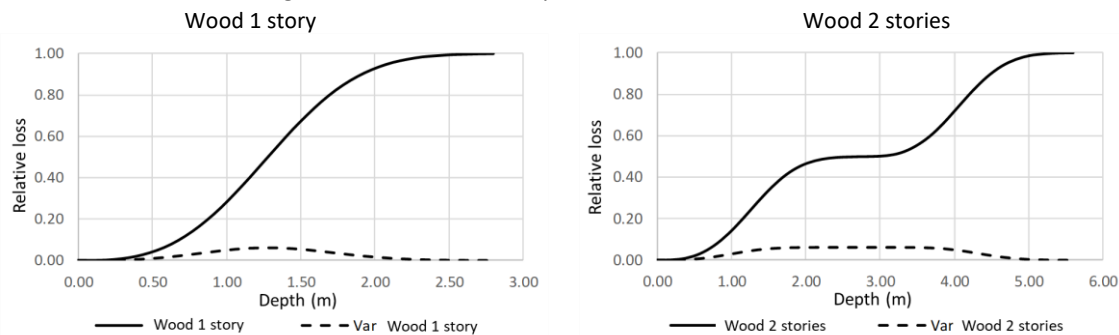
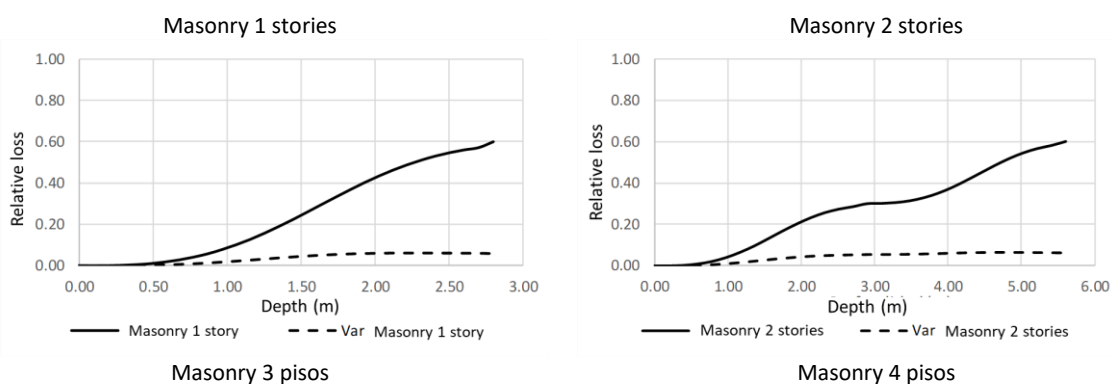


Figure 11. Flood Vulnerability Functions for Wood Structures



Masonry 3 pisos

Masonry 4 pisos

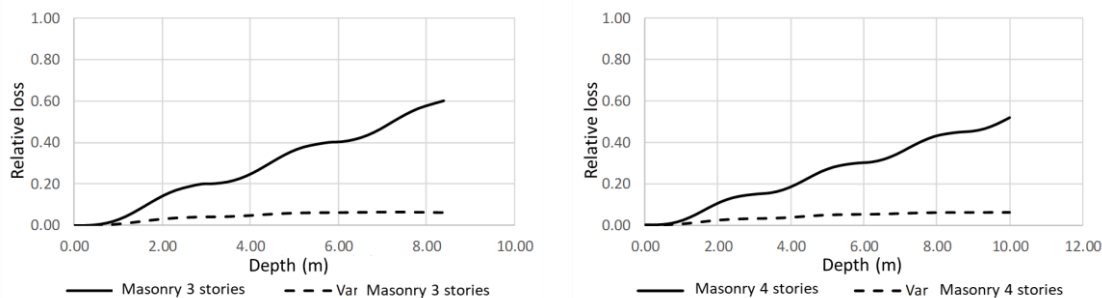


Figure 12. Flood Vulnerability Functions for Masonry Structures

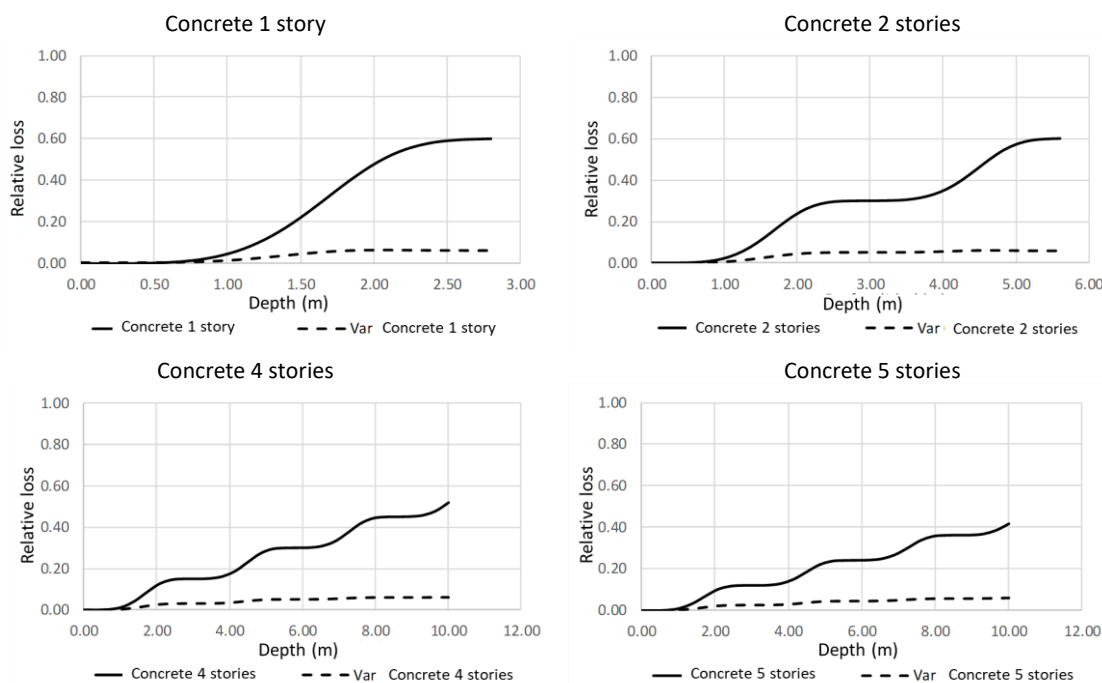


Figure 13. Flood Vulnerability Functions for Concrete Structures

Figure 14 through Figure 17 present a non-exhaustive collection of available seismic vulnerability functions for different general structural systems, expressed in terms of peak ground acceleration (PGA).

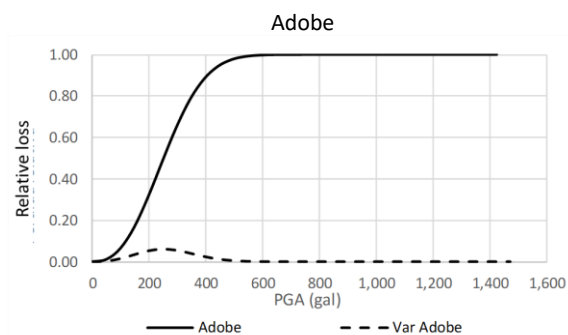


Figure 14. Seismic Vulnerability Functions for Adobe Structures

Wood

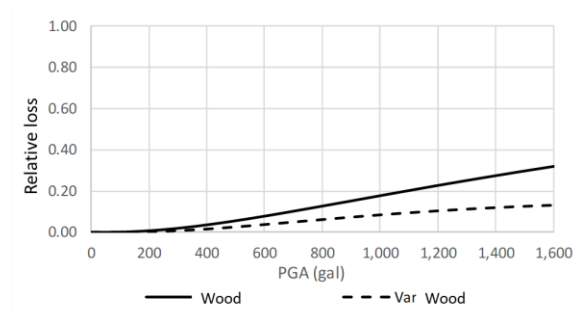


Figure 15. Seismic Vulnerability Functions for Wood Structures

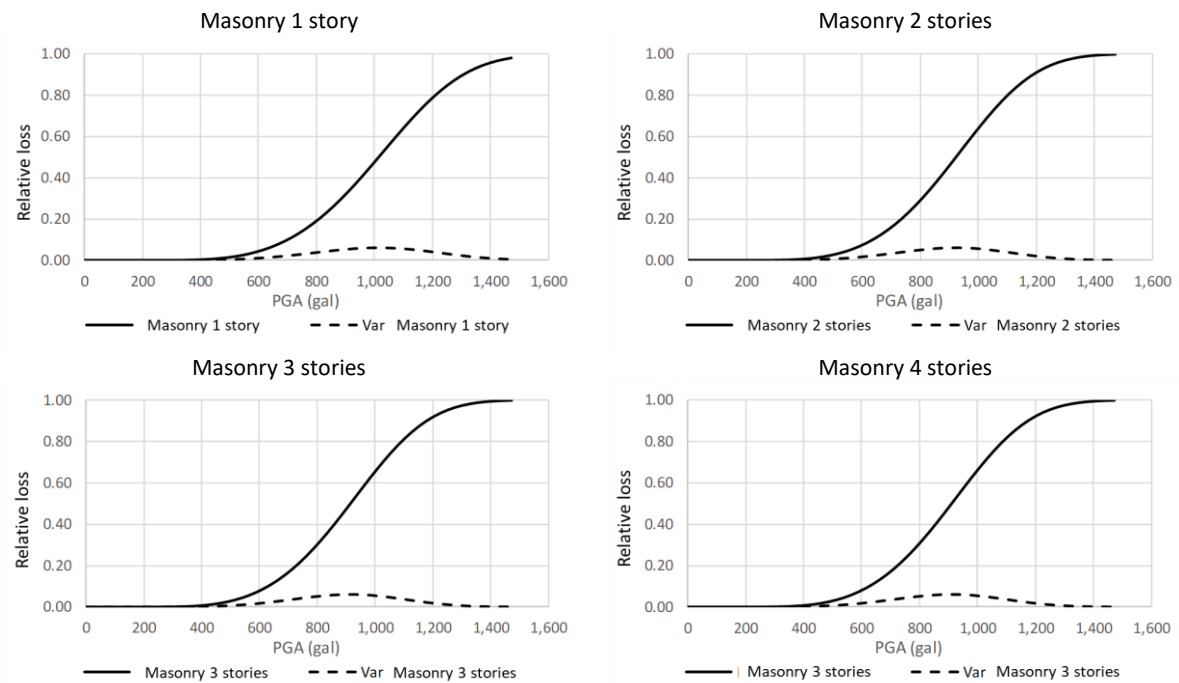


Figure 16. Seismic Vulnerability Functions for Masonry Structures

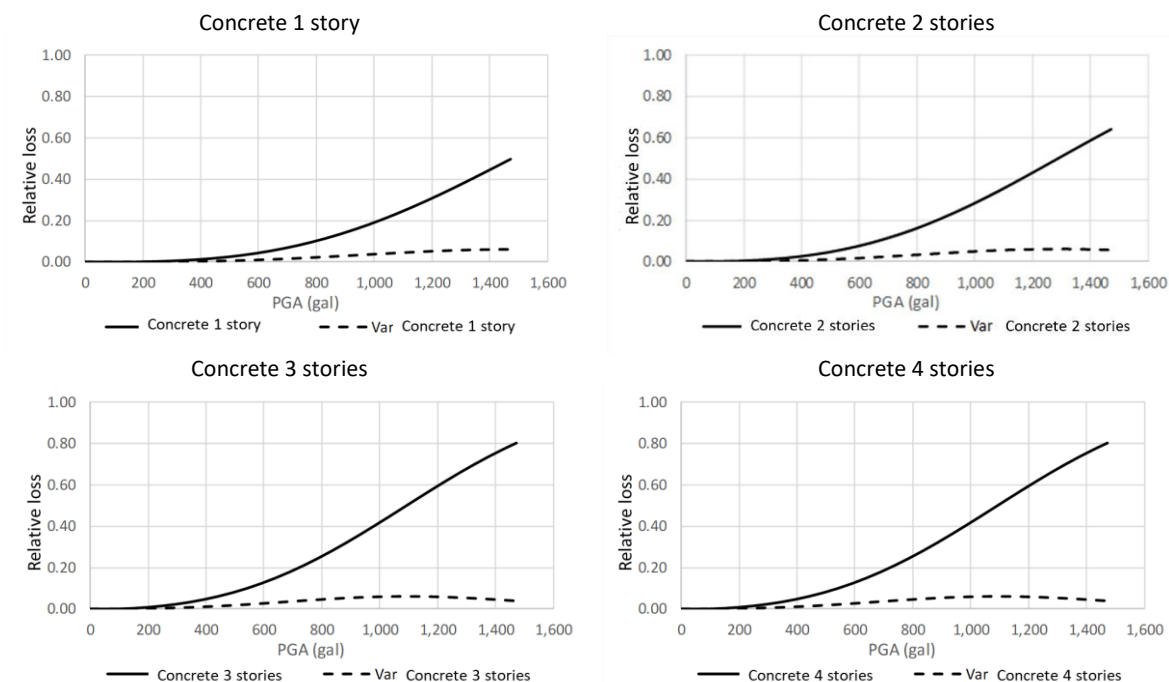


Figure 17. Seismic Vulnerability Functions for Concrete Structures

2.2.2 Vulnerability of the Health Sector

Based on the information used to construct the exposure model, the health sector in the canton of Heredia comprises the Heredia Cubujuquí Health Area (ASHC), the Heredia Virilla Health Area (ASHV), the San Vicente de Paul Hospital, and supporting clinics.

Table 2 lists the facilities associated with each of these health areas and the level of service they provide.

Table 2. Description of health areas in Heredia canton.

Service level	Health area	Health facility	
Level I	Heredia Cubujuquí Health Area (ASHC)	Main headquarters	
		Alternate headquarters	
		Stadium headquarters	
		EBAIS (Basic Comprehensive Healthcare Teams)	Bernardo Benavides
	Heredia Virilla Health Area (ASHV)	Main headquarters	
		EBAIS (Basic Comprehensive Healthcare Teams)	Bernardo Benavides – La Esperanza
			Guararí
			La Milpa
			Los Lagos
			Lagunilla
Level II	Supporting clinics	Cubujuquí	
		Guararí	
		San Joaquín	
		San Vicente de Paul Hospital	
	Regional hospitals	San Vicente de Paul Hospital	

To characterize healthcare facilities, archetype models are defined based on the degree of specialization and complexity of the services typically provided. The definition of each archetype is thus based on the cost relationship between the healthcare infrastructure (i.e., the construction of the facility) and its equipment (including installations, medical equipment, and general contents).

The characterization of healthcare facilities was based on the service levels defined by the Ministry of Health of Costa Rica. These service levels specify the degree of specialization of each facility, enabling the development of representative archetypes derived from their descriptions.

From a structural perspective, masonry or reinforced concrete buildings were considered for service levels I and II, while only reinforced concrete structures were assumed for service level III⁶. Additionally, the number of stories was incorporated into the classification, with a maximum of two stories for masonry buildings and up to six stories for reinforced concrete buildings. This categorization resulted in a total of 12 vulnerability functions for healthcare facilities, per hazard (earthquake and floods).

Table 3 presents the classification of healthcare facilities by archetype, according to the services provided and their level of complexity.

Table 3. Archetypes description of healthcare facilities.

Service Level	Healthcare Facility	Services Provided	Archetype
Level I	EBAIS headquarters Alternate sites	Nursing Clinical Laboratory Dental Care Wound Care Vaccination Station Social Work, Psychology, Nutrition, Family Medicine	S1
	Main headquarters Clinics	Pharmacy Clinical Laboratory Vaccination Department Dental Care Observation Area Social Work, Psychology Electrocardiograms Emergency Services General Management	S2
Level II	Regional Hospitals	Operating Rooms Laboratories Conventional and Specialized X-ray Laboratories Imaging Diagnosis Rooms Delivery Rooms Emergency Services Outpatient Services Pharmacy Dental Care	S3

⁶ Although there is no health facility in Heredia with this service level, the vulnerability functions were created and are available in the project Dataset.

Service Level	Healthcare Facility	Services Provided	Archetype
		Inpatient Care Machine Room	

The values for the construction-to-equipment cost ratio for each archetype are presented in Table 4. The value used for archetype S3 is based on equipment costs and built areas reported in the General Emergency Plan of the San Vicente de Paul Hospital. For archetypes S1 and S2, this ratio was adjusted to reflect the differences in specialized equipment present in Level I healthcare facilities relative to their construction value.

Table 4. Price ratio between construction and equipment for the archetypes

Archetype	Construction percentage	Equipment percentage
S1	74%	26%
S2	60%	40%
S3	40%	60%

Figure 18 through Figure 23 show the vulnerability functions developed for the three healthcare facility archetypes considered, for both flood and seismic hazards.

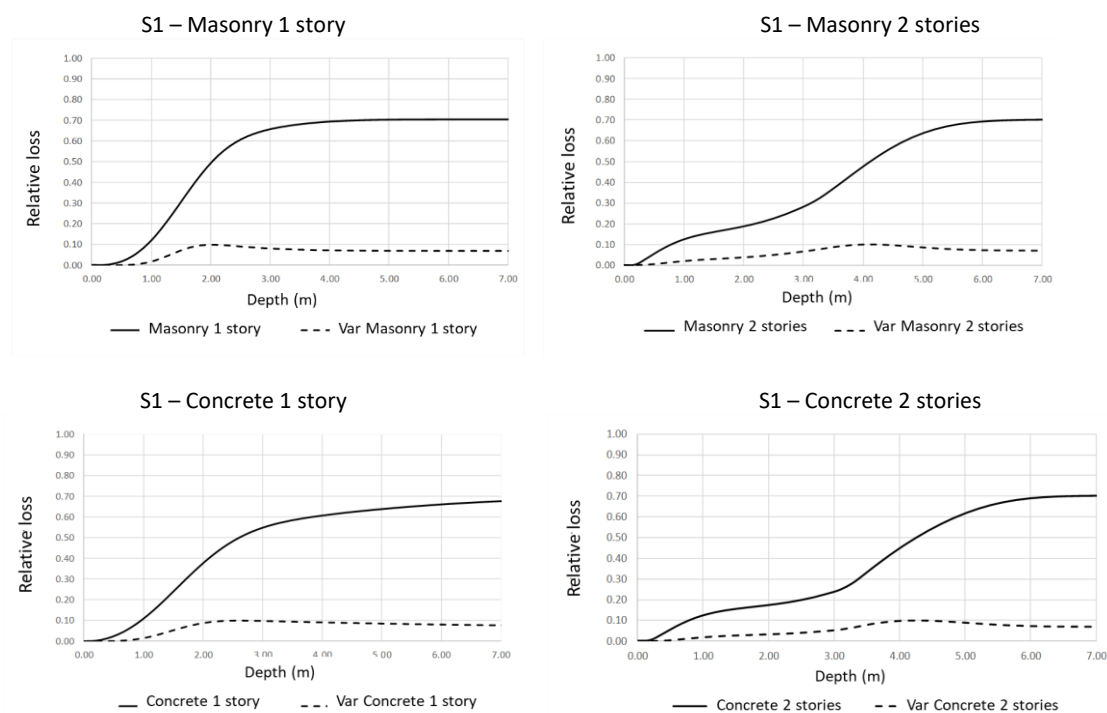


Figure 18. Flood vulnerability functions health archetypes S1

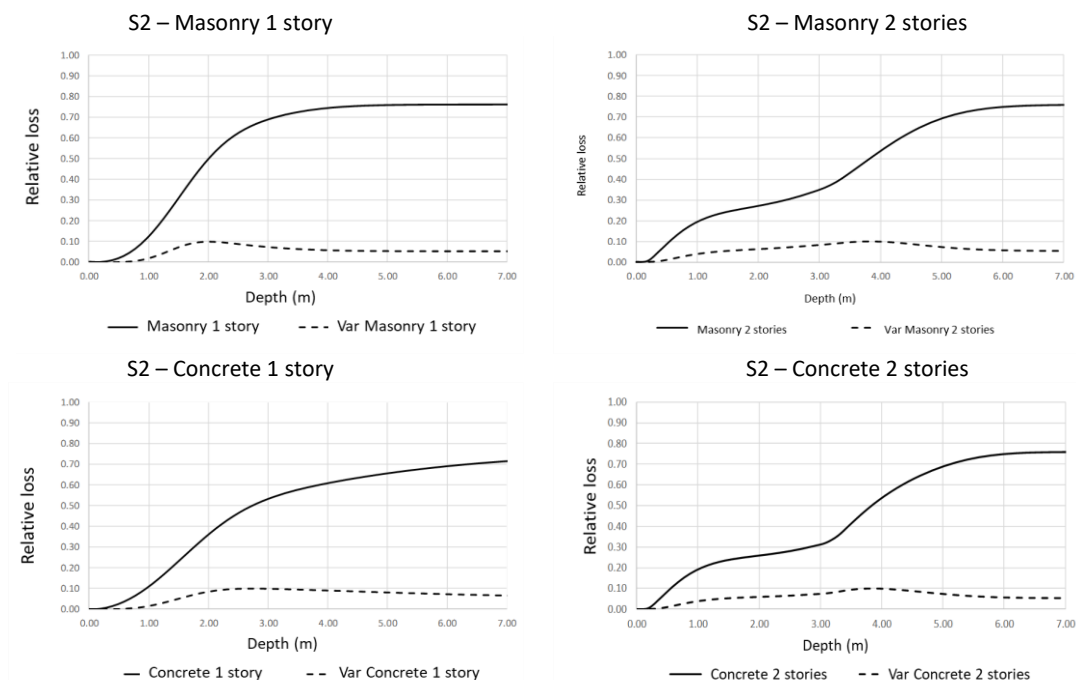


Figure 19. Flood vulnerability functions for health archetypes S2

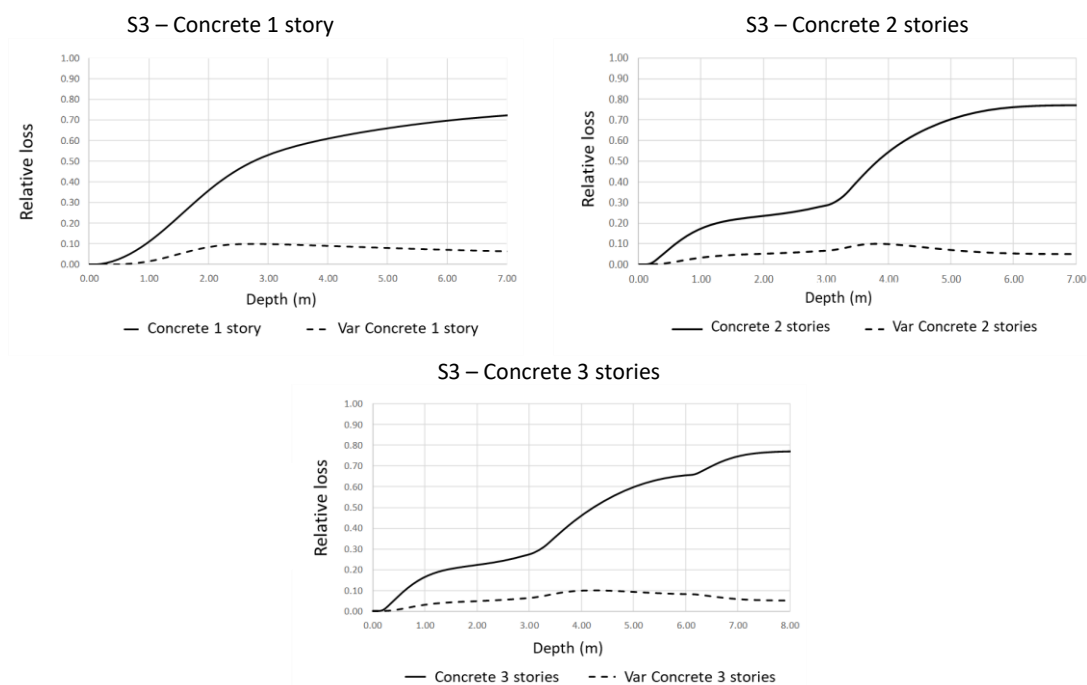


Figure 20. Flood vulnerability functions for health archetypes S3

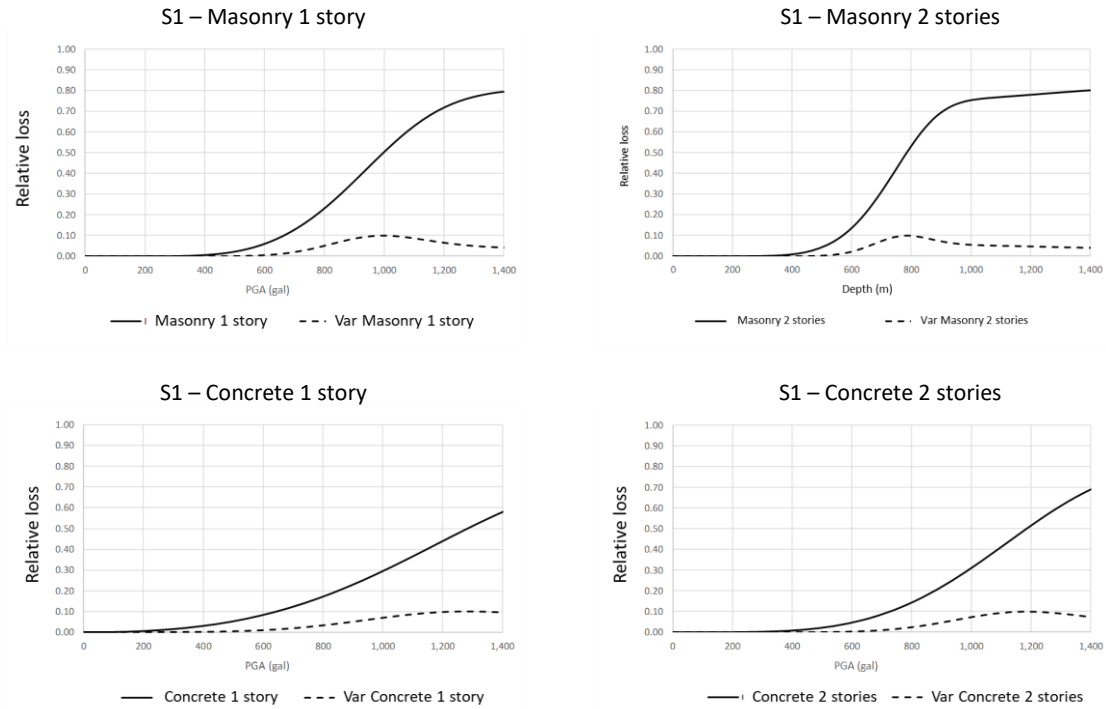


Figure 21. Seismic vulnerability functions for health archetypes S1

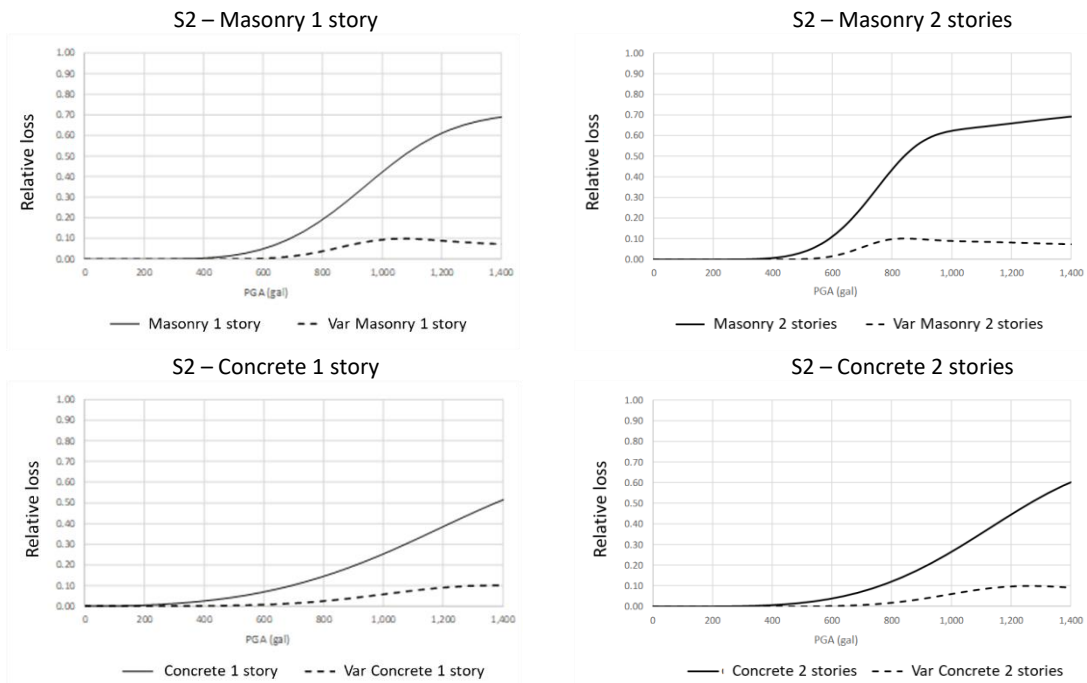


Figure 22. Seismic vulnerability functions for health archetypes S2.

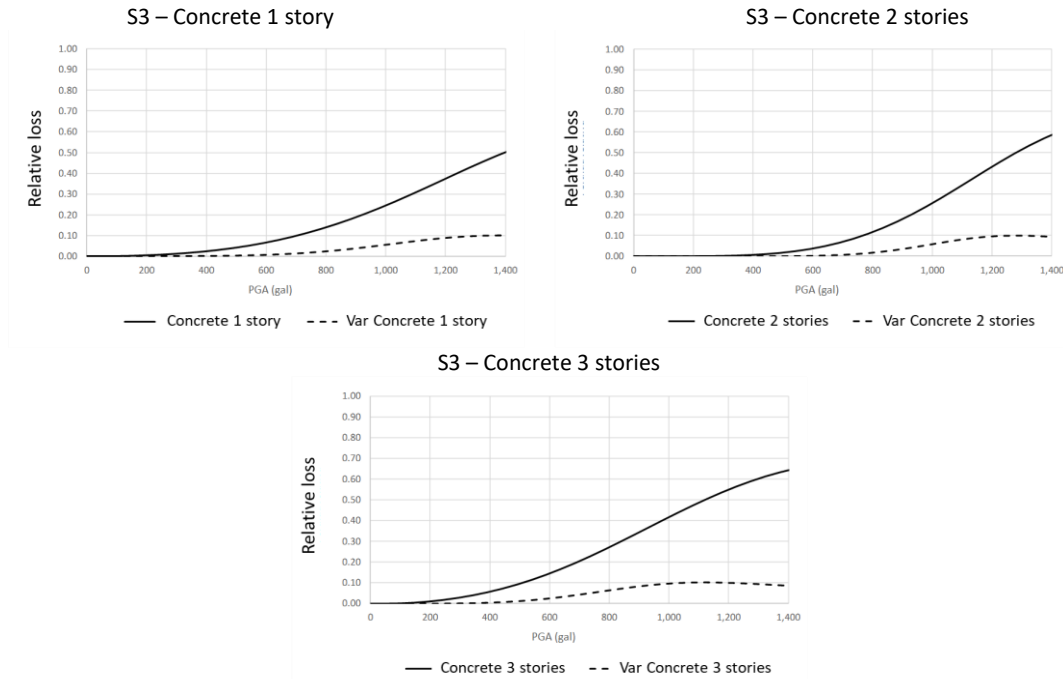


Figure 23. Seismic vulnerability functions for health archetypes S3.

2.3 Infrastructure Exposure Models

Infrastructure portfolios, like those for buildings, are developed from georeferenced information that includes vector-based geometric representations (point, line, or polygon) along with attributes that characterize each element. Each portfolio contains, at a minimum, a georeferenced geometry, an estimate of the element's economic replacement value, and a classification that enables its association with the appropriate vulnerability function.

This project considers the critical infrastructure sectors defined by Decree No. 42465 of 2020 for Costa Rica. These sectors include roads, railways, energy (electric power), telecommunications, hydrocarbons, and water supply and sewerage systems, all within the scope of the canton of Heredia. Each sector consists of multiple portfolios based on differences in the geometric representation of elements or variations in their attributes.

Five types of information sources were used to develop the various infrastructure portfolios:

- Official information from the canton of Heredia, provided by the local government through its geographic information system UBICA, as well as data from the Heredia Public Services Company (ESPH S.A.).
- Official information from national entities in Costa Rica, available through the National Territorial Information System (SNIT) or institutional web map servers, such as the Ministry of Public Works and Transport (MOPT), the National Road Council (CONAVI), the National Power and Light Company (CNFL), the Costa Rican Electricity Institute (ICE), the Telecommunications Superintendency (SUTEL), and the Costa Rican Institute of Aqueducts and Sewage (AyA).

- Data from the National Laboratory of Materials and Structural Models (LANAMME-UCR), of the Civil Engineering School at the University of Costa Rica, which conducts research and technical monitoring of Costa Rica’s Road network.
- Exposure model data from the Global Risk Assessment Framework (GRAF-2024) in Costa Rica, which consolidated inputs from the aforementioned sources.
- Data from the OpenStreetMap collaborative community project, which provides complementary information on road and urban infrastructure.

The following sections present the infrastructure portfolios developed for the canton of Heredia. For each case, the information sources, available attributes for characterizing exposed elements, and the procedures followed to construct each portfolio are detailed. Likewise, a coding system has been developed for all infrastructure elements considered in this study. Although the coding is explained in each section, a general code directory has been included in Annex A.2 for reference.

2.3.1 Road Network

The portfolio for the road sector consists of the road network and vehicular bridges located within the canton of Heredia. The primary data source for characterizing the road network was the UBICA geographic information system, due to its extensive spatial coverage and high level of detail within the canton. This information was complemented with elements from OpenStreetMap (OSM) that were not included in Heredia's official cartography.

The process of defining the final road network geometry involved several adjustments to ensure an accurate and reliable portfolio structure. Key actions included:

- Avoiding data duplication through spatial cross-checks between both data sources.
- Correcting geometric inconsistencies, particularly in the Varablanca district, due to georeferencing errors that could affect risk estimation.
- Identifying road segments recorded in OSM that are located on private properties (e.g., condominiums). These were included in the portfolio with a differentiated classification from the public national and cantonal road networks.
- Subdividing road segments into lengths of up to **25 meters** to enhance precision in risk assessment.

2.3.1.1 Attributes for Road Segments Characterization

The following attributes were defined to characterize the physical properties and economic valuation of the road network segments:

- Road Hierarchy (JERARQUIA): Obtained from UBICA. For segments sourced from OSM, the classification of adjacent roads and the “HIGHWAY” attribute were reviewed to assign the appropriate hierarchy.
- Number of Lanes (LANES_OSM): Extracted from OSM through spatial intersection. In cases where this information was unavailable, the modal value by hierarchy was assigned—typically two lanes.

- Pavement Surface Type (SURF_OSM): Also obtained from OSM. When this attribute was not available, pavement condition was assigned as paved for the districts of Heredia, Mercedes, San Francisco, and Ulloa, and unpaved for Varablanca. This assignment was based on diagnostic reports from LANAMME-UCR (2016, 2017) regarding the cantonal road network in Heredia.
- Terrain Slope (SLOPE): Derived from a slope map generated using Costa Rica's Digital Elevation Model (DEM).

2.3.1.2 Economic Valuation of Road Segments

To estimate the economic replacement value of road elements, the LANAMME-UCR reports from 2016 and 2017 were used as a reference. These reports calculated asset values based on typical pavement structures within the cantonal road network.

The final valuation incorporated the three previously mentioned classification variables, resulting in a total estimated value of \$98,625,227,300.

Figure 24 shows the road network established for the urban districts of the canton of Heredia within the scope of this project.

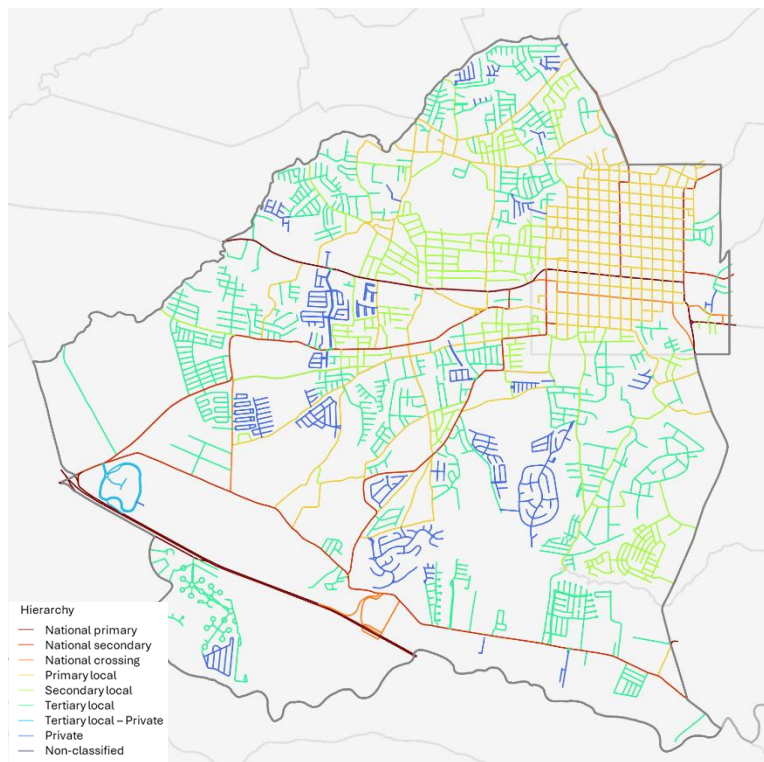


Figure 24. Map of the Heredia Road Network – Urban Area. Own elaboration.

2.3.1.3 Attributes for Characterizing Vehicular Bridges

To characterize vehicular bridges in the canton of Heredia, the primary data source was the LANAMME-UCR spatial database, which includes records of bridges belonging to both the National Road Network (RVN) and the Cantonal Road Network (RVC). This source was selected because it contains the most

comprehensive set of records for the canton. As with the road network, the data was supplemented with additional elements from OpenStreetMap (OSM) that were not included in other sources. The consolidated portfolio includes a total of 53 vehicular bridges, of which 9 were identified through OSM and validated using the official orthophotography of the canton of Heredia.

The LANAMME-UCR data provides most of the necessary attributes for bridge classification. However, when geometric attributes were missing, estimations were made using the cantonal orthophotography. It is important to note that structural attributes—such as material type, superstructure, or supports—cannot be inferred through this method, and therefore, these attributes were not assigned where data was lacking. For such bridges, vulnerability assignment was based solely on available variables, defining a representative curve aligned with the available characteristics.

For the physical characterization and estimation of the economic replacement value of vehicular bridges, the following attributes were defined:

- Length Classification (C_LARGO): Reclassification into ranges of the total bridge length.
- Number of Spans (N_CLARO): Number of structural spans in the bridge.
- Clear Height (ALT_LIBRE): Free height of the bridge, reclassified into 3.0-meter intervals.
- Type of Superstructure (TIPO_SUPER): Classified according to the NBI codes used in the report *Inventory of Bridges in the National Road Network of Costa Rica* (LANAMME-UCR, 2016).
- Structural Material (MATERIAL_EST): Classified into four categories: prestressed concrete [1], reinforced concrete [2], steel [3], and masonry [4].
- Type of Supports (APOYOS): Classified into four structural combinations: Rigid-Rigid [1], Rigid-Expansive [2], Fixed-Fixed [3], and Expansive-Expansive [4].

Based on these attributes, a classification typology was constructed using six coded variables: length classification (C#), number of spans (NC#), clear height (H#), type of superstructure (ES##), structural material (MT#), and type of supports (AP#), generating a composite code in the following format: C#_NC#_H#_ES##_MT#_AP#

2.3.1.4 Economic Valuation of Vehicular Bridges

The estimation of the economic replacement value was based on the unit costs per square meter reported in the LANAMME-UCR reports (2016 and 2017), specifically for bridges constructed with concrete and steel. Using this methodology, the total valuation of the 53 identified vehicular bridges amounts to ₡20,965,014,100.

Figure 25 shows the location of the vehicular bridges within the urban districts of the canton of Heredia included in this portfolio.

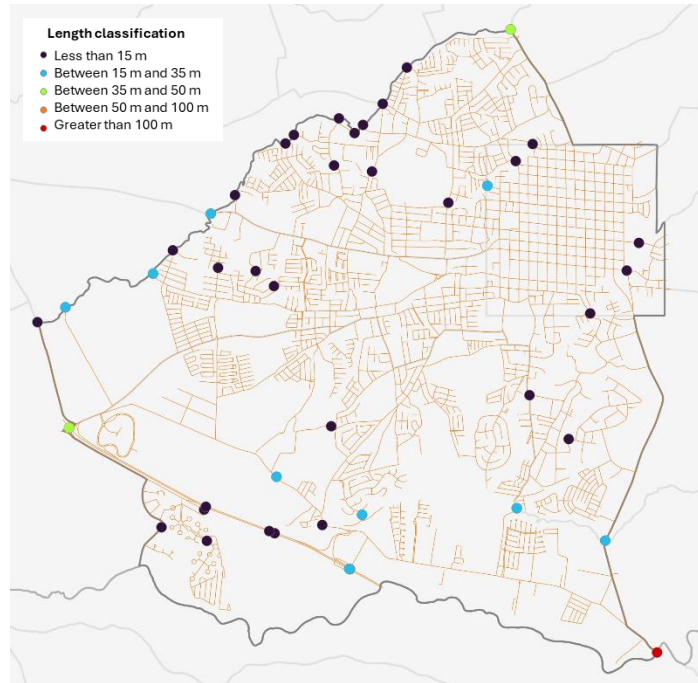


Figure 25. Map of vehicular bridge locations in the canton of Heredia – Urban area.

2.3.2 Rail Sector

The portfolio for the rail sector includes the segment of the San José – Heredia – Alajuela railway line that passes through the canton of Heredia. The primary source for characterizing this railway line was OpenStreetMap (OSM), which mainly provides the geometry of the alignment. This information was complemented by a survey of the type of substructure, conducted through visual analysis of the official orthophotography of the canton of Heredia in its urban area.

As with the road network portfolio, the railway line was segmented into sections, up to 25 meters in length to ensure a more precise risk assessment for each segment of the railway corridor.

2.3.2.1 Characterization Attributes

The following attributes were defined for the physical characterization of the railway corridor segments:

- **Substructure Material (MAT_SUBEST):** Determined through visual analysis of the canton's official orthophotography. Four categories were defined: concrete, asphalt, ballast, and bridge. The bridge category refers to segments crossing bodies of water (rivers or streams) that feature elevated infrastructure, presumably metallic.
- **Terrain Slope (SLOPE):** Obtained from a slope map derived from Costa Rica's Digital Elevation Model (DEM).

Based on these attributes, a railway classification typology was constructed using two variables: substructure material (XXX) and slope (S#), coded in the format: FR_XXX_S#, where "XXX" corresponds to the abbreviation of the substructure type. Note that the entire railway route within Heredia is single-track.

2.3.2.2 Economic Valuation

The economic valuation of each segment was estimated based on unit costs per linear meter, differentiated by substructure type and terrain slope.

- For segments with concrete or asphalt substructures, the LANAMME-UCR reports (2016, 2017) were used as references, adjusting costs according to the typical width of the railway corridor's cross-section and including an increase for the integration of rails within the pavement.
- For ballast segments, the unit value was estimated from costs defined in railway construction and rehabilitation projects in Costa Rica.
- For segments classified as bridges, the reference unit cost for steel bridges, as specified in the vehicular bridges' portfolio section, was applied.

The total economic valuation of the railway segment corresponding to the canton of Heredia, along the San José – Heredia – Alajuela route, is estimated at ₡986,648,800.

Figure 26 shows the location of the analyzed railway segment within the canton of Heredia.

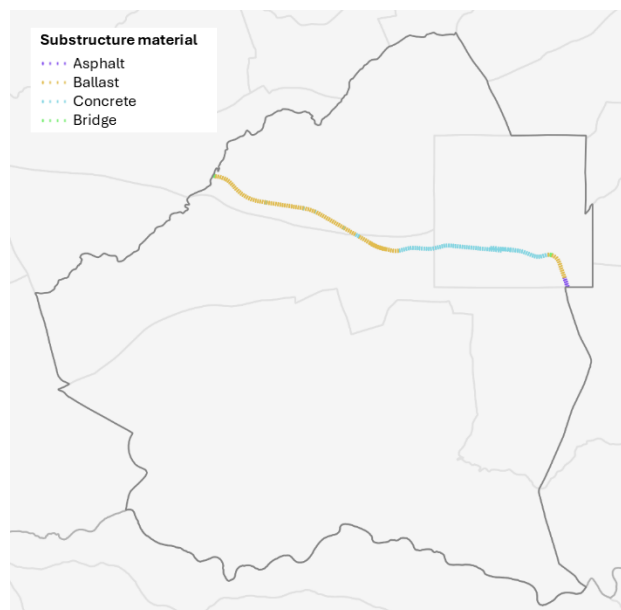


Figure 26. Railway route in the canton of Heredia – Urban area

2.3.3 Electric Power Sector

The portfolio for the electric power sector is structured into three components: generation, transmission, and distribution. Each of these components includes one or more infrastructure elements that collectively form the sector's portfolio.

Given the systemic nature of the electric power sector —where generation and transmission elements may be located outside the administrative boundaries of the canton but still directly influence its supply— external exposed elements beyond the canton of Heredia were also considered. Specifically, power

generation plants interconnected with transmission lines supplying the urban area of the canton were included.

2.3.3.1 Generation Component

The characterization of power generation infrastructure is based on official information published by the National Power and Light Company (CNFL) and the Costa Rican Electricity Institute (ICE). These sources identified two hydroelectric plants located on the Virilla River, which are part of the generation system supplying the canton.

The available attributes for each plant include:

- Type of generation plant
- Installed capacity (in megawatts, MW), which enables the estimation of the economic replacement value for each facility.

For the economic valuation of these plants, reference values published annually by the International Renewable Energy Agency (IRENA) in its *Renewable Power Generation Costs* report (IRENA, 2024) were used. This document provides investment costs per installed kilowatt (kW), disaggregated by technology type, project size, and geographic region.

The total installed generation capacity identified is 16.33 MW, and the estimated economic valuation for these two plants amounts to ₡28,867,904,000.

2.3.3.2 Transmission Component

The transmission component consists of three types of exposed elements: transmission *lines (circuits)*, *transmission towers*, and *electrical substations*. The composition of the portfolios for this component is based primarily on official information published by the National Power and Light Company (CNFL) and the Costa Rican Electricity Institute (ICE).

Transmission Lines

The lines included in this component correspond to high-voltage circuits directly connected to the canton of Heredia. Based on the available information, the following considerations apply:

- The geometry is linear and represents the entire circuit, which was segmented at its vertices — corresponding to support towers — based on analysis using official orthophotography.
- Each circuit includes an attribute for nominal voltage, which in this case is either 138 kV or 230 kV. Additionally, since these are high-voltage lines, it is inferred that they are three-phase, meaning each circuit is composed of three conductors.

For the economic valuation, a unit replacement cost per linear meter of conductor was defined, and based on the length of each segment, the total value per circuit was estimated. The total length of circuits associated with the transmission system in Heredia amounts to 48.72 km, with an overall economic valuation of ₡90,268,400.

Transmission Towers

Based on the circuit layouts, the locations of the transmission towers were identified. This information enables the identification of the number of circuits supported by each tower. Accordingly, structural typologies (“tower types”) were assigned, considering both the voltage and the number of circuits. In the exposure model, towers were identified ranging from single-circuit (1C) to four-circuit (4C), which directly impacts both the economic valuation and the vulnerability assignment for each element.

A total of 108 transmission towers were identified, with an estimated economic value of ₡2,141,500,000.

Figure 27 presents a schematic of tower types and their characteristic dimensions according to the number of circuits supported.

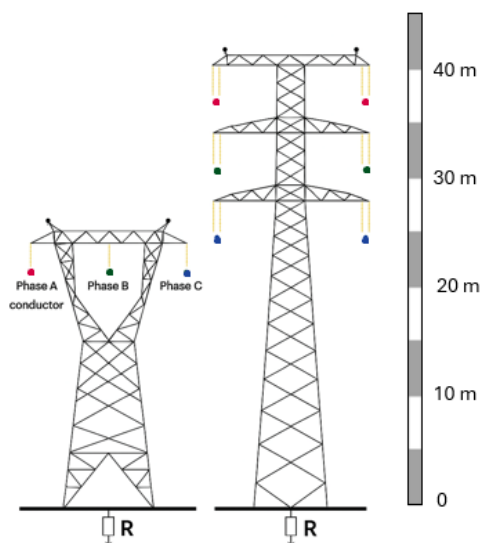


Figure 27. Diagram of power transmission towers: Single-circuit (left) and double-circuit (right).

Electric Substations

The third element of the transmission component is electrical substations. To include them in the portfolio, a proximity criterion was applied: only substations located within 100 meters of a transmission line were considered. Based on this criterion, six substations were identified, for which both maximum and minimum voltage levels were determined.

To estimate the economic value of these substations, a unit cost per square meter was used, based on a substation construction project completed in 2022 in the La Ribera district, near the canton of Heredia. The operational yard area of each substation — which houses the necessary electrical and mechanical equipment for energy transformation — was then estimated. Using this, the total economic valuation was calculated at ₡649,373,800.

The total economic valuation of the transmission system in the canton of Heredia amounts to ₡2,881,142,200, distributed as follows:

- Circuits: ₡ 90 268 400 (3.1%)
- Towers: ₡ 2 141 500 000 (74.3%)
- Substations: ₡ 649 373 000 (22.5%)

Figure 28 presents the power generation plants and the three components of the electrical transmission system associated with the supply of the canton of Heredia: circuits, towers, and substations.



Figure 28. Power generation and transmission system for the canton of Heredia.

2.3.3.3 Distribution Component

The distribution component consists of three types of exposed elements: *distribution lines (circuits)*, *poles*, and *transformers*. In this case, the information is limited exclusively to the canton of Heredia, as the medium- and low-voltage networks are directly responsible for connecting buildings to the final delivery of electric power.

Distribution Lines

The lines in this component correspond to medium- and low-voltage circuits within the canton of Heredia. The primary data source is the GRAF (2024) project, which provides the most complete geometric coverage of the network. Secondary sources included official data from the National Power and Light Company (CNFL), the Costa Rican Electricity Institute (ICE), and the Heredia Public Services Company (ESPH), both to incorporate additional geometries and to assign attributes related to the installation type (overhead or underground).

In addition to the linear geometry of each element, two key attributes are included:

- **Voltage Classification (CLASIF_TENSION):** Identifies whether the circuit is medium voltage (1 kV to 34.5 kV) or low voltage (<1 kV). Combined with the line length, this attribute enables the estimation of the exposed value based on the replacement cost of the cable (market value) and its installation.
- **Line Type (TYPE_LINE):** Indicates whether the line is overhead or underground. This attribute is critical for characterizing the vulnerability of the element to different hazards, as overhead lines depend on the supporting pole, while underground lines depend on the duct or conduit used.

The total length of the distribution circuits is 1,027.3 km, with an estimated economic valuation of ₡3,102,548,600.

Distribution Poles

This component includes support poles for electric distribution circuits and public lighting poles. The database was constructed using official information from the National Power and Light Company (CNFL), the Costa Rican Electricity Institute (ICE), and the Heredia Public Services Company (ESPH), providing both geometries and attributes across various zones of the canton.

The main attributes are:

- **Material:** Includes technical and construction descriptions such as “Self-supporting concrete” or “Metal tower type.” To standardize the information, a new attribute “Material_C” was created, coded with two characters:
 - Letter: material type (C: concrete, M: metal/steel, W: wood)
 - Number: support type (1: guyed with cables; 2: self-supporting)
- **Height:** Recorded values range between 4 and 17 meters, which were reclassified into five ranges of 3 meters each: 1: [3–6), 2: [6–9), 3: [9–12), 4: [12–15), 5: [15–18). This variable is significant because it influences the stiffness of the element, which is relevant in defining vulnerability.
- **Condition:** Refers to the percentage of the expected service life consumed, based on the material. This attribute was estimated using the installation year (AÑO_INSTAL) and classified as:
 - A: less than 50% of service life consumed
 - B: between 50% and 100% of service life
 - C: more than 100% (service life exceeded)

Using these three attributes, a typology was constructed with the coding format: POSTE_X#_H#_STX, where X# is the material and support type, H# is the reclassified height, and STX is the condition.

The economic valuation was performed based on material and height, using a weighted unit value for each material classification. This value was estimated by weighting market prices according to the number of elements in the portfolio, ensuring representativeness of the value used.

The portfolio of poles includes 11,814 elements, with a total economic valuation of ₡7,001,686,300.

Transformers

The third type of element corresponds to distribution transformers, with the GRAF (2024) project serving as the primary information source. The database includes point geometries and a typology attribute (TIPO) that classifies transformers as either overhead (mounted on top of a pole) or pad-mounted (ground level).

The typology attribute is key for vulnerability analysis, as the type of hazard and its potential impact vary significantly depending on whether the transformer is overhead or pad-mounted. This attribute also influences the economic valuation, as differentiated unit costs are assigned for each type. A specific replacement cost was defined for medium-to-low voltage transformers (34.5 kV to 1 kV), including the associated installation costs.

The portfolio includes 2,597 transformers, with a total economic valuation of ₡3,668,666,000.

The total economic valuation of the electrical distribution system in the canton of Heredia amounts to ₡13,772,900,900, distributed as follows:

- Circuits: ₡3,102,548,600 (22.5%)
- Poles: ₡7,001,686,300 (50.8%)
- Transformers: ₡3,668,666,000 (26.6%)

Figure 29 shows the location and characterization of the three components of the electrical distribution system in the canton of Heredia.

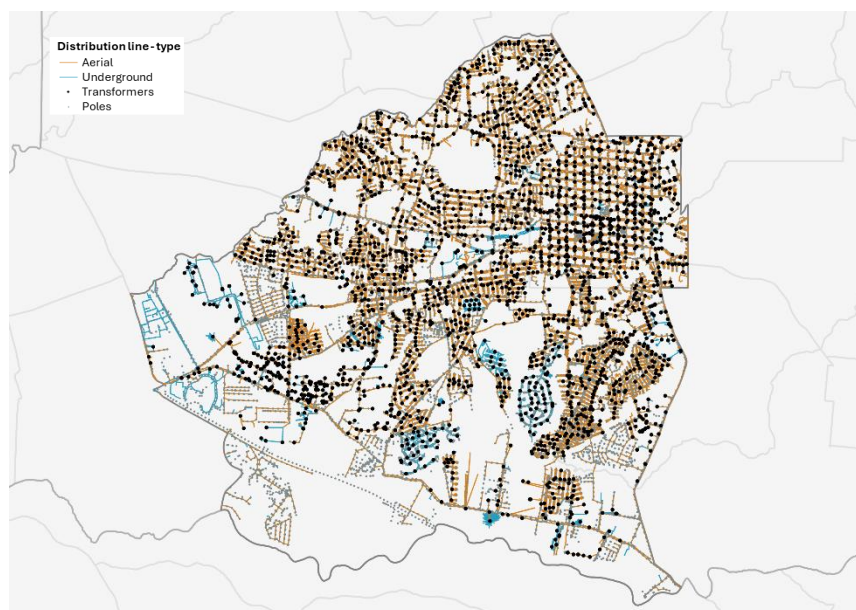


Figure 29. Power distribution system in Heredia – Urban area.

2.3.4 Telecommunications Sector

In this project, the telecommunications sector includes antennas and their respective support structures located within the canton of Heredia. The primary data source is the Superintendence of Telecommunications (SUTEL) of Costa Rica, whose georeferenced database contains records of radiating-receiving systems by operator, along with attributes for both the radiating-receiving system and its support structure. This enables a robust formation of the sectoral portfolio.

These databases have consistent attributes across operators, ensuring the completeness of records. However, during data processing, it was observed that some records from different operators are located within 50 meters of each other. A detailed review confirmed that these records correspond to radiating-receiving systems and not to distinct support structures, even though structural attributes are included. Therefore, it was concluded that a single telecommunications tower may host multiple radiating-receiving systems belonging to different operators.

Based on this, a specific layer of support structures was derived from the mobile operators' radiating-receiving system databases. This consolidation was carried out through the following procedure:

1. Identification of nearby records: Radiating-receiving systems located within 50 meters of each other were grouped, under the assumption that they belong to the same support structure. In the case of the canton of Heredia, the maximum distance between two systems on the same structure was found to be 48 meters. For each group, a centroid was calculated to represent the location of the corresponding support structure.
2. Assignment of radiating-receiving systems to each tower: Each calculated tower was linked to the radiating-receiving system records located within a 25-meter radius.
3. Transfer of structural attributes: For towers with a single associated record, the available attributes were directly assigned. For towers with multiple records, the attributes “TIPO_DE_ELEMENTO” (element type) and “ALTURA_TORRE” (tower height) were compared. If they matched, the attribute was directly assigned; in cases of discrepancy, an individual evaluation was conducted to determine whether the records represented distinct structures or minor inconsistencies in the data or measurements provided by each operator.
4. Estimation of the number of radiating-receiving systems per tower: It was assumed that for each technology present (2G, 3G, 4G, 5G), there is one radiating-receiving system composed of three antennas. Therefore, the total number of radiating-receiving systems per tower was estimated as the sum of systems by technology across all operator records associated with that tower.

2.3.4.1 Resulting Attributes

The consolidated database for towers or support structures includes the following key attributes:

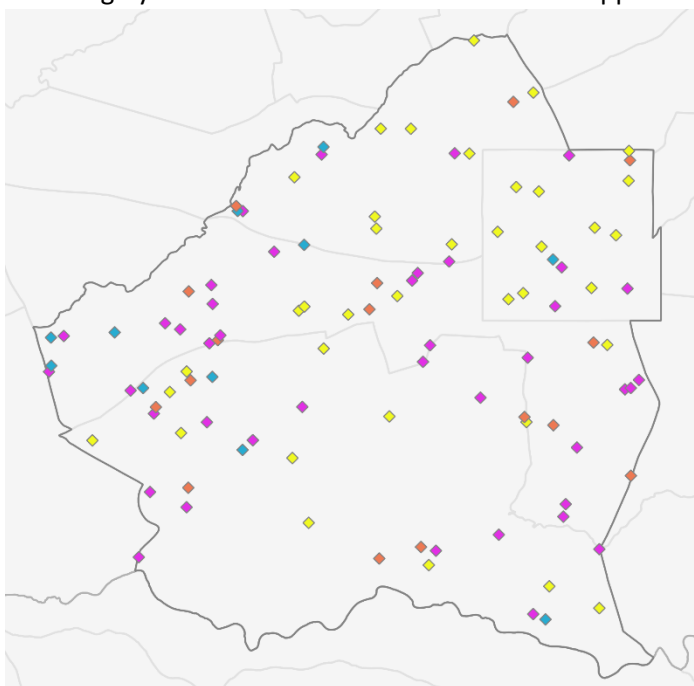
- Type of Support Structure (SOPORTE): Classified as building rooftops, monopole towers, guyed towers, self-supporting towers, temporary towers, and DAS systems within buildings.
- Structure Height (ALTURA_EST): Measured in meters from the rooftop (for buildings) or from ground level, as applicable. Heights were reclassified into five ranges: 1 = (0–15], 2 = (15–30], 3 = (30–45], 4 = (45–60], 5 = (60–75].
- Number of Radiating-Receiving Systems (N_ANTENAS): Total number of systems installed on each structure, regardless of the owning operator.

Based on these attributes, a classification system was developed for both vulnerability characterization and economic valuation, coded as: COM_XX_H#, where XX is the abbreviation of the support type and H# the height category. For rooftop systems or DAS, the height variable is omitted as it is not applicable.

2.3.4.2 Economic Valuation

The economic valuation of each record corresponds to the sum of the support structure value and the total value of the radiating-receiving systems. To estimate the value of the structures, reference costs from the Manual of Unit Values by Construction Typology of the Ministry of Finance of Costa Rica (2023) were used, covering monopole, guyed, and self-supporting towers. The temporary towers value was the same as monopole towers due to structural similarity. For DAS systems and rooftop structures, no economic value was assigned to the support structure itself, as these are part of the building portfolio already valued in the canton of Heredia.

The value of radiating-receiving systems was estimated using a unit price per system, including installation costs, enabling the calculation of the total value associated with each tower or structure. A total of 303 radiating-receiving systems were identified across 111 support structures, the locations of which are



shown in

Figure 30. The total economic valuation amounts to \$2,230,418,300.

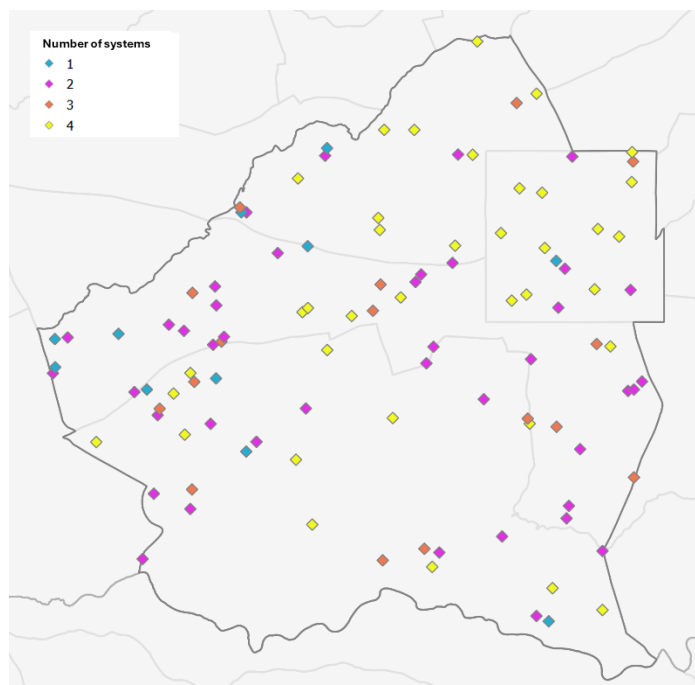


Figure 30. Location of radiating system supports in Heredia – Urban area.

2.3.5 Hydrocarbons Sector

The hydrocarbons sector considered in this project includes the pipeline lines (polyducts) that cross the urban area of the canton of Heredia. The information source was the Costa Rican Petroleum Refinery (RECOPE), which provided both the georeferenced geometry of the pipelines and the diameter attribute for each line.

In the case of Heredia, the pipelines traversing its territory correspond to Line 3 and Line 7 (segment El Alto – La Garita), with diameters of 150 mm and 300 mm, respectively. For vulnerability classification purposes, all segments were treated equally under the assumption that pipelines follow uniform design and construction standards, meaning that diameter does not significantly affect their structural exposure to hazards.

For the economic valuation, unit costs per linear meter were defined based on the pipeline diameter. The estimation relied on investment costs reported for the construction of Lines 6 and 7 in Costa Rica in 2014. The resulting unit values were:

- ₡323,100 per meter for pipelines with a 300 mm diameter.
- ₡290,200 per meter for pipelines with a 150 mm diameter.

The total length of pipelines within the canton is 12.22 km, resulting in a total economic valuation of ₡3,743,233,900.

Figure 31 presents the layout of the pipelines located within the canton of Heredia.

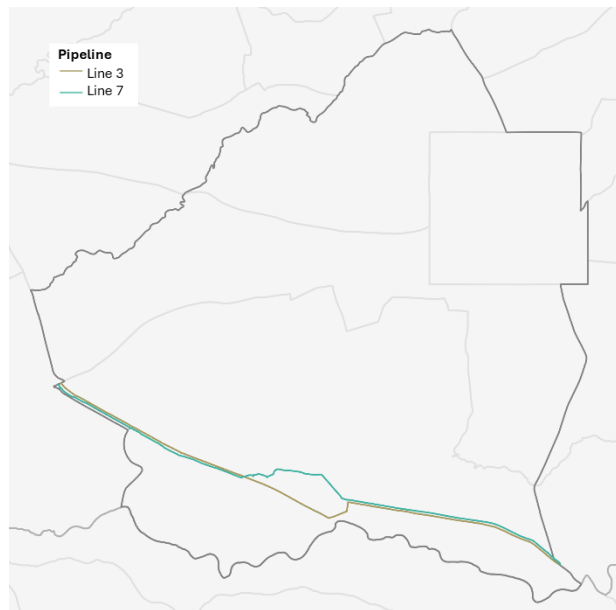


Figure 31. Pipeline layout in Heredia – Urban area.

2.3.6 Drinking Water

The drinking water sector comprises a variety of elements that form the supply system required to guarantee water provision to the population. Like the electrical power system, drinking water must be understood as a systemic service, where supply can originate outside the administrative boundaries of the canton of Heredia yet still needs to be included in the sector's risk assessment due to its direct impact on the urban territory.

The sources of information used to construct the exposure model for this sector come from the Heredia Public Services Company (ESPH) and the GRAF (2024) project, which is based on data provided by the same entity. To identify elements located outside the canton's administrative area, the interconnection of infrastructures through the ESPH's drinking water network pipelines was analyzed.

The following describes how all parts of the drinking water supply system in the canton of Heredia have been considered in this study.

2.3.6.1 Drinking Water Sources

The drinking water sources component in this study represents the structures responsible for the collection and treatment of water resources, specifically the collection systems, desanders, and drinking water treatment plants (PTAP). This approach is based on the typical spatial proximity of these structures within supply systems and the limited information available to accurately locate treatment plants within catchment zones.

In this case, the identified points are in the mountainous region north of Heredia's urban area, beyond the administrative limits of the canton, but correspond to structures that supply drinking water to its urban zone.

The data source used was the GRAF (2024) project, from which 28 drinking water sources supplying the urban population of the canton of Heredia were identified. However, the database does not contain specific attributes to characterize these elements based on variables such as type of intake, desander dimensions, or size of treatment units. Therefore, a single category was defined for all elements, which was then associated with a generic vulnerability model, built from an archetype that integrates the three mentioned structures (intake, desanders, and PTAP).

Given the attribute limitations, the economic valuation was based on the calculated flow needed to supply 250,000 people, corresponding to the approximate population of the urban districts of Heredia. This flow was then evenly distributed across the 28 identified points, assigning an approximate flow of 20 liters per second (lps) per source.

Based on this flow per point, it was assumed that each source includes:

- a lateral intake system,
- two desander units, and
- a drinking water treatment plant with a treatment capacity of up to 40 lps.

Using these technical assumptions, investment costs for water infrastructure in Central American and Latin American countries were consulted to estimate a representative unit value for systems with a 20 lps

capacity. The estimated unit value in this case is \$159,250,000, resulting in a total economic valuation of \$4,459,000,000 for the portfolio.

2.3.6.2 Storage Tanks

Storage tanks play a significant role in drinking water supply systems and are thus essential to the exposure model. These elements help regulate supply in response to demand fluctuations and ensure continuity of service, acting as intermediate reservoirs between the treatment stages and the final distribution of the resource, thereby enabling a stable supply of drinking water.

The source of information for the location and characterization of storage tanks was the GRAF (2024) project, which provides georeferenced representations and basic attributes for each structure.

A total of 53 storage tanks were identified, each with geometric and physical attributes such as volume, height, geometric-structural shape, and construction material. For vulnerability assessment purposes, the primary attribute considered was the construction material, as it determines the infrastructure's behavior in the face of various hazards.

The economic valuation was carried out using the unit values per cubic meter defined in the GRAF (2024) project, which are deemed appropriate and consistent for the purposes of this study. These values vary depending on the construction material and the tank's volume, with larger storage capacities benefiting from lower unit costs—reflecting economies of scale in construction processes.

The total economic valuation of the storage tanks serving the drinking water supply for the canton of Heredia is \$3,559,872,800.

2.3.6.3 Pumping Systems

Pumping systems play a crucial role in drinking water supply systems and are therefore important in the exposure model. These systems ensure the continuity of flow within the conveyance network, compensating for the topographical effects of the terrain.

The information source was the GRAF (2024) project, from which 17 pumping systems connected to the distribution and transmission network of the canton of Heredia were identified. However, the database lacks specific attributes to characterize the systems, such as the number of pumps or the pumped flow rate. The only available attribute is the “MATERIAL” field, which states: *“Consists of masonry and structural concrete booths, with most electromechanical elements made of steel and iron.”*

Given this, a single category was defined for all pumping systems, each associated with a generic vulnerability curve, developed from an archetype that considers the vulnerability of electromechanical equipment and the building housing the equipment.

For the economic valuation, the unit values per pumping system defined in the GRAF (2024) project were used, which are considered appropriate and consistent for the purposes of this study. The total economic valuation of the pumping systems serving the drinking water supply of the canton of Heredia is \$1,069,286,400.

Figure 32 shows the location of drinking water sources, storage tanks, and pumping systems that operate in the drinking water supply network of the canton of Heredia.

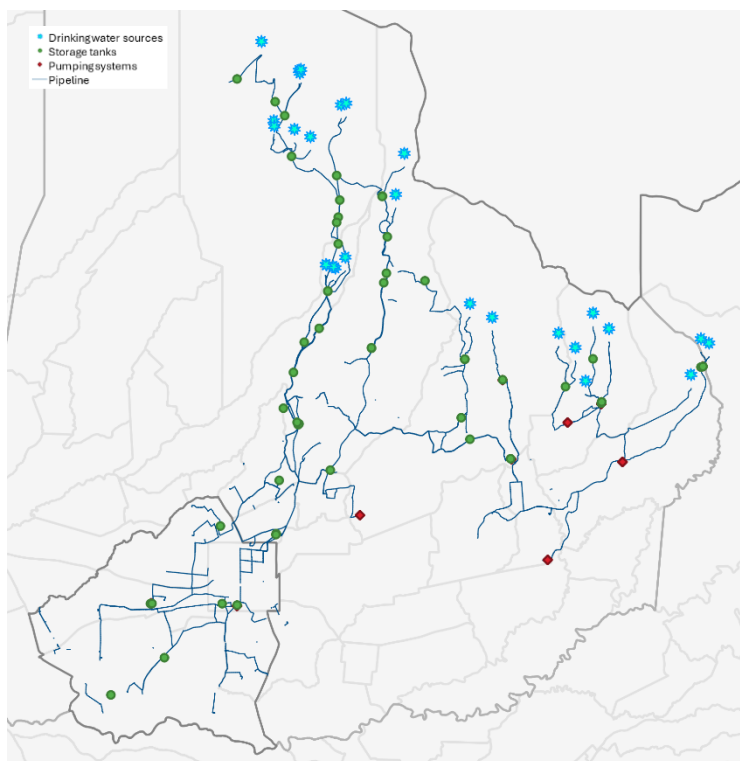


Figure 32. Drinking water supply elements for Heredia – Urban area.

2.3.6.4 Drinking Water Supply Network

The supply network consists of the system of pipelines used to transport drinking water from sources, storage tanks, and pumping systems to buildings. The data source used was the Heredia Public Services Company (ESPH), whose database provides the most comprehensive coverage of elements in the urban area of the canton, updated to 2024.

In constructing this portfolio, the following considerations were applied based on the database attributes:

- The drinking water distribution pipelines were limited to the administrative boundaries of the canton of Heredia, whereas the conveyance pipelines may extend beyond these boundaries due to their functional role in the supply system.
- The geometric elements representing the network were segmented into lengths of up to 50 meters, ensuring an adequate spatial resolution for risk assessment.

Based on the information provided by the ESPH, the following key attributes were defined for characterizing the network:

- Functional Classification of the Pipeline (SUBTYPE): Indicates the role each segment plays in the system, such as adduction, conveyance, distribution, pumping, or cleaning.
- Pipeline Diameter (DIÁMETRO).

- Manufacturing Material (MATERIAL): Classified according to the categories described in Table 5.

Table 5. Materials of the drinking water supply network pipelines

MATERIAL	Abbr.
Asbestos cement	AC
Steel	ACE
Reinforced concrete	CR
Ductil iron	HD
Cast iron	HF
Galvanized iron	HG
Black iron	HN
High-density polyethylene	PAD
Polyvinyl Chloride PVC	PVC

In this case, the material of the element was the attribute used to classify the pipelines in the drinking water supply network, as it is considered the most critical variable for assessing vulnerability to the hazards identified in this project.

It is important to note that some materials present in the network are no longer in use, either due to public health risks—as with asbestos cement—or because they have become obsolete due to low technical or commercial competitiveness, such as black iron. In these cases, for economic valuation purposes, the replacement material is considered —i.e., the commercially available pipe type that offers equivalent physical properties. In this analysis all iron pipes are replaced with ductile iron pipes, and asbestos cement pipes are replaced with PVC pipes.

The economic valuation of the supply network was estimated using unit costs per linear meter, differentiated by diameter and material. These values were defined based on updated market prices and include the associated civil works costs for replacement.

Figure 33 presents the supply network included in this portfolio, which has a total length of 568.4 km and an overall economic valuation of \$33,238,208,100.

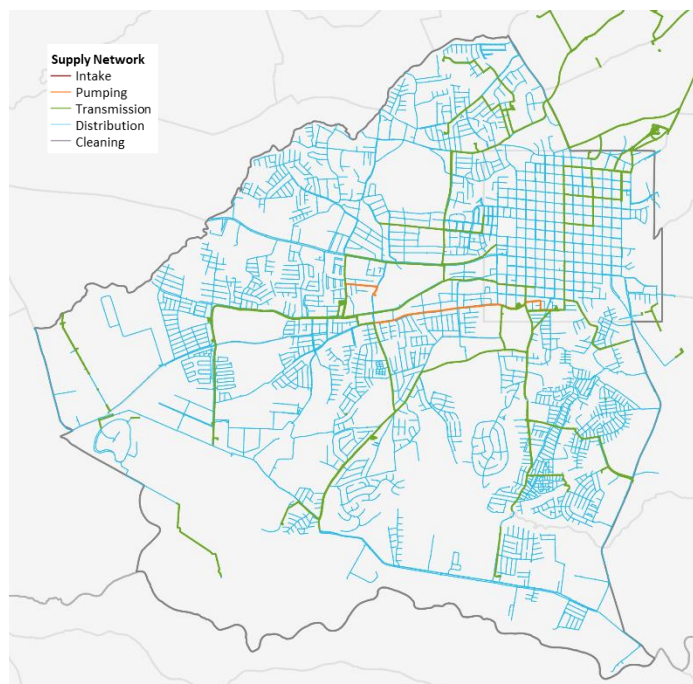


Figure 33. Drinking water network in Heredia.

2.3.6.5 Hydrants

Hydrants are included in this project due to their operational importance in emergency response, especially in the context of natural disasters. These elements provide immediate access to water resources for fire suppression, leak control, and other critical response actions. Therefore, their inclusion in the drinking water sector exposure model is essential to ensure a comprehensive system assessment.

The information source was the Heredia Public Services Company (ESPH), which provided a database with a wide range of technical attributes, including year of installation, diameters of the hydrant's main pipes, brand, model, among others. However, it was determined that these attributes do not significantly affect the physical vulnerability of hydrants to natural hazards and were therefore not included in the portfolio classification. Similarly, no other available attribute was found to substantially influence the economic valuation or risk characterization, so a single classification was applied to all records.

The economic valuation of hydrants was based on a unit value per element, estimated at ₡729,400, which includes both the cost of the hydrant itself and the installation or replacement costs. Based on the 924 hydrants identified in the canton of Heredia, the total economic valuation was estimated at ₡673,965,600.

Figure 34 shows the spatial distribution of hydrants in the urban area of the canton.

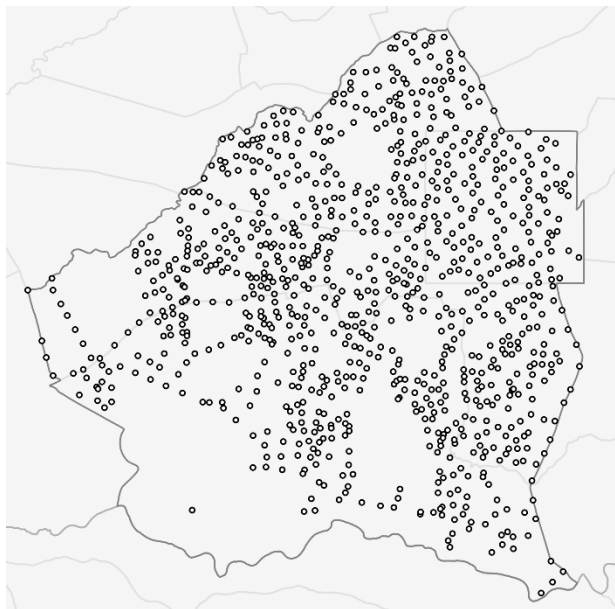


Figure 34. Hydrants in Heredia – Urban area.

2.3.7 Wastewater

The wastewater sector in this project consists of three elements that make up the sanitation system necessary for the proper disposal of wastewater from the population. The elements considered include *collectors* (wastewater pipelines), *manholes*, and *wastewater treatment plants* (WWTP or PTAR in Spanish).

The sources of information for constructing the exposure model for this sector come from the Heredia Public Services Company (ESPH), complemented by data from the GRAF (2024) project, which is also based on information provided by the ESPH.

The following describes how the components of the wastewater disposal system in the canton of Heredia have been considered.

2.3.7.1 Collector Network

In this project, the collector network is defined as the set of pipelines designed to transport wastewater from buildings to a final disposal point, either a water body or a wastewater treatment plant (WWTP/PTAR).

The primary source of information was the Heredia Public Services Company (ESPH), whose database offers the most complete coverage of existing elements. However, to strengthen spatial representation, geometries and additional attributes from the GRAF (2024) project were also incorporated.

It is important to note that the collector network coverage does not encompass the entire canton, due to two main factors:

1. Outdated cartographic records in areas with recent urban development, particularly in the Ulloa district, where new collectors have been installed but are not yet reflected in official records. This

situation was confirmed through cross-validation with data from the 2022 Census conducted by the INEC, which indicates the number of households connected to the sewer system. This information reveals higher actual coverage than what is currently represented in the ESPH's geospatial collector database, highlighting the need for updated mappings.

2. The presence of multiple areas within the canton that relies on individual disposal systems, primarily septic tanks, meaning that in these sectors, there is no centralized collector network.

Based on the database provided by ESPH, the following key attributes were identified for the technical characterization of the collector network:

- Pipe diameter (DIÁMETRO).
- Construction material (MATERIAL): Classified according to the categories listed in Table 6.

Table 6. Materials used in wastewater collector network pipes.

MATERIAL	Classification
Smooth PVC	M1
DPR PVC	M1
Concrete	M2
Alcarraza	M3
No information	M4

In this case, the material of the element was the attribute used to classify the wastewater collector network pipes, as it is considered the most critical variable for assessing vulnerability to the hazards addressed in this project.

It is important to note that alcarraza pipes correspond to a material that is no longer commercially used. Therefore, for economic valuation purposes, the replacement material is defined as DPR-type PVC. Similarly, for records lacking material information, DPR PVC was assigned as the representative material, as it is the most common among collectors with complete data.

The economic valuation of the collector network was estimated using unit costs per linear meter, differentiated by the diameter and material of each pipe. These values were defined based on updated market prices, including the costs of associated civil works required for replacement.

The consolidated collector network portfolio covers a total length of 160.3 km, with a total economic valuation of \$11,425,048,700.

2.3.7.2 Manholes

Manholes are vertical elements essential to the functioning of the wastewater collector network, as they enable both the interconnection of different pipeline segments and access for inspection and system maintenance. Since these networks transport wastewater containing suspended solid waste, operational access points are necessary at strategic locations to facilitate corrective interventions in cases of blockages or functional impairments of the collectors.

The primary source of information was the Heredia Public Services Company (ESPH), whose database provides the most comprehensive and detailed coverage of manholes, surpassing the information available in the GRAF (2024) project.

From the ESPH database, the following key attributes were identified for the technical and structural characterization of manholes:

- Manhole Depth (PROFUNDIDAD_M): Reclassified into ranges of 1.50 meters.
- Plan Dimensions (DIAMETRO_POZO): For circular manholes, the diameter is recorded; for rectangular manholes, two dimensions are specified. This is reflected in the FORMA field, categorized as circular or rectangular.
- Manhole Material (MATERIAL_POZO): Categories include concrete, PVC, brick, and other (unspecified).

Based on these attributes, a technical and economic classification was constructed for vulnerability assessment and portfolio valuation, using the following code format: POZ_FX_M#_H#, where:

- FX represents the shape of the manhole (C: circular, R: rectangular),
- M# corresponds to the structural material, and
- H# to the depth category.

The economic valuation of manholes differentiated between material types and their structural behavior:

- For concrete and masonry (brick) manholes, the valuation was based on the perimeter of the manhole (calculated from plan dimensions), depth, and material type, using a unit cost per square meter of built surface area.
- For prefabricated PVC manholes, a unit cost per linear meter of depth was defined, derived from market prices, and differentiated by manhole diameter (commonly 600 mm or 1200 mm).
- In records where the material information was missing, concrete was assigned as the reference material, being the most common in records with complete data.

The portfolio includes 2,317 manholes, with a total economic valuation of \$1,955,178,000.

2.3.7.3 Wastewater Treatment Plants

The inclusion of wastewater treatment plants (WWTP or PTAR) in the exposure model of this project is essential given their critical role in reducing the physical, chemical, and biological load of wastewater discharged into receiving bodies, such as rivers and streams. These infrastructures not only improve water quality but also contribute to environmental protection and public health, which justifies their inclusion in the risk assessment for the wastewater sector.

The data source used for the identification and characterization of WWTPs was the GRAF (2024) project, which records six treatment plants located within the urban perimeter of the canton of Heredia. As shown in Figure 35, these facilities are clearly connected to the wastewater collector network and are located near water bodies, making their inclusion in the exposure model technically relevant.

Among the available attributes in the GRAF (2024) project database, the attribute TIPO_TRATAM (treatment type) was identified as relevant for vulnerability classification. Based on this attribute, two main categories are defined:

- Tank-based treatment: Refers to plants that use tank-type structures to perform primary treatment with activated sludge.
- Stabilization pond treatment: Refers to plants operating through an aerobic process in ponds, typically involving a lower degree of mechanization.

This differentiation is useful both for vulnerability assessment to hazards and for calculating replacement costs.

The economic valuation of the WWTPs was taken directly from the values defined in the GRAF (2024) project, which are considered consistent with the criteria of this study. A unit value per plant was established, differentiated by treatment type, allowing for an accurate representation of replacement costs.

The total economic valuation of the six wastewater treatment plants identified in the canton of Heredia amounts to \$162,500,000.

Figure 35 shows the location of wastewater system elements, including collectors, manholes, and treatment plants, providing a spatial visualization of the sector's portfolio.

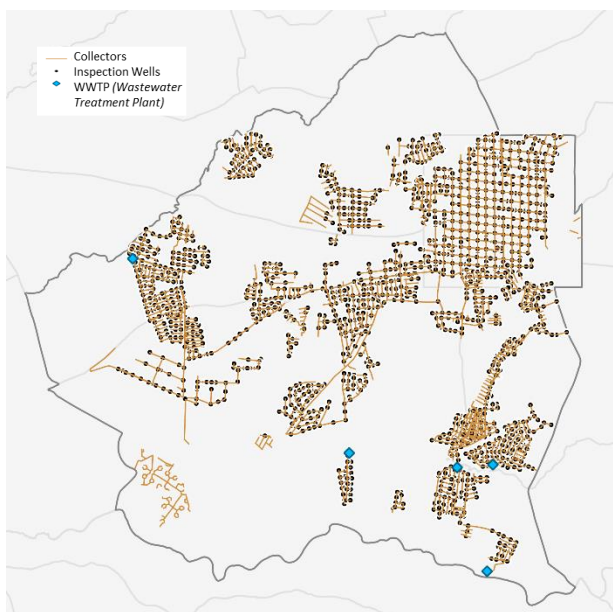


Figure 35. Wastewater system in canton of Heredia – Urban area.

2.3.8 Summary of Infrastructure Exposure in Heredia

Given the extensive number of sectors that make up the infrastructure portfolio of the canton of Heredia, this section presents a general summary, including the total estimated replacement value and the total number of individual elements comprising each sector considered.

Table 7. Economic valuation and elements of infrastructure in the Canton of Heredia.

Sector	Economic valuation (€)	Elements
Road network	119 590 241 400	340.5 km of roads 12 national bridges and 37 cantonal bridges
Rail network	986 648 800	4.9 km railway tracks
Electricity	45 521 947 100	2 energy generation plants (hydroelectrics) 6 substations 108 high-voltage transmisión towers 48.7 km of high-voltage circuits (transmissions) 2596 medium and low-voltage circuits (distribution) 11814 distribution poles 1027.3 km of medium and low-voltage circuits (distribution)
Telecommunications	2 230 418 300	110 telecommunication towers
Hydrocarbons	3 743 233 900	12.2 km of pipelines
Drinking water	43 000 332 900	28 drinking water sources 53 storage tanks 17 pumping systems 568.4 km of supply network 924 hydrants
Wastewater	13 542 726 700	160.3 km of collector network 2317 manholes 6 wastewater treatment plants

2.4 Infrastructure Vulnerability Models

To develop the vulnerability functions for infrastructure elements, a mixed approach was adopted. For complex elements, vulnerability archetypes were used. An archetype represents a simplified structure of a type of infrastructure, composed of subcomponents—such as buildings, electromechanical equipment, support structures, or control systems—each with specific technical properties and functions. These subcomponents are assigned individual vulnerability functions, which are then integrated into a composite curve, weighted according to their relative importance within the system.

However, for simple or standardized elements, such as pipelines, poles, storage tanks, electrical transmission towers, railway lines, or other elements, it is sufficient to directly assign a vulnerability curve. These curves are directly associated with the type of element based on its material, geometry, or structural condition, without the need to model a composite archetype.

The application of this methodological framework to the canton of Heredia has enabled an adequate characterization of the building and critical infrastructure portfolios, assigning vulnerability functions to each element according to its physical condition, predominant material, and functional relevance, forming the basis for the probabilistic loss estimation. It is important to clarify that the assigned vulnerability functions allow modeling only the direct loss relative to the replacement value of physical infrastructure assets. In other words, the modeling of losses does not include service interruptions in the infrastructure systems. This is because a model capable of incorporating variations in the supply and demand of the services provided, as a result of hazard events, is beyond the scope of this consultancy.

2.4.1 Road Sector

For the roadways, a total of 68 classification typologies were defined within the exposure portfolio, to which 3 seismic vulnerability functions and 8 flood vulnerability functions were assigned, as shown in Table 8.

The seismic vulnerability functions are based on the fragility curves for permanent surface deformation included in the Technical Manual of the HAZUS Seismic Model (FEMA, 2024). Meanwhile, the flood vulnerability functions were developed using the archetype methodology, assessing potential damage to the asphalt layer, as well as the base and sub-base structures, based on the floodwater depth.

Table 8. Road typologies and corresponding vulnerability curves.

Classification	Longitude [m]	Earthquake	Flood
NP_R0_S1	874	EQ_HRD1	FL_R1_S1
NP_R0_S2	1104	EQ_HRD1	FL_R1_S2
NP_R0_S3	200	EQ_HRD1	FL_R1_S3
NP_R0_S4	25	EQ_HRD1	FL_R1_S4
NP_R1_S1	5088	EQ_HRD1	FL_R1_S1
NP_R1_S2	9093	EQ_HRD1	FL_R1_S2
NP_R1_S3	1176	EQ_HRD1	FL_R1_S3
NP_R1_S4	200	EQ_HRD1	FL_R1_S4
NS_R0_S1	1061	EQ_HRD1	FL_R1_S1
NS_R0_S2	1823	EQ_HRD1	FL_R1_S2
NS_R0_S3	950	EQ_HRD1	FL_R1_S3
NS_R0_S4	500	EQ_HRD1	FL_R1_S4
NS_R1_S1	7144	EQ_HRD1	FL_R1_S1
NS_R1_S2	10861	EQ_HRD1	FL_R1_S2
NS_R1_S3	3000	EQ_HRD1	FL_R1_S3
NS_R1_S4	1850	EQ_HRD1	FL_R1_S4
NT_R0_S1	280	EQ_HRD1	FL_R1_S1
NT_R0_S2	1009	EQ_HRD1	FL_R1_S2
NT_R0_S3	64	EQ_HRD1	FL_R1_S3
NT_R1_S1	2106	EQ_HRD1	FL_R1_S1
NT_R1_S2	3318	EQ_HRD1	FL_R1_S2
NT_R1_S3	128	EQ_HRD1	FL_R1_S3
NT_R1_S4	47	EQ_HRD1	FL_R1_S4
LP_R0_S1	4614	EQ_HRD2	FL_R1_S1
LP_R0_S2	10774	EQ_HRD2	FL_R1_S2
LP_R0_S3	1758	EQ_HRD2	FL_R1_S3
LP_R0_S4	211	EQ_HRD2	FL_R1_S4
LP_R1_S1	19622	EQ_HRD2	FL_R1_S1
LP_R1_S2	21059	EQ_HRD2	FL_R1_S2
LP_R1_S3	600	EQ_HRD2	FL_R1_S3
LS_R0_S1	13106	EQ_HRD2	FL_R1_S1
LS_R0_S2	11664	EQ_HRD2	FL_R1_S2

Classification	Longitude [m]	Earthquake	Flood
LS_R0_S3	271	EQ_HRD2	FL_R1_S3
LS_R1_S1	11229	EQ_HRD2	FL_R1_S1
LS_R1_S2	11874	EQ_HRD2	FL_R1_S2
LS_R1_S3	642	EQ_HRD2	FL_R1_S3
LT_R0_S1	25543	EQ_HRD2	FL_R1_S1
LT_R0_S2	40331	EQ_HRD2	FL_R1_S2
LT_R0_S3	3220	EQ_HRD2	FL_R1_S3
LT_R0_S4	523	EQ_HRD2	FL_R1_S4
LT_R1_S1	14459	EQ_HRD2	FL_R1_S1
LT_R1_S2	22778	EQ_HRD2	FL_R1_S2
LT_R1_S3	771	EQ_HRD2	FL_R1_S3
LT_R1_S4	125	EQ_HRD2	FL_R1_S4
LT_R3_S1	75	EQ_HRD2	FL_R1_S1
LT_R3_S2	469	EQ_HRD2	FL_R1_S2
LT_R3_S3	60	EQ_HRD2	FL_R1_S3
LTP_R0_S1	51	EQ_HRD2	FL_R1_S1
LTP_R0_S2	328	EQ_HRD2	FL_R1_S2
LTP_R0_S3	25	EQ_HRD2	FL_R1_S3
LTP_R1_S1	1122	EQ_HRD2	FL_R1_S1
LTP_R1_S2	1731	EQ_HRD2	FL_R1_S2
LTP_R1_S3	20	EQ_HRD2	FL_R1_S3
PR_R0_S1	4799	EQ_HRD2	FL_R1_S1
PR_R0_S2	20597	EQ_HRD2	FL_R1_S2
PR_R0_S3	4090	EQ_HRD2	FL_R1_S3
PR_R0_S4	157	EQ_HRD2	FL_R1_S4
PR_R1_S1	2026	EQ_HRD2	FL_R1_S1
PR_R1_S2	5725	EQ_HRD2	FL_R1_S2
PR_R1_S3	150	EQ_HRD2	FL_R1_S3
NC_R0_S1	1786	EQ_HRD3	FL_R3_S1
NC_R0_S2	14033	EQ_HRD3	FL_R3_S2
NC_R0_S3	10762	EQ_HRD3	FL_R3_S3
NC_R0_S4	3835	EQ_HRD3	FL_R3_S4
NC_R3_S1	175	EQ_HRD3	FL_R3_S1
NC_R3_S2	900	EQ_HRD3	FL_R3_S2
NC_R3_S3	475	EQ_HRD3	FL_R3_S3
NC_R3_S4	25	EQ_HRD3	FL_R3_S4

Table 9 and Table 10 provide a summary description of the vulnerable elements associated with the seismic and flood vulnerability curves, respectively. Figure 36 and Figure 37 illustrate the seismic vulnerability curves and the flood vulnerability curves, respectively.

Table 9. Description of seismic vulnerability curves for roadways

Curve	Description
EQ_HRD1	National roads
EQ_HRD2	Urban or local roads
EQ_HRD3	Rural roads

Table 10. Description of flood vulnerability curves for roadways

Curve	Description
FL_R1_S1	Paved – Average terrain slope of 2.5%
FL_R1_S2	Paved – Average terrain slope of 10.0%
FL_R1_S3	Paved – Average terrain slope of 20.0%
FL_R1_S4	Paved – Average terrain slope of 30.0%
FL_R3_S1	Unpaved – Average terrain slope of 2.5%
FL_R3_S2	Unpaved – Average terrain slope of 10.0%
FL_R3_S3	Unpaved – Average terrain slope of 20.0%
FL_R3_S4	Unpaved – Average terrain slope of 30.0%

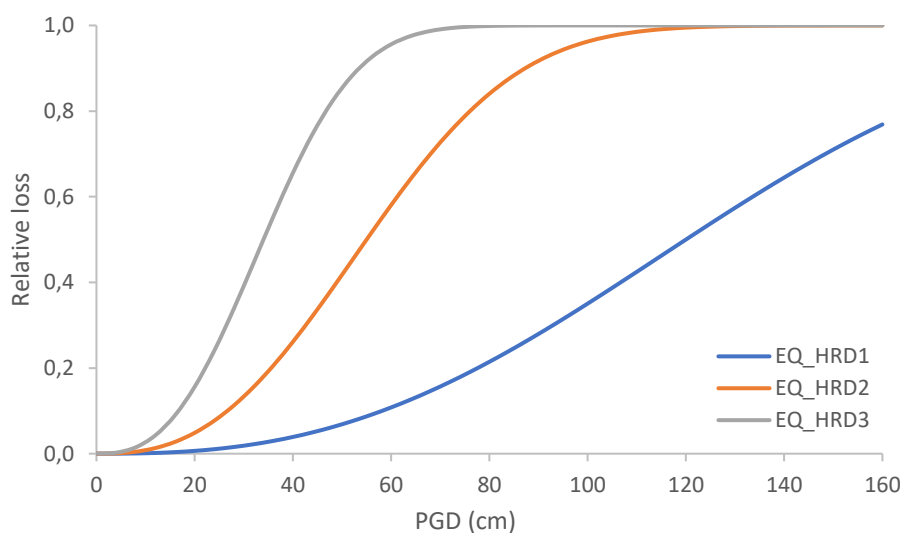


Figure 36. Seismic vulnerability curves for roadways.

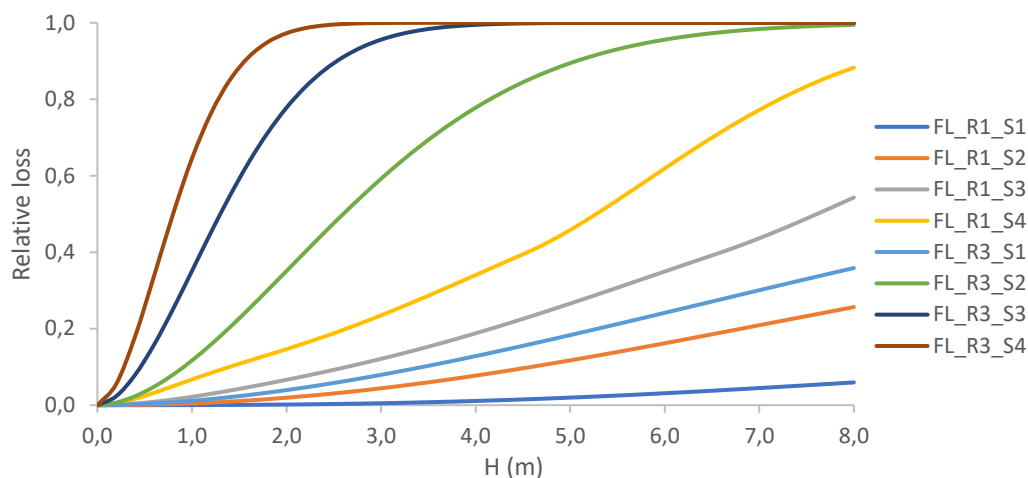


Figure 37. Flood vulnerability curves for roadways.

For road bridges, a total of 34 classification typologies were defined within the exposure portfolio, to which 13 seismic vulnerability functions and 1 flood vulnerability function were assigned, as shown in Table 11.

The seismic vulnerability functions are based on fragility curves for spectral acceleration at a period of 0.1 seconds, as included in the Technical Manual of the HAZUS Seismic Model (FEMA, 2024). On the other hand, it was determined that bridges are not vulnerable to flooding, and therefore a no-damage curve is assigned to all bridge typologies defined in the exposure model.

Figure 38 presents the seismic vulnerability curves for bridges.

Table 11. Bridge typologies and corresponding vulnerability curves.

Classification	Bridges	Earthquake	Flood
C1_NC1_H0_ES0_MT0_AP0	1	EQ_HWB28_R	No-daño
C1_NC1_H0_ES11_MT1_AP0	1	EQ_HWB28_R	No-daño
C1_NC1_H0_ES11_MT2_AP0	1	EQ_HWB28_R	No-daño
C1_NC1_H0_ES11_MT4_AP0	2	EQ_HWB28_R	No-daño
C1_NC1_H0_ES2_MT3_AP0	1	EQ_HWB12	No-daño
C1_NC1_H0_ES4_MT2_AP0	2	EQ_HWB10	No-daño
C1_NC1_H0_ES7_MT2_AP0	1	EQ_HWB22	No-daño
C1_NC1_H1_ES0_MT0_AP0	3	EQ_HWB28_R	No-daño
C1_NC1_H1_ES22_MT1_AP1	3	EQ_HWB17	No-daño
C1_NC1_H1_ES2_MT3_AP1	2	EQ_HWB24	No-daño
C1_NC1_H1_ES2_MT3_AP3	1	EQ_HWB24	No-daño
C1_NC1_H1_ES2_MT3_AP4	2	EQ_HWB24	No-daño
C1_NC1_H2_ES0_MT0_AP0	2	EQ_HWB28_R	No-daño
C1_NC1_H2_ES10_MT3_AP1	1	EQ_HWB26	No-daño
C1_NC1_H2_ES10_MT3_AP4	1	EQ_HWB26	No-daño
C1_NC1_H2_ES22_MT1_AP1	5	EQ_HWB17	No-daño
C1_NC1_H2_ES22_MT2_AP1	2	EQ_HWB10	No-daño
C1_NC1_H2_ES22_MT2_AP2	1	EQ_HWB11	No-daño

Classification	Bridges	Earthquake	Flood
C1_NC1_H2_ES2_MT3_AP1	2	EQ_HWB12	No-daño
C1_NC1_H3_ES22_MT1_AP1	1	EQ_HWB15	No-daño
C1_NC1_H3_ES22_MT2_AP4	1	EQ_HWB16	No-daño
C2_NC1_H0_ES10_MT3_AP0	1	EQ_HWB28_F	No-daño
C2_NC1_H0_ES11_MT4_AP0	1	EQ_HWB28_R	No-daño
C2_NC1_H0_ES2_MT1_AP0	2	EQ_HWB17	No-daño
C2_NC1_H1_ES2_MT2_AP1	1	EQ_HWB10	No-daño
C2_NC1_H1_ES4_MT1_AP1	1	EQ_HWB17	No-daño
C2_NC1_H2_ES0_MT0_AP0	1	EQ_HWB28_R	No-daño
C2_NC1_H2_ES22_MT1_AP1	1	EQ_HWB17	No-daño
C2_NC1_H2_ES2_MT3_AP3	2	EQ_HWB14	No-daño
C2_NC1_H2_ES2_MT3_AP4	1	EQ_HWB14	No-daño
C2_NC1_H3_ES0_MT0_AP0	2	EQ_HWB28_R	No-daño
C3_NC1_H0_ES2_MT1_AP0	2	EQ_HWB17	No-daño
C3_NC2_H0_ES4_MT1_AP0	1	EQ_HWB17_NC2	No-daño
C4_NC3_H0_ES2_MT3_AP0	1	EQ_HWB12_NC3	No-daño

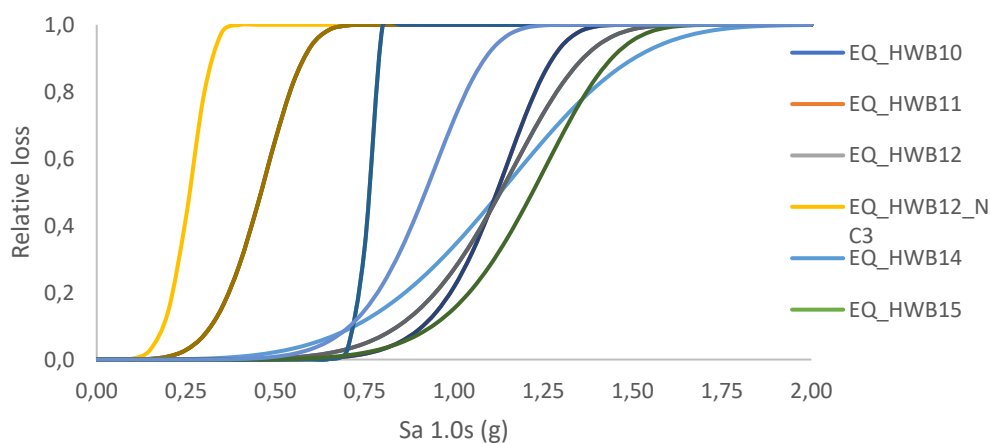


Figure 38. Seismic vulnerability curves for bridges.

2.4.2 Railway Sector

In the railway sector portfolio, 7 classification typologies were defined within the exposure portfolio, each assigned 3 seismic vulnerability functions and 6 flood vulnerability functions, as shown in Table 12.

Table 12. Railway typologies and corresponding vulnerability.

Classification	Longitude [m]	Earthquake	Flood
FR_ASF_S2	110	EQ_HRD2	FL_R1_S1
FR_BLT_S1	1341	EQ_RWY1	FL_R4_S1
FR_BLT_S2	1253	EQ_RWY1	FL_R4_S2
FR_BLT_S3	50	EQ_RWY1	FL_R4_S3
FR_CRO_S1	1255	EQ_HRD1	FL_R1_S1

FR_CRO_S2	812	EQ_HRD1	FL_R1_S2
FR_PTE	34	EQ_HWB28_R	No daño

Figure 39 presents the seismic vulnerability curves for railway segments excluding bridges, as the hazard intensity is expressed in PGD (permanent ground displacement, in cm). For railway bridges, the curve EQ_HWB28_R, shown in Figure 38, was assigned. Figure 40 presents the flood vulnerability curves for railway segments.

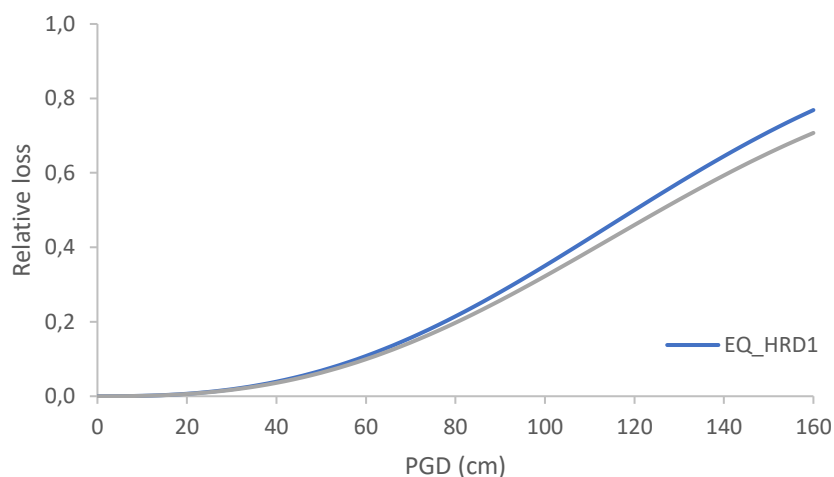


Figure 39. Seismic vulnerability curves for railways.

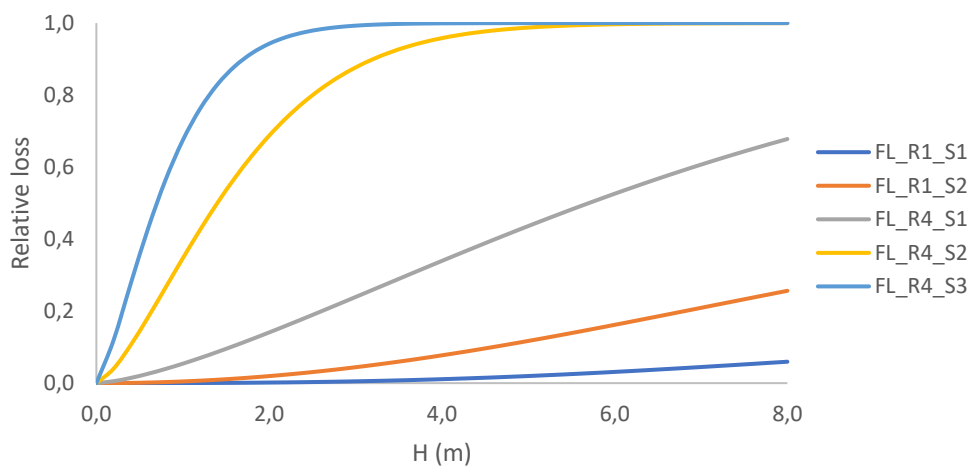


Figure 40. Flood vulnerability curves for railways.

2.4.3 Electric Power Sector

The electricity sector includes 65 classification typologies within the exposure portfolio, to which 59 seismic vulnerability functions and 4 flood vulnerability functions were assigned, as detailed in Table 13.

The seismic vulnerability functions for most elements in the portfolio are derived from fragility curves based on peak ground acceleration (PGA), as included in the Technical Manual of the HAZUS Seismic Model (FEMA, 2024).

For elements composed of multiple components, such as reservoir-based hydroelectric plants or substations, the vulnerability is represented using a composite curve built through the archetype methodology, designed to capture the impact of hazards across the various components of the exposed element.

Table 13. Electric power sector typologies and corresponding vulnerability curves.

Subsector	Classification	Earthquake	Flood
Generation	HID-EMB	EQ_HID-EMB*	FL_HID-EMB*
Transmission	SUBSTAT	EQ_HV-SUB	FL_SUBSTA*
	TL_CABLE	EQ_LTCAB	No damage
	LT_1C	EQ_LT1	No damage
	LT_2C	EQ_LT2	No damage
	LT_3C	EQ_LT2	No damage
	LT_4C	EQ_LT2	No damage
Distribution	TR_PED	EQ_TR-PED	FL_TR-PED
	TR_AER	EQ_DL-UMB	No damage
	DL_MT_SUB	No damage	No damage
	DL_MT_AER	EQ_DL-UMB	No damage
	DL_BT_SUB	No damage	No damage
	DL_BT_AER	EQ_DL-UMB	No damage
	POSTE_C1_H1_STA	EQ_POLE_C1_H1_STA	No damage
	POSTE_C1_H1_STB	EQ_POLE_C1_H1_STB	No damage
	POSTE_C1_H2_STA	EQ_POLE_C1_H2_STA	No damage
	POSTE_C1_H2_STB	EQ_POLE_C1_H2_STB	No damage
	POSTE_C1_H2_STC	EQ_POLE_C1_H2_STC	No damage
	POSTE_C1_H3_STA	EQ_POLE_C1_H3_STA	No damage
	POSTE_C1_H3_STB	EQ_POLE_C1_H3_STB	No damage
	POSTE_C1_H3_STC	EQ_POLE_C1_H3_STC	No damage
	POSTE_C1_H4_STA	EQ_POLE_C1_H4_STA	No damage
	POSTE_C1_H4_STB	EQ_POLE_C1_H4_STB	No damage
	POSTE_C1_H4_STC	EQ_POLE_C1_H4_STC	No damage
	POSTE_C1_H5_STA	EQ_POLE_C1_H5_STA	No damage
	POSTE_C1_H5_STB	EQ_POLE_C1_H5_STB	No damage
	POSTE_C1_H5_STC	EQ_POLE_C1_H5_STC	No damage
	POSTE_C2_H3_STA	EQ_POLE_C2_H3_STA	No damage
	POSTE_C2_H3_STB	EQ_POLE_C2_H3_STB	No damage
	POSTE_C2_H4_STA	EQ_POLE_C2_H4_STA	No damage
	POSTE_C2_H4_STB	EQ_POLE_C2_H4_STB	No damage
	POSTE_C2_H5_STA	EQ_POLE_C2_H5_STA	No damage
	POSTE_C2_H5_STB	EQ_POLE_C2_H5_STB	No damage
	POSTE_M1_H2_STA	EQ_POLE_M1_H2_STA	No damage
	POSTE_M1_H2_STB	EQ_POLE_M1_H2_STB	No damage
	POSTE_M1_H2_STC	EQ_POLE_M1_H2_STC	No damage
	POSTE_M1_H3_STA	EQ_POLE_M1_H3_STA	No damage
	POSTE_M1_H3_STB	EQ_POLE_M1_H3_STB	No damage
	POSTE_M1_H3_STC	EQ_POLE_M1_H3_STC	No damage

Subsector	Classification	Earthquake	Flood
	POSTE_M1_H4_STA	EQ_POLE_M1_H4_STA	No damage
	POSTE_M1_H4_STC	EQ_POLE_M1_H4_STC	No damage
	POSTE_M1_H5_STA	EQ_POLE_M1_H5_STA	No damage
	POSTE_M2_H1_STA	EQ_POLE_M2_H1_STA	No damage
	POSTE_M2_H2_STA	EQ_POLE_M2_H2_STA	No damage
	POSTE_M2_H2_STB	EQ_POLE_M2_H2_STB	No damage
	POSTE_M2_H2_STC	EQ_POLE_M2_H2_STC	No damage
	POSTE_M2_H3_STA	EQ_POLE_M2_H3_STA	No damage
	POSTE_M2_H3_STB	EQ_POLE_M2_H3_STB	No damage
	POSTE_M2_H3_STC	EQ_POLE_M2_H3_STC	No damage
	POSTE_M2_H4_STA	EQ_POLE_M2_H4_STA	No damage
	POSTE_M2_H4_STB	EQ_POLE_M2_H4_STB	No damage
	POSTE_M2_H4_STC	EQ_POLE_M2_H4_STC	No damage
	POSTE_M2_H5_STA	EQ_POLE_M2_H5_STA	No damage
	POSTE_M2_H5_STC	EQ_POLE_M2_H5_STC	No damage
	POSTE_W1_H2_STA	EQ_POLE_W1_H2_STA	No damage
	POSTE_W1_H2_STB	EQ_POLE_W1_H2_STB	No damage
	POSTE_W1_H2_STC	EQ_POLE_W1_H2_STC	No damage
	POSTE_W1_H3_STA	EQ_POLE_W1_H3_STA	No damage
	POSTE_W1_H3_STB	EQ_POLE_W1_H3_STB	No damage
	POSTE_W1_H3_STC	EQ_POLE_W1_H3_STC	No damage
	POSTE_W1_H4_STA	EQ_POLE_W1_H4_STA	No damage
	POSTE_W1_H4_STB	EQ_POLE_W1_H4_STB	No damage
	POSTE_W1_H4_STC	EQ_POLE_W1_H4_STC	No damage
	POSTE_W1_H5_STC	EQ_POLE_W1_H5_STC	No damage
	POSTE_W2_H4_STA	EQ_POLE_W2_H4_STA	No damage

* Functions developed using the archetype methodology for vulnerability curve estimation.

Figure 41 presents the seismic vulnerability curves for the elements of the sector, excluding the electric power distribution poles. Figure 42 presents the vulnerability curves for the 52 typologies of distribution poles present in the canton of Heredia. Figure 43 presents the flood vulnerability curves.

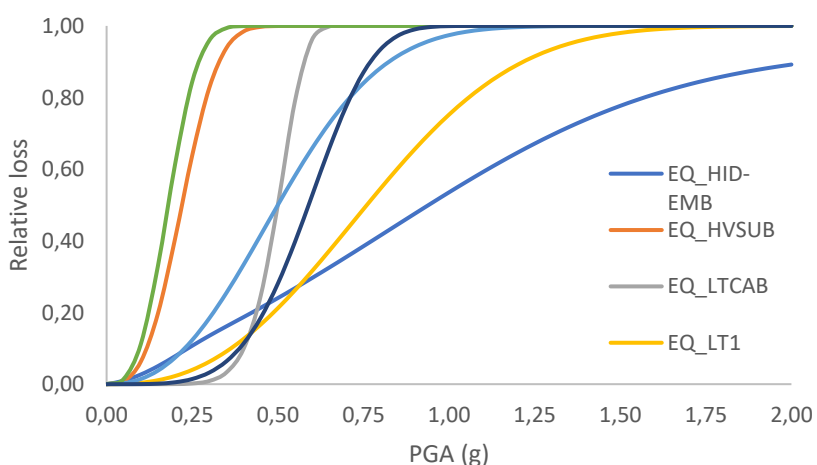


Figure 41. Seismic vulnerability curves for power distribution network elements.

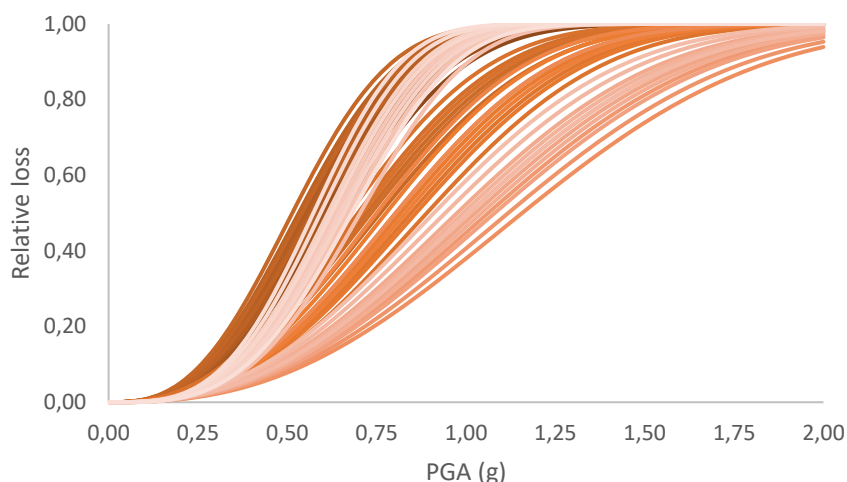


Figure 42. Seismic vulnerability curves for the poles of the electric power distribution network.

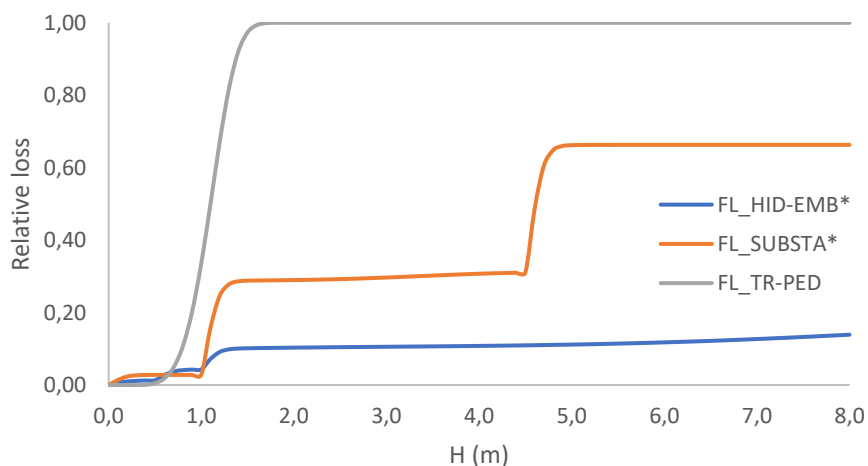


Figure 43. Flood vulnerability curves for the elements of the electric power sector portfolio.

2.4.4 Telecommunications Sector

The telecommunications sector includes 10 classification typologies within the exposure portfolio, to which 7 seismic vulnerability functions were assigned, as presented in Table 14.

For flood vulnerability, no-damage curves were assigned, based on the understanding that the metal support structures for antennas are not susceptible to flood damage, and that the sensitive electronic components, such as antennas or radio frequency (RF) units of the radiant systems, are located at heights exceeding 8.0 meters, well above potential floodwater levels.

Table 14. Telecommunication towers typologies and corresponding vulnerability curves.

Classification	Towers	Earthquake	Flood
COM_CU	18	Building	No damage

COM_TA_H2	21	EQ_WLS2_H2	No damage
COM_TA_H3	6	EQ_WLS2_H3	No damage
COM_TA_H4	3	EQ_WLS2_H4	No damage
COM_TA_H5	1	EQ_WLS2_H5	No damage
COM_TM_H1	4	EQ_WLS1_H1	No damage
COM_TM_H2	37	EQ_WLS1_H2	No damage
COM_TM_H3	8	EQ_WLS1_H3	No damage
COM_TV_H1	1	EQ_WLS1_H1	No damage
COM_TV_H2	11	EQ_WLS1_H2	No damage

The seismic vulnerability functions assigned to the elements in the portfolio are derived from fragility curves based on peak ground acceleration (PGA), as established in the Technical Manual of the HAZUS Seismic Model (FEMA, 2024).

For elements classified as “COM_CU”, corresponding to radiant-receiver systems located on rooftops, binary vulnerability functions were assigned. These functions establish a damage threshold at the seismic acceleration level associated with 85% structural damage to the supporting building. This approach reflects the functional dependency of the radiant system on the performance of the structure where it is installed.

Figure 44 presents the seven seismic vulnerability curves used in this portfolio.

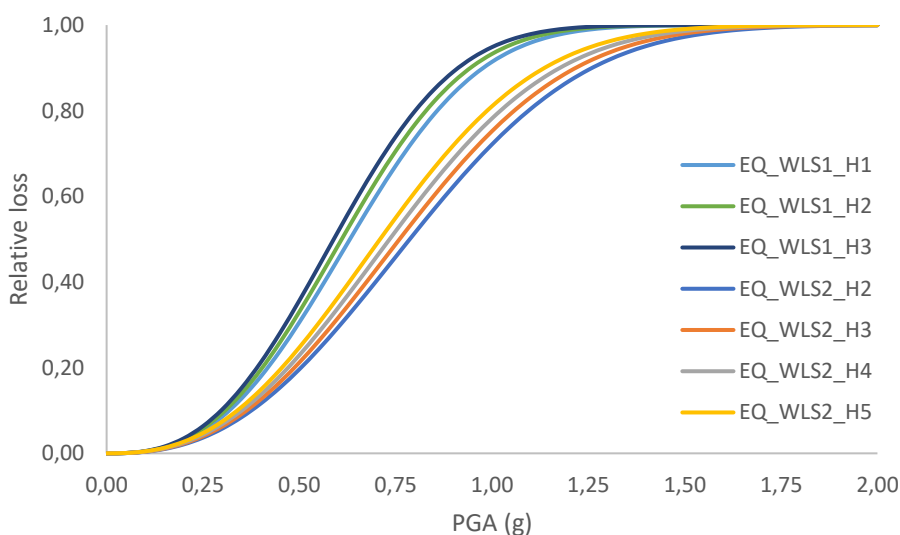


Figure 44. Seismic vulnerability curves for telecommunication towers.

2.4.5 Hydrocarbons Sector

The hydrocarbons sector includes a single typology corresponding to the pipeline (polyduct) that passes through the canton of Heredia. In this case, the vulnerability curve for buried pipelines from the Technical Manual of the HAZUS Seismic Model (FEMA, 2024) was assigned.

Additionally, a no-damage curve was assigned for flood vulnerability, as floodwater depths do not affect pipelines buried more than 1.50 meters deep.

Figure 45 presents the seismic vulnerability function assigned to the pipeline system.

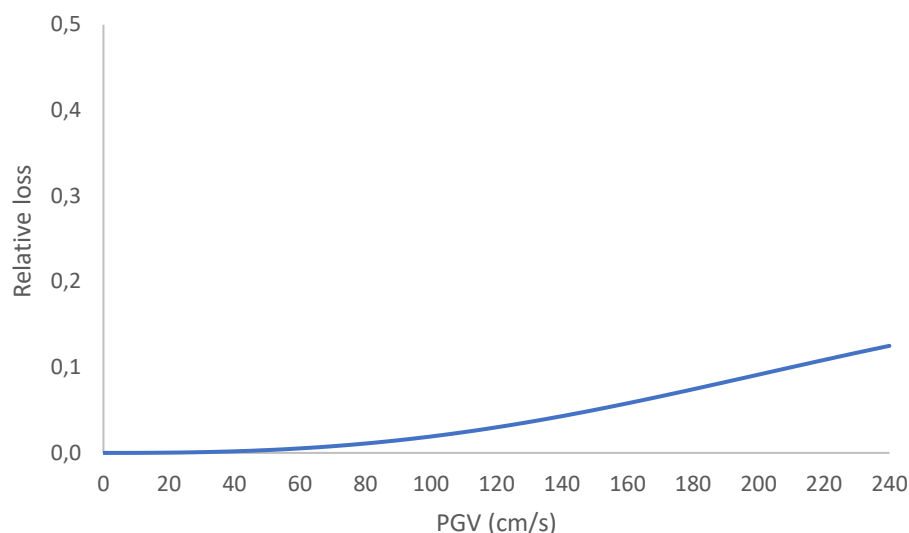


Figure 45. Seismic vulnerability curve for buried pipelines.

2.4.6 Drinking Water Sector

The drinking water sector includes 16 classification typologies, to which 6 seismic vulnerability functions and 3 flood vulnerability functions were assigned, as shown in Table 15.

Table 15. Drinking water sector typologies and corresponding vulnerability curves.

Classification	Earthquake	Flood
AP_FUENTE	EQ_AP-FUENTE*	FL_AP-FUENTE*
AP_TANQ_MC	EQ_PSTGC	No damage
AP_TANQ_MH	EQ_PSTGS	No damage
AP_TANQ_MO	EQ_PSTGC	No damage
AP_SIST-BOM	EQ_PPPS	FL_PPPS
TUB_AP_AC	EQ_PIPE	No damage
TUB_AP_ACE	EQ_PIPE	No damage
TUB_AP_CR	EQ_PIPE	No damage
TUB_AP_HD	EQ_PIPE	No damage
TUB_AP_HF	EQ_PIPE	No damage
TUB_AP_HG	EQ_PIPE	No damage
TUB_AP_HN	EQ_PIPE	No damage
TUB_AP_Otro	EQ_PIPE	No damage
TUB_AP_PAD	EQ_PIPE	No damage
TUB_AP_PVC	EQ_PIPE	No damage
AP_HDRT	No daño	No damage

* Functions developed using the archetype methodology for vulnerability curve estimation.

Figure 46 presents the seismic vulnerability curves for the evaluated typologies, based on peak ground acceleration (PGA).

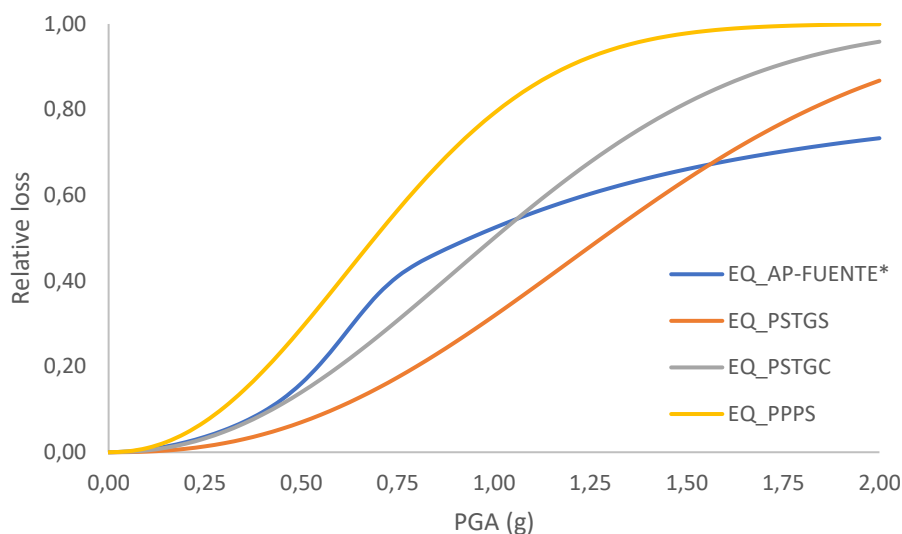


Figure 46. Seismic vulnerability curves for the drinking water sector.

The seismic vulnerability function for pipelines is the same as that used for the pipeline (polyduct); therefore, the applicable function can be seen in Figure 45. Figure 47 presents the two curves (excluding the no-damage curve) related to the drinking water sector for the canton of Heredia.

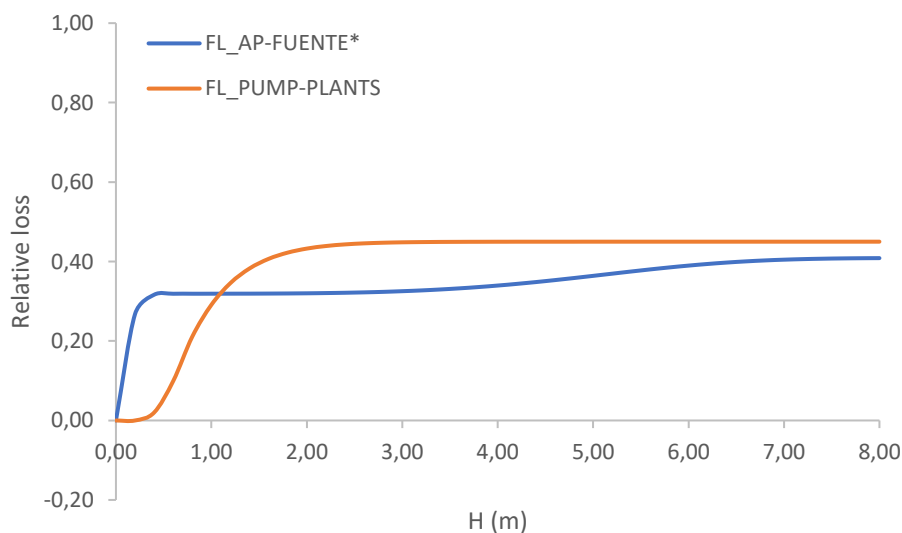


Figure 47. Flood vulnerability curves for the drinking water sector.

2.4.7 Wastewater Sector

The wastewater sector includes 22 classification typologies, to which 14 seismic vulnerability functions and 2 flood vulnerability functions (one of which is a no-damage curve) were assigned, as shown in Table 16.

Table 16. Wastewater sector elements typologies and corresponding vulnerability curves.

Classification	Earthquake	Flood
TUB_AR_M1	EQ_PIPE	No damage
TUB_AR_M2	EQ_PIPE	No damage
TUB_AR_M3	EQ_PIPE	No damage
TUB_AR_M4	EQ_PIPE	No damage
POZ_FC_M1_H0	EQ_PZ_M1-H0	No damage
POZ_FC_M1_H1	EQ_PZ_M1-H1	No damage
POZ_FC_M1_H2	EQ_PZ_M1-H2	No damage
POZ_FC_M1_H3	EQ_PZ_M1-H3	No damage
POZ_FC_M2_H0	EQ_PZ_M2-H0	No damage
POZ_FC_M2_H1	EQ_PZ_M2-H1	No damage
POZ_FC_M2_H2	EQ_PZ_M2-H2	No damage
POZ_FC_M2_H4	EQ_PZ_M2-H4	No damage
POZ_FC_M3_H0	EQ_PZ_M3-H0	No damage
POZ_FC_M3_H1	EQ_PZ_M3-H1	No damage
POZ_FC_M3_H2	EQ_PZ_M3-H2	No damage
POZ_FR_M1_H0	EQ_PZ_M1-H0	No damage
POZ_FR_M1_H1	EQ_PZ_M1-H1	No damage
POZ_FR_M2_H0	EQ_PZ_M2-H0	No damage
POZ_FR_M3_H0	EQ_PZ_M3-H0	No damage
POZ_FR_M3_H1	EQ_PZ_M3-H1	No damage
PTAR_T1	EQ_PSTGC	FL_PTAR1*
PTAR_T2	EQ_PWTS	No damage

Figure 48 presents the seismic vulnerability curves for the evaluated typologies, based on peak ground acceleration (PGA). The vulnerability function for pipelines, which is based on peak ground velocity (PGV), is shown in Figure 45.

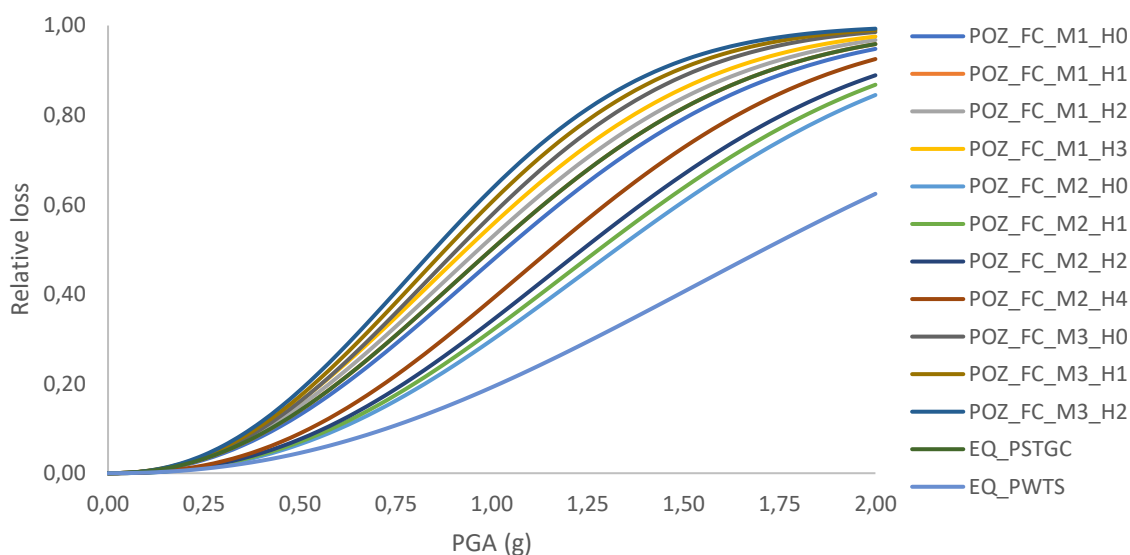


Figure 48. Seismic vulnerability curves for the wastewater sector.

Figure 49 presents the flood vulnerability curve for the wastewater treatment plant – type 1.

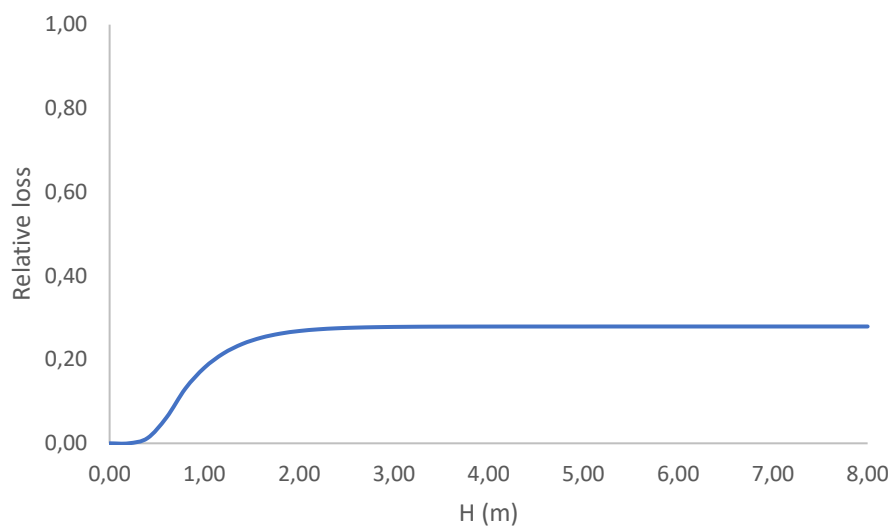


Figure 49. Flood vulnerability curve for a wastewater treatment plant.

3 OPERATIONAL PROJECT 1: DISASTER AND CLIMATE RISK ASSESSMENT FOR ROAD INFRASTRUCTURE – NATIONAL ROUTE 2 PANAMERICAN HIGHWAY (RN2)

This project involves the risk assessment of road infrastructure, specifically National Route 2 (Pan-American Highway), against multiple hazards including earthquakes, flooding, volcanic eruptions, and landslides.

3.1 Exposure Models

The portfolio for National Route No. 2 is developed from georeferenced information that includes vector geometric representation (point or line type) and attributes that enable the characterization of the elements. Each portfolio includes, at a minimum, a georeferenced geometry, an estimate of the replacement economic value of the element, and a classification that allows its association with the corresponding vulnerability function.

In this project, the components considered are the roads and bridges located along the route. For the characterization of each component, the main source of information is the data published by LANAMME-UCR, an academic entity attached to the School of Civil Engineering at the University of Costa Rica, which performs applied research and technical monitoring functions of the national road network.

The following sections present the portfolios developed for National Route No. 2. Each case describes the available attributes for the characterization of the exposed elements and the procedure followed for the generation of each portfolio. Likewise, a coding system has been developed for all infrastructure elements considered in this study. Although the coding is explained in each section, a general code directory has been included in Annex A.2 for reference.

3.1.1 Roadway

The road portfolio consists of the road sections belonging to Costa Rica's National Road Network (RVN), represented in vector polyline format. These geometries come from the official spatial database published by LANAMME-UCR. This database includes a variety of technical attributes that are key for both defining physical vulnerability and estimating the economic replacement value of road segments.

Below are the main attributes used, the categories they comprise, and their role within the exposure model:

- Natural terrain slope (TERRENO): This attribute classifies the terrain slope on which the road is built, in the following categories:
 - Flat [1]: slope between 0% and 5%
 - Slightly undulating [2]: slope between 6% and 14%
 - Very undulating [3]: slope between 15% and 25%
 - Mountainous [4]: slope greater than 25%

The natural ground slope corresponds to the slope of the road's cross section, calculated within a buffer width around the alignment that corresponds to the right-of-way of the section.

The classification presented allows differentiation between road profiles in flat and mountainous areas, which directly affects the selection of associated structural typologies. For example, in areas with steeper slopes, the presence of fills, cut slopes, or retaining structures is considered —factors that influence both the physical vulnerability and economic valuation of the road (see Figure 50).

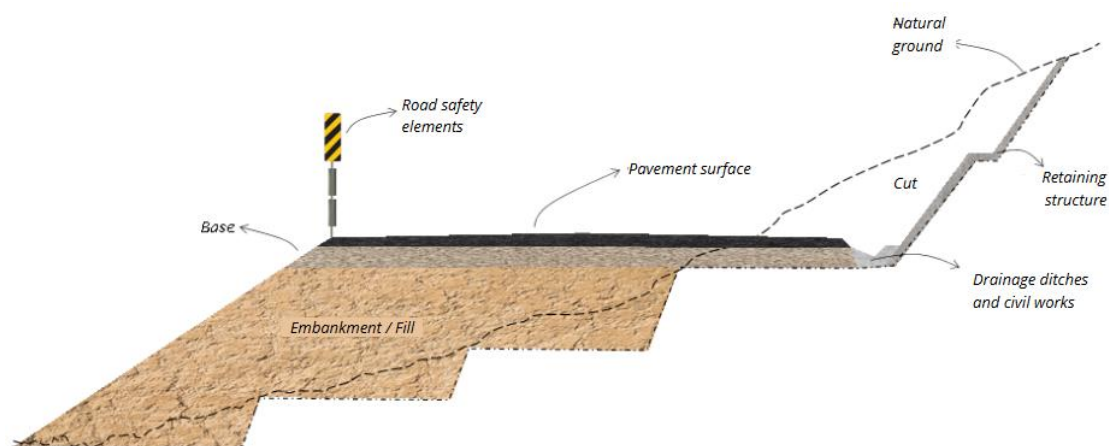


Figure 50. Cross-section of a roadway in a mountainous profile.

- Running surface (SUPERFICIE): Defines the type of material present on the upper layer of the roadway. Although most segments in the study area feature asphalt, two segments with concrete surfaces were identified, which alters the unit replacement cost.
- Paved surface width (ANCHO_SUP): Allows for a more precise calculation of the intervention area in each cross-section, directly affecting the economic valuation of the roadway segment.
- Shoulder width (ANCHO_ESP): While not intended for direct vehicular circulation, the shoulder is an integral part of the road profile and shares the same pavement structure as the running surface. Therefore, it must be included in the dimension and cost calculations.

Although the database contains other additional attributes — such as alignment slope, visibility, or signage condition — these are not considered relevant at this stage of the model, which is focused on estimating structural vulnerability and direct economic valuation of the infrastructure.

In this project, the original roadway segments were subdivided into sections with a maximum length of 25.0 meters to achieve a more accurate representation of exposure within the risk assessment framework. As part of this process, the slope was recalculated for each newly generated segment and reclassified according to the previously defined categories.

Based on the described technical attributes — type of running surface and natural terrain slope — a roadway classification typology was developed using the format: RN_R#_S#, where RN refers to National Route, R# represents the running surface category, and S# corresponds to the natural slope category.

3.1.1.1 Economic Valuation

For the estimation of the economic replacement value of the road segments, reference was made to LANAMME-UCR reports from 2016 and 2017 (LanammeUCR. 2016 a, b, c; LanammeUCR. 2017 a, b, c),, which calculated asset values based on standard pavement structures used in the cantonal road network.

Based on these values and considering an increase in the thickness of the subbase, base, and asphalt surface layers, an adjusted unit value was defined for pavements corresponding to the National Road Network. The resulting value was \$97,100 per square meter, calculated based on the width of the road profile and the length of each segment.

Additionally, adjustment factors were applied based on terrain slope, given its impact on stabilization activities (such as cuts and fills) and the need for increased structural thickness—particularly in the subbase layer—to ensure proper vertical alignment of the roadway.

As a result of this process, the total economic valuation of the 355.3 km of road analyzed is estimated at \$304,447,125,000. Figure 51 shows the road network classified by the natural terrain slope.



Figure 51. Map of RN2 roadways

3.1.2 Bridges

The bridge portfolio is composed of elements identified in the database titled *Bridges of the National Road Network*, developed by LANAMME-UCR. This database includes a variety of geometric, structural, and construction-related attributes that are key for characterizing physical vulnerability and, in some cases, for estimating their economic valuation.

In the case of National Route No. 2, a total of 65 bridges were identified, as shown in Figure 52, all of which contain a range of relevant attributes for structural classification.



Figure 52. Location of bridges of the RVN in the RN2.

Below is a description of the main attributes used, their categories, and their relevance within the exposure model:

- Total length (LARGO_TOTA) and total width (ANCHO_TOTA) of the bridge: These are key geometric attributes for economic valuation, allowing for the calculation of the total deck area and the determination of a replacement cost per square meter.
- Span class (CLASE_CAR): This refers to the classification of the bridge's maximum span (i.e., the longest segment without intermediate support). The categories are:

- Less than 15 m [1]
- Between 15 m and 35 m [2]
- Between 35 m and 50 m [3]
- Between 50 m and 100 m [4].

This attribute is highly relevant for seismic vulnerability assessment, as span length directly affects structural performance under dynamic loads.

- Number of spans (NUM_CLARO): Combined with the span class, this attribute helps understand the structural complexity and load-bearing scheme of the bridge based on its geometric configuration.
- Structural continuity (CONT_ESTRU): Indicates whether the bridge spans are continuous or simply supported. The recorded categories are:
 - Continuous (single span)
 - Continuous
 - Simply supported

Continuity affects the distribution of forces and therefore impacts structural vulnerability.

- Bridge material (MATERIAL_P): Describes the primary material used in the bridge's structure. This is crucial for both physical vulnerability (due to differences in mechanical behavior) and economic valuation. Identified categories include:
 - Prestressed concrete [1]
 - Reinforced concrete [2]
 - Steel [3]
- Type of superstructure (TIPOSUPER): Refers to the structural system that supports the bridge deck. Categories found along the route include:
 - Slab [1]
 - Multiple girders [2]
 - T girders [4]
 - Rigid frame [7]
- Truss (underpass) [10]

This attribute is directly related to structural stiffness and performance under extreme events.

- Physical condition of the superstructure (SUP_ESTR) and substructure (SUB_ESTR): Both are rated from 1 to 5, where 1 indicates no intervention is required and 5 indicates major intervention is needed. A composite structural condition index is derived from the sum of both values, with the following categories:
 - No information [0]
 - Good [B], sum between 1 and 4
 - Fair [R], sum between 5 and 7
 - Poor [M], sum between 8 and 10

Although the database includes other technical attributes that could provide a more detailed characterization of each bridge, they were not included in this model. This is because overly specific

classification increases heterogeneity without significantly improving the representation of vulnerability. Additionally, the goal of this project is not to conduct individualized assessments, but rather to build a robust representation of the aggregated portfolio, capturing the main variables that influence performance under hazards.

Based on the selected attributes, a structural typology was constructed using the following format:

C#_NC#_CT#_MT#_ES##_EST-X, where:

- C#: Maximum span classification
- NC#: Number of spans
- CT#: Type of structural continuity
- MT#: Bridge material
- ES##: Type of superstructure
- EST-X: Combined condition of the structure (substructure + superstructure)

3.1.2.1 Economic Value

For the estimation of the replacement economic value of the bridges, reference was made to the reports from LANAMME-UCR from the years 2016 and 2017, which establish unit values per square meter for bridges built with concrete and steel. At present value, these unit costs amount to \$1,757,000/m² for concrete bridges and \$1,952,000/m² for steel bridges.

Based on these values, the economic valuation of each bridge was calculated by considering both the structural material and the geometric dimensions —length and width— of each structure.

As a result, the total estimated economic valuation of the 65 bridges located along National Route No. 2 amounts to \$66,788,258,800.

3.2 Vulnerability Models

This section presents the physical vulnerability analysis of the infrastructure elements included in the exposure model for National Route No. 2. The vulnerability assessment serves as a critical input for risk estimation, as it allows the identification of the expected degree of impact on different components of the system in the event of natural hazards such as earthquakes and floods.

The adopted procedure is based on the technical classification of exposed elements, using physical, geometric, and structural attributes derived from official databases, particularly the one generated by LANAMME-UCR. These classifications enable the grouping of elements into structural typologies with homogeneous characteristics, to which specific vulnerability functions can be assigned.

The assignment of vulnerability curves follows two methodological approaches:

- Technical fragility curves sourced from the HAZUS Earthquake Model Manual (FEMA, 2024), adjusted to local conditions.
- Functions derived from structural archetypes, developed based on expected damage parameters for representative typologies.

The following sections detail the classification categories used for each portfolio (roads and bridges), as well as the vulnerability curves assigned to each structural typology for each hazard considered in the project.

Landslides and lahars are considered in this consultancy as very high-energy local events; therefore, a binary vulnerability model is applied. This means that once the event reaches the exposed element, 100% of its replacement value is lost. Consequently, no vulnerability functions are included for these two hazards.

Regarding floods, the scope of this consultancy includes fluvial and pluvial flooding, following the modeling approaches described in the Inception Report (Section 6.3). Therefore, flash floods, which do not correspond to river overflow phenomena, are not included within the modeling scope.

3.2.1 Roadways

The road portfolio of National Route No. 2 includes four classification typologies for the elements, to which one seismic vulnerability function, four flood vulnerability functions, and one volcanic ash vulnerability function were assigned, as shown in Table 17.

Table 17. Road typologies of RN2 and corresponding vulnerability curves.

Classification	Longitude (km)	Earthquake	Flood	Volcano - ash
RN_R1_S1	59.6	EQ_HRD1	FL_R1_S1	ASH_RD
RN_R1_S2	118.7	EQ_HRD1	FL_R1_S2	ASH_RD
RN_R1_S3	65.7	EQ_HRD1	FL_R1_S3	ASH_RD
RN_R1_S4	111.3	EQ_HRD1	FL_R1_S4	ASH_RD

The vulnerability function assigned for the seismic hazard corresponds to a curve for national roads, developed from the fragility curve parameters of the HAZUS Seismic Model Manual. The damage ratios used in this function are based on the upper limits of the ranges suggested by FHWA (2006), adopting values of 3% for slight damage, 15% for moderate damage, and 40% for severe damage. This selection aims to represent conservative conditions of the structural behavior of the national road network under seismic events.

The flood vulnerability curves, in turn, were developed based on road archetypes representing different terrain slope ranges, as defined by the LanammeUCR classification. Each archetype integrates the vulnerability curves of the components that make up the road—such as the asphalt layer, base, and subgrade—whose analytical functions were estimated from material loss calculations under surface flow and infiltration conditions specific to each slope category. In this way, the resulting curves reflect the expected variation in the magnitude of damage as a function of terrain slope and flood intensity.

In the case of volcanic ash hazard, the vulnerability function used corresponds to a curve associated with road operability losses as a function of the accumulated ash thickness on the pavement surface. This function allows for estimating the progressive reduction in road corridor functionality as volcanic material accumulation increases.

Figure 53 presents the seismic vulnerability function assigned to the roads.

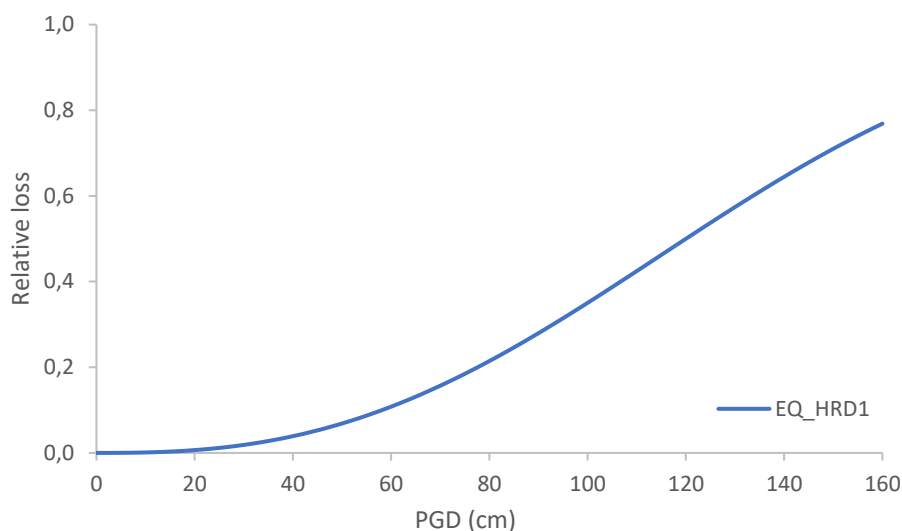


Figure 53. Seismic vulnerability curve for a national road.

Figure 54 presents flood vulnerability function assigned to each road typology.

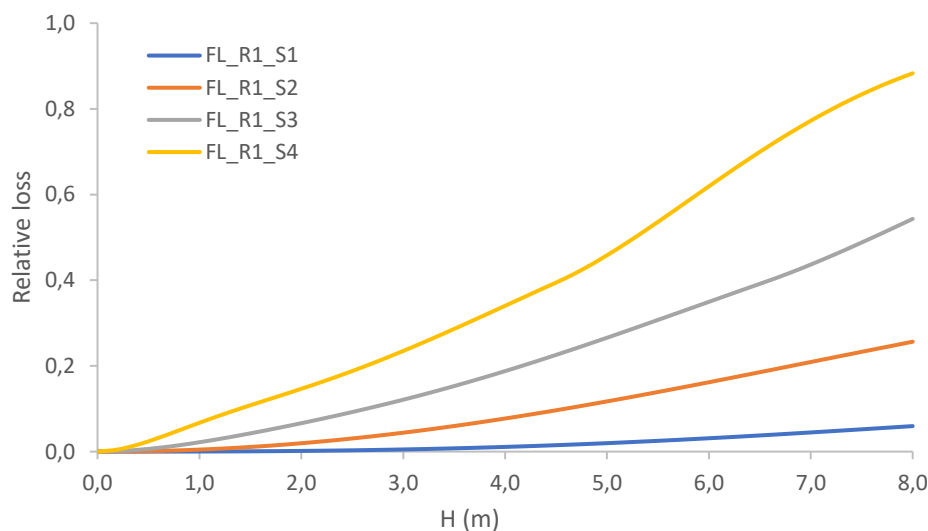


Figure 54. Flood vulnerability curves for paved road typologies.

Since volcanic ashfall typically does not cause direct structural damage to the road surface or pavement structure, its main impact is manifested in terms of loss of operability. In this regard, the methodology adopted in this study is based on a relative asset-based approach, which allows for the quantification of economic losses as a proportion of the replacement value of the road segment, based on the duration of closure caused by ash accumulation.

To do this, a relationship is established between the accumulated thickness of volcanic ash and the estimated operational interruption time of the road, considering standard conditions of institutional response and operability. Subsequently, the closure time is translated into a relative asset loss, proportional to the total economic value of the segment, assuming a useful life of 20 years (equivalent to 7,300 days). The relative loss is calculated using the following formula (Cardona et. al. 2021):

$$\text{Relative loss} = \frac{\text{Days of closure}}{7300 \text{ days}}$$

The relationship between closure days, intensity, and closure duration is presented in Table 18.

Table 18. Relationship between ash thickness and closure times.

Thickness (cm)	Category	Thickness of the category (cm)	Operational impact on the road	Days of closure (days)
0 a 1	Minor	0.5	No impact	0.00
1 a 5	Moderate	2.5	Reduced speed, minor cleanup	0.25
5 a 10	High	7.5	Temporary partial closure (from hours up to 1 day)	1.00
> 10	Severe – very high	15.0	Prolonged full closure (1 day to several days))	3.00

This approach allows for consistency with the structure of the exposure model and facilitates the integration of this effect into the vulnerability functions used for risk estimation. Figure 33 shows the vulnerability curve of the road to volcanic ashfall.

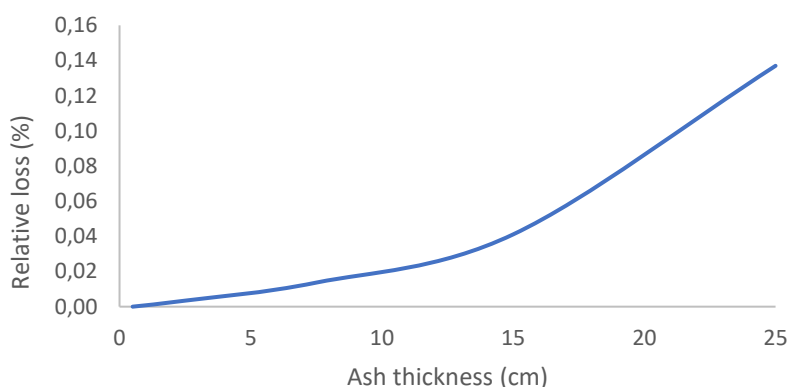


Figure 55. Ashfall vulnerability curve for roadways.

3.2.2 Bridges

The bridge portfolio of National Route No. 2 comprises 37 classification typologies, to which 25 seismic vulnerability functions were assigned, as presented in Table 20. The seismic vulnerability functions are based on fragility curves as a function of spectral acceleration for a period of 0.1 s included in the HAZUS Seismic Model Technical Manual (FEMA, 2024). The set of seismic vulnerability functions are presented in Figure 56. The bridge typologies are those defined for the exposure model (see Section 3.1.2).

With regard to flooding, an important clarification should be made. From the hazard perspective, the scope of the GRMA Costa Rica project includes only slow-onset flooding caused by river overbank flow. That is, other phenomena—particularly debris flows—are not included within the scope of this work. The modeling of debris flows requires additional modeling components that are not included in the methodological approach adopted here, and which relate to aspects such as mixed flow discharge generated by intense rainfall in catchments, the rheology and hydraulics of that mixed flow, and its impact on critical structures such as bridges, where local scour of piers contributes significantly to the final impact. Addressing a phenomenon of this nature requires a specific methodological approach that is very different from the one adopted in this work.

Given the limited scope of flood modeling adopted here, it is appropriate to distinguish between direct physical damage and operational damage to bridges, following an approach similar to that implemented for road segments and presented in Section 3.2.1. Slow-onset flooding due to river overbank flow is not expected to cause physical damage to bridges; therefore, a no-damage function was assigned with respect to direct loss.

Operational loss, which refers to possible interruptions in bridge service due to flooding of the road segment, is addressed using an approach similar to that previously presented for road segments affected by volcanic ash; that is, it is based on assuming service interruption times. Under this approach, the closure time is translated into a relative asset loss, proportional to the total economic value of the bridge, assuming a service life of 20 years (equivalent to 7,300 days). The relationship between days of closure, flood intensity, and closure duration is presented in Table 19.

Table 19. Relationship between flood and closure times in bridges.

Flood depth above deck level (m)	Operational impact to road	Closure time (days)	Relative loss (%)
0 a 0.1	Minor speed reduction	0.00	0
0.1 a 0.3	Moderate speed reduction	0.25	0.003
0.3 a 0.5	Short closure (less than 1 day)	0.5	0.007
> 0.5	Long closure (greater tan 1 day)	2.00	0.03

With regard to volcanic ash, bridges are not considered to be physically vulnerable to the accumulation of deposits; therefore, the potential effects are limited to a loss of functionality. This loss is treated in the same manner as for the road network portfolio, as it is primarily associated with the loss of operability of the roadway segments.

Table 20 presents the vulnerability functions assigned to each typology, according to the type of hazard.

Table 20. RN2 bridges typologies and corresponding vulnerability curves.

Classification	Bridges	Earthquake	Flood	Volcano - ashfall
C1_NC1_CT1_MT2_ES04_EST-B	1	EQ_HWB10_B	Operational	Operational_roads
C1_NC1_CT1_MT2_ES04_EST-R	3	EQ_HWB10_R	Operational	Operational_roads
C1_NC1_CT1_MT2_ES07_EST-R	3	EQ_HWB22_R	Operational	Operational_roads
C1_NC3_CT2_MT2_ES01_EST-B	1	EQ_HWB10_NC3_B	Operational	Operational_roads
C1_NC3_CT2_MT2_ES01_EST-R	3	EQ_HWB10_NC3_R	Operational	Operational_roads
C2_NC1_CT0_MT3_ES02_EST-R	1	EQ_HWB14_R	Operational	Operational_roads

Classification	Bridges	Earthquake	Flood	Volcano - ashfall
C2_NC1_CT1_MT1_ES04_EST-R	4	EQ_HWB17_R	Operational	Operational_roads
C2_NC1_CT1_MT2_ES04_EST-R	1	EQ_HWB10_R	Operational	Operational_roads
C2_NC1_CT1_MT3_ES02_EST-B	1	EQ_HWB12_B	Operational	Operational_roads
C2_NC2_CT0_MT1_ES02_EST-B	2	EQ_HWB19_B	Operational	Operational_roads
C2_NC2_CT0_MT1_ES02_EST-R	2	EQ_HWB19_R	Operational	Operational_roads
C2_NC2_CT0_MT3_ES02_EST-0	1	EQ_HWB14_R	Operational	Operational_roads
C2_NC2_CT0_MT3_ES02_EST-B	1	EQ_HWB14_B	Operational	Operational_roads
C2_NC3_CT0_MT2_ES02_EST-R	2	EQ_HWB11_NC3_R	Operational	Operational_roads
C2_NC3_CT0_MT2_ES04_EST-B	1	EQ_HWB11_NC3_B	Operational	Operational_roads
C2_NC3_CT0_MT2_ES04_EST-R	4	EQ_HWB11_NC3_R	Operational	Operational_roads
C2_NC3_CT0_MT3_ES02_EST-B	2	EQ_HWB14_NC3_B	Operational	Operational_roads
C2_NC3_CT0_MT3_ES02_EST-R	5	EQ_HWB14_NC3_R	Operational	Operational_roads
C2_NC3_CT2_MT2_ES04_EST-B	1	EQ_HWB10_NC3_B	Operational	Operational_roads
C2_NC3_CT2_MT2_ES04_EST-R	5	EQ_HWB10_NC3_R	Operational	Operational_roads
C2_NC3_CT2_MT2_ES07_EST-B	2	EQ_HWB22_NC3_B	Operational	Operational_roads
C2_NC3_CT2_MT3_ES02_EST-B	1	EQ_HWB12_NC3_B	Operational	Operational_roads
C2_NC3_CT2_MT3_ES02_EST-M	1	EQ_HWB12_NC3_M	Operational	Operational_roads
C2_NC3_CT2_MT3_ES02_EST-R	1	EQ_HWB12_NC3_R	Operational	Operational_roads
C2_NC4_CT0_MT2_ES04_EST-R	1	EQ_HWB11_NC4_R	Operational	Operational_roads
C2_NC4_CT0_MT3_ES02_EST-B	1	EQ_HWB14_NC4_B	Operational	Operational_roads
C2_NC4_CT0_MT3_ES02_EST-R	3	EQ_HWB14_NC4_R	Operational	Operational_roads
C2_NC4_CT2_MT3_ES02_EST-R	1	EQ_HWB12_NC4_R	Operational	Operational_roads
C3_NC1_CT0_MT1_ES02_EST-B	1	EQ_HWB19_B	Operational	Operational_roads
C3_NC1_CT1_MT1_ES02_EST-B	1	EQ_HWB17_B	Operational	Operational_roads
C3_NC2_CT0_MT3_ES10_EST-R	1	EQ_HWB28	Operational	Operational_roads
C3_NC3_CT0_MT3_ES10_EST-M	1	EQ_HWB28	Operational	Operational_roads
C3_NC3_CT0_MT3_ES10_EST-R	2	EQ_HWB28	Operational	Operational_roads
C4_NC1_CT0_MT1_ES02_EST-R	1	EQ_HWB19_R	Operational	Operational_roads
C4_NC3_CT0_MT3_ES10_EST-M	1	EQ_HWB28	Operational	Operational_roads
C4_NC3_CT2_MT3_ES10_EST-R	1	EQ_HWB28	Operational	Operational_roads
C4_NC4_CT2_MT3_ES10_EST-M	1	EQ_HWB28	Operational	Operational_roads

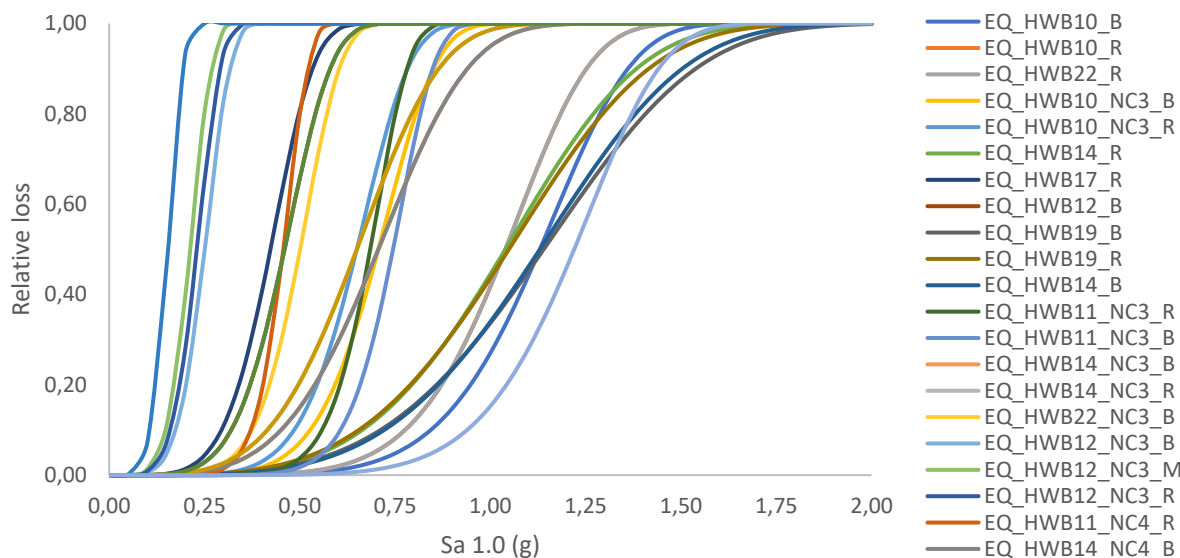


Figure 56. Seismic vulnerability curves for bridges typologies⁷.

⁷ Sa 1.0 corresponds to the spectral acceleration for a fundamental vibration period of 1 second.

4 OPERATIONAL PROJECT 2: FLOOD AND DROUGHT RISK FOR SMALL AND MEDIUM-SCALE AGRICULTURAL PRODUCERS

This project consists of a climate risk assessment, considering flooding, heavy rainfall, and drought, for the national portfolio of coffee, sugarcane, and extensive grazing beef cattle, mainly focused on small and medium-scale producers, particularly those implementing NAMA practices. However, as added value, the entire national portfolio of the mentioned products is also modeled in order to visualize the contrast between NAMA and non-NAMA producers, as agreed directly with the project's Technical Working Group.

4.1 Exposure Models

To define the characteristics of each portfolio for risk modeling purposes, both official and unofficial data were collected and analyzed regarding productive areas, product types, yield, and average annual production. *The Inception Report* of this study includes a compilation of the information sources consulted. This section highlights the sources from which the data used to build the models were extracted.

In general, the exposure models for the productive systems included in this project can be summarized into three main layers:

- *Soil layer*: contains parameters that define the soil from an agronomic perspective. This is a required input for modeling risk in crop production and extensive livestock systems.
- *Crop layer*: contains parameters related to the development and productivity of crops — in this case, specifically coffee and sugarcane.
- *Livestock layer*: includes, on one hand, the distribution and characteristics of pastures, and on the other, the distribution of animals by herd, according to age and physiological condition.

4.1.1 Soil Layer

In order to characterize the physical properties relevant for risk analysis across Costa Rican territory, dominant soil textures were assigned to each of the soil orders present in the country. This was based on the *Soil Map of Costa Rica* at a 1:200,000 scale, developed by the Ministry of Agriculture and Livestock (MAG) in collaboration with MINAE and CATIE (MAG-MINAE-CATIE, 2002). This map classifies the country's soils according to the USDA *Soil Taxonomy* system, allowing each cartographic unit to be linked to well-documented physical characteristics found in scientific literature.

The assignment of textures was done using typical properties associated with each soil order, according to widely accepted pedological descriptions. These properties include horizon development, clay content, permeability, and the degree of profile evolution. Figure 57 presents the soil map by orders.

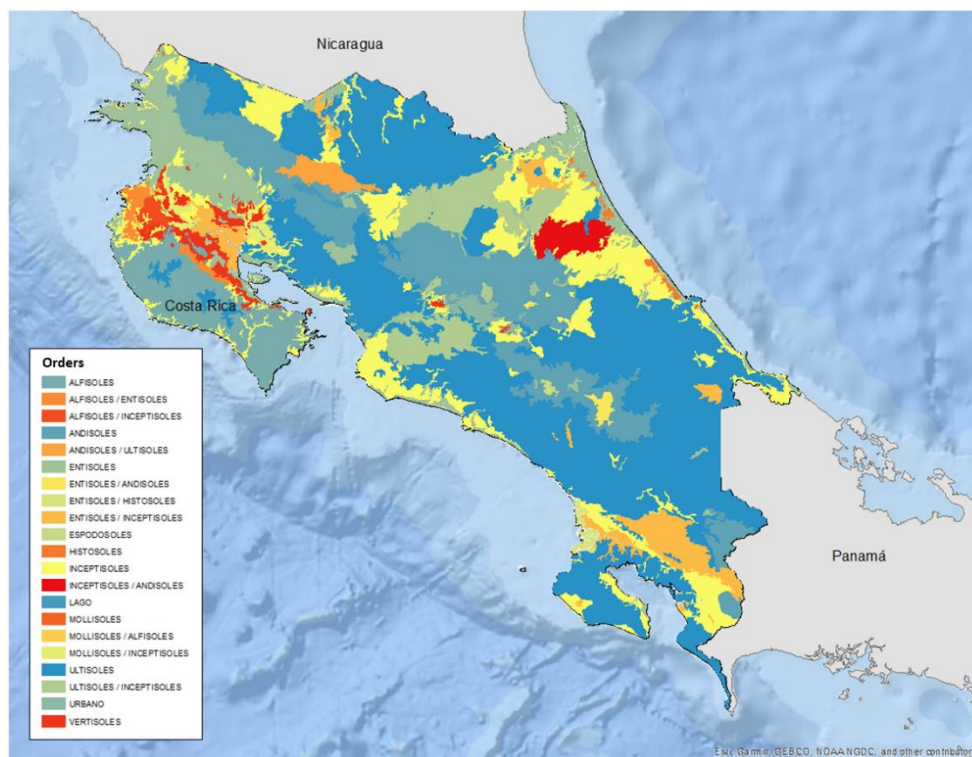


Figure 57. Map of soil orders (MAG-MINAE-CATIE, 2002).

Summary of criteria used to define soil textures:

- *Alfisols and Ultisols*: These soils have well-developed B horizons with clay accumulation, typically resulting in clay loam or silty clay loam textures and medium to low permeability (Soil Survey Staff, 2014; Brady & Weil, 2016).
- *Entisols*: Young soils with minimal horizon development, often associated with alluvial or colluvial materials. They tend to have sandy or sandy loam textures (Soil Survey Staff, 2014; Buol et al., 2011).
- *Inceptisols*: Soils with intermediate development, typically with loam textures and good infiltration capacity (Brady & Weil, 2016).
- *Andisols*: Common in volcanic areas, these soils have high porosity and low bulk density, generally exhibiting loam or sandy loam textures, with high water retention capacity (FAO, 1998; Brady & Weil, 2016).
- *Mollisols*: Soils rich in organic matter, typically with stable granular structure and silty loam textures (Buol et al., 2011).
- *Vertisols*: Characterized by high content of expansive clay (e.g., montmorillonite), these soils have clay textures and very limited permeability (Soil Survey Staff, 2014).
- *Histosols*: Organic soils often saturated with water, commonly with silty textures due to organic matter accumulation in poorly drained environments (FAO, 1998).
- *Spodosols*: Found in sandy areas with podzolization, associated with sandy loam textures (Soil Survey Staff, 2014).

- *Urban areas and water bodies:* Considered impervious surfaces, in line with standard hydrological modeling practices and hydrologic group classifications (Brady & Weil, 2016).

The assignment presented above is summarized in the following table.

Table 21. Summary of texture assignment to soil orders

Soil Order	Assigned Texture
ALFISOLS	Clay loam
ALFISOLS / ENTISOLS	Sandy clay loam
ALFISOLS / INCEPTISOLS	Loam
ANDISOLS	Loam
ANDISOLS / ULTISOLS	Clay loam
ENTISOLS	Sandy loam
ENTISOLS / ANDISOLS	Sandy loam
ENTISOLS / HISTOSOLS	Silty
ENTISOLS / INCEPTISOLS	Loam
SPODOSOLS	Sandy loam
HISTOSOLS	Silty
INCEPTISOLS	Loam
INCEPTISOLS / ANDISOLS	Loam
LAKE	Impermeable
MOLLISOLS	Silty loam
MOLLISOLS / ALFISOLS	Clay loam
MOLLISOLS / INCEPTISOLS	Loam
ULTISOLS	Clay loam
ULTISOLS / INCEPTISOLS	Silty clay loam
URBAN	Impermeable
VERTISOLS	Clay

Defining textures based on soil orders enables consistent integration of textural properties into hydrologic group analysis and runoff modeling, supporting effective simulation of water response processes. Figure 58 shows the nationally assigned soil textures, and Table 22 presents the soil modeling parameters associated with each texture type.

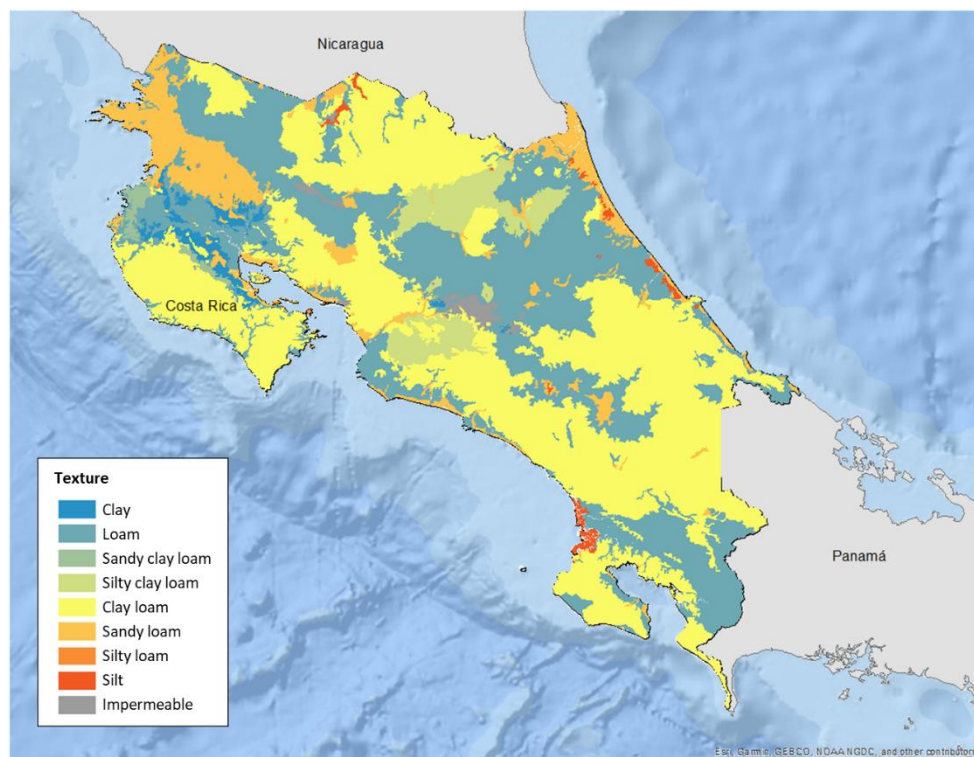


Figure 58. Assigned soil texture map (Own elaboration).

Table 22. Parameters used in modeling according to soil texture (Taken from Raes et al. 2011)

Texture	TXT	SAT ⁸ [%vol]	FC [%vol]	PWP [%vol]	TAW [%vol]	Ksat [mm/d]	Group
Sand	0	36	13	6	70	3000	A
Loamy sand	1	38	16	8	80	2200	A
Sandy loam	2	41	22	10	120	1200	A
Loam	3	46	31	15	160	500	B
Silty loam	4	46	33	13	200	575	B
Silt	5	43	33	9	240	500	B
Sandy clay loam	6	47	32	20	120	225	C
Clay loam	7	50	39	23	160	125	C
Silty clay loam	8	52	44	23	210	150	C
Sandy clay	9	50	39	27	120	35	D
Silty clay	10	54	50	32	180	100	D
Clay	11	55	54	39	150	35	D
Impermeable	12	0.5	0.3	0.1	2	0	D
Water	-1	0.5	0.3	0.1	2	0	D

⁸ SAT: Saturation. FC: Field Capacity. PWP: Permanent Wilting Point. TAW: Total Available Water. Ksat: Saturated hydraulic conductivity of the soil. Group: Hydrologic classification group. For further details regarding the role of each parameter in the calculation method, the reader is invited to consult the Inception Report of this consultancy, section 9.4.

4.1.2 Crop Layer

The crop layer represents the spatial distribution of agricultural crops under consideration—coffee and sugarcane—and groups the productive units over which risk is assessed. To construct this layer, data from the VI National Agricultural Census (INEC, 2014) and the most recent National Agricultural Survey (ENA, 2023) were used. In addition, altitude ranges suitable for each crop (EOSDA, 2025) and the country's agricultural land cover maps (SNIT, 2017; SNIT, 2018; Vargas, M., 2020) were considered.

Thus, a set of cultivated land units is defined, representing the full portfolio's spatial distribution. Each unit corresponds to a polygon on the agricultural land cover map, and a soil type is assigned based on its geographic location. Figure 59 shows the spatial distribution of the polygons that make up the exposure model for each crop.

Coffee cultivation spans across 64 cantons, covering approximately 74,000 hectares. Sugarcane is present in 59 cantons, with 56,619 hectares planted as of 2023 (ENA, 2023). According to the Agricultural Census (INEC, 2014), by 2014, 89.4% of the coffee-growing area and 96.5% of the sugarcane area were in their productive age. These figures are used to estimate the percentage of the total area currently assumed to be in active production.

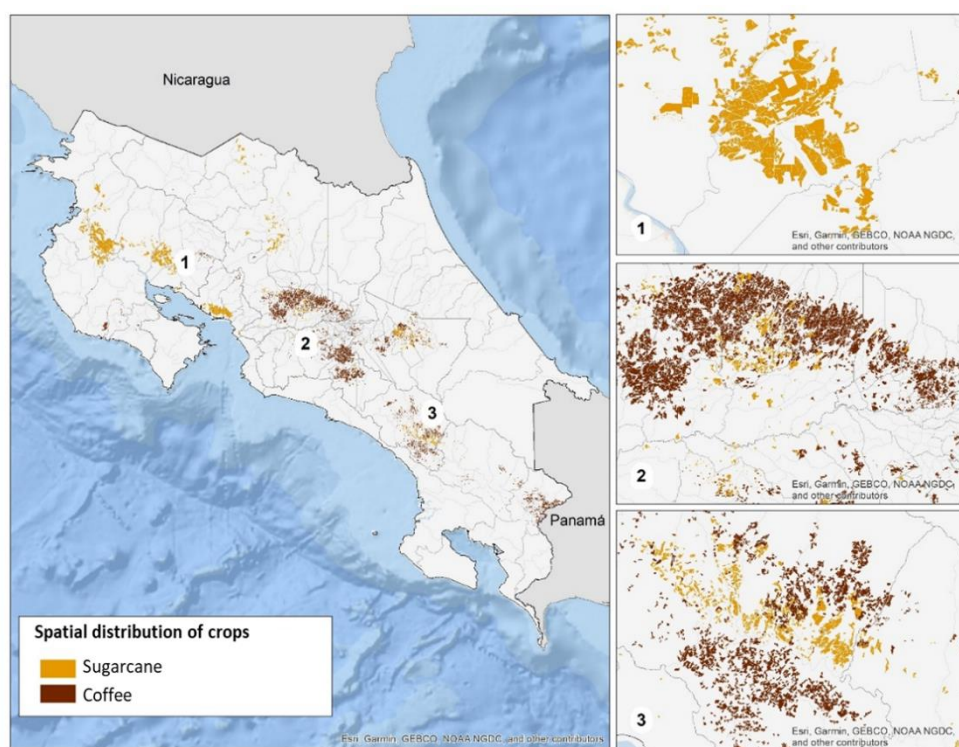


Figure 59. Spatial distribution of sugarcane and coffee (Information extracted from SNIT, 2018; Vargas, 2020).

According to LAICA (2022), there are 7,078 sugarcane producers in Costa Rica, of which 97.7% are small or medium-sized. Since the exact location of each producer was not available, a spatial analysis was carried out based on cultivation polygons and planted area, preserving the relationship between producer and total surface area. As a result, a set of georeferenced data was obtained, representing approximately 7,000 productive units. Figure 60 shows the planted area of sugarcane, while Figure 61 displays the spatial distribution of producers, classified by size (MAG, 2013); small (< 25 ha), medium (25–75 ha) and large (> 75 ha).

Similarly, ICAFE (2024) reports 25,549 coffee producers in Costa Rica, of whom 84.8% deliver fewer than 100 fanegas, highlighting a high concentration of small producers (ICAFE, 2023). For the coffee portfolio, georeferenced data were used to represent around 25,000 productive units. Figure 62 illustrates the planted area with coffee, and Figure 63 shows the location of coffee producers, also classified into three categories (MAG, 2013): small (< 15 ha), medium (15–50 ha) and large (> 50 ha).

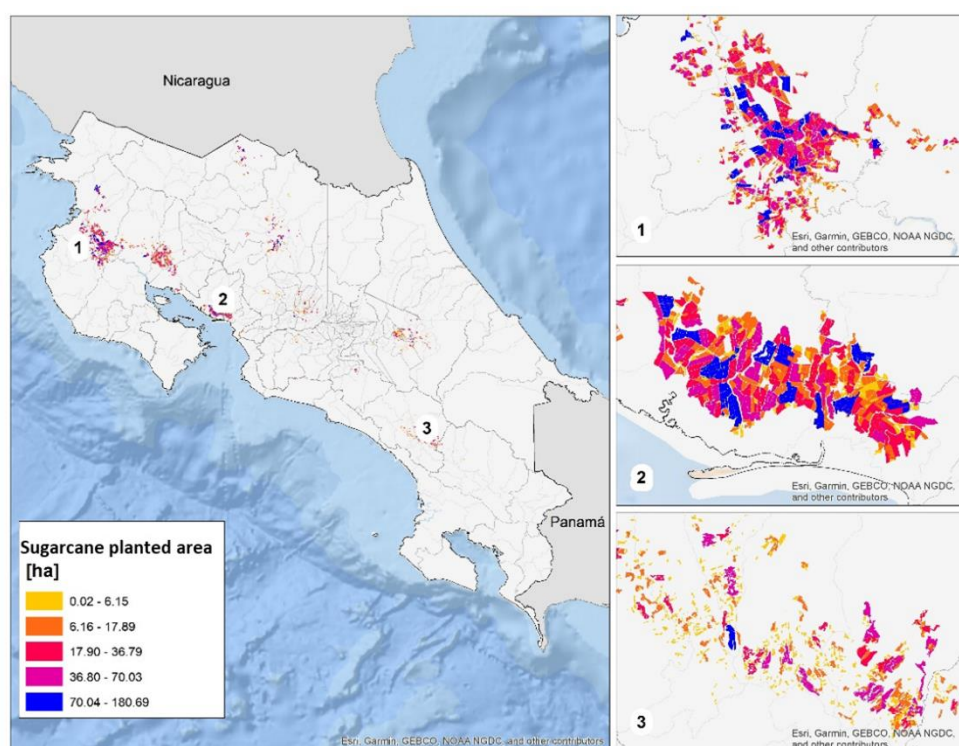


Figure 60. Distribution of sugarcane cultivated units (Own elaboration based on Vargas, 2020).

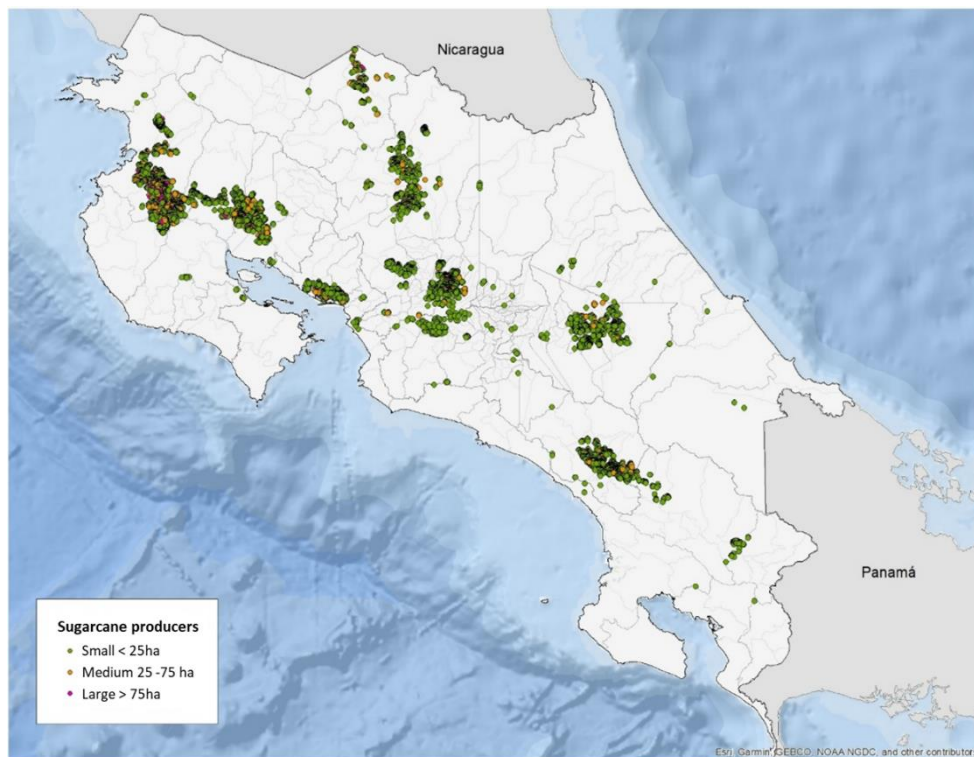


Figure 61. Sugarcane producers (Own elaboration based on Vargas, 2020).

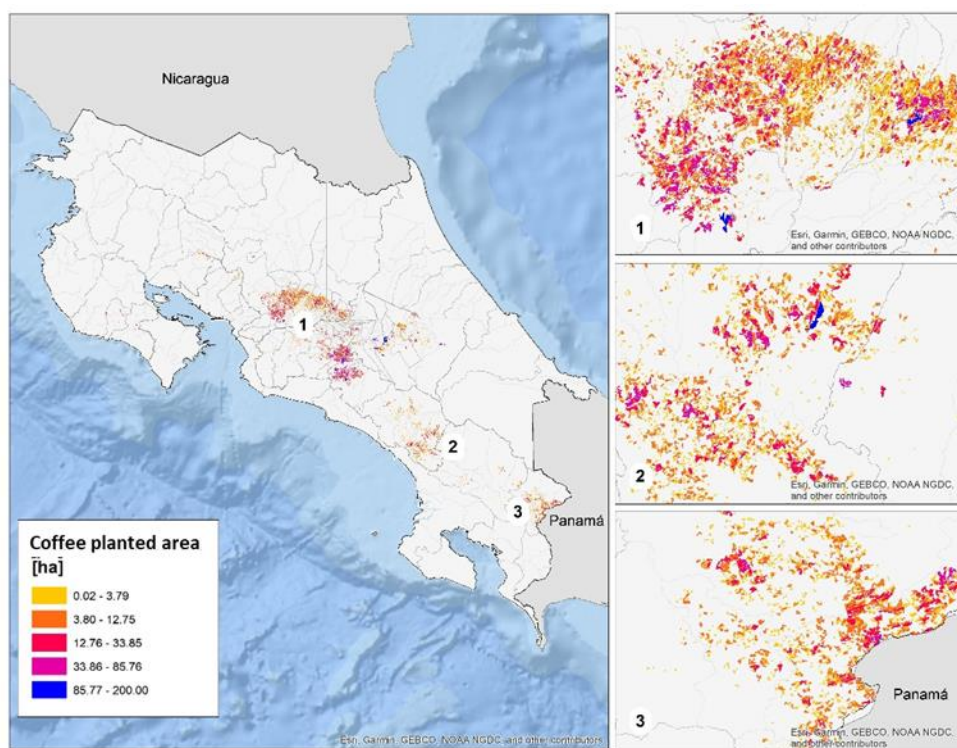


Figure 62. Distribution of coffee cultivated units (Own elaboration based on SNIT, 2018; Vargas, 2020).

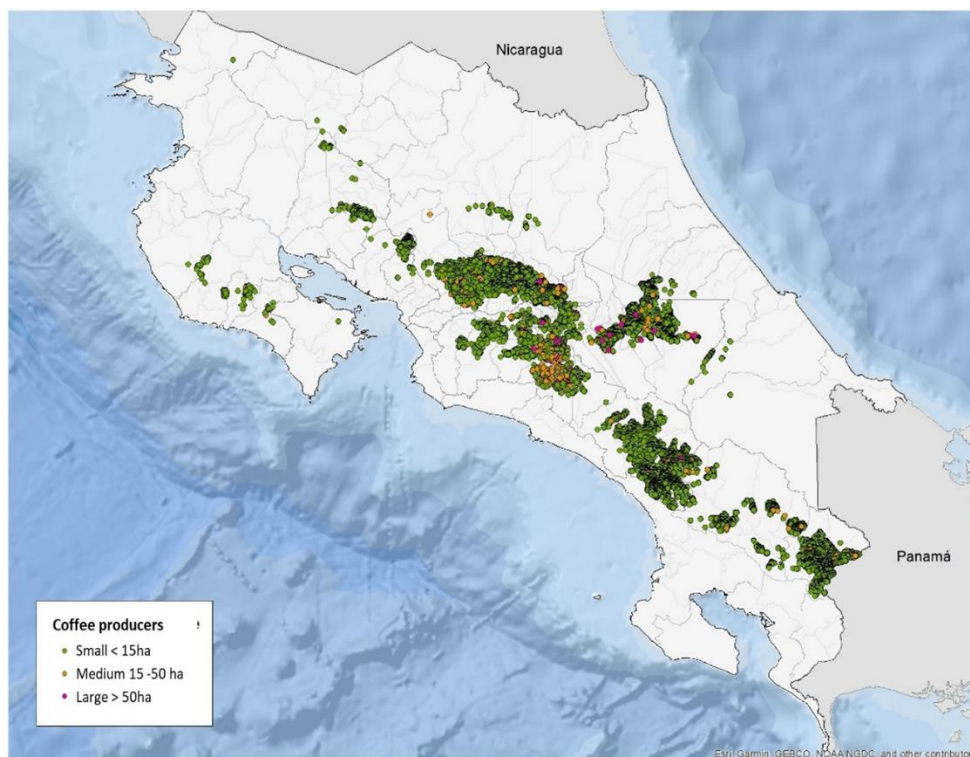


Figure 63. Coffee producers (Own elaboration based on SNIT, 2018; Vargas, 2020).

4.1.2.1 Yield and Production Cost

The selected agricultural products are valued based on the reported production prices (ICAFE & UEEM, 2025; SEPSA, 2025). Production costs include both direct and indirect expenses required to generate the agricultural product.

For coffee, agricultural production costs include the cost of the technological package (labor and inputs), direct costs such as harvesting and transportation, as well as other indirect costs, which include crop depletion, depreciation, maintenance, and administrative expenses (see Annex A.3). Table 23 presents the total production cost in Costa Rican colones (CRC) for different coffee yield levels.

Table 23. Coffee yield and production cost for 2025 (Information extracted from ICAFE & UEEM, 2025).

Yield fan/ha	Total cost of production CRC/fan
22.4	104,599.43
30.5	85,802.83
37.4	78,569.99
40	78,288.22

The production costs of sugarcane include mechanized or contracted tasks, manual labor (which covers social charges and labor insurance), inputs, and other costs such as transportation of inputs, administration, and contingencies (see Annex A.2). Table 24 presents the yield and total production cost for sugarcane.

Table 24. Sugarcane yield and production cost for 2025 (Information extracted from SEPSA, 2025).

Yield TCH ⁹	Total cost of production CRC/ton
65	25,663.22
60	15,864.75
50	18,298.71
40	21,549.62
30	27,234.50

4.1.2.2 Crop Seasonality

To model crop vulnerability, it is essential to have seasonal data specific to each region and crop. *Seasonality*, understood as the number of calendar days covering the development cycle (from planting to maturity), allows for the definition of crop phases. These data are used to correlate the daily evolution of the plant with precipitation and temperature series, in order to evaluate potential reductions in yield due to water deficit or excess.

In 2018, the Tropical Agricultural Research and Higher Education Center (CATIE) conducted a study identifying agricultural practices to mitigate the impact of adverse events on priority crops in Costa Rica, such as coffee and sugarcane. Of particular value in that study is the detailed specification of phenological cycle phases by production region, including cultivar varieties used, planting date, total cycle duration, and duration of each phase. Both coffee and sugarcane are classified as perennial crops.

Figure 63 illustrates the adjustments made to the months and duration intervals of each crop phase in the Brunca production region. This figure shows how the sugarcane cycle is distributed throughout the year, considering the climatic conditions of the region. Four main phases are identified, starting with the germination or sprouting phase (phase 1), followed by intermediate development phases (phases 2 and 3), and finalizing with the maturation phase (phase 4). The duration of each phase is influenced by the crop variety and local edaphoclimatic conditions.

Additionally, the diagram highlights the influence of the rainy season (April to November) on the first three phases, while the dry season (December to March) is favorable for the maturation phase. These phases were adapted by CATIE based on expert consultation and literature review.

⁹ Ton of cane per hectare

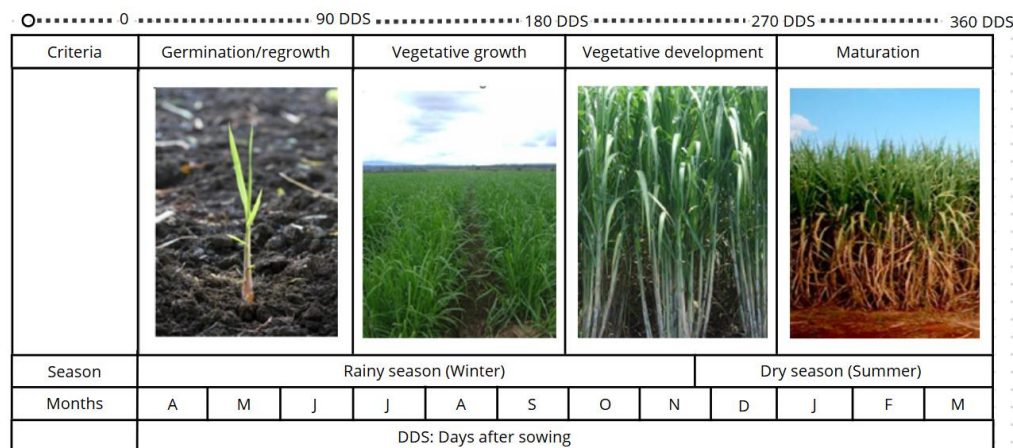


Figure 64. Phenological cycle phases of the sugarcane crop in the Brunca production region (CATIE, 2018).

Similarly, coffee cultivation presents a well-defined phenological cycle, although with a longer duration due to the particularities of its development. As an example, Figure 65 illustrates the adjustments made to the months and duration intervals of each phase in the Turrialba production region. It shows how the coffee phenological cycle develops over a period of approximately two years, influenced by the region's climatic conditions. The coffee cycle is divided into six main phases, starting with seed selection and preparation (phase 0) and concluding with the plant's natural dormancy and defoliation (phase 6), with the duration varying depending on the variety and local edaphoclimatic conditions.

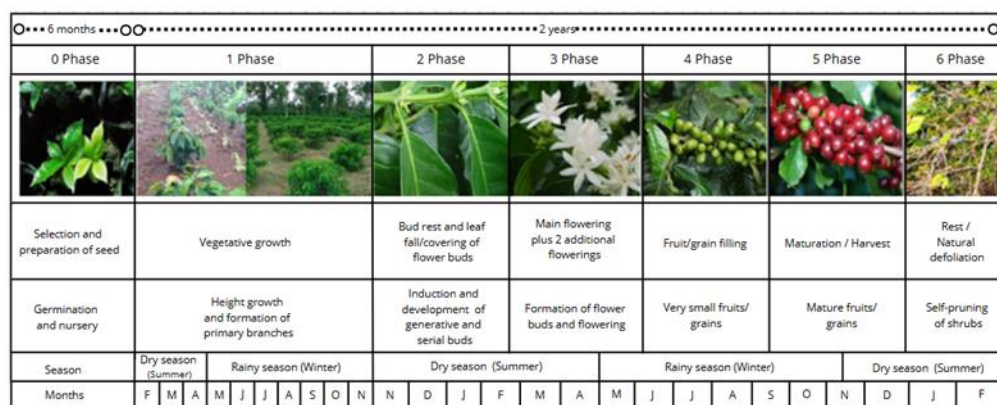


Figure 65. Phases of the Coffee Phenological Cycle in the Los Santos Production Region (CATIE, 2018).

4.1.3 Livestock Layer

The extensive cattle ranching risk model implemented consists of two submodels: one associated with pastures, in which grass development is simulated following the same principles as for agricultural products, and another associated with livestock, in which the demand and supply of feed for animals within a production unit is determined. Therefore, the livestock layer in the exposure model includes two subcomponents: pastures and cattle heads.

4.1.3.1 Pastures

In this study, pasture areas are considered analogous to permanent herbaceous crops. However, it is not assumed that pastures follow a defined phenological cycle as seen in other permanent crops, since the primary goal here is to maximize dry matter production, rather than the production of fruit or tubers. Therefore, the modeled growth parameter corresponds to total biomass, from which dry matter is estimated as a fraction.

The livestock exposure portfolio includes natural pastures throughout the country. Figure 66 shows the geographic distribution of pastures in Costa Rica, based on information from SNIT (2017). Costa Rica has 1,523,048 hectares of natural pasture.

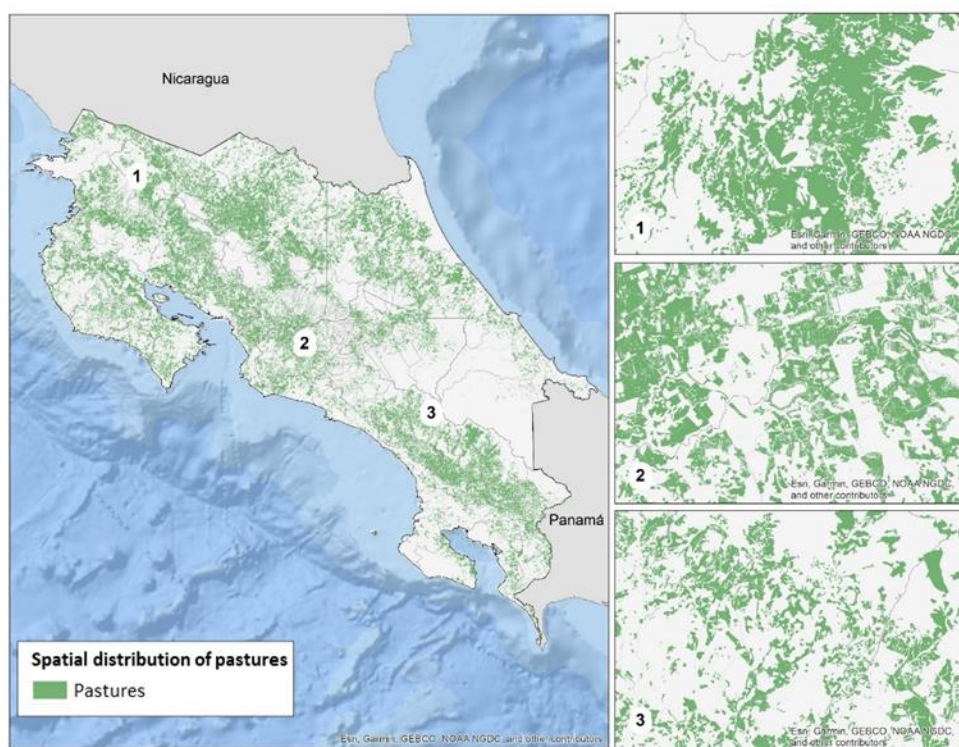


Figure 66. Spatial distribution of pastures (Information obtained from SNIT, 2017).

4.1.3.2 Cattle heads

The existing cattle heads in the country are distributed across the portfolio of natural pastures. Only extensively grazed beef cattle were considered in the analysis. The data were sourced from the *Encuesta Nacional Agropecuaria (ENA, 2023)*, which provides figures on cattle heads by sex and production purpose for the year 2023.

Nationally, 27.8% of the animals are males and 72.2% are females. Table 25 presents the national totals. Table 26, Table 27 and Table 28 show the breakdown of cattle by purpose (meat, dairy, dual-purpose), sex (male, female), and age group.

Table 25. Total cattle by sex and purpose (ENA, 2023).

Purpose	Total	Sex	
		Males	Females
Total	1,510,563	420,620	1,089,943
Meat	901,299	325,247	576,052
Milk	284,904	16,505	268,399
Dual purpose	322,599	77,107	245,492
Work	1,761	1,761	

Table 26. Total beef cattle by sex and age group (ENA, 2023).

Age	Total	Sex	
		Males	Females
Total	901,299	325,247	576,052
< 1 year	207,177	104,928	102,249
1 – 2 years	280,810	142,039	138,771
>2 years	413,312	78,280	335,032

Table 27. Total dairy cattle by sex and age group (ENA, 2023).

Age	Total	Sex	
		Males	Females
Total	284,904	16,505	268,399
< 1 year	60,499	9,432	51,067
1 – 2 years	50,875	3,412	47,463
>2 years	173,530	3,661	169,869

Table 28. Total dual-purpose cattle by sex and age group (ENA, 2023).

Age	Total	Sex	
		Males	Females
Total	322,599	77,107	245,492
< 1 year	99,012	49,867	49,145
1 – 2 years	69,405	18,220	51,185
>2 years	154,182	9,020	145,162

According to CCAFS (2015) and INEC (2014), there are more than 37,000 cattle producers in Costa Rica. For the development of the livestock model, the portfolio represents approximately 38,000 productive units, which provides coverage close to the reported figures.

Figure 67 shows the territorial extent associated with these producers, Figure 68 presents their geographic distribution classified by herd size per producer, and finally, Figure 68 displays the classification of livestock producers into three categories (MAG, 2013): small (<75 ha), medium (75–200 ha), and large (>200 ha).

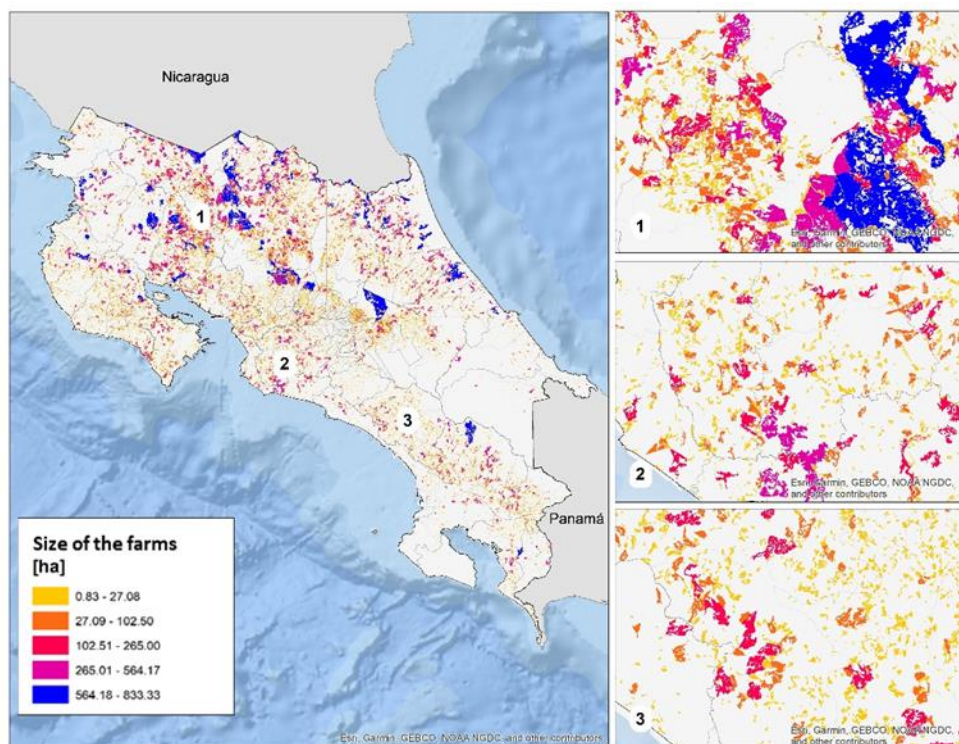


Figure 67. Territorial extent of livestock producers.

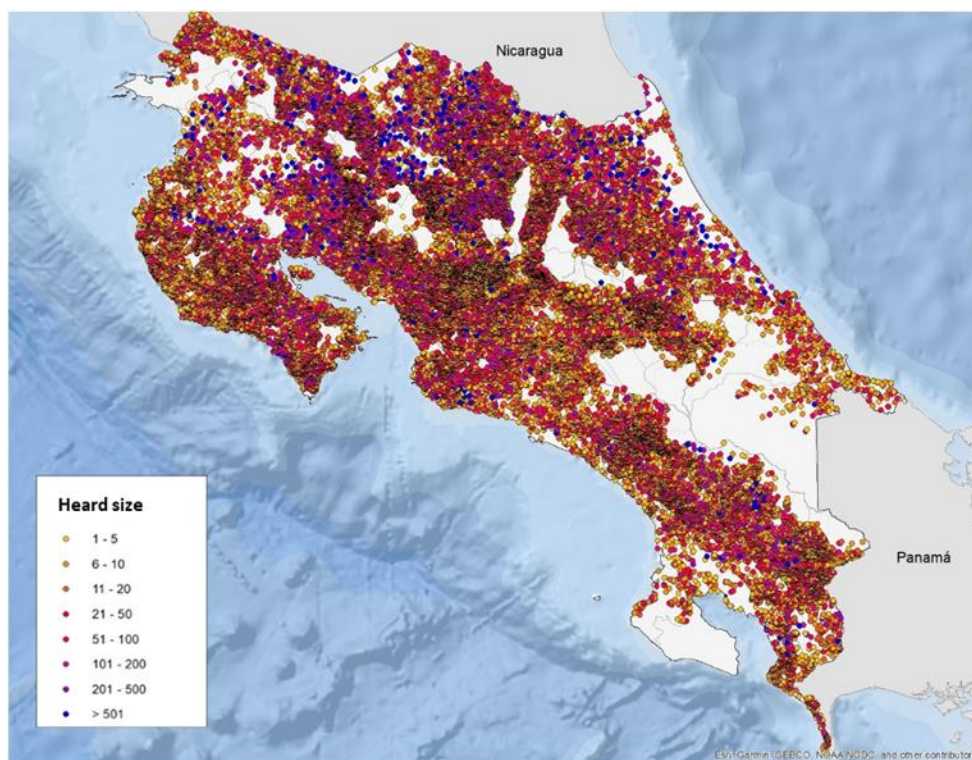


Figure 68. Herd size.

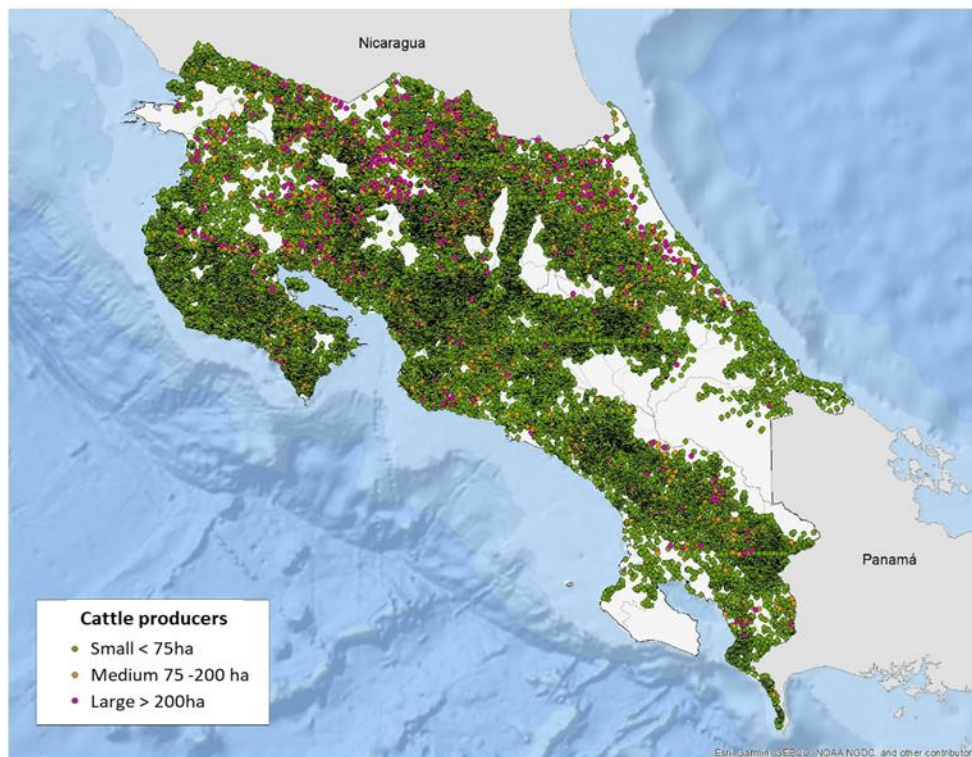


Figure 69. Cattle producers.

Cattle were valued based on statistical data from the Livestock Corporation (CORFOGA, 2025), which reports an average live animal price of 2,567 CRC/kg. Figure 70 shows the average auction prices differentiated by sex (males and females), expressed in current Costa Rican colones per kilogram. A more detailed description of these prices is available in Annex 3 (see A.3).

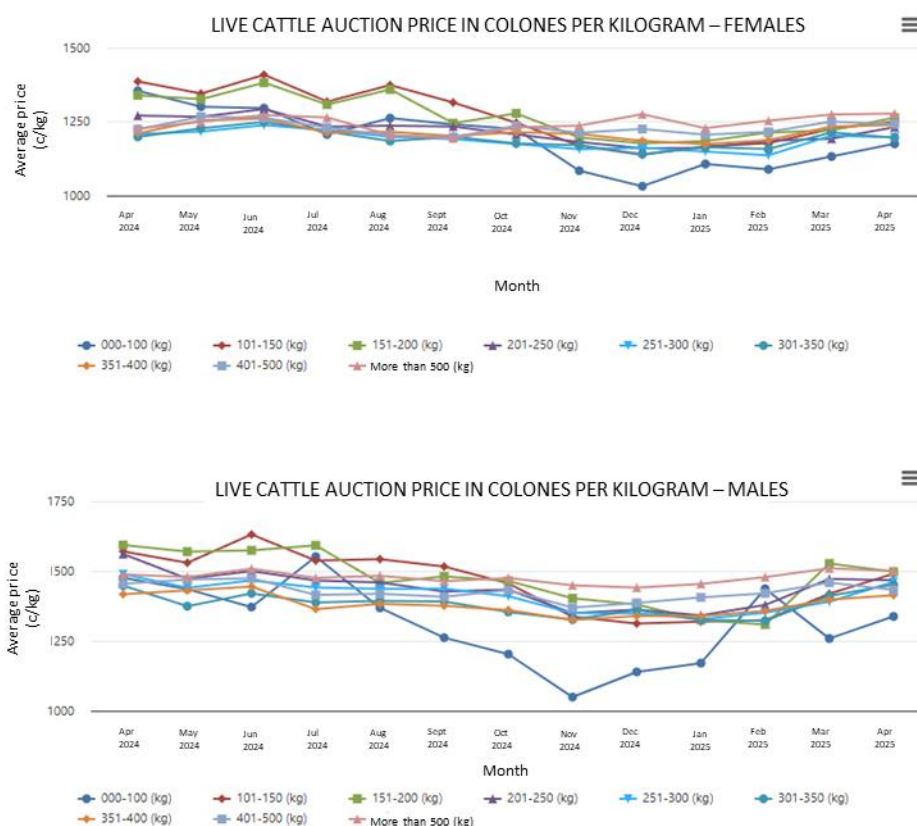


Figure 70. Carcass price in colones per kilogram. Source: CORFOGA, 2025.

4.1.4 NAMA Farms and Plots

Costa Rica has made significant progress in the implementation of Nationally Appropriate Mitigation Actions (NAMAs) in the agricultural sector through programs of planned and systematically executed activities (International Fund for Agricultural Development, 2025).

The first agricultural NAMA was developed for coffee cultivation, starting in 2011 with the goal of reducing greenhouse gas (GHG) emissions and improving production efficiency. Currently, this initiative is in a phase of consolidation and expansion, focused on extending its reach to vulnerable populations, including women, youth, and indigenous producers.

Meanwhile, the livestock NAMA began its pilot phase in 2014 and is now in its second scaling-up phase (2023–2026). This stage aims to implement practices such as rotational grazing, silvopastoral systems, bio-inputs, the use of solar energy, and biodigesters on a broader scale. It is supported by monitoring systems (MRV) and decentralized technical assistance.

As for the sugarcane NAMA, it is currently in its pilot implementation phase, designed based on prior experiences of the coffee and livestock NAMAs. This phase includes validating sustainable practices in 35 pilot farms distributed across six sugarcane regions in the country, with a focus on mitigation, climate resilience, and productive sustainability.

The Ministry of Agriculture and Livestock (MAG) of Costa Rica provided information to give an overview of the first phase of the NAMAs, specifically regarding the identification of Pilot Farms (PF) and the establishment of Pilot Plots (PP).

For the livestock sector, MAG contributed the following information:

- Basic data on NAMA farms including ID, address, location, latitude, longitude, production type, among others.
- Pasture area in hectares by species, broken down by region.
- General structure of land use and livestock composition within the NAMA farms.

Regarding the coffee sector, MAG provided relevant information on the implementation of the Coffee NAMA, which includes:

- A list of demonstration plots under the Coffee NAMA that are potential candidates for the MRV system (without geographic coordinates).
- A technical progress report on the scaling-up of the Coffee NAMA.
- The Coffee NAMA Baseline for Costa Rica.
- The Coffee NAMA form, including the activities to be implemented.

Based on this information and the “Sugarcane NAMA Costa Rica” report developed by LAICA, approximate locations were assigned to the pilot farms and plots using district- or canton-level references. A total of 514 livestock farms, 35 pilot sugarcane farms, and 23 coffee demonstration plots were georeferenced. Figure 71 presents the estimated geographic distribution of pilot farms related to the Livestock and Sugarcane NAMAs, as well as the demonstration plots for coffee.

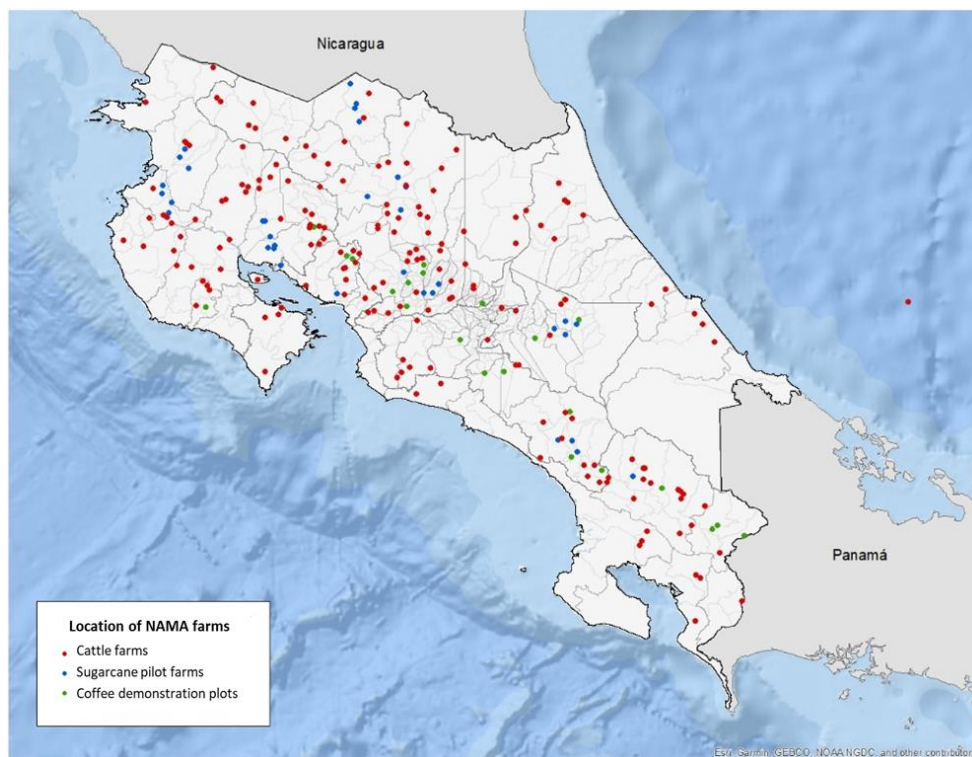


Figure 71. Location NAMA farms.

4.2 Vulnerability Models

The modeling of vulnerability in crops in this study follows the yield calculation methodology defined by the FAO¹⁰. Vulnerability is defined in terms of yield loss experienced by the crop during a production period affected by drought or waterlogging. In turn, vulnerability in livestock is quantified based on the pasture's ability to provide sufficient caloric content to sustain animal productivity, by measuring the land's carrying capacity and its variations due to simulated hazards.

The definition of the parameters of the vulnerability models, as well as their variation in response to the assessed hazards—that is, how the impact of the considered hazards is dynamically captured—is presented in detail in the Inception Report (Sections 9.5 and 9.6).

4.2.1 Coffee and Sugarcane Crops

Based on an extensive literature review, the key variables for the water response model were defined for both coffee and sugarcane crops. The characterization focused on phenological, morphological, and agronomic management aspects such as crop cycle, rooting depth, canopy cover, crop coefficients, stress sensitivity, and water productivity.

¹⁰ AquaCrop model from FAO. See Raes, et al. (2011).

Table 29 presents a description of the parameters that define the water response model. This model simulates the development of each crop under conditions approximating real-life scenarios in Costa Rica, distinguishing between climatic zones and typical production systems in the country.

Table 29. Description of variables in the water response model.

Variable	Description	Unit
CropType	Crop type: '1' - Leafy vegetables, '2' - Root/tuber, '3' - Fruit/grain	[-]
CalendarType	Growth cycle determination: '1' - Calendar days, '2' - Accumulated Growing Degree Days (GDD)	[-]
SwitchGDD	Convert calendar days to GDD ('0': No; '1': Yes)	[-]
PlantingDate	Planting date	(dd/mm)
HarvestDate	Last harvest day	(dd/mm)
Emergence	Time from planting to emergence	days or GDD
MaxRooting	Time from planting to maximum root depth	days or GDD
Senescence	Time from planting to senescence	days or GDD
Maturity	Time from planting to maturity	days or GDD
Hlstart	Time from planting to the start of yield formation	days or GDD
Flowering	Duration of flowering (-999 for non-fruit/grain crops)	days or GDD
YldForm	Duration of yield formation	days or GDD
GDDmethod	Method used to calculate GDD: '1': $T_{avg} = (T_x + T_n) / 2$; '2': $T_{avg} = (T^*x + T^*n) / 2$; '3': $T_{avg} = (T^*x + T_n) / 2$	[-]
Tbase	Base temperature below which crop development stops	[°C]
Tupp	Upper temperature threshold above which crop development stops	[°C]
PolHeatStress	Pollination affected by heat stress (0: No; 1: Yes)	[-]
Tmax_up	Maximum air temperature at which pollination begins to fail	[°C]
Tmax_lo	Maximum air temperature at which pollination completely fails	[°C]
PolColdStress	Pollination affected by cold stress (0: No; 1: Yes)	[-]
Tmin_up	Maximum air temperature below which pollination begins to fail	[°C]
Tmin_lo	Air temperature below which pollination completely fails	[°C]
BioTempStress	Biomass production affected by temperature stress (0: No; 1: Yes)	[-]
GDD_up	Minimum GDD required for total biomass production	[°C/day]
GDD_lo	GDD at which biomass production does not occur	[°C/day]
fshape_b	Shape factor describing the reduction in biomass production due to insufficient GDD	[-]
PctZmin	Initial percentage of minimum effective root depth	[%]
Zmin	Minimum effective root depth	[m]
Zmax	Maximum root depth	[m]
fshape_r	Shape factor describing root expansion	[-]
fshape_ex	Shape factor describing the effects of water stress on root expansion	[-]
SxTopQ	Maximum water extraction in the upper root zone	[m³/m³/day]
SxBotQ	Maximum water extraction in the lower root zone	[m³/m³/day]
a_Tr	Parameter describing the effect of canopy decline on the plant's transpiration/photosynthesis capacity	[-]
SeedSize	Surface area of soil covered by a plant at 90% germination	[cm²]

Variable	Description	Unit
PlantPop	Number of plants per hectare	[Plants/ha]
CCmin	Minimum canopy fraction required to ensure crop formation	[canopy fraction]
CCx	Maximum canopy cover	[soil cover fraction]
CDC	Canopy decline coefficient	[fraction per day/GDD]
CGC	Canopy growth coefficient	[fraction per day/GDD]
Kcb	Crop coefficient when canopy growth is complete but before senescence	[-]
fage	Crop coefficient decrease due to aging	[%/day]
WP	Normalized water productivity for ET ₀ and CO ₂	[g/m ²]
WP _y	Adjustment to normalized water productivity for ET ₀ and CO ₂ during yield formation	[% de WP]
fsink	Evaluation of the crop's CO ₂ uptake and response capacity Cereals (Maize, Rice, Wheat, Sunflower, Sorghum): between 0 and 0.2 Legumes (Soybean, Bean): between 0.2 and 0.4 Undetermined (Tomato, Quinoa): between 0.4 and 0.6 Roots and tubers (Potato, Beet): between 0.6 and 0.8	[-]
bsted	Adjustment of water productivity for CO ₂ , based on Steduto et al. 2007	[-]
bface	Water productivity adjustment based on lab trials (FACE experiments)	[-]
HI0	Reference harvest index	[-]
HIini	Initial harvest index	[-]
dHI_pre	Possible increase of harvest index due to water stress before flowering	[%]
a_HI	Coefficient describing the positive impact on HI from stomatal closure during yield formation	[-]
b_HI	Coefficient describing the negative impact on HI from stomatal closure during yield formation	[-]
dHI0	Maximum allowed increase of harvest index above the reference	[-]
Determinant	Crop production linked to flowering ('0': Indeterminate, '1': Determinate)	[-]
exc	Excess of potential fruits	[%]
MaxFlowPct	Percentage of the total flowering period in which the peak bloom occurs	[%]
p_up1	Upper threshold of soil water depletion for water stress effects on canopy expansion	[0 - 1]
p_up2	Upper threshold of soil water depletion for water stress effects on stomatal control of the canopy	[0 - 1]
p_up3	Upper threshold of soil water depletion for water stress effects on canopy senescence	[0 - 1]
p_up4	Upper threshold of soil water depletion for water stress effects on canopy pollination	[0 - 1]
p_lo1	Lower threshold of soil water depletion for water stress effects on canopy expansion	[0 - 1]
p_lo2	Lower threshold of soil water depletion for water stress effects on stomatal control of the canopy	[0 - 1]
p_lo3	Lower threshold of soil water depletion for water stress effects on canopy senescence	[0 - 1]
p_lo4	Lower threshold of soil water depletion for water stress effects on canopy pollination	[0-1]
fshape_w1	Shape factor describing the effects of water stress on canopy expansion	[-]
fshape_w2	Shape factor describing the effects of water stress on stomatal control	[-]
fshape_w3	Shape factor describing the effects of water stress on canopy senescence	[-]
fshape_w4	Shape factor describing the effects of water stress on pollination	[-]
ETadj	Adjustment to water stress threshold depending on daily ET ₀ (0: 'No', 1: 'Yes')	[-]
Aer	Volume below saturation at which aeration stress begins	[%]
LagAer	Number of days to consider stress due to lack of aeration	days
beta	Reduction of the lower soil water availability threshold when senescence is triggered by water stress	[%]
GermThr	Proportion of total available water in the root zone required for crop germination	[0 - 1]

The parameterization of the coffee crop was based on experimental studies conducted in mid-elevation coffee plantations in Costa Rica, particularly in the Central Valley and mountainous areas between 900 and

1600 meters above sea level. The crop type was considered as fruit (CropType = 3), with a calendar based on days (CalendarType = 1), which appropriately reflects the seasonal annual cycles of the crop.

The simulation calendar was set from August 15 (sowing or sprouting of the new cycle) to July 10 of the following year (harvest), covering the typical annual cycle of the coffee bean in areas with a defined dry season and a main flowering after the first rains (ICO, 2020; ICAFE, 2018).

The phenological development values (Emergence = 6 days, MaxRooting = 55 days, Senescence = 300 days, Maturity = 330 days) were adjusted based on the physiological development of the crop from flowering to fruit maturation (Vaast et al., 2005; Carr, 2012). The harvest index (HI0 = 0.1) represents the percentage of biomass corresponding to the bean, while Hlini = 0.01 reflects the initial low yield accumulation. Typical values were used for Arabica coffee grown under partial shade, such as Kcb = 1.05, CGC = 0.012, and CDC = 0.01, which reflect a slow initial growth but dense canopy coverage at maturity.

Water productivity (WP = 18 g/m²) was based on yield reports for coffee under optimal management in humid tropical conditions with adequate rainfall (Carr, 2012; Pérez & Romero, 2016). The rooting depth (Zmax = 2 m) was selected considering the deep root exploration in well-developed coffee plantations in deep loam soils.

Standard thresholds were used for water and thermal stress, while the planting density (PlantPop = 4000 plants/ha) reflects typical spacing in traditional Costa Rican production systems (ICAFE, 2018). The SeedSize = 15 cm² was assumed to represent the area covered by an established coffee seedling.

For sugarcane, it was simulated as a root/stem crop with high biomass potential (CropType = 2), using calendar days (CalendarType = 1), with a growth cycle from January 1 to December 31, reflecting continuous cane growth throughout a full year in tropical conditions.

The phenological development was parameterized with Emergence = 30 days, MaxRooting = 150 days, Maturity = 360 days, representing the slow yet steady vegetative growth of the crop. Senescence was adjusted to Senescence = 330 days, allowing for a slight loss of leaves before harvest. Values of HI0 = 0.35 and WP = 20 g/m² were assigned based on agronomic studies of production under irrigation or optimal conditions (Inman-Bamber & Muchow, 2000; FAO, 2021).

The crop coefficient Kcb = 1.25 and the values CGC = 0.12 and CDC = 0.012 reflect the high rate of aerial biomass growth in warm climates. The maximum root depth was estimated at Zmax = 2 m, and water extraction was adjusted with SxTopQ = 0.048 and SxBotQ = 0.012, according to the root behavior of varieties used in Costa Rica.

The planting density (PlantPop = 12000 plants/ha) reflects the number of active buds planted per hectare, and the seed area (SeedSize = 15 cm²) was assumed to represent the initial leaf area. Water stress responses were included with thresholds adapted to reflect sugarcane's moderate drought tolerance during early growth stages (Singels & Donaldson, 2000).

Table 30 presents the parameter values assigned to each agricultural product model (see their descriptions in Table 29).

Table 30. Assigned parameter values for the water response models of coffee and sugarcane crops.

Variable	Coffee	Sugarcane	Unit
CropType	3	2	[-]
CalendarType	1	1	[-]
SwitchGDD	0	0	[-]
PlantingDate	15/08	01/01	(dd/mm)
HarvestDate	10/07	31/12	(dd/mm)
Emergence	6	30	días
MaxRooting	55	150	días
Senescence	300	330	días
Maturity	330	360	días
Hlstart	80	120	días
Flowering	30	0	días
YldForm	230	180	días
GDDmethod	2	2	[-]
Tbase	12	15	[°C]
Tupp	30	35	[°C]
PolHeatStress	0	0	[-]
Tmax_up	0	0	[°C]
Tmax_lo	0	0	[°C]
PolColdStress	0	0	[-]
Tmin_up	0	0	[°C]
Tmin_lo	0	0	[°C]
BioTempStress	0	0	[-]
GDD_up	0	0	[°C/day]
GDD_lo	0	0	[°C/day]
fshape_b	13.8	13.8	[-]
PctZmin	70	70	[%]
Zmin	0.3	0.3	[m]
Zmax	2	2	[m]
fshape_r	1.3	15	[-]
fshape_ex	-6	-6	[-]
SxTopQ	0.024	0.048	[m³/m³/day]
SxBotQ	0.006	0.012	[m³/m³/day]
a_Tr	1	1	[-]
SeedSize	15	15	[cm²]
PlantPop	4000	12000	[Plants/ha]
CCmin	0.07	0.05	[canopy fraction]
CCx	0.95	0.95	[soil cover fraction]
CDC	0.01	0.012	[fraction per day/GDD]
CGC	0.012	0.12	[fraction per day/GDD]
Kcb	1.05	1.25	[-]
fage	0.15	0.15	[%/day]
WP	18	20	[g/m²]
WPy	100	100	[% de WP]
fsink	0.5	0.7	[-]
bsted	0.000138	0.000138	[-]
bface	0.001165	0.001165	[-]

Variable	Coffee	Sugarcane	Unit
Hl0	0.1	0.35	[-]
Hlini	0.01	0.01	[-]
dHI_pre	10	2	[%]
a_HI	10	-	[-]
b_HI	8	10	[-]
dHI0	15	5	[-]
Determinant	1	0	[-]
exc	50	-	[%]
MaxFlowPct	33.33	33.33	[%]
p_up1	0.25	0.2	[0 - 1]
p_up2	0.5	0.6	[0 - 1]
p_up3	0.85	0.7	[0 - 1]
p_up4	0.9	0.8	[0 - 1]
p_lo1	0.55	0.6	[0 - 1]
p_lo2	1	1	[0 - 1]
p_lo3	1	1	[0 - 1]
p_lo4	1	1	[0-1]
fshape_w1	3	3	[-]
fshape_w2	3	3	[-]
fshape_w3	3	3	[-]
fshape_w4	1	1	[-]
ETadj	1	1	[-]
Aer	5	5	[%]
LagAer	3	3	days
beta	12	12	[%]
GermThr	0.2	0.2	[0 - 1]

4.2.2 Pastures for Extensive Cattle Ranching

To simulate the development of pasture for cattle ranching in Costa Rica, a detailed parameterization was carried out based on scientific and technical literature. This parameterization considered both the edaphoclimatic conditions of the Costa Rican humid tropics and the agronomic characteristics of commonly used pasture species in livestock systems, such as *Brachiaria brizantha*, *Panicum maximum* (Mombasa grass), *Paspalum notatum*, and other species adapted to continuous grazing.

The edaphoclimatic conditions are established by location, based on the soil model considered and the meteorological simulations generated from the available historical data. In this way, the climate and soil of each location are represented as accurately as possible given the scale of the model.

The parameter values assigned to the water response model were selected based on recommendations established by the FAO (2021), complemented by specific studies on tropical grasses and forage crops. A calendar-day approach (CalendarType = 1) was used due to its greater practical applicability in tropical areas, where temperatures remain relatively stable throughout the year (Steduto et al., 2009).

The simulated cycle is set between May and September, coinciding with the beginning and peak of the rainy season in Costa Rica, which enables rapid vegetative coverage and biomass production (Méndez et al., 2015). Phenological parameters such as Emergence, MaxRooting, Maturity, and Senescence were defined considering the average establishment, growth, and cutting times of tropical grasses (CIRAD, 2018; Embrapa, 2020).

Canopy cover (CCx) was set at 0.95, reflecting the potential of these crops to fully cover the soil under optimal conditions. Plant density (PlantPop = 200,000) was estimated considering the basal coverage of creeping and tufted tropical grasses (González & Gómez, 2014). The canopy growth and decline coefficients (CGC and CDC) were set at 0.12 and 0.15, respectively, consistent with observed rates under intensive management.

Water productivity (WP = 15 g/m²) falls within the reported range for forage grasses under humid tropical conditions, while the harvest index (HI0 = 0.9) represents the high proportion of usable biomass in grazing or direct cutting systems (Pérez & Romero, 2016). It was also assumed that the crop is indeterminate (Determinant = 0), allowing for multiple cuts per year, although in this simulation a single establishment cycle was considered. A *Determinant* value of 0 in the simulation indicates that the pasture can continue growing continuously throughout the crop cycle, which is suitable for modeling continuous grazing conditions. This setting allows for multiple cuts during the cycle, thereby simulating the repeated use of pasture by livestock.

However, since the objective is to assess the continuous availability of pasture throughout the year, a series of simulations is conducted by adjusting the sowing dates in a staggered manner—that is, the planting and harvesting dates are modified to perform multiple simulations. In this way, it is possible to determine the amount of dry matter available for livestock each month of the year, ensuring that pasture remains continuously available without interruptions.

Crop responses to water and heat stress, both for root expansion and canopy development, were modeled with standard values adjusted by institutions such as CIRAD (2018) and Embrapa (2020). The effect of temperature stress on biomass (BioTempStress = 1) was included, and temperature thresholds (Tbase = 10°C, Tupp = 40°C) were established according to the optimal growth range of these species.

The parameterized model, as described, enables simulation of the growth, development, and productivity of tropical pastures under field conditions in Costa Rica. Table 31 compiles the water response model values for pastures.

Table 31. Assigned parameter values for the water response model of pastures.

Variable	Pastures	Unit
CropType	3	[-]
CalendarType	1	[-]
SwitchGDD	0	[-]
PlantingDate	01/05	(dd/mm)
HarvestDate	30/09	(dd/mm)
Emergence	10	days
MaxRooting	45	days
Senescence	60	days

Variable	Pastures	Unit
Maturity	75	days
Hlstart	20	days
Flowering	0	days
YldForm	55	days
GDDmethod	2	[-]
Tbase	10	[°C]
Tupp	40	[°C]
PolHeatStress	0	[-]
Tmax_up	0	[°C]
Tmax_lo	0	[°C]
PolColdStress	0	[-]
Tmin_up	0	[°C]
Tmin_lo	0	[°C]
BioTempStress	1	[-]
GDD_up	8	[°C/day]
GDD_lo	2	[°C/day]
fshape_b	10	[-]
PctZmin	60	[%]
Zmin	0.3	[m]
Zmax	1.2	[m]
fshape_r	12	[-]
fshape_ex	-5	[-]
SxTopQ	0.05	[m³/m³/day]
SxBotQ	0.015	[m³/m³/day]
a_Tr	1	[-]
SeedSize	10	[cm²]
PlantPop	200000	[Plants/ha]
CCmin	0.05	[canopy fractioin]
CCx	0.95	[soil cover fraction]
CDC	0.15	[fraction per day/GDD]
CGC	0.12	[fraction per day/GDD]
Kcb	1.0	[-]
fage	0.2	[%/day]
WP	15	[g/m²]
WPpy	20	[% de WP]
fsink	0.3	[-]
bsted	0.000138	[-]
bface	0.001165	[-]
HIO	0.9	[-]
HIini	0.02	[-]
dHI_pre	5	[%]
a_HI	-8	[-]
b_HI	-8	[-]
dHIO	5	[-]
Determinant	0	[-]
exc	20	[%]

Variable	Pastures	Unit
MaxFlowPct	33.33	[%]
p_up1	0.25	[0 - 1]
p_up2	0.5	[0 - 1]
p_up3	0.8	[0 - 1]
p_up4	0.8	[0 - 1]
p_lo1	0.5	[0 - 1]
p_lo2	1	[0 - 1]
p_lo3	1	[0 - 1]
p_lo4	1	[0-1]
fshape_w1	3	[-]
fshape_w2	3	[-]
fshape_w3	3	[-]
fshape_w4	1	[-]
ETadj	1	[-]
Aer	5	[%]
LagAer	3	days
beta	10	[%]
GermThr	0.25	[0 - 1]

4.2.3 Nutritional Contribution of Pastures

In risk modeling, it is necessary to simulate pasture development to determine the dry matter content that each pasture unit can provide to feed livestock. *The inception Report* of this consultancy contains in detail the methodological approach for modeling the nutritional contribution of pastures and the requirements of the animals that consume them.

According to the National Institute for Agricultural Technology Innovation and Transfer (INTA, 2006), a bovine requires between 7% and 10% of its body weight in fresh forage daily to maintain adequate nutrition. These values vary depending on the species of pasture considered.

Martínez (2018) presents the bromatological composition of 31 pasture species used to feed animals in Costa Rica, for 3 to 4 different cutting ages. The pastures studied by Martínez (2018) are distributed throughout Costa Rica, including the dry tropics, the humid tropics, and the high dairy production zones of the country.

Table 32 presents an example of the information reported by Martínez (2018).

Table 32. Nutritional composition of *Brachiaria* sp pasture under grazing in Costa Rica, cut at less than 20 days of age. Values expressed as percentage of dry matter. Taken from Martínez (2018).

Nutrient	Samples	Maximum	Minimum	Average	Coefficient of variation (%)
Dry matter (% of biomass)	12	31.40	12.00	20.07	27.74
Crude protein	4	12.68	5.69	9.20	42.86
Ether extract	3	3.33	1.80	2.77	30.50
Ash	3	10.33	5.40	8.62	32.39

Neutral detergent fiber treated with amylase (NDF)	3	63.85	44.12	57.18	19.78
Acid detergent fiber (ADF)	3	37.20	31.37	35.06	9.16
Acid detergent lignin (ADL)	3	3.38	3.00	3.22	6.16
In vitro dry matter digestibility (IVDMD)	1	61.30	61.30	61.30	0

5 OPERATIONAL PROJECT 3: EXPOSURE AND RISK ASSESSMENT OF SMALL AND MEDIUM-SIZED HOTELS AND HOSTELS UNDER THE FU-TURISMO PROGRAM

Tourism is one of the main drivers of Costa Rica's economy, significantly contributing to economic output and job creation. This project aims to assess disaster risk for this sector, focusing primarily on hotel facilities owned by small and medium-sized entrepreneurs, in the face of riverine and coastal flooding, earthquakes, and tsunamis.

The hotel infrastructure consists mainly of buildings, so this exposure and vulnerability model includes only buildings. Impacts on the sector associated with potential damage or loss to related infrastructure elements (e.g., power grid, road network, potable water system), impacts on adjacent sectors (restaurants, cafés), as well as effects on hotel staff and tourists themselves, will be addressed in a later phase through a holistic risk assessment framework using a system of indicators. This was agreed upon directly with the Technical Working Group for this project. Therefore, this report includes only the aspects related to the development of the exposure and vulnerability models for hotel buildings.

5.1 Exposure Model

To build the exposure model for buildings in the tourism sector, various information sources were consulted, including both official sources and open-access global databases. The following section describes the consulted sources according to the attribute being characterized.

5.1.1 Geographic Location

5.1.1.1 Cartography - Buildings

The National Territorial Information System (SNIT) provides nationwide building and construction coverage, which includes a descriptive attribute labeled "CATEGORIA." This category specifies buildings used for hotel purposes, as shown in Figure 72.

The building coverage contains a total of 4,609 building footprint records classified as hotels. A data-cleaning process was required¹¹, since in many cases, multiple footprint records correspond to the same hotel, or the building footprint includes nearby structures that are not part of the hotel category, as illustrated in Figure 72.

¹¹ This was an individual review process for each polygon

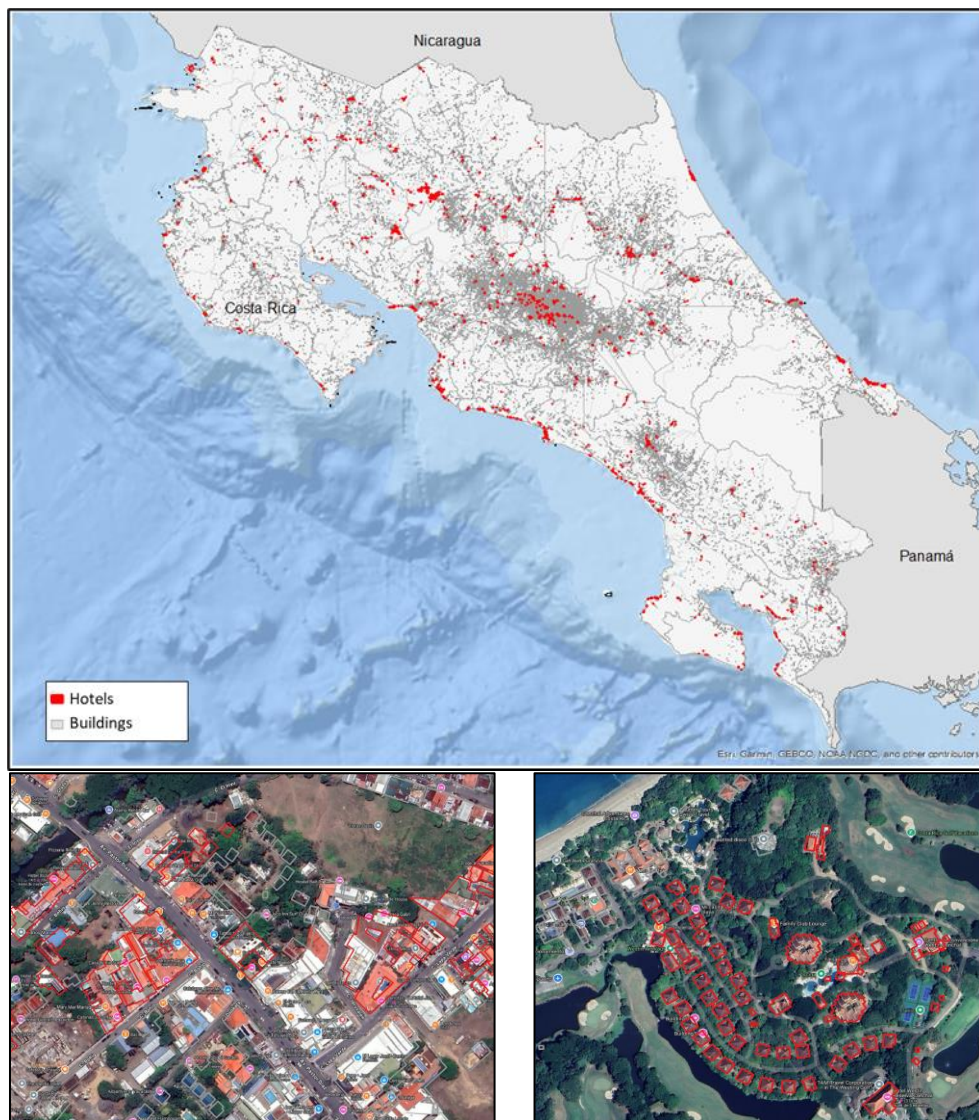


Figure 72. Buildings cartography (Hotel Category) – SNIT.

5.1.1.2 Esencial Costa Rica

Esencial Costa Rica, the country brand that aims to promote Costa Rica's image internationally by encouraging sustainable tourism, provides on its website detailed information about accommodations in the country. This includes data such as geographic location, number of rooms, star rating, available amenities

Through this source, information was gathered for a total of 569 hotels, with their spatial distribution across the country illustrated in Figure 73.

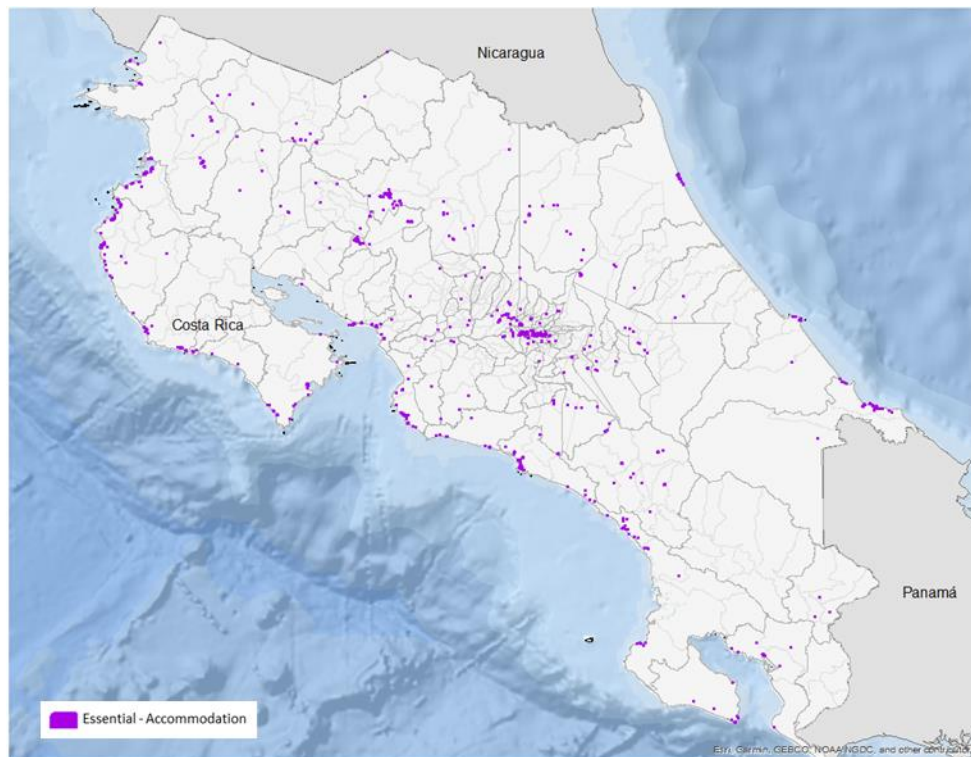


Figure 73. Hotels - Esencial Costa Rica website.

5.1.1.3 Google Maps

Google Maps combines satellite imagery of the terrain with the overlay of various layers, such as landmarks, detailed information about places, and points of interest. This makes it a particularly useful tool for locating sites or services of interest.

Google uses a combination of official sources, automated data extraction (from web content, public records, and device signals), and user contributions to generate place labels on its maps and services. In addition, users can contribute by submitting reviews, ratings, and photos, which help enrich and verify the information shown on the maps.

As illustrated in Figure 74, in the hybrid map view of Google Maps, one of the categories of labeled points of interest corresponds to lodging establishments, marked with the  label. These tagged places not only provide location data but also include rating information, such as star classifications and user reviews, contributed by visitors.

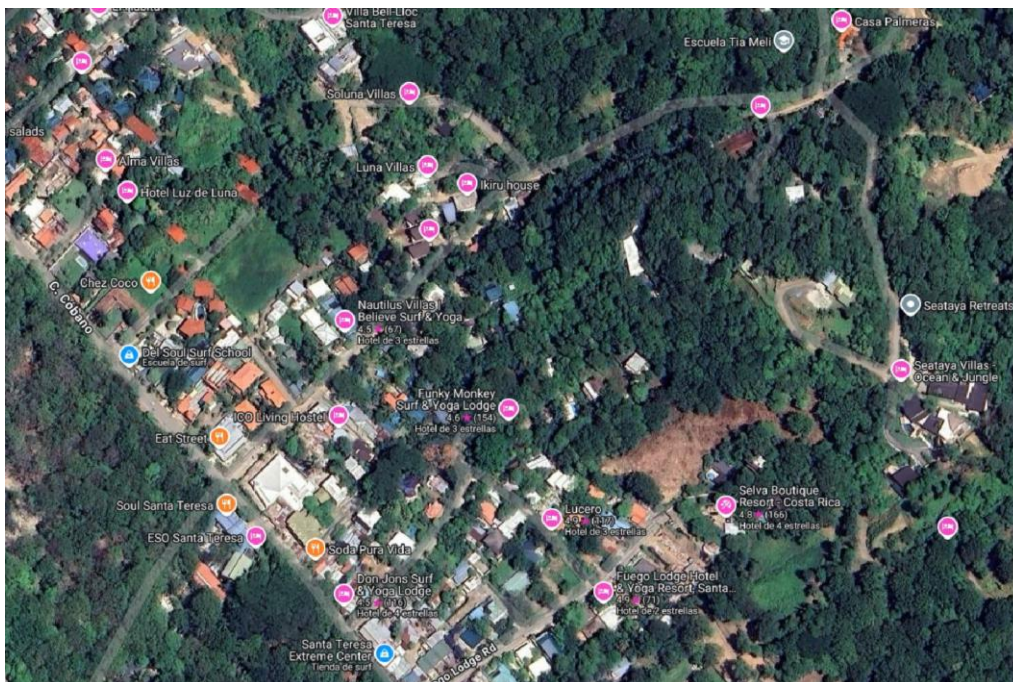


Figure 74. Place labels for lodging– Google maps.

In the query conducted using these Google Maps layers, location information was obtained for 1,478 lodging establishments, along with their corresponding star ratings and visitor review ratings. Figure 75 shows the spatial distribution of lodging locations across the country as obtained from Google Maps.

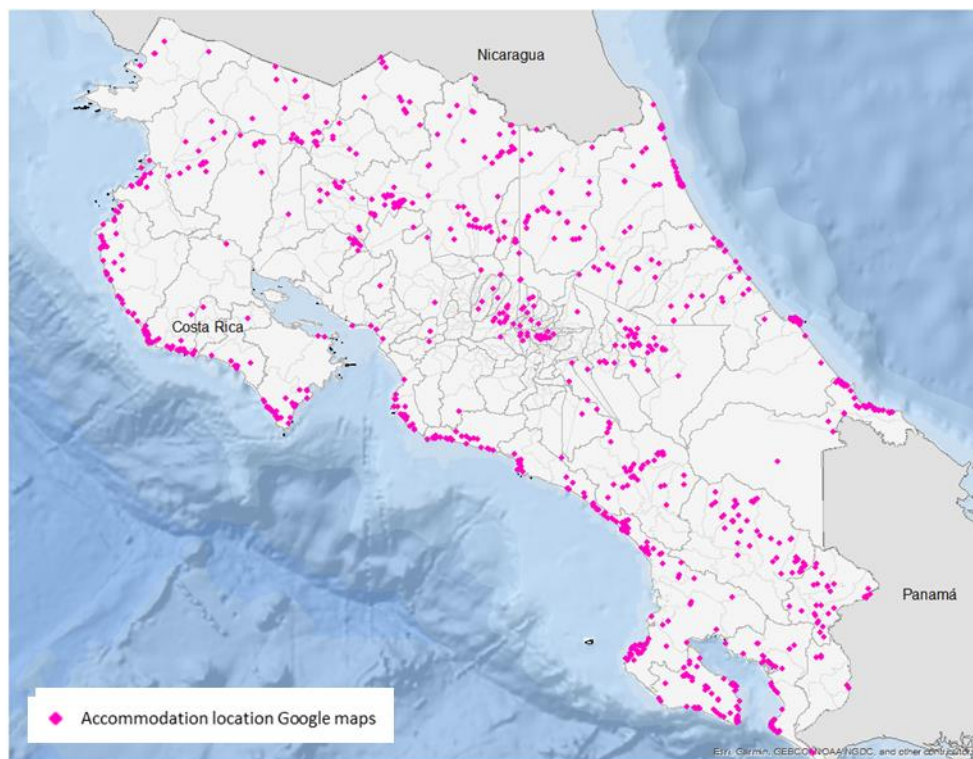


Figure 75. Lodging establishments– Google maps.

5.1.1.4 Final Locations in the Model

To determine the georeferenced location of the hotels, the information gathered from *Esencial Costa Rica* was combined with the lodging data from Google Maps, resulting in an exposure database with geographic coordinates representing the centroid of each hotel. A spatial overlay of this point database with the building footprint layer categorized as "hotel" was then performed, allowing for the determination of hotel locations in polygon form using the associated building footprint. Figure 76 shows the resulting database. Figure 77 illustrates the hotel database in more detail, compiled from the various sources.

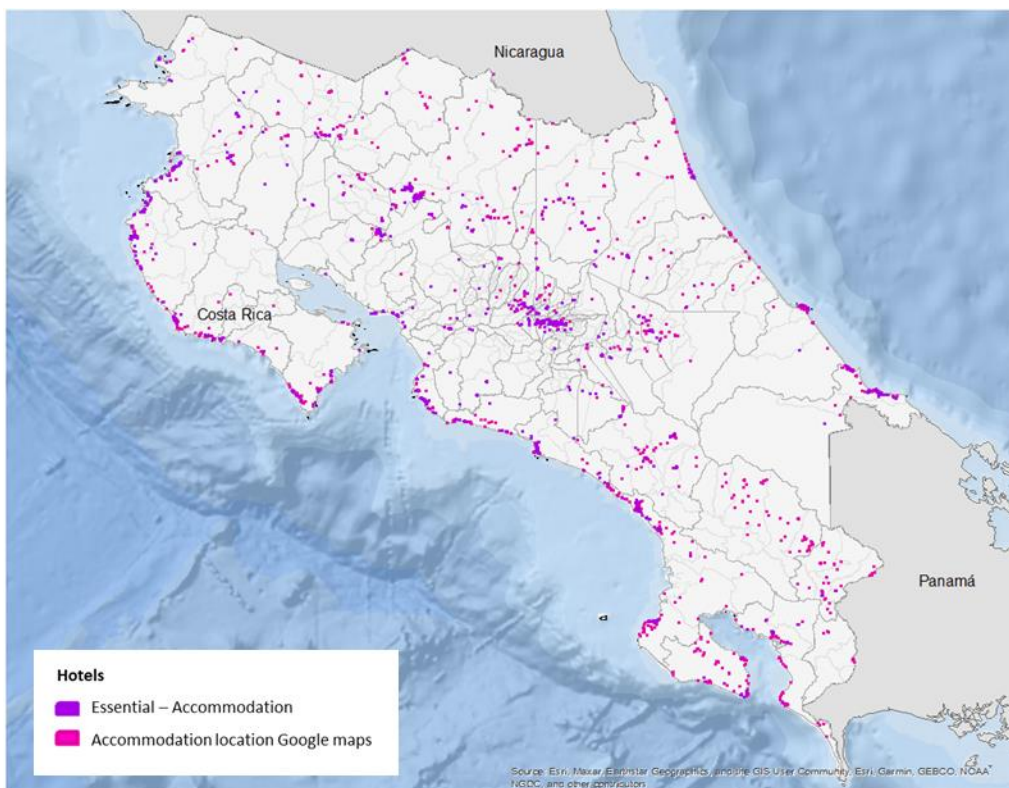


Figure 76. Georeferenced hotel database in Costa Rica.



Figure 77. Detailed georeferenced hotels database in Costa Rica.

5.1.2 Hotel Classification

5.1.2.1 Classification of Lodging According to ICT registration

According to statistics published by the Costa Rican Tourism Institute (ICT)¹², the estimated lodging supply in the country for the year 2024 is 3,068 lodging establishments, excluding various forms of accommodation such as houses, apartments, and cabins (referred to as vacation rentals).

The lodging supply is segmented by ICT into establishments registered and not registered with ICT. Establishments registered with ICT are those that hold a Tourism Declaration, Tourism Contract, or CST (Certification for Sustainable Tourism). These recognitions are granted by the ICT to companies that apply for them, free of charge, and must meet technical, economic, and legal requirements.

On the other hand, non-registered establishments are those that do not have a Tourism Declaration (vacation rentals are not included).

For 2024, the estimated supply is:

- Registered with the ICT: 766 establishments, totaling 29,490 rooms (average of 38.5 rooms per establishment).
- Not registered with the ICT: 2,303 establishments, totaling 26,616 rooms (average of 11.6 rooms per establishment).

Figure 78 presents the distribution by Tourism Planning Unit of rooms and establishments in Costa Rica (both registered and not registered with ICT).

TOTAL ACCOMMODATION OFFER ACCORDING TO PLANNING UNIT					
2024					
Tourism Planning Unit	Quantity		Room/Estab	Porcentual distributioin	
	Rooms	Establishments		Rooms	Establishments
Total	56106	3068	18.3	100	100
Caribe	5055	381	13.3	9	12.4
Guanacaste	14626	628	23.3	26.1	20.5
Llanuras del Norte	5478	313	17.5	9.8	10.2
Pacifico Medio	6570	365	18	11.7	11.9
Pacifico Sur	5461	466	11.7	9.7	15.2
Puntarenas	5840	419	13.9	10.4	13.7
Valle Central	13076	496	26.4	23.3	16.2

Note: Estimation of the total number of tourist establishments in the country; vacation rentals are not included.

Source: ICT, Tourism Infrastructure System year-end 2024.

Figure 78. Total lodging supply by planning unit – ICT.

Tourism Declaration (Registered with the ICT)

According to the Costa Rican Tourism Institute (ICT), the tourism declaration is a recognition granted to tourism-related businesses that voluntarily request it. To obtain it, companies must meet technical, economic, and legal requirements outlined in the *Regulations for Tourism Businesses and Activities*. These

¹² <https://www.ict.go.cr/es/administrar-estadistica/cifras-tur%C3%ADsticas/oferta-de-hospedaje/2865-oferta-hospedaje-2003-2024/file.html>

requirements aim to ensure the legal compliance of tourism activities and achieve one of the department's main objectives: the highest quality in Costa Rica's tourism products.

Benefits of the Tourism Declaration include:

- Inclusion in the official ICT listings and website.
- Access to training provided by the ICT.
- Mandatory for obtaining a tourism contract.
- Eligibility for official categorization.
- Promotion through the website www.visitcostarica.com (Esencial Costa Rica).
- Participation in international tourism fairs.
- Potential to participate in international cooperative campaigns with travel agencies and airlines.
- Opportunity to join targeted marketing campaigns coordinated with local hoteliers to offer tourist discounts.
- Distribution of promotional materials at ICT Tourism Information Centers.
- Eligibility to obtain the *Marca País* certification.

To obtain the Tourism Declaration, the ICT requires the following technical and economic criteria:

1. A clear and detailed description of the business activity, including infrastructure: number and type of rooms, equipment, reception, lobby, lounge, public and accessible restrooms, pools, storage areas, staff facilities, gym, spa, parking, bar, restaurant, etc.
2. Employment and investment details: number of direct jobs, value of land, infrastructure, furniture, equipment, or rental costs.
3. Submission of original or certified copies (by a lawyer) of the sanitary operating permit and business license, both referring to the commercial establishment.
4. Proof of good standing with CCSS, FODESAF, corporate tax (if applicable), and tax obligations with the Ministry of Finance.
5. A minimum score of 20% (equivalent to one star) must be obtained and maintained, as outlined in the Evaluation Tools annexed to the Regulations for this service category.

Accommodation not registered with the ICT may be unregistered due to non-compliance with the above requirements or simply lack of interest from the operator.

Non-traditional Lodging

Non-traditional lodging is a type of tourist accommodation that involves the temporary rental of a dwelling or part of it for tourism purposes, for a minimum of 24 hours and up to a maximum of one year, without offering typical hotel services (such as 24-hour reception, daily cleaning, restaurant, etc.).

In 2019, the Government of Costa Rica enacted Law 9742 to regulate non-traditional lodging activities and the use of digital platforms for short-term rentals. The law sets clear conditions for both hosts and platforms and ensures the protection of the end user.

Key characteristics include:

- It can be offered by individuals or legal entities (not necessarily tourism businesses).
- Includes properties such as houses, apartments, bungalows, or rooms in family homes.
- Typically offered through digital platforms such as Airbnb, Vrbo, Booking, among others.
- Does not need to be categorized as a hotel, hostel, or cabins, but must be registered with the Costa Rican Tourism Institute (ICT).

Table 33 presents a summary of the main differences between traditional lodging (counted in ICT supply) and non-traditional lodging.

Table 33. Differences between traditional and non-traditional lodging.

Traditional Lodging	Non-traditional Lodging
Hotels, hostels, cabins	Houses, apartments, rented rooms
Historically regulated	Recently regulated (since 2019)
Hotel services included	Limited services, at host's discretion
Requires tourism permits	Requires registration as a tourism activity with ICT
Commercial on a large scale	Usually run by small owners or families

5.1.2.2 Lodging Classification According to Star Rating

According to the *Hotel Classification Manual for Costa Rica* by the Costa Rican Tourism Institute (ICT)¹³, hotels in the country are classified based on the range of services offered to guests. The defined categories are described below:

- **Full service:** Typically located in urban or vacation areas, these are often multi-story establishments with formal restaurants and recreational facilities. They offer maid service, and rooms include amenities such as telephones, televisions, and private bathrooms.
- **Limited service:** Smaller than full-service hotels, often with an informal atmosphere. They may have dining services. Rooms and bathrooms usually provide only basic amenities, and the focus is on personalized guest attention. These tend to include lodges, bed and breakfasts, guesthouses, and inns, often located in rural or mountainous areas near national parks, with simple or rustic facilities.
- **Minimal service:** These vary in size from single-story to multi-story buildings. Guests are expected to be self-sufficient. Typically, they do not offer dining or restaurant services and can be located in either urban or resort areas. This category includes apartments, condos, and cabins, which can range from luxurious to very simple.

According to these categories, full-service and limited-service establishments are assigned a star rating based on the range of services offered, as shown in Table 34. Minimal-service establishments are also classified using the star rating system, although they cannot reach the maximum number of stars due to their limited services. The classification does not consider the number of rooms, the establishment's name, or its size.

¹³ <https://www.ict.go.cr/es/root-documentos-no-apagar/legislaci%C3%B3n-de-empresas/manuales/577-manual-de-clasificaci%C3%B3n-hotelera/file.html>

Table 34. Star rating classification according to service. Source: Hotel Classification Manual – ICT.

Service description	Star rating
Best available	5
Excellent facilities and wide range of services	4
Very good facilities and variety of services	3
Exceeds minimum requirements	2
Meets minimum requirements for cleanliness and comfort	1

To classify the hotels by star rating, we began with the classification provided on the *Esencial Costa Rica* website for the hotels promoted by this initiative (see their distribution in Figure 79 (a)). Similarly, the star rating and guest reviews were taken into account for lodging places tagged on Google Maps (see their distribution in Figure 79 (b)). Finally, based on the star classifications given to hotels on the *Esencial Costa Rica* and Google Maps platforms, the categorization described in the *Hotel Classification Manual for Costa Rica*, and the classification of accommodations according to ICT registration, a star rating was assigned to each hotel included in the constructed exposure database. The resulting distribution is shown in Figure 79 (c).

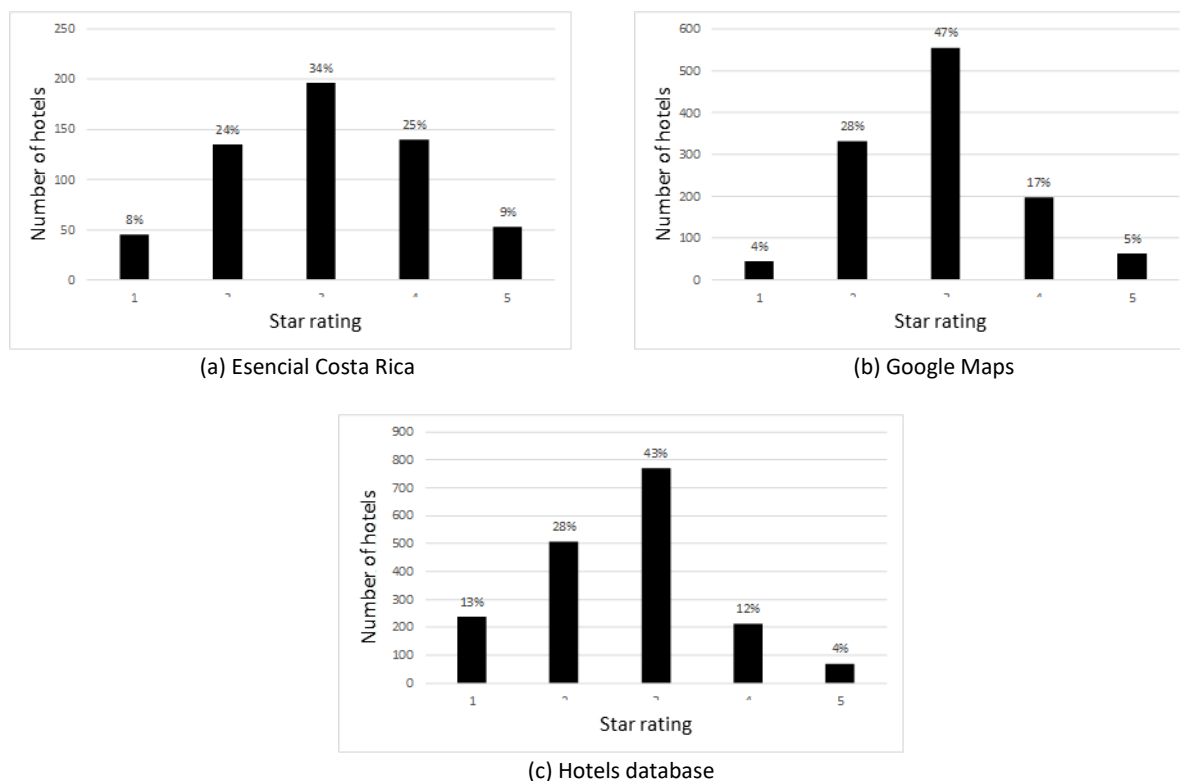


Figure 79. Star rating distribution

Figure 80 illustrates the geographic distribution of star ratings for the hotels included in the exposure model.

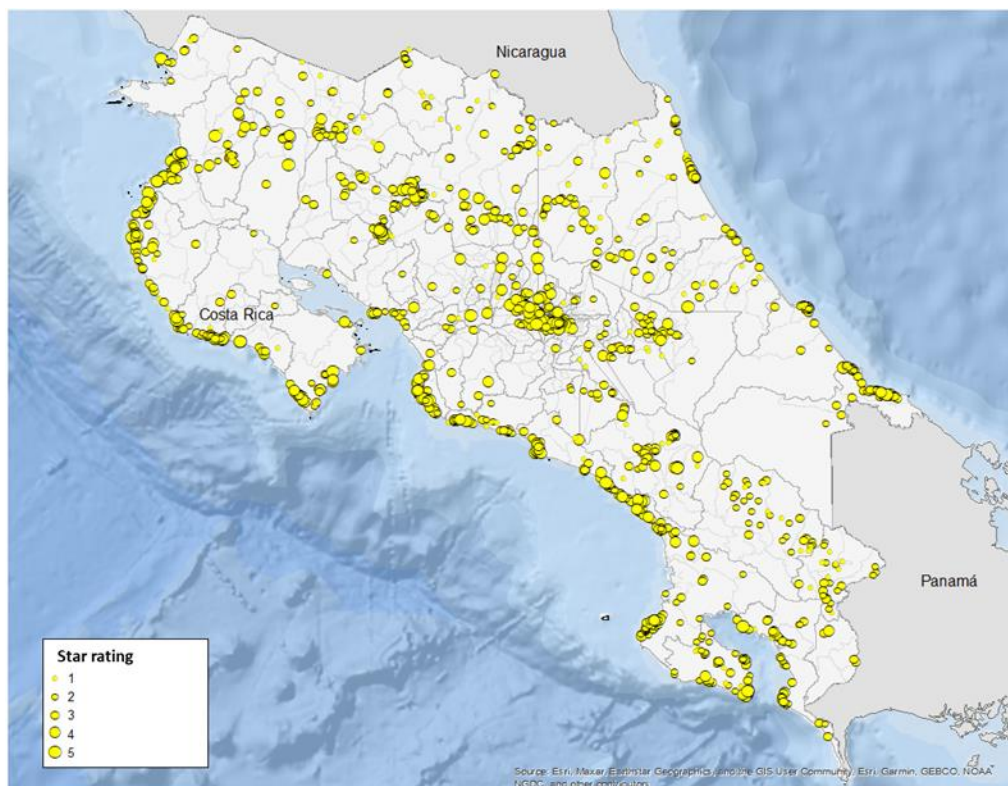


Figure 80. Geographic distribution of star ratings.

5.1.3 Number of Stories

To determine the number of floors of buildings in the tourism sector, the GHS-BUILT-H raster spatial dataset (Pesaresi, M.; Politis, P. 2023) from the Copernicus program was consulted. This dataset provides global spatial information services freely and openly. GHS-BUILT-H represents the spatial distribution of building heights, derived from the combination and filtering of global digital elevation models (DEMs) and satellite imagery.

To estimate the height of the hotels, a spatial intersection was performed between the GHS-BUILT-H raster dataset and the building footprints classified as hotels. From this spatial operation, the height value (in meters) associated with each hotel was extracted. Subsequently, this height was divided by a standard value of 3 meters per floor in order to estimate the number of floors per building.

Figure 81 shows the height distribution (in meters) of buildings for Costa Rica, which can be used to estimate the number of floors when no other data sources are available. Figure 82 presents the resulting floor count distribution in the hotel sector across Costa Rica.

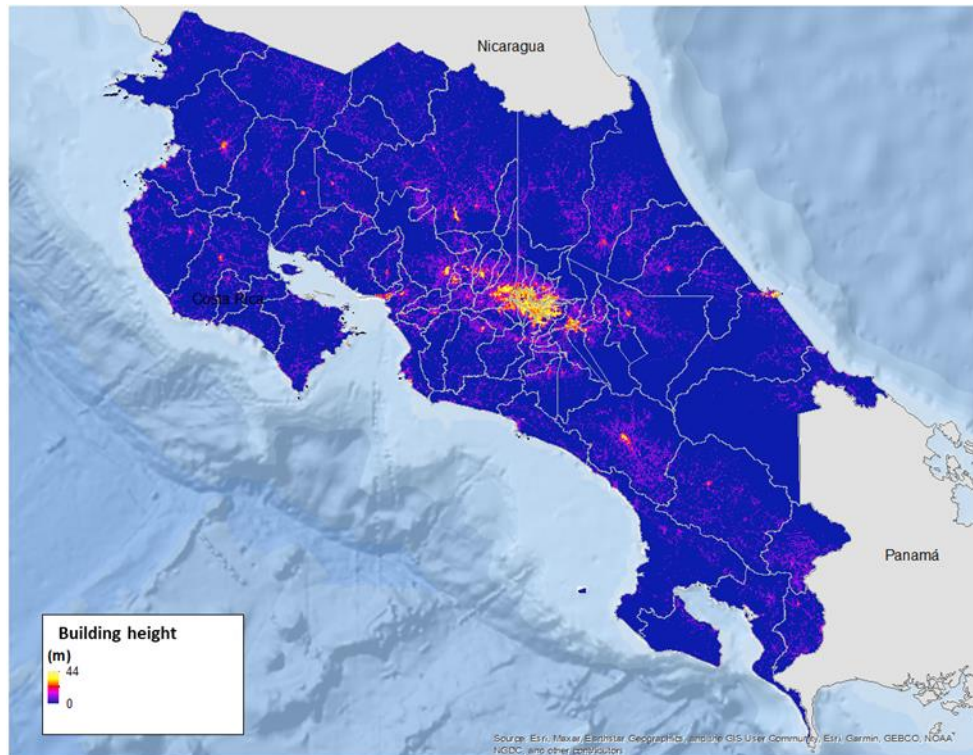


Figure 81. Building height - GHS-BUILT-H.

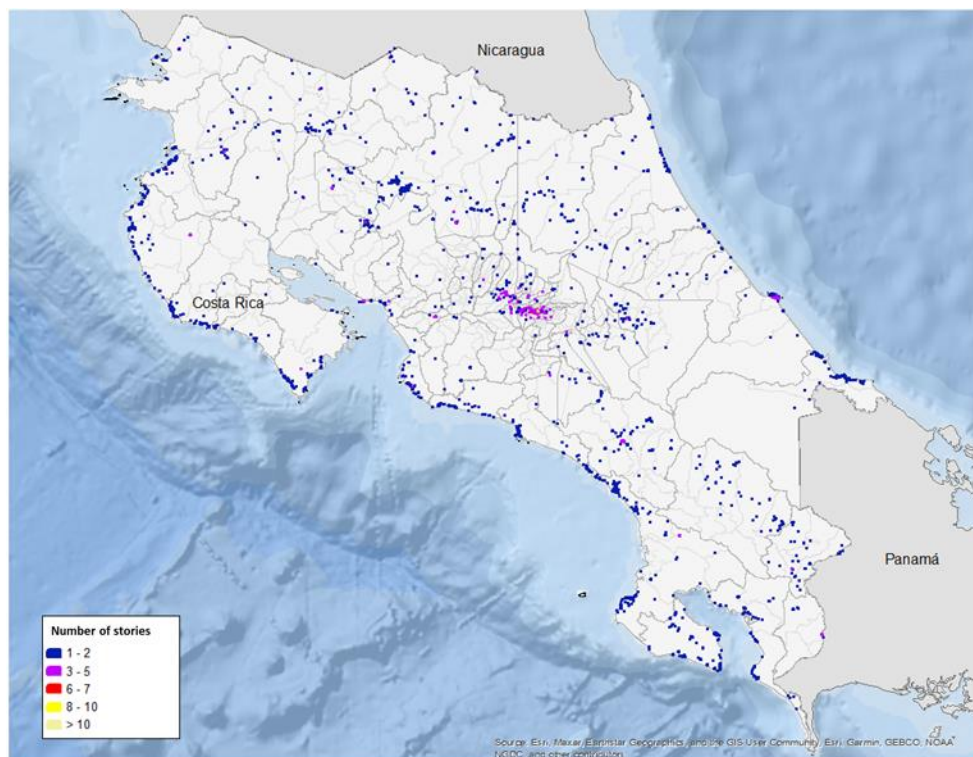


Figure 82. Number of stories in the hotel sector.

5.1.4 Economic Valuation

To estimate the economic valuation of hotels, the Manual of Base Unit Values by Construction Typology was consulted. This tool was developed by the Technical Standardization Body of the Ministry of Finance of Costa Rica to determine the replacement cost of buildings, installations, and complementary works for fiscal purposes. In this manual, hotel constructions are classified according to the characteristics indicated in Table 35.

Table 35. Characterization of hotel constructions in the manual of base unit values by construction typology.

Hotel type	Structure	Description	Value (¢/m ²)
HT01	Integral masonry, prefabricated or metal profiles	Simple design buildings with a reception area and rooms. All hallways have smoke detectors and fire extinguishers. No gardens or elevators. One to three floors; generally, the first is used for commercial purposes.	690,000
HT02	Reinforced concrete columns and beams, prefabricated and/or metal profiles	Simple design buildings with a reception area, lobby, and basic restaurant. All hallways with smoke detectors and fire extinguishers. Simple gardens. No elevator. One to three floors.	745,000
HT03	Reinforced concrete columns and beams, prefabricated and/or metal profiles	Includes lobby, reception, restaurant, and conference rooms. Quality finishes with porcelain bathroom tiling (up to 1.5 m), wooden doors, hot/cold water system with electric pump. Smoke detectors and extinguishers in all hallways. Maintained gardens, proper signage and lighting, located in pleasant and safe urban areas. Elevator present. One to three floors.	820,000
HT04	Reinforced concrete or prefabricated columns and beams, and/or metal profiles	Includes lobby and reception, conference rooms, bar, one or two well-finished restaurants, souvenir shops, possibly beauty salon and barbershop. Noise insulation, good views from rooms and public areas. Hot/cold water system with electric pump, fire protection system, A/C, emergency power plant. Meticulously maintained gardens, clear signage, proper lighting, safe and quiet urban locations. Elevators. Multi-story hotels.	865,000
HT05	Cast-in-place or prefabricated reinforced concrete and/or metal profiles	Elegant and luxurious designs. Large windows with reflective aluminum frames and insulated glass, lounges, conference rooms, restaurants, large lobby, bars, gyms, car rental, retail stores, possibly beauty salon, barbershop, casino. Wide, carpeted hallways. Excellent natural and artificial lighting and ventilation, noise insulation. Good views from rooms and public areas. Hot/cold water system with pump, A/C, fire protection, emergency power plant. Smoke detectors and extinguishers in all hallways. Meticulously maintained gardens, complete signage, proper lighting, located in safe, quiet, and pleasant areas. Multiple elevators and service elevators. Multi-story hotels.	1,080,000

Taking into account the characteristics of the hotels—such as the services offered, approximate built-up floor areas, and number of stories, —the economic valuation was carried out by calculating the total built area (floor area multiplied by the number of stories) and multiplying it by the unit value of the corresponding construction typology.

5.2 Vulnerability Model

To classify the vulnerability of buildings in the hotel sector, the structural classification reported in the Manual of Base Unit Values by Construction Typology (see Table 36) was used. Although this classification defines five types of hotels, from a structural point of view, it is divided into two groups:

- Integral masonry, prefabricated, or metal profiles
- Reinforced concrete columns and beams, prefabricated and/or metal profiles

Regarding building contents, the Hotel Classification Manual for Costa Rica was used to determine the possible contents of each building and to characterize them according to the level of service and the number of stars assigned to the establishment.

Table 36 presents this information, linking the level of services provided with the furnishing and physical contents of the establishment.

Table 36. Hotel classification according to the hotel classification manual for Costa Rica.

Service/Star rating	1	2	3	4	5
Full service					
Architecture and Landscaping / Green Areas	Basic	Basic	In good condition	Extremely well maintained	Impeccably maintained
Lobby and Public Spaces	Modest reception furniture	Modest reception furniture	Furniture in good condition	Furniture in good condition, gift shops, elevators	Elegant and luxurious furniture, gift shops, elevators
Rooms	Few furnishings, in good condition	Few furnishings, in good condition	Very good quality furniture, telephone, TV	Very good quality furniture, telephone, TV, mechanical ventilation	Like-new furniture, telephone, TV, mechanical ventilation
Bathroom	Private, comfortable for one person	Private, comfortable for one person	Private, comfortable for one person	Private, excellent condition, comfortable for one person	Private, comfortable for two people
Recreational Facilities	Not applicable	At least one recreational service	At least two types of recreational services	At least three types of recreational services	At least four types of recreational services
Dining Facilities	Dining room with service	Dining room with service	Dining room with service and restaurant	Two types of dining areas, restaurant	Various types of dining areas, luxury restaurants
Guest Services	Laundry, business services	Laundry, business services	Laundry, business services	Laundry, business services	Laundry, business services
Limited service					
Architecture and Landscaping / Green Areas	Basic	Basic	In good condition	Extremely well maintained	Impeccably maintained
Lobby and Public Spaces	Modest reception furniture	Modest reception furniture	Furniture in good condition	Furniture in good condition, gift shops, elevators	Elegant and luxurious furniture, gift shops, elevators
Rooms	Few furnishings, in good condition	Few furnishings, in good condition	Very good quality furniture, telephone, TV	Very good quality furniture, telephone, TV, mechanical ventilation	Like-new furniture, telephone, TV, mechanical ventilation
Bathroom	Private, comfortable for one person	Private, comfortable for one person	Private, comfortable for one person	Private, excellent condition, comfortable for one person	Private, comfortable for two people
Recreational Facilities	Not applicable	At least one recreational service	At least two types of recreational services	At least three types of recreational services	At least four types of recreational services
Dining Rooms or Restaurants	Dining room with service	Dining room with service	Dining room with service	Dining room with service	Dining room with service
Guest Services	Laundry, business services	Laundry, business services	Laundry, business services	Laundry, business services	Laundry, business services
Minimal service					

Service/Star rating	1	2	3	4	5
Architecture and Landscaping / Green Areas	Basic	Basic	In good condition	Extremely well maintained	
Lobby and Public Spaces	Modest reception furniture	Modest reception furniture	Furniture in good condition	Furniture in good condition, gift shops, elevators	
Units (apartments, rooms, suites, etc.)	Few furnishings, in good condition	Few furnishings, in good condition	Very good quality furniture, telephone, TV	Very good quality furniture, telephone, TV, mechanical ventilation	
Bathroom	Shared, comfortable for one person	Shared, comfortable for one person	Shared, comfortable for one person	Shared, comfortable for one person	
Common Areas	Not applicable	Not applicable	Common room, TV	Common room, TV	
Dining or Kitchen Facilities	Not applicable	Refrigerator, sink, coffee maker	Refrigerator, sink, coffee maker	Refrigerator, sink, coffee maker	

On the other hand, in the Manual of Unit Base Values by Construction Typology, five types of hotel constructions are reported, which are grouped into two structural types, as indicated in Table 37.

Table 37. Description of hotel type building structure.

Hotel type	Structure	Description
HT01	Solid masonry, prefabricated, or metal profiles	Simply designed buildings with a reception area and the remainder as bedrooms. All corridors are equipped with fire detectors and extinguishers. No gardens or elevators. Hotels range from one to three stories. Generally, the first floor is used for commercial purposes.
HT02	Reinforced concrete columns and beams, prefabricated and/or metal profiles	Simply designed buildings. Includes a reception area, lobby, and a simple restaurant. All corridors are equipped with fire detectors and extinguishers. Basic gardens. No elevator. Hotels range from one to three stories.
HT03	Reinforced concrete columns and beams, prefabricated and/or metal profiles	Includes lobby, reception, restaurant, and conference rooms, with quality doors, bathrooms tiled up to 1.5 meters in porcelain, and wooden doors. Cold and hot water system with electric pump. All corridors have fire detectors and extinguishers. Well-maintained gardens, clear signage, and lighting in good condition, located in pleasant and safe city areas. Elevator included. Hotels range from one to three stories.
HT04	Reinforced concrete columns and beams, prefabricated and/or metal profiles	Includes lobby and reception, conference rooms, bar, one or two restaurants with good quality finishes. Gift and souvenir shops may also include beauty salon and barbershop. Noise insulation. Good views from rooms and public areas. Cold and hot water system with electric pump, fire protection system, air conditioning, emergency generator. All corridors have fire detectors and extinguishers. Meticulously maintained gardens, clear and complete signage, lighting in good condition, located in pleasant, safe, and quiet areas. Elevators included. Multi-story hotels.
HT05	Reinforced concrete columns and beams poured on-site or prefabricated and/or metal profiles	Elegant and luxurious designs. Large windows with reflective aluminum frames and insulated glass, living rooms, conference rooms, restaurants, spacious lobby, bars, gyms, car rentals, clothing, jewelry, craft and gift shops; may also include beauty salon, barbershop, and casino. Wide, carpeted access corridors to bedrooms. Excellent artificial and natural lighting and ventilation, with noise insulation. Good views from rooms and public areas. Cold and hot water system with electric pump, air conditioning, fire protection system, emergency generator. All corridors have fire detectors and extinguishers. Meticulously maintained gardens, clear and complete signage, lighting in good condition, located in pleasant, safe, and quiet areas. Several elevators and service elevators. Multi-story hotels.

Additionally, the hotel classification manual for *Costa Rica* categorizes the physical infrastructure of the establishment based on the range of services offered to guests. Based on the characterization and classification of hotels according to these information sources, the classification shown in Table 38 was developed. This table categorizes hotels according to structure type, star rating, and range of services provided, focusing on the provision of services through the furnishings and physical contents of the establishment.

Table 38. Hotel classification by structure type, star rating, and services provided

Structure Type	Star rating	Services
A - Solid masonry, prefabricated, or metal profiles	1	Simple architecture Modest furniture in lobby and public areas Rooms with few furnishings in good condition Private or shared bathroom Limited or no dining service Limited guest services
	2	Simple architecture Modest furniture in lobby and public areas Rooms with few furnishings in good condition Private bathroom At least one recreational service Dining service Guest services
	3	Architecture in good condition Lobby and public area furniture in good condition Rooms with very good furnishings, phone, TV Private bathroom At least two types of recreational services Dining service and restaurant Guest services
	4	Extremely well-maintained architecture Very good quality lobby and public furniture, gift shops Rooms with very good furnishings, phone, TV, mechanical ventilation Private bathroom in excellent condition At least three types of recreational services Two types of dining services and restaurant Guest services
	5	Impeccably maintained architecture Elegant and luxurious furniture in lobby and public areas, gift shops Rooms with like-new furniture, phone, TV, mechanical ventilation Private bathroom, comfortable for two people At least four types of recreational services Various types of dining rooms and luxury restaurants Guest services
B - Reinforced concrete frame, prefabricated and/or metal profiles	1	Simple architecture Modest furniture in lobby and public areas Rooms with few furnishings in good condition Private bathroom Limited or no dining service Limited guest services
	2	Simple architecture Modest furniture in lobby and public areas Rooms with few furnishings in good condition Private bathroom At least one recreational service Dining service Guest services
	3	Architecture in good condition Lobby and public area furniture in good condition Rooms with very good furnishings, phone, TV

Structure Type	Star rating	Services
		Private bathroom At least two types of recreational services Dining service and restaurant Guest services
	4	Extremely well-maintained architecture Very good quality furniture in lobby and public areas, elevator, gift shops Rooms with very good furnishings, phone, TV, mechanical ventilation Private bathroom in excellent condition At least three types of recreational services Two types of dining services and restaurant Guest services
	5	Impeccably maintained architecture Elegant and luxurious furniture in lobby and public areas, elevator, gift shops Rooms with like-new furniture, phone, TV, mechanical ventilation Private bathroom, comfortable for two people At least four types of recreational services Various types of dining rooms and luxury restaurants Guest services

To characterize the vulnerability of hotels, archetype models are defined according to the physical structure of the hotel and the services it provides. The definition of the archetype is thus based on the price ratio between the building (i.e., the construction of the establishment) and its equipment (furniture, installations, and general contents).

For the determination of the price ratios, the base value per square meter of the hotel construction (structure) was taken from the value reported for high-quality housing, according to Costa Rica's Manual of Base Unit Values by Construction Typology. Specifically, typology VC05 was considered, with a value of \$485,000/m² for masonry constructions, and typology VC06, with a value of \$545,000/m² for concrete constructions.

To estimate the value of the contents, the base construction value (according to typology VC05 or VC06, as applicable) was subtracted from the reported per-square-meter value for the hotel type in Costa Rica's Manual of Base Unit Values by Construction Typology, which includes both the building and the contents.

Table 39 shows the classification of hotel archetypes, according to structure type, star rating, and services provided.

Table 39. Price ratio between construction and equipment for hotel archetypes.

Structure	Star rating	Archetype	Construction percentage	Furniture and services percentage
A - Solid masonry, prefabricated, or metal profiles	1	Hotels_A1_2	70%	30%
	2			
	3	Hotels_A3	63%	37%
	4	Hotels_A4	60%	40%
	5	Hotels_A5	47%	53%
B - Reinforced concrete frame, prefabricated and/or metal profiles	1	Hotels_B1_2	73%	27%
	2			
	3	Hotels_B3	66%	34%
	4	Hotels_B4	63%	37%

	5	Hotels_B5	50%	50%
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In order to facilitate the understanding of the procedure for assigning vulnerability functions, Figure 81 presents a flowchart of the implemented process. Upon completion of the procedure shown in Figure 81, the *number of floors* attribute is added individually to determine the corresponding vulnerability curve.

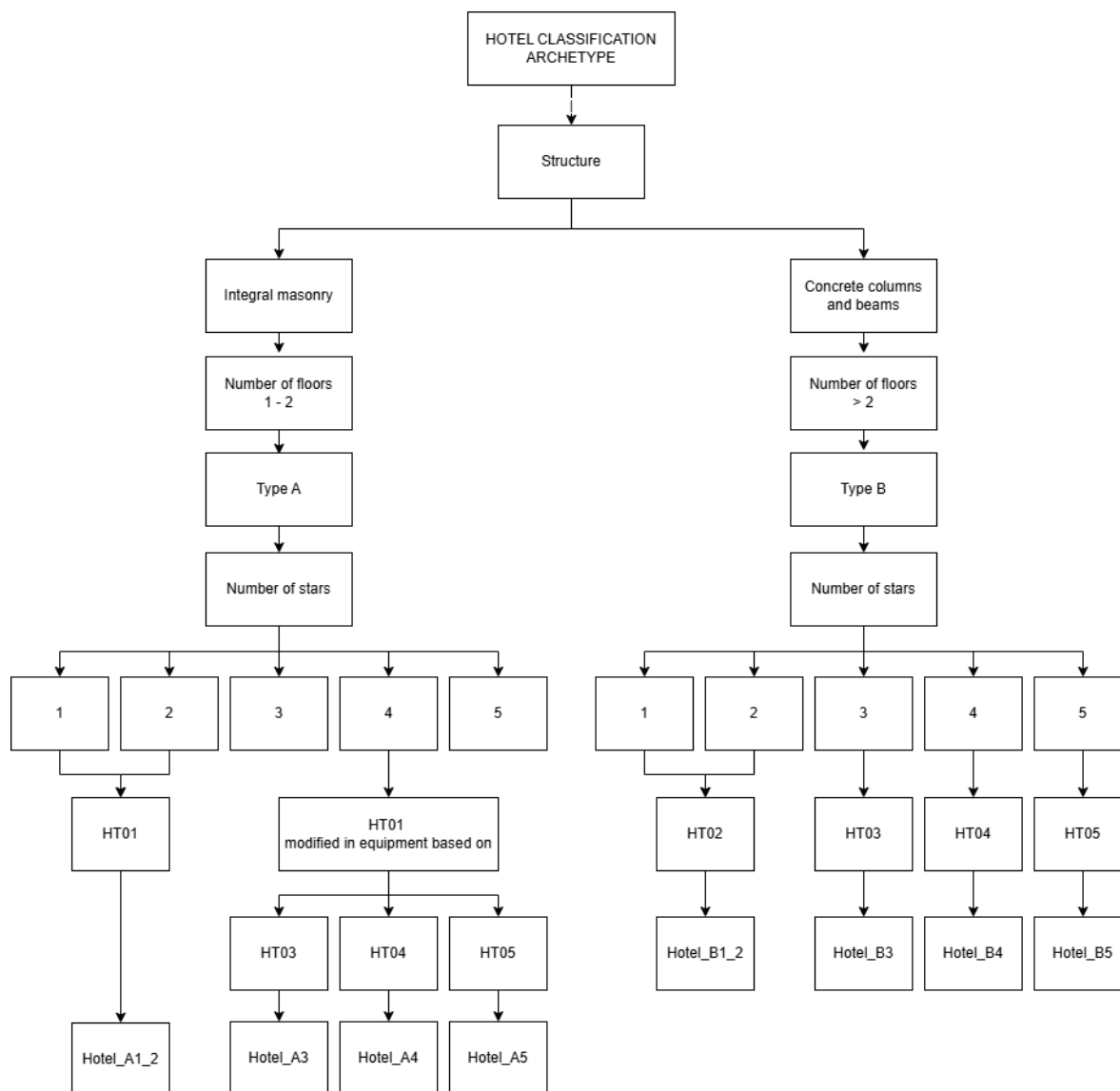


Figure 83. Flowchart for the Assignment of Vulnerability Models to Hotels

Figure 84 to Figure 86 show the vulnerability functions obtained for the considered hotel sector archetypes, in the face of floods, earthquakes, coastal flooding, and tsunamis.

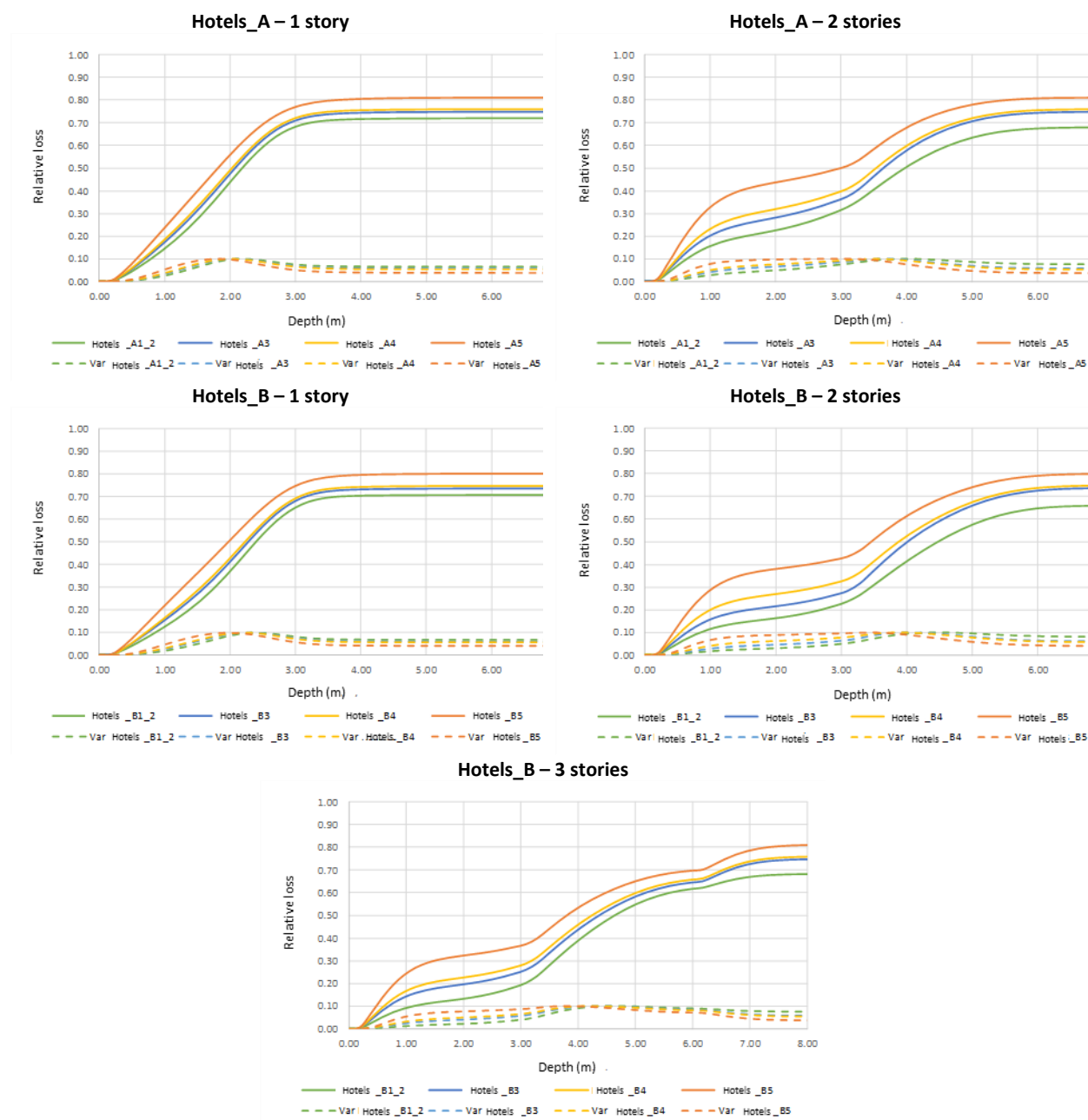


Figure 84. Flood vulnerability functions of hotels archetypes.

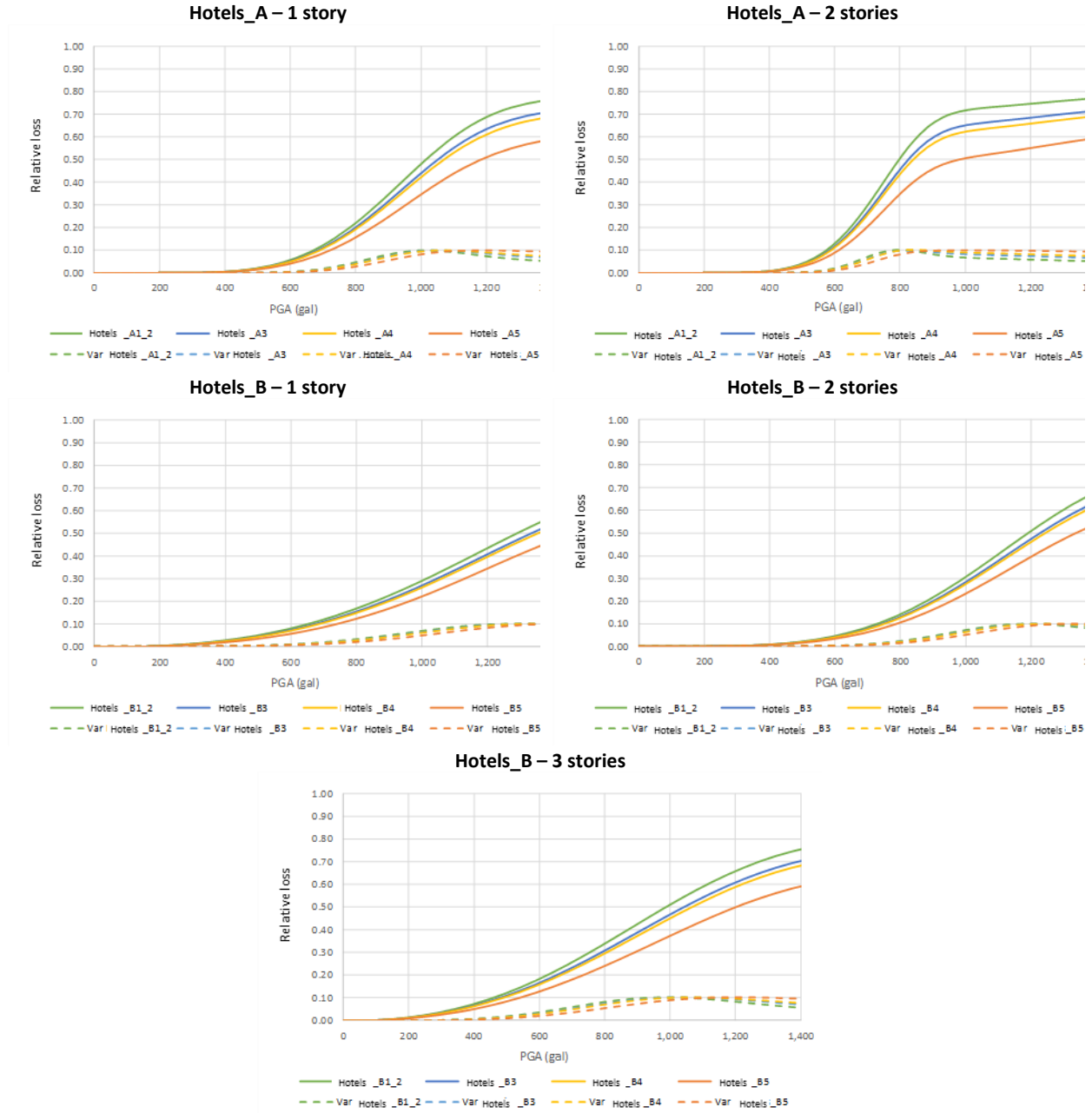


Figure 85. Seismic vulnerability functions of hotels archetypes.

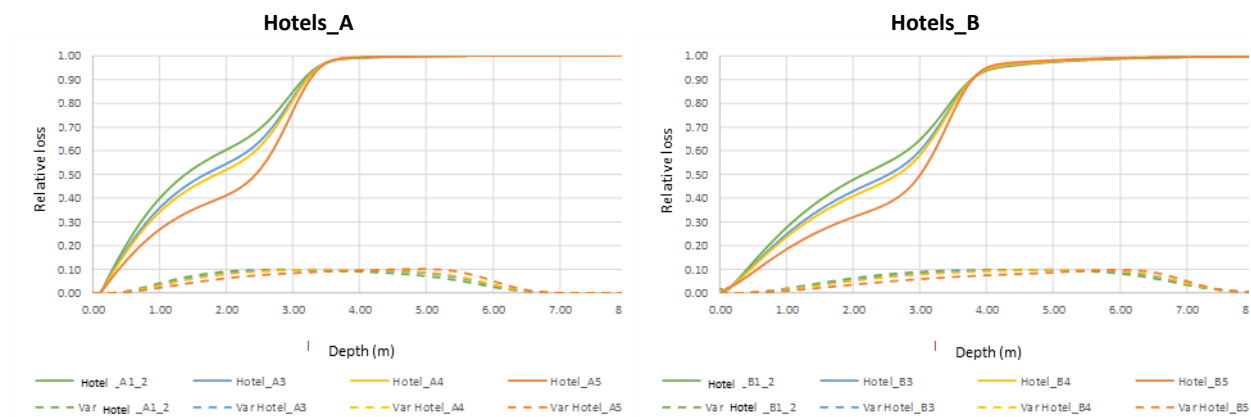


Figure 86. Coastal flooding and tsunami vulnerability functions of hotels archetypes.

6 CAPACITY DEVELOPMENT PROGRAM

As part of the capacity-building process within this consultancy, the *Probabilistic Disaster Risk Modeling Course* is being developed. This course includes content with an emphasis on understanding and constructing vulnerability models and their application in risk assessments. This component seeks to enhance the technical knowledge required to appropriately incorporate these inputs into disaster risk modeling.

The main objective of the course is to provide participants with the necessary scientific foundations to understand and perform risk modeling, as well as to interpret its results. By the end of the training process, participants will be able to carry out risk assessments for natural hazards using advanced tools from the CAPRA-ROBOT system. This training is aimed at professionals, specialists, and researchers associated with the Technical Working Group of the GRMA – Costa Rica program, as well as staff from other interested institutions with backgrounds in fields such as Earth sciences, engineering, mathematics, physics, econometrics, or financial/actuarial analysis.

The asynchronous course officially began on March 18, 2025, with *Module 1*, which covers general foundations of probabilistic risk assessment. After completing this module, participants proceeded to *Module 2*, focused on natural hazard modeling and the assessment of vulnerability of exposed elements. A significant portion of the course is dedicated to the analysis of exposure and vulnerability as essential components of risk evaluation.

Module 2, which began on May 13, 2025, allows each participant to select a hazard of interest from those considered in the GRMA project. This module provides theoretical and practical materials on hazard and vulnerability modeling for all threats covered by the project, enabling specialized and context-specific training for the participants. This includes training activities on damage and vulnerability models for seismic hazards, gravitational flows, hurricane winds and storm surges, and floods, as well as livestock stress and carrying capacity under extreme weather and flooding events.

For exposure modeling, the course covers the minimum requirements for creating a database of exposed elements, such as geolocation, characterization, and economic valuation. Additionally, it includes relevant considerations for exposure modeling in the agricultural and livestock sectors.

In the vulnerability section, the focus is on the physical vulnerability of exposed elements to various hazards. Participants learn to construct vulnerability functions and apply concepts of binary vulnerability in hazards such as landslides. These sessions combine theoretical lessons with assisted practices using specialized software.

The theoretical sessions are complemented by hands-on workshops, where participants learn to use the *Vulnerability Studio* software for modeling vulnerability functions associated with different structural types depending on the hazard being studied. *Vulnerability Studio* is a tool that models the vulnerability of exposed elements through mathematical functions that relate hazard intensity to direct physical impact. It implements several methods for creating vulnerability functions tailored to different hazard types, allowing the estimation of loss probability functions for varying intensity levels.

Table 40 presents a detailed breakdown of the topics covered in the vulnerability-related units for each type of hazard.

Table 40. Topics covered in the vulnerability related units.

Hazard	Topic
All	Damage models: Fragility and vulnerability functions - Fragility curves - Vulnerability curves - Binary vulnerability (landslides)
Earthquake	- Structural behavior under cyclic lateral loads - Behavior of structures sensitive to peak ground acceleration - Behavior of structures sensitive to inter-story drift
Tropical cyclone (cyclonic wind and storm surge flood)	- Effects of wind on structures - Pressure loads on buildings - Cyclic wind loads on tall buildings - Vulnerability to wind field - Vulnerability to debris impact - Vulnerability to storm surge flooding
Volcano (gravity flows)	- High-energy localized events - Binary vulnerability - Roof resistance to volcanic ash deposits
Landslides	- Rainfall-landslide thresholds - Landslides triggered by intense rainfall - Landslides triggered by earthquakes
Drought	- Exposed elements in the agricultural sector and their characteristics - Soil characteristics required for vulnerability modeling - Crop water response model - Water balance - Crop development - Biomass production - Yield

Next, a summary is provided of the number of participants enrolled by hazard type and the institutions they belong to. It is important to note that participants may register for more than one hazard, according to their interests.

Table 41. Number of participants and institutions, by hazard type.

Hazard	Participants and institutions
Earthquake	19 participants - Aseguradora Sagikor Costa Rica S.A. - Comisión Nacional de Prevención de Riesgos y Atención de Emergencias - Escuela de Geología, Universidad de Costa Rica - Instituto Nacional de Seguros - Laboratorio Nacional de Materiales y Modelos Estructurales, Universidad de Costa Rica - MNK Seguros - Municipalidad Heredia - Seguros LAFISE Costa Rica S.A. - Superintendencia General de Seguros
Tropical cyclones	21 participants - ASSA Compañía de Seguros - Banco Central de Costa Rica

	- Comisión Nacional de Prevención de Riesgos y Atención de Emergencias - GIZ (Futurismo) - Instituto Meteorológico Nacional (IMN) - Laboratorio Nacional de Materiales y Modelos Estructurales, Universidad de Costa Rica - Ministerio de Agricultura y Ganadería - Municipalidad Heredia - Seguros LAFISE Costa Rica S.A. - Superintendencia General de Seguros
Volcano	15 participants - Aseguradora Sagicor Costa Rica S.A. - Comisión Nacional de Prevención de Riesgos y Atención de Emergencias - Escuela de Geología, Universidad de Costa Rica - Laboratorio Nacional de Materiales y Modelos Estructurales, Universidad de Costa Rica - Ministerio de Agricultura y Ganadería - Municipalidad Heredia - Superintendencia General de Seguros
Landslides	26 participants - Banco Central de Costa Rica - Comisión Nacional de Prevención de Riesgos y Atención de Emergencias - Escuela de Geología, Universidad de Costa Rica - GIZ (Futurismo) - Instituto Meteorológico Nacional (IMN) - Laboratorio Nacional de Materiales y Modelos Estructurales, Universidad de Costa Rica - Ministerio de Agricultura y Ganadería - Municipalidad Heredia - Superintendencia General de Seguros
Drought	18 participants - ASSA Compañía de Seguros - Banco Central de Costa Rica - Comisión Nacional de Prevención de Riesgos y Atención de Emergencias - GIZ (Futurismo) - Instituto Meteorológico Nacional (IMN) - Laboratorio Nacional de Materiales y Modelos Estructurales, Universidad de Costa Rica - Ministerio de Agricultura y Ganadería - Superintendencia General de Seguros
Flood	25 participantes - ASSA Compañía de Seguros - Banco Central de Costa Rica - Comisión Nacional de Prevención de Riesgos y Atención de Emergencias - GIZ (Futurismo) - Instituto Meteorológico Nacional (IMN) - Instituto Nacional de Seguros - Laboratorio Nacional de Materiales y Modelos Estructurales, Universidad de Costa Rica - Ministerio de Agricultura y Ganadería - MNK Seguros - Municipalidad Heredia - Seguros LAFISE Costa Rica S.A. - Superintendencia General de Seguros

Two meetings have been held with the technical working groups in order to share progress and the methodology of the consultancy. During these sessions, the main challenges associated with the progress of the modeling have been discussed, as well as the available information sources and the identified data gaps. In addition, the technical groups have provided feedback to the consultant regarding their expectations for the deliverables and expected results, and the next steps have been jointly reviewed to ensure compliance with the established schedule and objectives.

Furthermore, a centralized dataset has been created, in which all products generated to date are available, allowing consultation and review by the working groups and any other interested parties. This repository facilitates process transparency, promotes technical collaboration, and ensures that the information remains accessible to support monitoring of the consultancy's progress.

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Vaast, P., Bertrand, B., Perriot, J. J., Guyot, B., & Génard, M. (2005). Fruit thinning and shade improve bean characteristics and beverage quality of coffee (*Coffea arabica* L.) under optimal conditions. *Journal of the Science of Food and Agriculture*, 85(13), 197–204.

A.1 ALTERNATIVE SOURCES OF INFORMATION FOR OTHER CANTONS

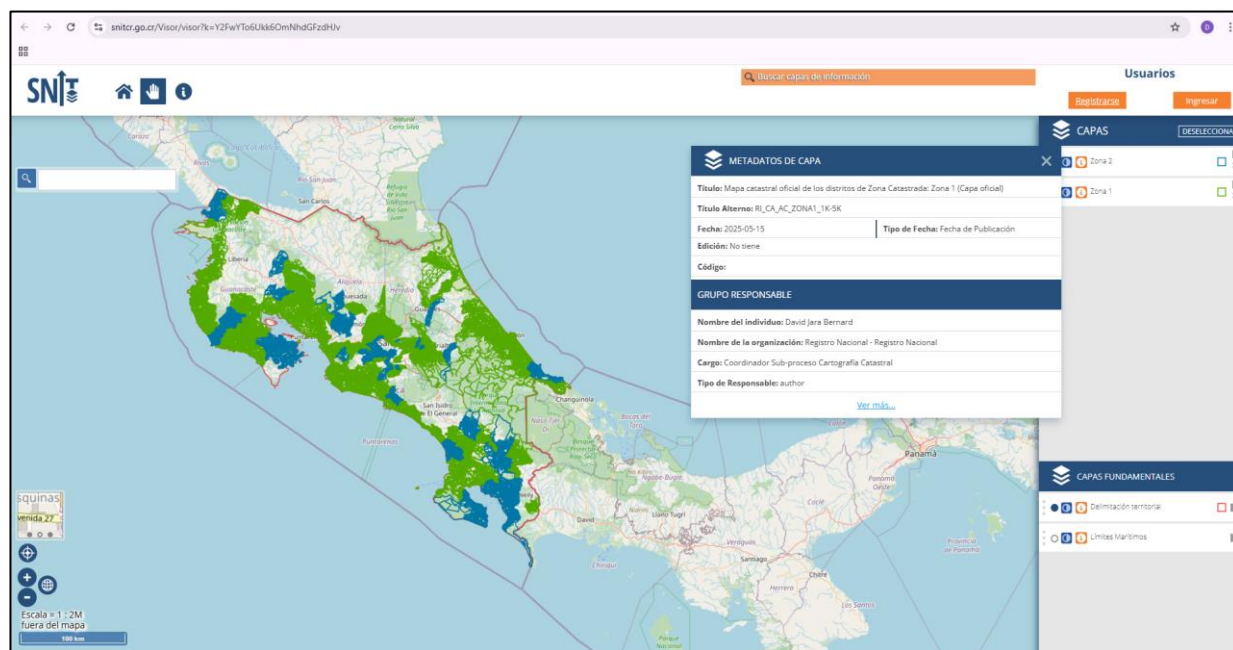
As presented in sections 2.1 and 2.2 of this report, there is a large amount of data available for creating an exposure model of buildings and infrastructure for the canton of Heredia, most of which are of sufficient quality. Since this is a particular advantage of the Heredia canton, which may not be shared by other cantons in Costa Rica, this section lists alternative information sources that can serve as references for future modeling processes aiming to replicate the risk modeling work in other cantons of the country.

A.1.1 General Geographic Location of Buildings

In cases where cadastral information is not available, the following are other official and global sources of information that can be publicly consulted and offer downloadable data as georeferenced databases.

Cadastral map in the National Territorial Information System (SNIT)

The SNIT platform publishes Costa Rica's official cadastral map, which contains information on the location, identification, and boundaries of land parcels for most of the country. Figure 87 shows the cadastral map as displayed in the SNIT viewer.



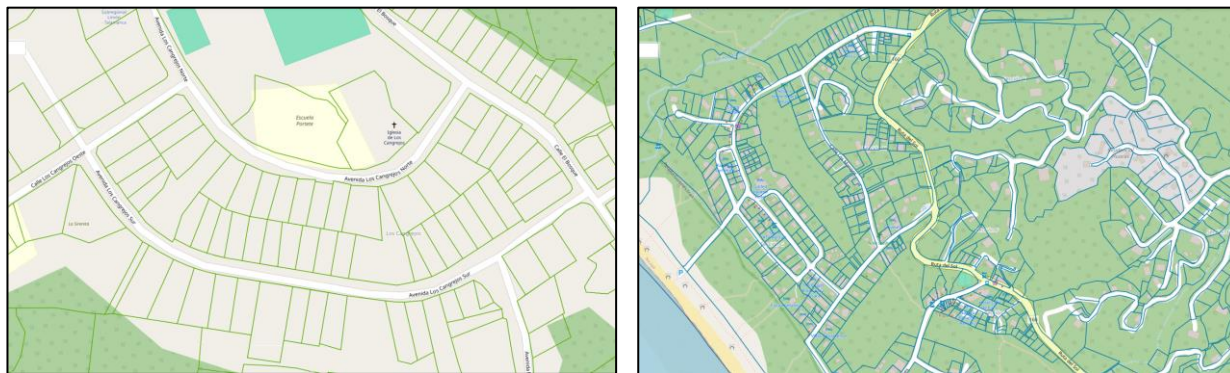


Figure 87. Cadastral map – SNIT¹⁴.

Building Cartography

Among the cartographic datasets from the National Geographic Institute consulted through the National Territorial Information System (SNIT), there is nationwide coverage of buildings and constructions derived from orthophotos taken between 2015 and 2018. As shown in Figura 88, the coverage represents blocks of contiguous buildings, which may contain within a single block constructions with different owners, number of floors, usage sectors, structural systems, among other attributes.

Therefore, in order to obtain the location and boundaries of individual buildings, it is necessary to combine the geometry of the building cartography—which provides information on built-up areas without including the land parcel area—with the geometry of the cadastral map, which provides the boundaries of the parcels. This combination allows for the independent characterization of each building.

¹⁴ <https://www.snitcr.go.cr/Visor/visor?k=Y2FwYT06Ukk6OmNhdGFzdHJv>
https://www.snitcr.go.cr/ico_servicios_ogc_info?k=bm9kbzo6Mjk=&nombre=Registro%20Inmobiliario

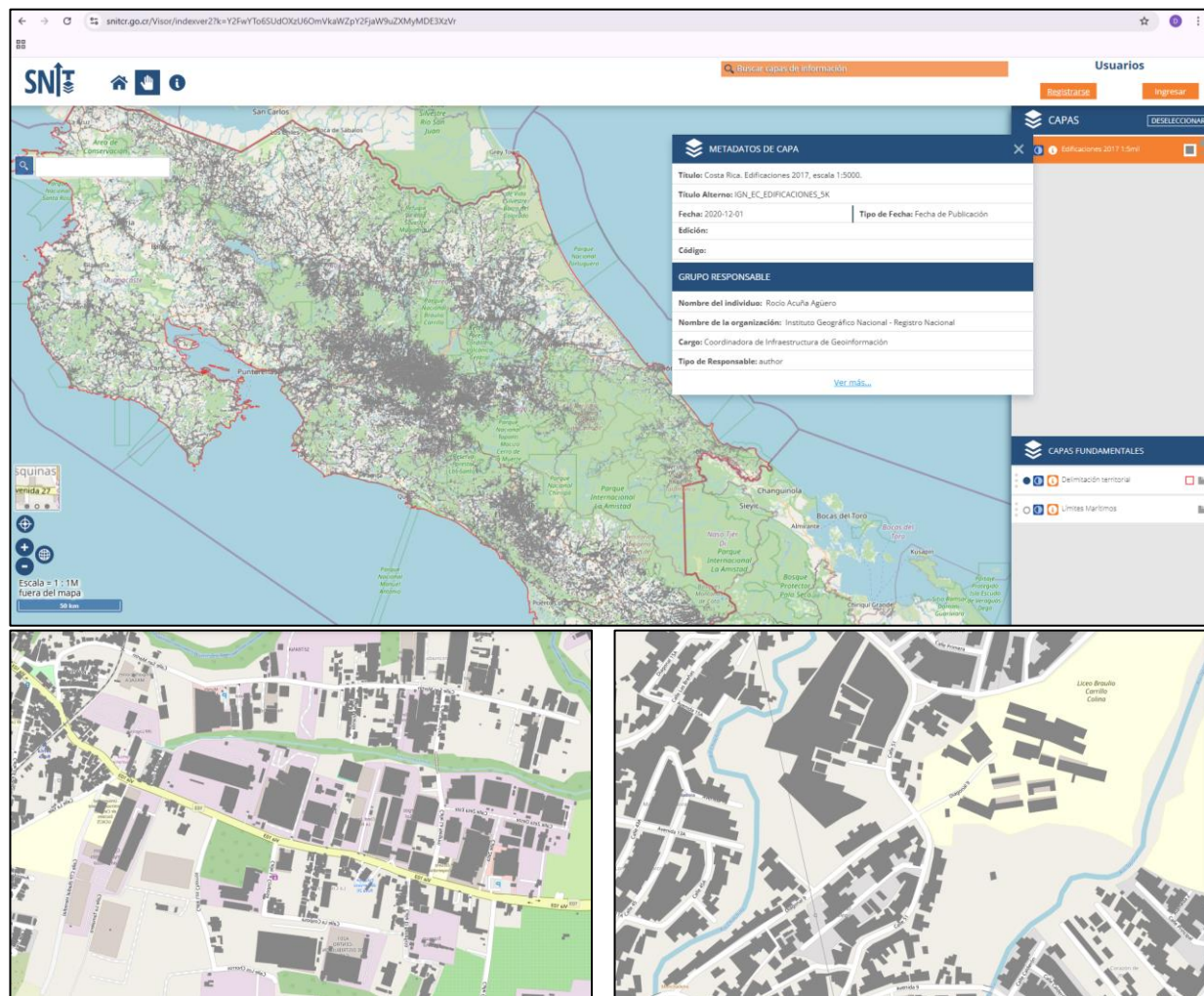


Figura 88. Cartografía edificaciones - SNIT¹⁵.

Google Research Open Buildings

When official information on the georeferencing of buildings is not available, there are global open-access databases that can be consulted and downloaded, such as Google Research Open Buildings. This open dataset of building footprints contains the outlines of buildings derived from a deep learning model trained to identify building footprints from high-resolution satellite imagery. Each building in this dataset includes the georeferenced polygon describing its footprint on the ground, a confidence score indicating the certainty of its detection, and the approximate built-up area. Figure 89 illustrates the data downloaded for Costa Rica.

¹⁵https://www.snitcr.go.cr/Metadatos/full_metadata2?k=Y2FwYW1ldGFkYXRvczo6Y2FwYT06SUdOXzU6OmVkaWZpY2FjaW9uZXMzMDE3XzVr



Figure 89. Open Buildings – Google Research.

A. 1.2 Essential Buildings

To determine the geographic location of public buildings that must ensure the continuity of critical services after the occurrence of a disaster, the coverage of buildings and constructions published on the platform of the National Territorial Information System (SNIT) is available for the entire country. This layer of building footprints includes the descriptive attribute "Categoría", which allows the classification of

buildings according to their usage sector. This enables the identification of buildings such as hospitals and health centers, Red Cross facilities, police stations, fire stations, government buildings, among others, as shown in Figure 90.

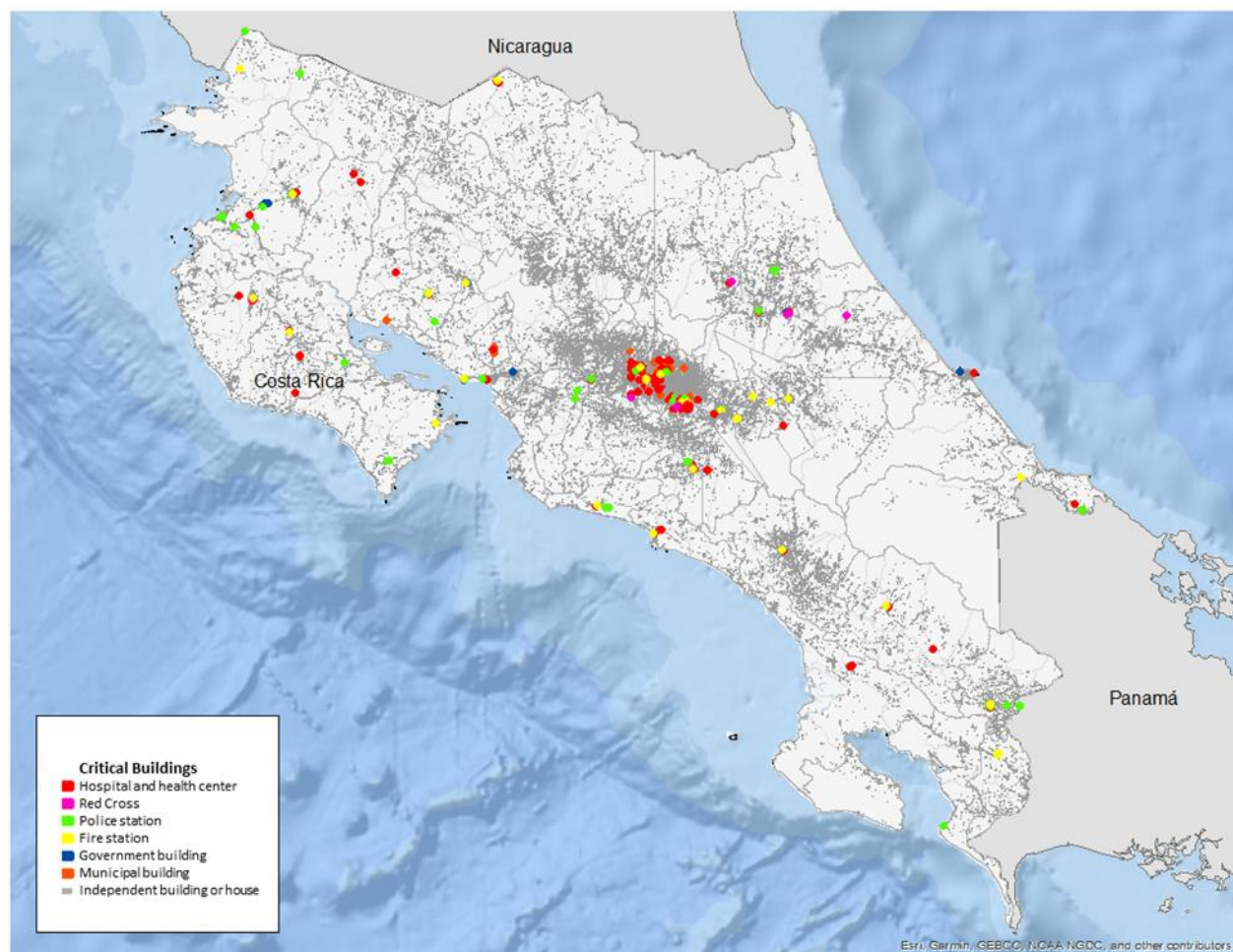


Figure 90. Essential buildings – Costa Rica.

A. 1.3 Educational Buildings

The open data layer from SIGMEP contains information on educational centers across the entire country. This information can be complemented with the building footprint coverage from SNIT, mentioned in the previous sections, to identify educational centers anywhere in the country (see Figure 91).

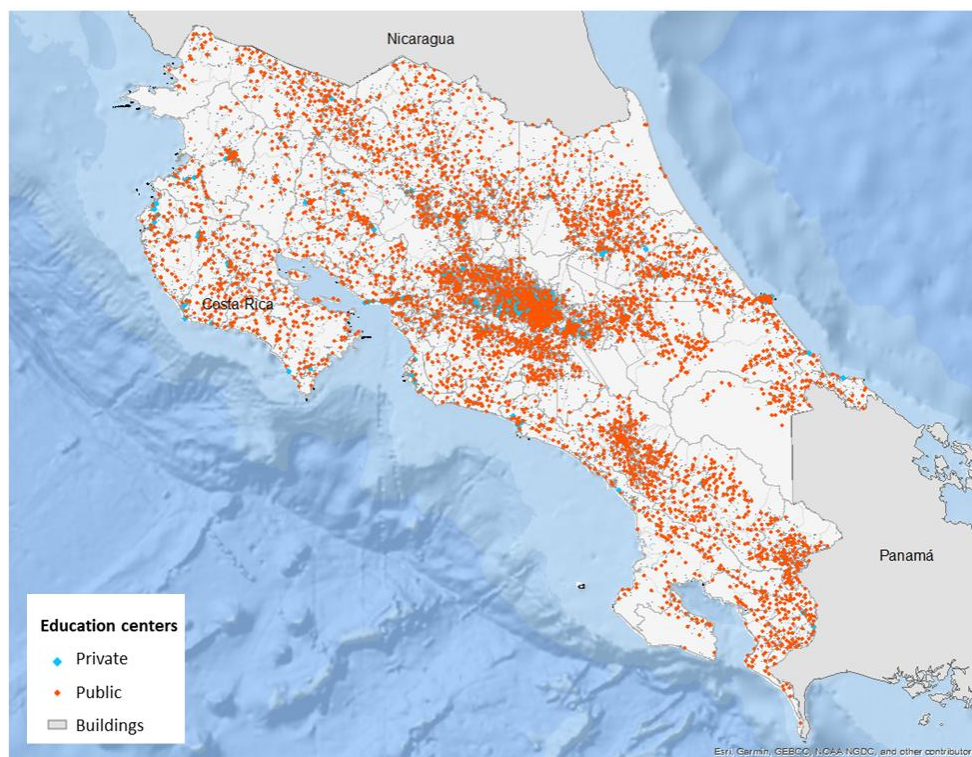


Figure 91. Educational establishments Costa Rica – SIGMEP.

A. 1.4 Number of Stories

Copernicus is a European Union Earth observation program that offers global spatial information services openly and free of charge. This information is based on satellite Earth observation and in-situ data, aiming to describe human presence on the planet.

Among the available data, the GHS-BUILT-H raster dataset (Pesaresi, M.; Politis, P. 2023) provides the spatial distribution of building heights, derived from a combination and filtering of global digital elevation models (DEM) and satellite imagery using linear regression techniques.

Figure 92 shows the distribution of building height in meters consulted for Costa Rica, which can be used to determine the number of floors in buildings when no other sources of information are available.

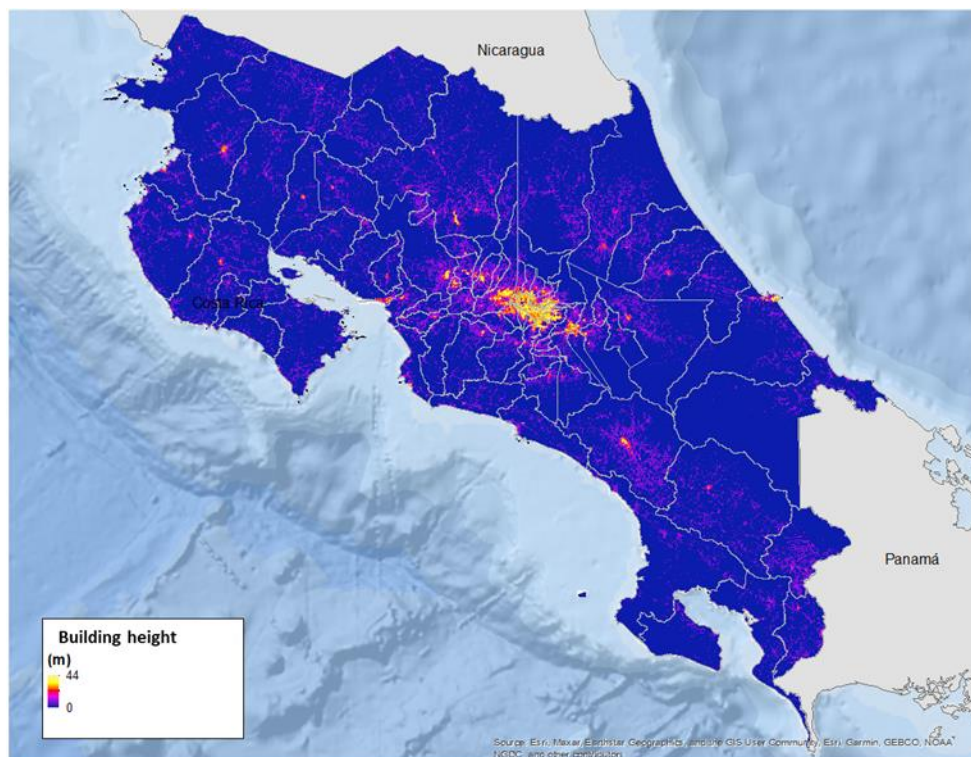


Figure 92. Building height - GHS-BUILT-H.

A. 1.5 Building Use

As an alternative source for identifying land-use sectors in Costa Rica, the “CATEGORIA” attribute in the *Cartografía Edificaciones* layer published by SNIT is available. This attribute provides a detailed classification of the use of buildings throughout the country, as illustrated in Figure 93.

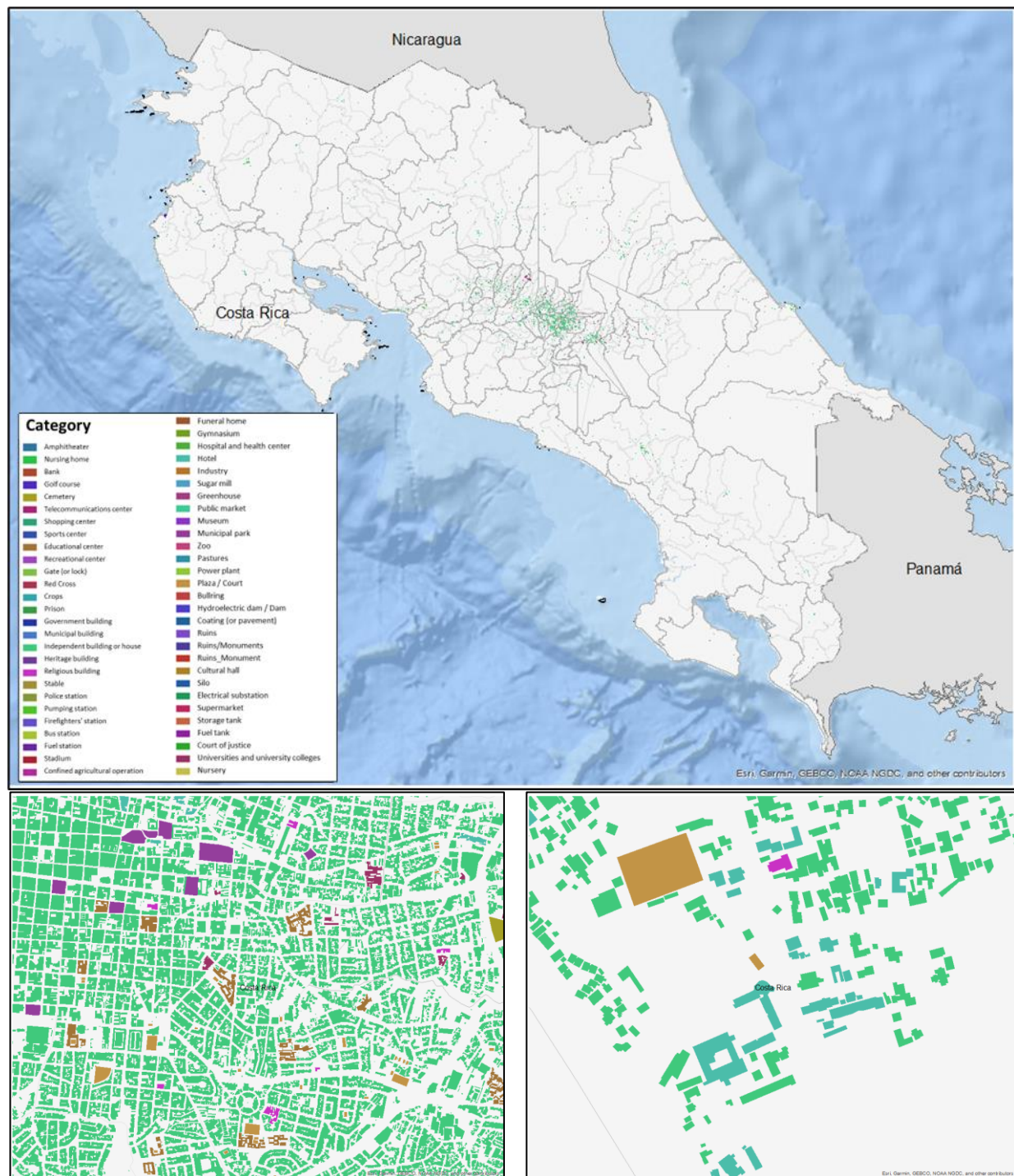


Figure 93. Category (Building Use).

A. 1.6 Building Typologies

An important source of information for classifying the vulnerability of buildings in the country is the *Cartografía Edificaciones* layer published by SNIT, as it includes the category attribute, which allows for the discrimination of buildings by their use. With the support of the characterization provided in the

Manual of Base Unit Values by Construction Typology, it is possible to assign a typology to each building according to its category and other variables such as number of floors and built area.

As a complement, among the publicly accessible sources containing information on building characteristics is the National Population and Housing Census from the National Institute of Statistics and Censuses (INEC). INEC's data systems provide information on predominant materials in walls and roofs, as well as the physical condition of the dwelling, among other variables. This information is available at various levels of geographic disaggregation, down to the minimum geo-statistical unit, which in urban areas can represent the block level. This data can offer an approximation of the geographic distribution of variables (wall material, roof material, condition) even at the block level. Table 42 presents a sample of the information available from INEC on the distribution of predominant materials in exterior walls, in this case consulted by region.

Table 42. Predominant exterior wall material – INEC.

Predominant material in exterior walls (number of dwellings)									
Region	Block or brick	Wainscot (cement-wood, cement-fiber cement)	Wood	Prefabricated or tiles	Fibrolite, Ricalt (fiber cement sheet)	Natural fibers (bamboo, cane, chonta palm)	Scrap material	Other (zinc, adobe)	Total
Central	502,322	46,984	82,014	80,067	26,800	178	1,143	15,983	755,491
Chorotega	52,464	12,328	12,007	11,201	2,539	4	239	1,802	92,584
Pacífico central	36,916	11,933	6,899	10,163	3,747		199	1,833	71,690
Brunica	32,129	24,025	155,957	17,325	3,342	116	164	920	93,978
Huetar Atlántico	50,863	15,264	23,597	12,802	4,958	510	164	1,158	109,316
Huétar Norte	36,187	17,997	20,059	10,271	3,071		219	1,101	88,905
Total	710,881	128,531	160,533	141,829	44,457	808	2,128	22,797	1,211,964

A.2 INFRASTRUCTURE CLASSIFICATION CODE DIRECTORY

Sector	Portfolio	Coding SE field	Code	Attribute	Value	Description
Road	Road segment	XX_R#_S#	XX	Classification	NP	Primary national road
					NS	Secondary national road
					NT	National crossing road
					LP	Primary local road
					LS	Secondary local road
					LT	Tertiary local road
					LTP	Private tertiary local road
					NC	Unclassified (rural roads in Heredia)
			R#	Road surface type	0	No information
					1	Paved
					2	Improved Surface
					3	Unpaved
			S#	Ground slope	1	Cross slope between 0% and 5%
					2	Cross slope between 6% and 14%
					3	Cross slope between 15% and 25%
					4	Cross slope greater than 25%
Road	Vehicular bridges	C#_NC#_H#_ES##_MT#_AP#	C#	Bridge length	1	Bridge length less than 15 m
					2	Bridge length between 15 m and 35 m
					3	Bridge length between 35 m and 50 m
					4	Bridge length between 50 m and 100 m
					5	Bridge length greater than 100 m
			NC#	Number of spans	[1 - 3]	Number of bridge spans (up to 3 in Heredia)
			H#	Vertical clearance	0	No information
					1	From 0 to 3 m
					2	From 3 to 6 m
					3	From 6 to 9 m
			ES##	Superstructure type (NBI code)	0	No information
					2	Multiple beam
					4	T-Beam or Double-T Beam
					7	Frame or portal frame
					10	Through truss
					11	Deck arch
					22	Channel beam

			MT##	Predominant structural material	1	Prestressed concrete
					2	Reinforced concrete
					3	Steel
					4	Masonry
			AP#	Bearings	1	Rigid
					2	Rigid–Expansive
					3	Fixed
					4	Expansive
Railway	Railway corridor	FR_XXX_S#	XXX	Section type	ASF	Section with asphalt surface
					BLT	Section with ballast surface
					CRO	Section with reinforced concrete surface
					PTE	Bridge
			S#	Ground slope	1	Cross slope (to railway alignment) between 0% and 5%
					2	Cross slope (to railway alignment) between 6% and 14%
					3	Cross slope (to railway alignment) between 15% and 25%
Electric power	Power generation	HID-EMB	-	Type of power generation plant	-	Reservoir hydroelectric plant
Electric power	Transmission (TL) – Line	TL_CABLE	-	Transmission line element (TL)	CABLE	High voltage -three phase- circuit
Electric power	Transmission (TL) – Tower	TL_#C	#C	Transmission line circuits (TL)	[1-4]	Number of circuits on the tower
Electric power	Substation	SUBSTAT	-	-	-	Electrical substation
Electric power	Distribution (DL) – Line	DL_XT_XXX	XT	Distribution line voltage (DL)	BT	Low-voltage line
					MT	Medium-voltage line
			XXX	Distribution line installation	AER	Overhead line
					SUB	Underground line
Electric power	Distribution (DL) – Pole	POSTE_X#_H#_STX	X	Element material	C	Concrete
					M	Metal (typically steel)
					W	Wood
			#	Support type	1	Cable-supported (guyed)
					2	Self-supported
			H#	Height classification	1	Post height between 3 m and 6 m

					2	Post height between 6 m and 9 m
					3	Post height between 9 m and 12 m
					4	Post height between 12 m and 15 m
					5	Post height between 15 m and 18 m
			STX	Element condition	A	Pole with less than 50% of service life used
					B	Pole with 50% to 100% of service life used
					C	Pole with more than 100% of service life used (service life exceeded)
Electric power	Distribution (DL) – Transformer	TR_XXX	XXX	Transformer installation	AER	Overhead transformer (pole-mounted)
					PED	Pad-mounted transformer
Telecommunications	Antennas	COM_XX_HX	XX	Support structure type	CU	Rooftop or Distributed Antenna System (DAS)
					TM	Monopole or temporary tower
					TA	Self-supporting tower
					TV	Guyed tower
			HX	Height classification	1	Towers up to 15 m high
					2	Towers between 15 m and 30 m high
					3	Towers between 30 m and 45 m high
					4	Towers between 45 m and 60 m high
Hydrocarbons	Pipeline (poliduct)	POLIDUCTO	-	-	-	Pipeline (poliduct)
Potable water	Water sources	AP_FUENTE	-	-	-	Water intake and treatment structures
Potable water	Storage tank	AP_TANQUE_MX	MX	Tank material	C	Reinforced concrete tank
					H	Iron or steel tank
					O	Tank made of other material
Potable water	Pumping system	SIST_BOMBO	-	-	-	Water pumping/reboosting system
Potable water	Water supply network	TUB_AP_XXX	XXX	Pipe material	AC	Asbestos cement
					ACE	Steel
					CR	Reinforced concrete
					HD	Ductile iron
					HF	Cast iron
					HG	Galvanized iron
					HN	Black iron

					PAD	High-Density Polyethylene (HDPE)
					PVC	Polyvinyl Chloride (PVC)
Potable water	Fire hydrants	HIDRANTE	-	-	-	Column-type fire hydrant, cast iron
Wastewater	Sewer collector network	TUB_AR_M#	M#	Pipe material	1	Smooth or DPR Polyvinyl Chloride (PVC)
					2	Concrete
					3	Clay pipe (earthenware)
					4	No information
Wastewater	Manholes (inspection wells)	POZ_FX_M#_H#	FX	Well shape	C	Circular
					R	Rectangular
			M#	Well material	1	Concrete
					2	Polyvinyl Chloride (PVC)
					3	Brick
			H#	Depth classification	0	Well depth up to 1.5 m
					1	Well depth between 1.5 m and 3.0 m
					2	Well depth between 3.0 m and 4.5 m
					3	Well depth between 4.5 m and 6.0 m
Wastewater	Wastewater treatment plants	PTAR_T#	T#	Type of treatment plant	1	Activated sludge treatment (concrete tanks)
					2	Stabilization ponds (earth-excavated with geosynthetics)

A.3 AGRICULTURAL PRODUCTION COSTS

A.1.7 Coffee Production Costs

Below are the official tables of agricultural production costs for coffee cherries, prepared based on the technology used by producers, as established by the Costa Rican Coffee Institute (ICAPE) and the Economic and Market Studies Unit (UEEM) (2025).

Structure of Agricultural Production Costs for Coffee Fruit

Field Study (a) – Farms of 20 to 26 fanegas^(b)/ha

Harvest 2024–2025 (Apr–Mar)

Productivity: 22.4 fan/ha

Item / Description	Direct costs		Indirect Costs (CRC)	Total Accumulated (CRC)
	Labor (CRC)	Materials (CRC)		
Pruning	53,919.26	0.00	0.00	53,919.26
Suckering	70,980.27	0.00	0.00	70,980.27
Shade management	67,600.26	0.00	0.00	67,600.26
Plant replacement	16,739.11	41,249.42	0.00	57,988.53
Fertilizer application	34,604.90	247,957.75	0.00	282,562.65
Fertilizers application (2nd line)	18,469.87	63,022.21	0.00	81,209.91
Spraying	38,207.67	239,547.83	0.00	277,755.50
Manual weed control	101,078.48	0.00	0.00	101,078.48
Herbicide application	37,941.91	8,701.54	0.00	46,643.80
Pest control	31,341.04	4,302.71	0.00	35,643.75
Farm maintenance	24,947.72	0.00	0.00	24,947.72
Social charges	246,780.30	0.00	0.00	246,780.30
Technological Package	CRC/ha 795,790.99	557,619.98	0.00	1,353,410.97
Cost	CRC/fan 35,526.38	24,893.75	0.00	60,420.13
	USD/fan 69.17	48.47	0.00	117.64
Coffee fruit harvest	647,621.41	-	-	647,621.41
General transport	-	-	63,961.11	63,961.11
Direct Cost +	CRC/ha 1,443,412.39	557,619.98	63,961.11	2,064,993.49
Transport	CRC/fan 64,438.05	24,893.75	2,855.41	92,187.21
	USD/fan 125.46	48.47	5.56	179.49
Crop depletion	-	-	101,603.31	101,603.31
Depreciation	-	-	25,471.20	25,471.20
Maintenance	-	-	105,118.31	105,118.31
Admin expenses	-	-	45,841.01	45,841.01
Total Other Indirect	CRC/ha 0.00	0.00	278,033.82	278,033.82
Costs	CRC/fan 0.00	0.00	12,412.22	12,412.22
	USD/fan 0.00	0.00	24.17	24.17
Total Agricultural	CRC/ha 1,443,412.39	557,619.98	341,994.94	2,343,027.32
Production Cost	CRC/fan 64,438.05	24,893.75	15,267.63	104,599.43
	USD/fan 125.46	48.47	29.73	203.66

Notes

a/ Based on the technical structure of costs according to ECFPAC0910.

b/ Fanega (fan): a unit of volume equivalent to 400 liters or two double hectoliters (2 Dhl).

c/ Exchange rate (average for the harvest): **₡513.60 CRC/USD**

Source: Instituto del Café de Costa Rica (ICAPE)

Cost structure of agricultural production of coffee cherries. Farms of 20 to 26 fanegas per hectare. Harvest 2024–2025 (Apr–Mar). Information quoted directly from ICAPE & UEEM (2025).

Structure of Agricultural Production Costs for Coffee Fruit
Field Study (a) – Farms of 26 to 34 fanegas(b)/ha
Harvest 2024–2025 (Apr–Mar)

Productivity: 30.5 fan/ha

Cost Item	Technical Coefficient	Technical Unit	Unit Cost	Cost Unit	Total cost			
					Total Cost (CRC/ha)	(CRC/fan)	(USD/fan)	
1. Labor								
Crop labor	321.8	hh/ha	1,609.53	CRC/hh	750,763.82	24,615.21	47.94	28.70%
Social charges	44.95%	%	723.48	CRC/hh	232,817.07	7,633.35	14.87	8.90%
2. Inputs								
Seedbed (replanting)	152	pta/ha	286.45	CRC/pta	43,541.05	1,427.58	2.78	1.70%
Complete formula	635.1	kg/ha	387.7	CRC/kg	246,230.95	8,073.15	15.72	9.40%
Nitrogen formula	221	kg/ha	282.3	CRC/kg	62,388.01	2,045.51	3.98	2.40%
pH corrector	1.037	L/ha	56,000.00	CRC/L	58,050.85	1,903.31	3.71	2.20%
Fungicide (triazole)	1.034	L/ha	30,131.33	CRC/L	31,246.19	1,024.47	2	1.20%
Fungicide (strobilurin)	0.307	L/ha	33,924.63	CRC/L	37,995.06	1,245.73	2.43	1.50%
Fungicide (copper)	0.773	kg/ha	18,722.49	CRC/kg	14,472.48	474.51	0.92	0.60%
Foliar (zinc)	2.281	L/ha	16,579.64	CRC/L	37,821.52	1,240.69	2.42	1.50%
Foliar (general)	3.33	L/ha	7,072.90	CRC/L	23,552.76	772.22	1.5	0.90%
Coadjuvants	2.69	L/ha	8,246.05	CRC/L	21,456.72	703.48	1.37	0.80%
Herbicide (glyphosate)	3.299	L/ha	3,346.06	CRC/L	11,041.09	362	0.71	0.40%
Herbicide (paraquat)	1.912	L/ha	2,227.65	CRC/L	4,259.27	139.65	0.27	0.20%
Diffusers	6	und/ha	500	CRC/und	3,000.00	98.43	0.19	0.10%
Insecticide	0.161	kg/ha	12,177.87	CRC/kg	1,963.64	64.38	0.13	0.00%
Technological Package Cost (CRC):					1,335,395.21	43,783.45	85.28	0.51
3. Harvest								
Coffee fruit harvest	30.5	fan/ha	28,911.67	CRC/fan	881,805.94	28,911.67	56.31	33.70%
4. Transport								
Transport (fertilizer & lime)	1,532.20	kg/ha	14.92	CRC/kg	29,750.00	2,614.75	5.09	3.00%
Transport (nursery)	152	pta/ha	26.96	CRC/pta	4,098.24	134.37	0.26	0.20%
Transport (coffee fruit)	30.5	fan/ha	1,731.11	CRC/fan	52,799.00	1,731.11	3.37	2.00%
Direct Costs + Transport:					2,296,951.14	75,309.87	146.68	0.88
5. Otros costos indirectos								
Crop depletion				CRC/ha	320,035.16	10,492.96	20.44	12.20%
Depreciation:					143,604.64	4,708.35	9.17	5.50%
Constructions				CRC/ha	25,471.20	835.12	1.63	1.00%
Agricultural equipment				CRC/ha	11,196.10	367.09	0.71	0.40%
Maintenance					14,275.10	468.04	0.91	0.50%
Constructions				CRC/ha	105,118.31	3,446.50	6.71	4.00%
Means of transport				CRC/ha	10,255.62	336.25	0.65	0.40%
Agricultural equipment				CRC/ha	90,935.28	2,981.48	5.81	3.50%
Agricultural equipment				CRC/ha	3,297.55	108.12	0.21	0.00
Agricultural implements				CRC/ha	629.85	20.65	0.04	0.10%
Administrative expenses				CRC/ha	45,841.01	1,502.98	2.93	1.80%
Total Agricultural Coffee Production Cost (CRC)					2,616,986.30	85,802.83	167.12	100.00%

Notes

a/ Based on the technical cost structure and ICAFE Agricultural Production Study 2009–2010 (ECPAC09-10).

b/ *Fanega* (fan): unit of volume equivalent to 400 liters or two double hectoliters (2 Dhl).

c/ Exchange rate (average for the harvest): CRC/USD = 513.43.

Source: *Instituto del Café de Costa Rica (ICAFE)*

Cost structure of agricultural production of coffee cherries. Farms of 26 to 34 fanegas per hectare. Harvest 2024–2025 (Apr–Mar). Information quoted directly from ICAFE & UEEM (2025).

Structure of Agricultural Production Costs for Coffee Fruit
Field Study (a) – Farms of 34 to 40 fanegas^(b)/ha
Harvest 2024–2025 (Apr–Mar)

Productivity: 37.4 fan/ha

Cost Item	Technical Coefficient	Technical Unit	Unit Cost	Cost Unit	Total cost			%
					Total Cost (CRC/ha)	(CRC/fan)	(USD/fan)	
1. Labor								
Crop labor	314.3	hh/ha	1,609.53	CRC/hh	733,266.24	19,606.05	26.37	25.0%
Social charges	44.95%	Porc.	723.48	CRC/hh	227,390.44	6,079.97	8.11	7.7%
2. Inputs								
Seedbed (replanting)	141	plants/ha	286.45	CRC/plant	40,396.00	1,079.95	1.45	1.4%
Complete formula	742.6	kg/ha	387.94	CRC/kg	287,906.20	7,699.03	10.1	9.8%
Nitrogen formula	245.2	kg/ha	282.3	CRC/kg	69,193.00	1,850.58	2.41	2.4%
pH corrector	683.6	kg/ha	180.93	CRC/kg	123,745.00	3,308.52	4.34	4.2%
Fungicide (triazole)	1.548	L/ha	30,131.33	CRC/L	46,643.30	1,247.15	1.63	2.0%
Fungicide (strobilurin)	0.453	L/ha	36,193.43	CRC/L	16,398.00	438.59	0.57	0.7%
Fungicide (copper)	2.153	kg/ha	12,789.44	CRC/kg	27,561.00	736.97	0.97	1.0%
Foliar (zinc)	1.649	L/ha	6,372.90	CRC/L	10,513.00	281.07	0.37	0.4%
Foliar (boron)	3.618	L/kg/ha	8,276.90	CRC/L	29,957.00	801.52	1.05	1.0%
Foliar (general)	3.618	L/kg/ha	7,672.90	CRC/L	27,758.00	742.16	0.97	1.0%
Coadjuvants	3.336	L/ha	8,246.00	CRC/L	27,508.82	735.53	0.93	1.0%
Herbicide (glyphosate)	2.279	L/ha	3,324.86	CRC/L	7,582.00	202.64	0.27	0.2%
Herbicide (paraquat)	1.917	L/ha	2,227.65	CRC/L	4,274.00	114.18	0.15	0.1%
Diffusers	9	unit/ha	13400	CRC/unit	120,600.00	3224.87	4.22	4.1%
Insecticide	0.394	kg/ha	12,177.87	CRC/kg	4,798.00	128.29	0.17	0.2%
Technological Package Cost (CRC):					1,408,726.92	37,666.50	47.90	47.9%
3. Harvest								
Coffee fruit harvest	37.4	fan/ha	28,911.67	CRC/fan	1,081,296.46	28,911.67	36.87	36.8%
4. Transport								
Transport (fertilizer & lime)	1,671.40	kg/ha	14.92	CRC/kg	24,928.63	666.55	0.87	0.8%
Transport (nursery)	141	plants/ha	26.96	CRC/plant	3,801.66	101.63	0.13	0.1%
Transport (coffee fruit)	37.4	fan/ha	1,731.11	CRC/fan	64,743.69	1,731.11	2.24	2.2%
Direct Costs + Transport:					2,583,497.65	69,077.48	87.90	87.9%
5. Otros costos indirectos				CRC/ha	355,019.84	9,492.51	18.51	12.10%
Crop depletion					178,589.32	4,775.12	9.31	6.10%
Depreciation:								
Constructions					11,196.10	299.36	0.58	0.40%
Agricultural equipment					14,275.10	381.69	0.74	0.50%
Maintenance								
Constructions					10,255.62	274.21	0.53	0.30%
Means of transport					90,935.28	2431.42	4.74	3.10%
Agricultural equipment					3,297.55	88.17	0.17	0.10%
Agricultural implements					629.85	16.84	0.03	0.00%
Administrative expenses				CRC/ha	45,841.01	1225.7	2.39	1.60%
Total Agricultural Coffee Production Cost (CRC)					2,616,986.30	85,802.83	167.12	100.00%

Notes

a/ Based on the technical cost structure and ICAFE Agricultural Production Study 2009–2010 (ECPAC09-10).

b/ *Fanega* (fan): unit of volume equivalent to 400 liters or two double hectoliters (2 Dhl).

c/ Exchange rate (average for the harvest): CRC/USD = 513.43.

Source: *Instituto del Café de Costa Rica (ICAFC)*

Cost structure of agricultural production of coffee cherries. Farms of 34 to 40 fanegas per hectare. Harvest 2024–2025 (Apr–Mar). Information quoted directly from ICAFE & UEEM (2025).

Structure of Agricultural Production Costs for Coffee Fruit

Field Study (a) – Farms of 40 to 70 fanegas(b)/ha

Harvest 2024–2025 (Apr–Mar)

Productivity: 40 fan/ha

Cost Item	Technical Coefficient	Technical Unit	Unit Cost	Cost Unit	Total cost			%
					Total Cost (CRC/ha)	(CRC/fan)	(USD/fan)	
1. Labor								
Crop labor	340.6	hh/ha	1,609.53	CRC/hh	794,624.48	19,865.61	38.79	25.40%
Social charges	44.95%	%	723.48	CRC/hh	246,418.56	6,160.46	12.03	7.90%
2. Inputs								
Seedlings (replanting)	90	plants/ha	286.45	CRC/plant	25,780.50	644.51	1.26	0.90%
Complete fertilizer	765	kg/ha	387.7	CRC/kg	296,593.71	7,414.84	14.48	9.50%
Nitrogen fertilizer	225	kg/ha	282.3	CRC/kg	63,517.20	1,587.93	3.1	2.00%
Acidity corrector	900	kg/ha	180.93	CRC/kg	162,837.00	4,070.93	7.95	5.40%
Fungicide (triazol)	1.248	L/ha	30,132.53	CRC/L	37,633.04	940.83	1.84	1.20%
Fungicide (bitertanol)	0.469	L/ha	36,193.43	CRC/L	16,988.73	424.72	0.83	0.60%
Fungicide (copper)	2.049	kg/ha	12,789.44	CRC/kg	26,187.83	654.7	1.28	0.90%
Fungicide (Fumibion)	2.046	L/ha	15,537.90	CRC/L	31,786.55	794.66	1.55	1.00%
Surfactant adjuvant	3.38	L/ha	11,337.56	CRC/L	38,322.38	958.06	1.87	1.30%
Herbicide (glyphosate)	6	L/ha	3,375.78	CRC/L	20,254.68	506.37	0.99	0.60%
Herbicide (glufosinate)	6	L/ha	6,835.38	CRC/L	41,012.28	1025.31	2	1.00%
Adjuvant (pH regulator)	0.624	L/kg-ha	6,331.23	CRC/L-kg	3,950.69	98.77	0.19	0.10%
Dispersers (Borer)	0	unit/ha	0.00	CRC/unit	0.00	0	0	0.00%
Insecticide (Borer)	1.4	L/ha	12177.87	CRC/kg	17,049.02	426.23	0.83	0.60%
Technological Package Cost (CRC):					1,509,623.13	37,666.50	73.69	48.20%
3. Harvest								
Coffee fruit harvest	40	fan/ha	28,911.67	CRC/fan	1,156,466.80	28,911.67	56.45	36.90%
4. Transport								
Transport (fertilizer & lime)	1,890.00	kg/ha	14.92	CRC/kg	28,189.35	704.73	1.38	0.90%
Transport (nursery)	140	plants/ha	26.96	CRC/plant	3,774.40	94.36	0.18	0.10%
Transport (coffee fruit)	40	fan/ha	1,731.11	CRC/fan	69,244.59	1,731.11	3.38	2.20%
Direct Costs + Transport:					2,583,497.65	37,740.58	87.90	87.9%
5. Otros costos indirectos				CRC/ha	368,004.45	9,200.12	17.95	11.80%
Crop depletion					191,574.33	4,789.36	9.35	6.10%
Depreciation:				CRC/ha	11,196.10	279.9	0.55	0.40%
Constructions					14,275.10	357.38	0.7	0.50%
Agricultural equipment				CRC/ha	10,255.62	256.39	0.5	0.30%
Maintenance					90,935.28	2273.38	4.44	3.10%
Constructions				CRC/ha	3,297.55	82.44	0.16	0.10%
Means of transport				CRC/ha	629.85	15.74	0.03	0.00%
Agricultural equipment				CRC/ha	45,841.01	1145.53	2.24	1.60%
Agricultural implements				CRC/ha				
Administrative expenses				CRC/ha				
Total Agricultural Coffee Production Cost (CRC)					3,131,528.72	78,288.22	152.86	100.00%

Notes

a/ The basis of this cost structure is ICAFE's technical recommendations for coffee crop assistance.

b/ Fanega: volume unit equal to 400 liters (2 double hectoliters).

c/ Average Exchange Rate of Harvest [BCCR]: CRC/USD = 512.17.

Source: Instituto del Café de Costa Rica (ICAPE).

Cost structure of agricultural production of coffee cherries. Farms of 40 to 70 fanegas per hectare. Harvest 2024–2025 (Apr–Mar). Information quoted directly from ICAFE & UEEM (2025).

A. 1.8 Sugarcane Production Costs

The cost model for sugarcane cultivation is presented, developed by the Executive Secretariat for Agricultural Sector Planning (SEPSA, 2025). The tables show the production cost based on crop yield.

Activity: SUGAR CANE (<i>Saccharum officinarum</i>)						Cut: 1			
Cost Unit: Hectares									
System: Conventional dryland			Yield: 65			Cost Unit: ton			
Location: Central Pacific Region			Cost Cycle: 12 months			Cycle measure: months			
Prepared by: Based on support from DIECA and the Central Pacific Region Directorate			Exchange Rate: ₡501.15			Updated: 26/3/2025			
MECHANIZED / CONTRACTED LABOR									
Task / Inputs	Category	Notes	Unit	Quantity	Unit Cost	Total Cost (CRC)	Total Cost (USD)	%	
Land tilling (heavy harrow)	Land preparation		ha	1	₡31,900.00	₡31,900.00	\$63.65	1.91%	
Subsoiling (1 pass)	Land preparation		ha	1	₡33,000.00	₡33,000.00	\$65.85	1.98%	
Harrowing (finisher)	Land preparation		ha	1	₡26,400.00	₡26,400.00	\$52.68	1.58%	
Furrowing and fertilizing	Land preparation		ha	1	₡19,800.00	₡19,800.00	\$39.51	1.19%	
Mechanical planting cover	Contracted labor		machine hour	1	₡18,700.00	₡18,700.00	\$37.31	1.12%	
Cane loading	Contracted labor		t	65	₡1,680.00	₡109,200.00	\$217.90	6.55%	
Hauling (harvest and inputs)	Contracted labor		t	65	₡2,815.00	₡182,975.00	\$365.11	10.97%	
Total mechanized labor:						₡421,975.00	\$842.01	25.30%	
MANUAL LABOR									
Task / Inputs	Category	Notes	Unit	Quantity	Unit Cost	Total Cost (CRC)	Total Cost (USD)	%	
Seed unloading (Loader)	Pre-planting work		man-hour	16	₡1,529.62	₡24,473.90	\$48.84	1.47%	
Cutting, irrigation, and stage (1.5 m)	Pre-planting work		man-hour	81	₡1,529.62	₡123,899.12	\$247.23	7.43%	
Weed control (Pre-emergence)	Cultural work		man-hour	8	₡1,529.62	₡12,236.95	\$24.42	0.73%	
First fertilization	Manual fertilization		man-hour	8	₡1,529.62	₡12,236.95	\$24.42	0.73%	
Second fertilization	Manual fertilization		man-hour	8	₡1,529.62	₡12,236.95	\$24.42	0.73%	
Mechanical application	Pest and disease control		man-hour	8	₡1,529.62	₡12,236.95	\$24.42	0.73%	
Rodenticide application	Pest and disease control		man-hour	4	₡1,529.62	₡6,118.48	\$12.21	0.37%	
Manual cutting (Burned cane)	Manual harvest		man-hour	170	₡1,529.62	₡260,013.19	\$518.25	15.55%	
Canal rounds and burning	Manual harvest		man-hour	8	₡1,529.62	₡12,236.95	\$24.42	0.73%	
Maintenance of paths and roads	Farm maintenance		man-hour	16	₡1,529.62	₡24,473.90	\$48.84	1.47%	
Subtotal manual labor:						₡500,185.33	\$998.08	29.99%	
Social and labor insurance charges (6%)					0	43.50%	₡217,563.94	\$434.13	13.04%
Total manual labor:						₡717,749.28	\$1,432.20	43.03%	
INPUTS (SUPPLIES)									
Task / Inputs	Category	Notes	Unit	Quantity	Unit Cost	Total Cost (CRC)	Total Cost (USD)	%	
Seed	Seed		t	12	₡20,000.00	₡240,000.00	\$478.90	14.39%	
Fertilizer 11-52-0	Fertilizers		sack	4	₡17,495.00	₡69,980.00	\$139.64	4.20%	
Fertilizer Urea 46%	Fertilizers	1	sack	8	₡18,511.00	₡148,088.00	\$295.50	8.88%	
Ametryne, Terbutylazine	Herbicide		L	4	₡2,545.00	₡10,180.00	\$20.31	0.61%	
Diuron	Herbicide		kg	1	₡3,213.00	₡3,213.00	\$6.41	0.19%	
2,4-D, Picloram	Herbicide	1	gl	0.3	₡14,028.00	₡4,208.40	\$8.40	0.25%	
Coadjuvant	Adjuvants and adherents		kg	0.25	₡2,009.00	₡502.25	\$1.00	0.03%	
Coumatetralyl	Rodenticide		kg	1.5	₡6,300.00	₡9,450.00	\$18.86	0.57%	
Total inputs:						₡485,621.65	\$969.01	29.11%	
OTHERS									
Task / Inputs	Category	Notes	Unit	Quantity	Unit Cost	Total Cost (CRC)	Total Cost (USD)	%	
Soil analysis	Soil analysis	2	global	1	₡8,000.32	₡8,000.32	\$15.96	0.48%	
Supervision (administration)	Administrative expenses		global	1	₡10,481.90	₡10,481.90	\$20.92	0.63%	
Subtotal other costs:						₡18,482.22	\$36.88	1.11%	
Contingencies (5%)						₡24,281.08	\$48.45	1.46%	
Total other costs:						₡42,763.30	\$85.33	2.56%	
TOTAL PRODUCTION COST						Total Cost (CRC)	Total Cost (USD)		
						₡1,668,109.23	\$3,328.56	100.00%	
Unit cost						₡25,663.22	\$51.21 /ton		

ASSUMPTIONS AND NOTES

Prices according to the survey of agricultural input prices, SEPSA, December 2024.

It is recommended to perform a soil analysis before planting to validate the soil's nutritional status and adjust fertilization accordingly.

Sugarcane production cost model for a yield of 65 (tons/ha). Information quoted verbatim from SEPSA (2025).

Activity: SUGAR CANE (*Saccharum officinarum*)

Cost Unit: Hectares

Cut: 1

System: Conventional dryland Yield: 65 Cost Unit: ton
 Location: Central Pacific Region Cost Cycle: 12 months Cycle measure: months
 Prepared by: Based on support from DIECA and the Central Pacific Region Directorate Exchange Rate: \$501.15 Updated: 26/3/2025

MECHANIZED / CONTRACTED LABOR								
Task / Inputs	Category	Notes	Unit	Quantity	Unit Cost	Total Cost (CRC)	Total Cost (USD)	%
Land tilling (heavy harrow)	Land preparation		ha	1	\$31,900.00	\$31,900.00	\$63.65	1.91%
Subsoiling (1 pass)	Land preparation		ha	1	\$33,000.00	\$33,000.00	\$65.85	1.98%
Harrowing (finisher)	Land preparation		ha	1	\$26,400.00	\$26,400.00	\$52.68	1.58%
Furrowing and fertilizing	Land preparation		ha	1	\$19,800.00	\$19,800.00	\$39.51	1.19%
Mechanical planting cover	Contracted labor		machine hour	1	\$18,700.00	\$18,700.00	\$37.31	1.12%
Cane loading	Contracted labor		t	65	\$1,680.00	\$109,200.00	\$217.90	6.55%
Hauling (harvest and inputs)	Contracted labor		t	65	\$2,815.00	\$182,975.00	\$365.11	10.97%
Total mechanized labor:						\$421,975.00	\$842.01	25.30%

MANUAL LABOR								
Task / Inputs	Category	Notes	Unit	Quantity	Unit Cost	Total Cost (CRC)	Total Cost (USD)	%
Seed unloading (Loader)	Pre-planting work		man-hour	16	\$1,529.62	\$24,473.90	\$48.84	1.47%
Cutting, irrigation, and stage (1.5 m)	Pre-planting work		man-hour	81	\$1,529.62	\$123,899.12	\$247.23	7.43%
Weed control (Pre-emergence)	Cultural work		man-hour	8	\$1,529.62	\$12,236.95	\$24.42	0.73%
First fertilization	Manual fertilization		man-hour	8	\$1,529.62	\$12,236.95	\$24.42	0.73%
Second fertilization	Manual fertilization		man-hour	8	\$1,529.62	\$12,236.95	\$24.42	0.73%
Mechanical application	Pest and disease control		man-hour	8	\$1,529.62	\$12,236.95	\$24.42	0.73%
Rodenticide application	Pest and disease control		man-hour	4	\$1,529.62	\$6,118.48	\$12.21	0.37%
Manual cutting (Burned cane)	Manual harvest		man-hour	170	\$1,529.62	\$260,013.19	\$518.25	15.55%
Canal rounds and burning	Manual harvest		man-hour	8	\$1,529.62	\$12,236.95	\$24.42	0.73%
Maintenance of paths and roads	Farm maintenance		man-hour	16	\$1,529.62	\$24,473.90	\$48.84	1.47%
Subtotal manual labor:						\$500,185.33	\$998.08	29.99%
Social and labor insurance charges (6%)							\$434.13	13.04%
Total manual labor:						\$717,749.28	\$1,432.20	43.03%

INPUTS (SUPPLIES)								
Task / Inputs	Category	Notes	Unit	Quantity	Unit Cost	Total Cost (CRC)	Total Cost (USD)	%
Seed	Seed		t	12	\$20,000.00	\$240,000.00	\$478.90	14.39%
Fertilizer 11-52-0	Fertilizers		sack	4	\$17,495.00	\$69,980.00	\$139.64	4.20%
Fertilizer Urea 46%	Fertilizers		sack	8	\$18,511.00	\$148,088.00	\$295.50	8.88%
Ametryne, Terbutylazine	Herbicide		L	4	\$2,545.00	\$10,180.00	\$20.31	0.61%
Diuron	Herbicide		kg	1	\$3,213.00	\$3,213.00	\$6.41	0.19%
2,4-D, Picloram	Herbicide		gl	0.3	\$14,028.00	\$4,208.40	\$8.40	0.25%
Coadjuvant	Adjuvants and adherents		kg	0.25	\$2,009.00	\$502.25	\$1.00	0.03%
Coumatetralyl	Rodenticide		kg	1.5	\$6,300.00	\$9,450.00	\$18.86	0.57%
Total inputs:						\$485,621.65	\$969.01	29.11%

OTHERS								
Task / Inputs	Category	Notes	Unit	Quantity	Unit Cost	Total Cost (CRC)	Total Cost (USD)	%
Soil analysis	Soil analysis		global	1	\$8,000.32	\$8,000.32	\$15.96	0.48%
Supervision (administration)	Administrative expenses		global	1	\$10,481.90	\$10,481.90	\$20.92	0.63%
Subtotal other costs:						\$18,482.22	\$36.88	1.11%
Contingencies (5%)						\$24,281.08	\$48.45	1.46%
Total other costs:						\$42,763.30	\$85.33	2.56%

TOTAL PRODUCTION COST						Total Cost (CRC)	Total Cost (USD)	
						\$1,668,109.23	\$3,328.56	100.00%
Unit cost						\$25,663.22	\$51.21 /ton	

ASSUMPTIONS AND NOTES

Prices according to the survey of agricultural input prices, SEPSA, December 2024.
 It is recommended to perform a soil analysis before planting to validate the soil's nutritional status and adjust fertilization accordingly.

Sugarcane production cost model for a yield of 60 (tons/ha). Information quoted verbatim from SEPSA (2025).

Activity: SUGAR CANE (*Saccharum officinarum*)
Cost Unit: Hectares

Cut: 3

System: Conventional dryland

Yield: 50

Cost Unit: ton

Location: Central Pacific Region

Cost Cycle: 12 months

Cycle measure: months

Prepared by: Based on support from DIECA and the
Central Pacific Region Directorate

Exchange Rate: €\$01.15

Updated: 26/3/2025

MECHANIZED / CONTRACTED LABOR								
Task / Inputs	Category	Notes	Unit	Quantity	Unit Cost	Total Cost (CRC)	Total Cost (USD)	%
Cane loading	Contracted labor		t	50	€1,680.00	€84,000.00	\$167.61	9.18%
Hauling (harvest and inputs)	Contracted labor		t	50	€2,815.00	€140,750.00	\$280.85	15.38%
Total mechanized labor:						€224,750.00	\$448.47	2456.00%

MANUAL LABOR								
Task / Inputs	Category	Notes	Unit	Quantity	Unit Cost	Total Cost (CRC)	Total Cost (USD)	%
Weed control (Pre-emergence)	Cultural work		man-hour	8	€1,529.62	€12,236.95	\$24.42	1.34%
Fertilizer application	Manual fertilization		man-hour	8	€1,529.62	€12,236.95	\$24.42	1.34%
Mechanical application	Pest and disease control		man-hour	8	€1,529.62	€12,236.95	\$24.42	1.34%
Rodenticide application	Pest and disease control		man-hour	4	€1,529.62	€6,118.48	\$12.21	0.67%
Manual cutting (Burned cane)	Manual harvest		man-hour	170	€1,529.62	€260,035.19	\$518.82	28.24%
Canal rounds and burning	Manual harvest		man-hour	8	€1,529.62	€12,236.95	\$24.42	1.34%
Maintenance of paths and roads	Farm maintenance		man-hour	16	€1,529.62	€24,473.90	\$48.84	2.67%
Subtotal manual labor:						€339,575.36	\$677.59	37.11%
Social and labor insurance charges (6%)				0	43.50%	€147,703.96	\$294.73	16.14%
Total manual labor:						€487,279.32	\$972.32	53.26%

INPUTS (SUPPLIES)								
Task / Inputs	Category	Notes	Unit	Quantity	Unit Cost	Total Cost (CRC)	Total Cost (USD)	%
Fertilizer Urea 46%	Fertilizers	1 sack		8	€18,511.00	€148,088.00	\$295.50	16.19%
Ametryne, Terbutylazine	Herbicide	L		4	€2,545.00	€10,180.00	\$20.31	1.11%
Diuron	Herbicide	kg		1	€3,213.00	€3,213.00	\$6.41	0.35%
2,4-D, Picloram	Herbicide	1 gl		0.3	€14,028.00	€4,208.40	\$8.40	0.46%
Coadjuvant	Adjuvants and adherents	kg		0.25	€2,009.00	€502.25	\$1.00	0.05%
Coumatetralyl	Rodenticide	kg		1.5	€6,300.00	€9,450.00	\$18.86	1.03%
Total inputs:						€175,641.65	\$350.48	19.20%

OTHERS								
Task / Inputs	Category	Notes	Unit	Quantity	Unit Cost	Total Cost (CRC)	Total Cost (USD)	%
Soil analysis	Soil analysis	2 global		1	€8,000.32	€8,000.32	\$15.96	0.87%
Supervision (administration)	Administrative expenses	global		1	€10,481.90	€10,481.90	\$20.92	1.15%
Subtotal other costs:						€18,482.22	\$36.88	2.02%
Contingencies (5%)						€8,782.08	\$17.52	0.0096
Total other costs:						€27,264.30	\$54.40	0.0298

TOTAL PRODUCTION COST						Total Cost (CRC)	Total Cost (USD)	
						€914,935.28	\$1,825.67	100.00%
Unit cost						€18,298.71		/ton

ASSUMPTIONS AND NOTES

Prices according to the survey of agricultural input prices, SEPSA, December 2024.

It is recommended to perform a soil analysis before planting to validate the soil's nutritional status and adjust fertilization accordingly.

Sugarcane production cost model for a yield of 50 (tons/ha). Information quoted verbatim from SEPSA (2025).

Activity: SUGAR CANE (*Saccharum officinarum*)

Cost Unit: Hectares

Cut: 4

System: Conventional dryland

Yield: 40

Cost Unit: ton

Location: Central Pacific Region

Cost Cycle: 12 months

Cycle measure: months

Prepared by: Based on support from DIECA and the
Central Pacific Region Directorate

Exchange Rate: ₡501.15

Updated: 26/3/2025

MECHANIZED / CONTRACTED LABOR								
Task / Inputs	Category	Notes	Unit	Quantity	Unit Cost	Total Cost (CRC)	Total Cost (USD)	%
Cane loading	Contracted labor		t	40	₡1,680.00	₡67,200.00	\$134.09	7.80%
Harvest and input transport	Contracted labor		t	40	₡2,815.00	₡112,600.00	\$224.68	13.06%
Total mechanized labor:						₡179,800.00	\$358.77	20.86%

MANUAL LABOR								
Task / Inputs	Category	Notes	Unit	Quantity	Unit Cost	Total Cost (CRC)	Total Cost (USD)	%
Weed control (Pre-emergent)	Cultural labor		man-hour	8	₡1,529.62	₡12,236.95	\$24.42	1.42%
Fertilizer application	Manual fertilization		man-hour	8	₡1,529.62	₡12,236.95	\$24.42	1.42%
Mechanical application	Pest and disease control		man-hour	8	₡1,529.62	₡12,236.95	\$24.42	1.42%
Rodenticide application	Pest and disease control		man-hour	4	₡1,529.62	₡6,118.48	\$12.21	0.71%
Manual cutting (Burned cane)	Manual harvest		man-hour	170	₡1,529.62	₡260,035.19	\$518.89	30.71%
Row burning and cleaning	Manual harvest		man-hour	8	₡1,529.62	₡12,236.95	\$24.42	1.42%
Maintenance of rows and roads	Farm maintenance		man-hour	16	₡1,529.62	₡24,473.90	\$48.84	2.84%
Subtotal manual labor:						₡339,575.36	\$677.59	39.39%
Social and labor insurance charges (6%)				0	43.50%	₡147,703.96	\$294.73	17.14%
Total manual labor:						₡487,279.32	\$972.32	56.53%

INPUTS (SUPPLIES)								
Task / Inputs	Category	Notes	Unit	Quantity	Unit Cost	Total Cost (CRC)	Total Cost (USD)	%
Fertilizer Urea 46%	Fertilizers	1 sack		8	₡18,511.00	₡148,088.00	\$295.50	17.18%
Ametryn, Terbutylazine	Herbicide	L		4	₡2,545.00	₡10,180.00	\$20.31	1.18%
Diuron	Herbicide	kg		1	₡3,213.00	₡3,213.00	\$6.41	0.37%
2,4-D, Picloram	Herbicide	1 gal		0.3	₡14,028.00	₡4,208.40	\$8.40	0.49%
Adjuvant	Adjuvants and surfactants	kg		0.25	₡2,009.00	₡502.25	\$1.00	0.06%
Coumatetralyl	Rodenticide	kg		1.5	₡6,300.00	₡9,450.00	\$18.86	1.10%
Total inputs:						₡175,641.65	\$350.48	20.38%

OTHERS								
Task / Inputs	Category	Notes	Unit	Quantity	Unit Cost	Total Cost (CRC)	Total Cost (USD)	%
Supervision (administration)	Administrative expenses		global	1	₡10,481.90	₡10,481.90	\$20.92	1.22%
Subtotal other costs:						₡10,481.90	\$20.92	1.22%
Contingencies (5%)						₡8,782.08	\$17.52	0.0096
Total other costs:						₡27,264.30	\$54.40	0.0298

TOTAL PRODUCTION COST						Total Cost (CRC)	Total Cost (USD)	
						₡816,984.96	\$1,712.00	100.00%
Unit cost						₡21,549.62	\$43.00 / ton	—

ASSUMPTIONS AND NOTES

Prices according to the survey of agricultural input prices, SEPSA, December 2024.

Sugarcane production cost model for a yield of 40 (tons/ha). Information quoted verbatim from SEPSA (2025).

Activity: SUGAR CANE (*Saccharum officinarum*)
Cost Unit: Hectares

Cut: 5

System: Conventional dryland

Yield: 30

Cost Unit: ton

Location: Central Pacific Region

Cost Cycle: 12 months

Cycle measure: months

Prepared by: Based on support from DIECA and the
Central Pacific Region Directorate

Exchange Rate: ₡501.15

Updated: 26/3/2025

MECHANIZED / CONTRACTED LABOR								
Task / Inputs	Category	Notes	Unit	Quantity	Unit Cost	Total Cost (CRC)	Total Cost (USD)	%
Cane loading	Contracted labor		t	30	₡1,680.00	₡50,400.00	\$100.57	6.17%
Transport of harvest and supplies	Contracted labor		t	30	₡2,815.00	₡84,450.00	\$168.51	10.34%
Total mechanized labor:						₡134,850.00	\$269.08	16.50%

MANUAL LABOR								
Task / Inputs	Category	Notes	Unit	Quantity	Unit Cost	Total Cost (CRC)	Total Cost (USD)	%
Weed control (Pre-emergent)	Cultural labors		man-hour	8	₡1,529.62	₡12,236.95	\$24.42	1.50%
Fertilizer application	Manual fertilization		man-hour	8	₡1,529.62	₡12,236.95	\$24.42	1.50%
Mechanical application	Pest and disease control		man-hour	8	₡1,529.62	₡12,236.95	\$24.42	1.50%
Rodenticide application	Pest and disease control		man-hour	4	₡1,529.62	₡6,118.48	\$12.21	0.75%
Manual cutting (burned cane)	Manual harvest		man-hour	170	₡1,529.62	₡260,035.19	\$518.88	31.83%
Rounds and burning of cane field	Manual harvest		man-hour	8	₡1,529.62	₡12,236.95	\$24.42	1.50%
Maintenance of rows and roads	Farm maintenance		man-hour	16	₡1,529.62	₡24,473.90	\$48.84	3.00%
Subtotal manual labor:						₡339,575.36	\$677.59	41.46%
Social and labor insurance charges (6%)				0	43.50%	₡147,703.96	\$294.73	18.18%
Total manual labor:						₡487,279.32	\$972.32	59.64%

INPUTS (SUPPLIES)								
Task / Inputs	Category	Notes	Unit	Quantity	Unit Cost	Total Cost (CRC)	Total Cost (USD)	%
Fertilizer Urea 46%	Fertilizers	1 sack		8	₡18,511.00	₡148,088.00	\$295.50	18.13%
Ametryn, Terbutylazine	Herbicide	L		4	₡2,545.00	₡10,180.00	\$20.31	1.25%
Diuron	Herbicide	kg		1	₡3,213.00	₡3,213.00	\$6.41	0.39%
2,4-D, Picloram	Herbicide	1 gal		0.3	₡14,028.00	₡4,208.40	\$8.40	0.52%
Adjuvant	Adjuvants and surfactants	kg		0.25	₡2,009.00	₡502.25	\$1.00	0.06%
Coumatetralyl	Rodenticide	kg		1.5	₡6,300.00	₡9,450.00	\$18.86	1.16%
Total inputs:						₡175,641.65	\$350.48	21.50%

OTHERS								
Task / Inputs	Category	Notes	Unit	Quantity	Unit Cost	Total Cost (CRC)	Total Cost (USD)	%
Supervision (administration)	Administrative expenses		global	1	₡10,481.90	₡10,481.90	\$20.92	1.28%
Subtotal other costs:						₡10,481.90	\$20.92	1.28%
Contingencies (5%)						₡8,782.08	\$17.52	0.0107
Total other costs:						₡19,263.98	\$38.44	0.0236

TOTAL PRODUCTION COST						Total Cost (CRC)	Total Cost (USD)	
						₡817,034.96	\$1,630.32	100.00%
Unit cost						₡27,234.50	\$54.34 / ton	—

ASSUMPTIONS AND NOTES

Prices according to the survey of agricultural input prices, SEPSA, December 2024.

Sugarcane production cost model for a yield of 30 (tons/ha). Information quoted verbatim from SEPSA (2025).

A.4 LIVESTOCK COSTS

Average auction price for live cattle, female category [CRC/kg]. Information extracted from CORFOGA (2025).

Month	000-100 (kg)	101-150 (kg)	151-200 (kg)	201-250 (kg)	251-300 (kg)	301-350 (kg)	351-400 (kg)	401-500 (kg)	> 500 (kg)
April 2024	1354.44	1386.04	1339.32	1270.63	1208.35	1198.86	1210.95	1224.55	1226.67
May 2024	1300.71	1345.32	1326.47	1266.67	1216.83	1227.82	1254.91	1267.16	1249.92
June 2024	1295.85	1408.98	1382.23	1293.09	1238.72	1249.23	1260.72	1262.98	1272.57
July 2024	1206.86	1317.95	1308.11	1233.26	1221.63	1217.03	1213.07	1230.19	1264.37
August 2024	1262.26	1374.02	1359.42	1236.56	1198.99	1184.41	1215.87	1202.96	1204.98
September 2024	1241.12	1315.08	1245.2	1233.87	1191.39	1199.2	1201.7	1198.15	1194.28
October 2024	1225.02	1246.44	1278.14	1206.92	1174.64	1176.26	1214.55	1236.66	1230.78
November 2024	1084.1	1169	1196.45	1181.62	1157.09	1170.61	1208.9	1212.65	1236.6
December 2024	1031.52	1138.13	1176.9	1159.85	1161.69	1139.9	1185.09	1225.46	1275.54
January 2025	1106.97	1166.27	1184.06	1161.57	1149.17	1163.52	1174.29	1206.09	1228.2
February 2025	1088.83	1177.51	1213.32	1185.72	1136.24	1157.68	1187.58	1215.54	1253.52
March 2025	1132.17	1225.63	1220.7	1192.52	1202.75	1213.79	1233.66	1250.32	1274.52
April 2025	1175.31	1250.1	1263.42	1231.24	1197.48	1195.74	1239.16	1242.31	1277.52

Average auction price for live cattle, male category [CRC/kg]. Information extracted from CORFOGA (2025).

Month	000-100 (kg)	101-150 (kg)	151-200 (kg)	201-250 (kg)	251-300 (kg)	301-350 (kg)	351-400 (kg)	401-500 (kg)	> 500 (kg)
April 2024	1475.98	1570.07	1592.97	1560.83	1488.92	1447.77	1416.95	1454.52	1487.77
May 2024	1435.01	1529.47	1569.37	1472.41	1440.08	1374.21	1430.72	1469.48	1478.42
June 2024	1371.17	1630.73	1573.98	1499.69	1466.27	1419.92	1444.32	1473.92	1508.51
July 2024	1551.18	1537.29	1591.62	1466.07	1441.12	1387.47	1363.73	1414.6	1475.6
August 2024	1368.12	1542.37	1457.64	1459.12	1436.31	1393.28	1382.61	1418.55	1482.9
September 2024	1261.64	1516.06	1480.72	1426.48	1436.87	1390.85	1375.76	1407.91	1463.37
October 2024	1202.76	1455.92	1464.81	1433.51	1409.79	1353.51	1360.19	1432.1	1474.9
November 2024	1049.2	1336.76	1402.59	1349.14	1349.73	1326.07	1324.89	1369.15	1448.93
December 2024	1139.12	1312.09	1380	1361.92	1348.92	1360.87	1339.1	1385.8	1440.62
January 2025	1170.73	1319.18	1325	1341.31	1328	1325.02	1339.19	1405.72	1453.87
February 2025	1436.45	1324.17	1308.43	1378.77	1351.06	1321.85	1357.47	1420.25	1478.26
March 2025	1258.66	1418.71	1526.73	1471.8	1390.19	1411.28	1397.71	1458.47	1509.74
April 2025	1337.47	1490.22	1497.51	1467.07	1461.15	1450.96	1413.57	1432.8	1500.5

A.5 LIST OF VULNERABILITY FUNCTIONS AND INFORMATION SOURCES

Below are presented the name, description, source, functional form, and hazard intensity measure to which each vulnerability model is indexed. The vulnerability models of Operational Project 2 (agriculture) are not included, as they do not follow vulnerability functions and are fully defined in Section 4.2 of this document.

A. 1.9 Strategic Project: Heredia

Earthquake

Sector	Portfolio	Curve	Description	Source	Function type	Intensity	Units
Buildings	Buildings	EQ_S_1	Structural steel - 1 story	INGENIAR	Archetype - Non-parametric	Sa - 0.23s	gal
		EQ_S_2	Structural steel - 2 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.37s	gal
		EQ_S_3	Structural steel - 3 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.50s	gal
		EQ_S_8	Structural steel - 8 stories	INGENIAR	Archetype - Non-parametric	Sa - 1.0s	gal
		EQ_A_1	Adobe - 1 story	INGENIAR	Archetype - Non-parametric	PGA	gal
		EQ_B_1	Bahareqe - 1 story	INGENIAR	Archetype - Non-parametric	PGA	gal
		EQ_B_2	Bahareqe - 2 stories	INGENIAR	Archetype - Non-parametric	PGA	gal
		EQ_CB_A_1	Concrete masonry - high class - 1 story	INGENIAR	Archetype - Non-parametric	PGA	gal
		EQ_CB_A_2	Concrete masonry - high class - 2 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.13s	gal
		EQ_CB_A_3	Concrete masonry - high class - 3 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.17s	gal
		EQ_CB_A_4	Concrete masonry - high class - 4 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.21s	gal
		EQ_CB_A_5	Concrete masonry - high class - 5 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.25s	gal
		EQ_CB_B_1	Concrete masonry - low class - 1 story	INGENIAR	Archetype - Non-parametric	PGA	gal
		EQ_CB_M_1	Concrete masonry - middle class - 1 story	INGENIAR	Archetype - Non-parametric	PGA	gal
		EQ_CB_M_2	Concrete masonry - middle class - 2 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.14s	gal
		EQ_CB_M_3	Concrete masonry - middle class - 3 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.18s	gal
		EQ_CB_M_4	Concrete masonry - middle class - 4 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.49s	gal
		EQ_CB_M_5	Concrete masonry - middle class - 5 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.26s	gal
		EQ_C_1	Reinforced concrete - 1 story	INGENIAR	Archetype - Non-parametric	Sa - 0.23s	gal
		EQ_C_2	Reinforced concrete - 2 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.37s	gal
		EQ_C_3	Reinforced concrete - 3 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.49s	gal
		EQ_C_4	Reinforced concrete - 4 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.60s	gal
		EQ_C_5	Reinforced concrete - 5 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.70s	gal
		EQ_C_6	Reinforced concrete - 6 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.80s	gal
		EQ_C_7	Reinforced concrete - 7 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.88s	gal
		EQ_C_8	Reinforced concrete - 8 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.97s	gal

Sector	Portfolio	Curve	Description	Source	Function type	Intensity	Units
		EQ_C_9	Reinforced concrete - 9 stories	INGENIAR	Archetype - Non-parametric	Sa - 1.05s	gal
		EQ_W	Wood	INGENIAR	Archetype - Non-parametric	PGA	gal
		EQ_PRE_1	Precast - 1 story	INGENIAR	Archetype - Non-parametric	Sa - 0.23s	gal
		EQ_PRE_2	Precast - 2 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.38s	gal
		EQ_PRE_3	Precast - 3 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.50s	gal
		EQ_PRE_4	Precast - 4 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.62s	gal
		EQ_PRE_5	Precast - 5 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.72s	gal
		EQ_PRE_6	Precast - 6 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.82s	gal
		EQ_PRE_7	Precast - 7 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.91s	gal
		EQ_PRE_8	Precast - 8 stories	INGENIAR	Archetype - Non-parametric	Sa - 1.00s	gal
		EQ_PRE_9	Precast - 9 stories	INGENIAR	Archetype - Non-parametric	Sa - 1.10s	gal
	Hospitals	EQ_HS_CB_A1_1	Concrete masonry - Archetype1 - 1 story	INGENIAR	Archetype - Non-parametric	PGA	gal
		EQ_HS_CB_A1_2	Concrete masonry - Archetype1 - 2 stories	INGENIAR	Archetype - Non-parametric	PGA	gal
		EQ_HS_C_A2_1	Reinforced concrete - Archetype2 - 1 story	INGENIAR	Archetype - Non-parametric	Sa - 0.23s	gal
		EQ_HS_C_A2_2	Reinforced concrete - Archetype2 - 2 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.37s	gal
		EQ_HS_C_A3_1	Reinforced concrete - Archetype3 - 1 story	INGENIAR	Archetype - Non-parametric	Sa - 0.23s	gal
		EQ_HS_C_A3_2	Reinforced concrete - Archetype3 - 2 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.37s	gal
		EQ_HS_C_A3_3	Reinforced concrete - Archetype3 - 3 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.49s	gal
		EQ_HS_C_A3_4	Reinforced concrete - Archetype3 - 4 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.60s	gal

Pluvial and Fluvial Flood

Sector	Portfolio	Curve	Description	Source	Function type	Intensity	Units
Buildings	Buildings	FL_S_1	Structural steel - 1 story	INGENIAR	Archetype - Non-parametric	Height	m
		FL_S_2	Structural steel - 2 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_S_3	Structural steel - 3 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_S_8	Structural steel - 8 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_A_1	Adobe - 1 story	INGENIAR	Archetype - Non-parametric	Height	m
		FL_B_1	Bahareque - 1 story	INGENIAR	Archetype - Non-parametric	Height	m
		FL_B_2	Bahareque - 2 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_CB_A_1	Concrete masonry - alto - 1 story	INGENIAR	Archetype - Non-parametric	Height	m
		FL_CB_A_2	Concrete masonry - alto - 2 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_CB_A_3	Concrete masonry - alto - 3 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_CB_A_4	Concrete masonry - alto - 4 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_CB_A_5	Concrete masonry - alto - 5 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_CB_B_1	Concrete masonry - bajo - 1 story	INGENIAR	Archetype - Non-parametric	Height	m
		FL_CB_M_1	Concrete masonry - medio - 1 story	INGENIAR	Archetype - Non-parametric	Height	m

Sector	Portfolio	Curve	Description	Source	Function type	Intensity	Units
		FL_CB_M_2	Concrete masonry - medio - 2 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_CB_M_3	Concrete masonry - medio - 3 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_CB_M_4	Concrete masonry - medio - 4 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_CB_M_5	Concrete masonry - medio - 5 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_C_1	Reinforced concrete - 1 story	INGENIAR	Archetype - Non-parametric	Height	m
		FL_C_2	Reinforced concrete - 2 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_C_3	Reinforced concrete - 3 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_C_4	Reinforced concrete - 4 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_C_5	Reinforced concrete - 5 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_C_6	Reinforced concrete - 6 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_C_7	Reinforced concrete - 7 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_C_8	Reinforced concrete - 8 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_C_9	Reinforced concrete - 9 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_W	Wood	INGENIAR	Archetype - Non-parametric	Height	m
		FL_PRE_1	Precast - 1 story	INGENIAR	Archetype - Non-parametric	Height	m
		FL_PRE_2	Precast - 2 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_PRE_3	Precast - 3 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_PRE_4	Precast - 4 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_PRE_5	Precast - 5 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_PRE_6	Precast - 6 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_PRE_7	Precast - 7 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_PRE_8	Precast - 8 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_PRE_9	Precast - 9 stories	INGENIAR	Archetype - Non-parametric	Height	m
	Hospitals	FL_HS_CB_A1_1	Concrete masonry - Archetype1 - 1 story	INGENIAR	Archetype - Non-parametric	Height	m
		FL_HS_CB_A1_2	Concrete masonry - Archetype1 - 2 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_HS_C_A2_1	Reinforced concrete - Archetype2 - 1 story	INGENIAR	Archetype - Non-parametric	Height	m
		FL_HS_C_A2_2	Reinforced concrete - Archetype2 - 2 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_HS_C_A3_1	Reinforced concrete - Archetype3 - 1 story	INGENIAR	Archetype - Non-parametric	Height	m
		FL_HS_C_A3_2	Reinforced concrete - Archetype3 - 2 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_HS_C_A3_3	Reinforced concrete - Archetype3 - 3 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_HS_C_A3_4	Reinforced concrete - Archetype3 - 4 stories	INGENIAR	Archetype - Non-parametric	Height	m

A. 1.10 Operational Project 1: National Route RN2

Earthquake

Sector	Portfolio	Curve	Description	Source	Function type	Intensity	Units
Roads	Road segment	EQ_RN_S2	National roads – no retaining walls	INGENIAR	Archetype - Non-parametric	PGD	cm
		EQ_RN_S3	National roads - slope regrading	INGENIAR	Archetype - Non-parametric	PGD	cm
		EQ_RN_S4	National roads – retaining walls and slope regrading	INGENIAR	Archetype - Non-parametric	PGD	cm
	Bridges	EQ_HWB1_NC3	Bridge HWB1 - 3 spans (HAZUS)	HAZUS EQ Model 6.1	ATC-13	Sa - 1.0s	g
		EQ_HWB1_NC4	Bridge HWB1 - 4 spans (HAZUS)	HAZUS EQ Model 6.1	ATC-13	Sa - 1.0s	g
		EQ_HWB5_NC3	Bridge HWB5 - 3 spans (HAZUS)	HAZUS EQ Model 6.1	ATC-13	Sa - 1.0s	g
		EQ_HWB5_NC4	Bridge HWB5 - 4 spans (HAZUS)	HAZUS EQ Model 6.1	ATC-13	Sa - 1.0s	g
		EQ_HWB10	Bridge HWB10	HAZUS EQ Model 6.1	ATC-13	Sa - 1.0s	g
		EQ_HWB10_NC3	Bridge HWB10 - 3 spans (HAZUS)	HAZUS EQ Model 6.1	ATC-13	Sa - 1.0s	g
		EQ_HWB10_SK15	Bridge HWB10 - bias: 15° (HAZUS)	HAZUS EQ Model 6.1	ATC-13	Sa - 1.0s	g
		EQ_HWB10_SK30	Bridge HWB10 - bias: 30° (HAZUS)	HAZUS EQ Model 6.1	ATC-13	Sa - 1.0s	g
		EQ_HWB11	Bridge HWB11	HAZUS EQ Model 6.1	ATC-13	Sa - 1.0s	g
		EQ_HWB12	Bridge HWB12	HAZUS EQ Model 6.1	ATC-13	Sa - 1.0s	g
		EQ_HWB12_NC2	Bridge HWB12 - 2 spans (HAZUS)	HAZUS EQ Model 6.1	ATC-13	Sa - 1.0s	g
		EQ_HWB12_NC2_SK19	Bridge HWB12 - 2 spans and bias 19° (HAZUS)	HAZUS EQ Model 6.1	ATC-13	Sa - 1.0s	g
		EQ_HWB12_NC3	Bridge HWB12 - 3 spans (HAZUS)	HAZUS EQ Model 6.1	ATC-13	Sa - 1.0s	g
		EQ_HWB12_NC3_SK15	Bridge HWB12 - 3 spans and bias 15° (HAZUS)	HAZUS EQ Model 6.1	ATC-13	Sa - 1.0s	g
		EQ_HWB12_NC4	Bridge HWB12 - 4 spans (HAZUS)	HAZUS EQ Model 6.1	ATC-13	Sa - 1.0s	g
		EQ_HWB12_NC4_SK55	Bridge HWB12 - 4 spans and bias 55° (HAZUS)	HAZUS EQ Model 6.1	ATC-13	Sa - 1.0s	g
		EQ_HWB15	Bridge HWB15	HAZUS EQ Model 6.1	ATC-13	Sa - 1.0s	g
		EQ_HWB15_NC3	Bridge HWB15 - 3 spans (HAZUS)	HAZUS EQ Model 6.1	ATC-13	Sa - 1.0s	g
		EQ_HWB15_NC4	Bridge HWB15 - 4 spans (HAZUS)	HAZUS EQ Model 6.1	ATC-13	Sa - 1.0s	g
		EQ_HWB17	Bridge HWB17	HAZUS EQ Model 6.1	ATC-13	Sa - 1.0s	g
		EQ_HWB17_NC2	Bridge HWB17 - 2 spans (HAZUS)	HAZUS EQ Model 6.1	ATC-13	Sa - 1.0s	g
		EQ_HWB17_NC2_SK40	Bridge HWB17 - 2 spans and bias: 40° (HAZUS)	HAZUS EQ Model 6.1	ATC-13	Sa - 1.0s	g
		EQ_HWB17_SK40	Bridge HWB17 - bias: 40° (HAZUS)	HAZUS EQ Model 6.1	ATC-13	Sa - 1.0s	g
		EQ_HWB23	Bridge HWB23	HAZUS EQ Model 6.1	ATC-13	Sa - 1.0s	g
		EQ_HWB28	Bridge HWB28	HAZUS EQ Model 6.1	ATC-13	Sa - 1.0s	g

Pluvial and Fluvial Flood

Sector	Portafolio	Curva	Descripción	Fuente	Tipo de función	Intensidad	Unidad
Roads	Road segment	FL_RN_S2	National roads - slope max 14%	INGENIAR	Archetype - Non-parametric	Height	m
		FL_RN_S3	National roads - slope max 25%	INGENIAR	Archetype - Non-parametric	Height	m
		FL_RN_S4	National roads - slope greater than 25%	INGENIAR	Archetype - Non-parametric	Height	m
	Bridges	FL_BRIDGE	Bridges - limited operation	INGENIAR	Non-parametric	Height	m

Volcanic Ash

Sector	Portfolio	Curve	Description	Source	Function type	Intensity	Units
Roads	Road segment and bridges	ASH_RD	Roads - limited operation	INGENIAR	Non-parametric	Espesor	cm

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Earthquake

Sector	Portfolio	Curve	Description	Source	Function type	Intensity	Units
Hotels	Hotels	EQ_H_CB_A1_2_1	Concrete masonry - Type A1_2 - 1 story	INGENIAR	Archetype - Non-parametric	PGA	gal
		EQ_H_CB_A3_1	Concrete masonry - Type A3 - 1 story	INGENIAR	Archetype - Non-parametric	PGA	gal
		EQ_H_CB_A4_1	Concrete masonry - Type A4 - 1 story	INGENIAR	Archetype - Non-parametric	PGA	gal
		EQ_H_CB_A5_1	Concrete masonry - Type A5 - 1 story	INGENIAR	Archetype - Non-parametric	PGA	gal
		EQ_H_CB_A1_2_2	Concrete masonry - Type A1_2 - 2 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.13s	gal
		EQ_H_CB_A3_2	Concrete masonry - Type A3 - 2 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.13s	gal
		EQ_H_CB_A4_2	Concrete masonry - Type A4 - 2 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.13s	gal
		EQ_H_CB_A5_2	Concrete masonry - Type A5 - 2 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.13s	gal
		EQ_H_C_B1_2_1	Reinforced concrete - Type B1_2 - 1 story	INGENIAR	Archetype - Non-parametric	Sa - 0.23s	gal
		EQ_H_C_B3_1	Reinforced concrete - Type B3 - 1 story	INGENIAR	Archetype - Non-parametric	Sa - 0.23s	gal
		EQ_H_C_B4_1	Reinforced concrete - Type B4 - 1 story	INGENIAR	Archetype - Non-parametric	Sa - 0.23s	gal
		EQ_H_C_B5_1	Reinforced concrete - Type B5 - 1 story	INGENIAR	Archetype - Non-parametric	Sa - 0.23s	gal
		EQ_H_C_B1_2_2	Reinforced concrete - Type B1_2 - 2 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.37s	gal
		EQ_H_C_B3_2	Reinforced concrete - Type B3 - 2 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.37s	gal
		EQ_H_C_B4_2	Reinforced concrete - Type B4 - 2 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.37s	gal
		EQ_H_C_B5_2	Reinforced concrete - Type B5 - 2 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.37s	gal
		EQ_H_C_B1_2_3	Reinforced concrete - Type B1_2 - 3 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.49s	gal
		EQ_H_C_B3_3	Reinforced concrete - Type B3 - 3 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.49s	gal

Sector	Portfolio	Curve	Description	Source	Function type	Intensity	Units
		EQ_H_C_B4_3	Reinforced concrete - Type B4 - 3 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.49s	gal
		EQ_H_C_B5_3	Reinforced concrete - Type B5 - 3 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.49s	gal
		EQ_H_C_B1_2_4	Reinforced concrete - Type B1_2 - 4 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.60s	gal
		EQ_H_C_B3_4	Reinforced concrete - Type B3 - 4 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.60s	gal
		EQ_H_C_B4_4	Reinforced concrete - Type B4 - 4 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.60s	gal
		EQ_H_C_B5_4	Reinforced concrete - Type B5 - 4 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.60s	gal
		EQ_H_C_B1_2_5	Reinforced concrete - Type B1_2 - 5 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.70s	gal
		EQ_H_C_B3_5	Reinforced concrete - Type B3 - 5 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.70s	gal
		EQ_H_C_B4_5	Reinforced concrete - Type B4 - 5 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.70s	gal
		EQ_H_C_B5_5	Reinforced concrete - Type B5 - 5 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.70s	gal
		EQ_H_C_B1_2_6	Reinforced concrete - Type B1_2 - 6 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.79s	gal
		EQ_H_C_B3_6	Reinforced concrete - Type B3 - 6 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.79s	gal
		EQ_H_C_B4_6	Reinforced concrete - Type B4 - 6 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.79s	gal
		EQ_H_C_B5_6	Reinforced concrete - Type B5 - 6 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.79s	gal
		EQ_H_C_B1_2_7	Reinforced concrete - Type B1_2 - 7 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.88s	gal
		EQ_H_C_B3_7	Reinforced concrete - Type B3 - 7 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.88s	gal
		EQ_H_C_B4_7	Reinforced concrete - Type B4 - 7 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.88s	gal
		EQ_H_C_B5_7	Reinforced concrete - Type B5 - 7 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.88s	gal
		EQ_H_C_B1_2_8	Reinforced concrete - Type B1_2 - 8 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.97s	gal
		EQ_H_C_B3_8	Reinforced concrete - Type B3 - 8 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.97s	gal
		EQ_H_C_B4_8	Reinforced concrete - Type B4 - 8 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.97s	gal
		EQ_H_C_B5_8	Reinforced concrete - Type B5 - 8 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.97s	gal
		EQ_H_C_B1_2_9	Reinforced concrete - Type B1_2 - 9 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.69s	gal
		EQ_H_C_B3_9	Reinforced concrete - Type B3 - 9 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.69s	gal
		EQ_H_C_B4_9	Reinforced concrete - Type B4 - 9 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.69s	gal
		EQ_H_C_B5_9	Reinforced concrete - Type B5 - 9 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.69s	gal
		EQ_H_C_B1_2_10	Reinforced concrete - Type B1_2 - 10 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.74s	gal
		EQ_H_C_B3_10	Reinforced concrete - Type B3 - 10 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.74s	gal
		EQ_H_C_B4_10	Reinforced concrete - Type B4 - 10 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.74s	gal
		EQ_H_C_B5_10	Reinforced concrete - Type B5 - 10 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.74s	gal
		EQ_H_C_B1_2_11	Reinforced concrete - Type B1_2 - 11 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.79s	gal
		EQ_H_C_B3_11	Reinforced concrete - Type B3 - 11 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.79s	gal
		EQ_H_C_B4_11	Reinforced concrete - Type B4 - 11 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.79s	gal
		EQ_H_C_B5_11	Reinforced concrete - Type B5 - 11 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.79s	gal
		EQ_H_C_B1_2_12	Reinforced concrete - Type B1_2 - 12 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.84s	gal
		EQ_H_C_B3_12	Reinforced concrete - Type B3 - 12 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.84s	gal
		EQ_H_C_B4_12	Reinforced concrete - Type B4 - 12 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.84s	gal
		EQ_H_C_B5_12	Reinforced concrete - Type B5 - 12 stories	INGENIAR	Archetype - Non-parametric	Sa - 0.84s	gal

Pluvial and Fluvial Flood

Sector	Portfolio	Curve	Description	Source	Function type	Intensity	Units
Hotelerio	Hoteles	FL_H_CB_A1_2_1	Concrete masonry - Type A1_2 - 1 story	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_CB_A3_1	Concrete masonry - Type A3 - 1 story	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_CB_A4_1	Concrete masonry - Type A4 - 1 story	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_CB_A5_1	Concrete masonry - Type A5 - 1 story	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_CB_A1_2_2	Concrete masonry - Type A1_2 - 2 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_CB_A3_2	Concrete masonry - Type A3 - 2 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_CB_A4_2	Concrete masonry - Type A4 - 2 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_CB_A5_2	Concrete masonry - Type A5 - 2 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B1_2_1	Reinforced concrete - Type B1_2 - 1 story	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B3_1	Reinforced concrete - Type B3 - 1 story	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B4_1	Reinforced concrete - Type B4 - 1 story	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B5_1	Reinforced concrete - Type B5 - 1 story	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B1_2_2	Reinforced concrete - Type B1_2 - 2 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B3_2	Reinforced concrete - Type B3 - 2 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B4_2	Reinforced concrete - Type B4 - 2 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B5_2	Reinforced concrete - Type B5 - 2 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B1_2_3	Reinforced concrete - Type B1_2 - 3 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B3_3	Reinforced concrete - Type B3 - 3 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B4_3	Reinforced concrete - Type B4 - 3 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B5_3	Reinforced concrete - Type B5 - 3 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B1_2_4	Reinforced concrete - Type B1_2 - 4 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B3_4	Reinforced concrete - Type B3 - 4 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B4_4	Reinforced concrete - Type B4 - 4 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B5_4	Reinforced concrete - Type B5 - 4 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B1_2_5	Reinforced concrete - Type B1_2 - 5 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B3_5	Reinforced concrete - Type B3 - 5 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B4_5	Reinforced concrete - Type B4 - 5 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B5_5	Reinforced concrete - Type B5 - 5 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B1_2_6	Reinforced concrete - Type B1_2 - 6 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B3_6	Reinforced concrete - Type B3 - 6 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B4_6	Reinforced concrete - Type B4 - 6 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B5_6	Reinforced concrete - Type B5 - 6 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B1_2_7	Reinforced concrete - Type B1_2 - 7 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B3_7	Reinforced concrete - Type B3 - 7 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B4_7	Reinforced concrete - Type B4 - 7 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B5_7	Reinforced concrete - Type B5 - 7 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B1_2_8	Reinforced concrete - Type B1_2 - 8 stories	INGENIAR	Archetype - Non-parametric	Height	m

Sector	Portfolio	Curve	Description	Source	Function type	Intensity	Units
		FL_H_C_B3_8	Reinforced concrete - Type B3 - 8 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B4_8	Reinforced concrete - Type B4 - 8 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B5_8	Reinforced concrete - Type B5 - 8 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B1_2_9	Reinforced concrete - Type B1_2 - 9 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B3_9	Reinforced concrete - Type B3 - 9 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B4_9	Reinforced concrete - Type B4 - 9 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B5_9	Reinforced concrete - Type B5 - 9 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B1_2_10	Reinforced concrete - Type B1_2 - 10 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B3_10	Reinforced concrete - Type B3 - 10 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B4_10	Reinforced concrete - Type B4 - 10 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B5_10	Reinforced concrete - Type B5 - 10 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B1_2_11	Reinforced concrete - Type B1_2 - 11 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B3_11	Reinforced concrete - Type B3 - 11 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B4_11	Reinforced concrete - Type B4 - 11 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B5_11	Reinforced concrete - Type B5 - 11 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B1_2_12	Reinforced concrete - Type B1_2 - 12 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B3_12	Reinforced concrete - Type B3 - 12 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B4_12	Reinforced concrete - Type B4 - 12 stories	INGENIAR	Archetype - Non-parametric	Height	m
		FL_H_C_B5_12	Reinforced concrete - Type B5 - 12 stories	INGENIAR	Archetype - Non-parametric	Height	m

Coastal Flood

Sector	Portfolio	Curve	Description	Source	Function type	Intensity	Units
Hotels	Hotels	CFL_H_CB_A1_2_1	Concrete masonry - Type A1_2 - 1 story	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_CB_A3_1	Concrete masonry - Type A3 - 1 story	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_CB_A4_1	Concrete masonry - Type A4 - 1 story	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_CB_A5_1	Concrete masonry - Type A5 - 1 story	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_CB_A1_2_2	Concrete masonry - Type A1_2 - 2 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_CB_A3_2	Concrete masonry - Type A3 - 2 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_CB_A4_2	Concrete masonry - Type A4 - 2 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_CB_A5_2	Concrete masonry - Type A5 - 2 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B1_2_1	Reinforced concrete - Type B1_2 - 1 story	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B3_1	Reinforced concrete - Type B3 - 1 story	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B4_1	Reinforced concrete - Type B4 - 1 story	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B5_1	Reinforced concrete - Type B5 - 1 story	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B1_2_2	Reinforced concrete - Type B1_2 - 2 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B3_2	Reinforced concrete - Type B3 - 2 stories	INGENIAR	Archetype - Non-parametric	Height	m

Sector	Portfolio	Curve	Description	Source	Function type	Intensity	Units
		CFL_H_C_B4_2	Reinforced concrete - Type B4 - 2 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B5_2	Reinforced concrete - Type B5 - 2 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B1_2_3	Reinforced concrete - Type B1_2 - 3 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B3_3	Reinforced concrete - Type B3 - 3 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B4_3	Reinforced concrete - Type B4 - 3 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B5_3	Reinforced concrete - Type B5 - 3 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B1_2_4	Reinforced concrete - Type B1_2 - 4 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B3_4	Reinforced concrete - Type B3 - 4 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B4_4	Reinforced concrete - Type B4 - 4 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B5_4	Reinforced concrete - Type B5 - 4 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B1_2_5	Reinforced concrete - Type B1_2 - 5 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B3_5	Reinforced concrete - Type B3 - 5 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B4_5	Reinforced concrete - Type B4 - 5 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B5_5	Reinforced concrete - Type B5 - 5 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B1_2_6	Reinforced concrete - Type B1_2 - 6 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B3_6	Reinforced concrete - Type B3 - 6 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B4_6	Reinforced concrete - Type B4 - 6 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B5_6	Reinforced concrete - Type B5 - 6 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B1_2_7	Reinforced concrete - Type B1_2 - 7 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B3_7	Reinforced concrete - Type B3 - 7 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B4_7	Reinforced concrete - Type B4 - 7 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B5_7	Reinforced concrete - Type B5 - 7 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B1_2_8	Reinforced concrete - Type B1_2 - 8 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B3_8	Reinforced concrete - Type B3 - 8 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B4_8	Reinforced concrete - Type B4 - 8 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B5_8	Reinforced concrete - Type B5 - 8 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B1_2_9	Reinforced concrete - Type B1_2 - 9 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B3_9	Reinforced concrete - Type B3 - 9 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B4_9	Reinforced concrete - Type B4 - 9 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B5_9	Reinforced concrete - Type B5 - 9 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B1_2_10	Reinforced concrete - Type B1_2 - 10 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B3_10	Reinforced concrete - Type B3 - 10 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B4_10	Reinforced concrete - Type B4 - 10 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B5_10	Reinforced concrete - Type B5 - 10 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B1_2_11	Reinforced concrete - Type B1_2 - 11 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B3_11	Reinforced concrete - Type B3 - 11 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B4_11	Reinforced concrete - Type B4 - 11 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B5_11	Reinforced concrete - Type B5 - 11 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B1_2_12	Reinforced concrete - Type B1_2 - 12 stories	INGENIAR	Archetype - Non-parametric	Height	m

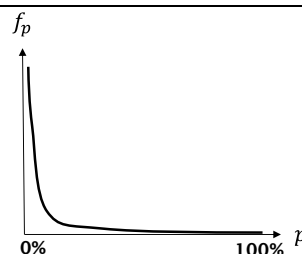
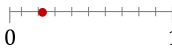
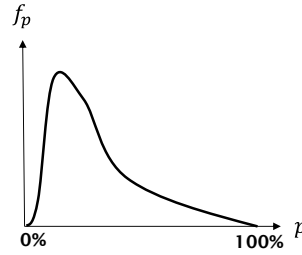
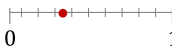
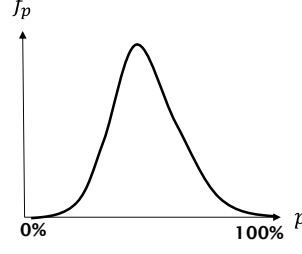
Sector	Portfolio	Curve	Description	Source	Function type	Intensity	Units
		CFL_H_C_B3_12	Reinforced concrete - Type B3 - 12 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B4_12	Reinforced concrete - Type B4 - 12 stories	INGENIAR	Archetype - Non-parametric	Height	m
		CFL_H_C_B5_12	Reinforced concrete - Type B5 - 12 stories	INGENIAR	Archetype - Non-parametric	Height	m

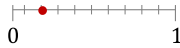
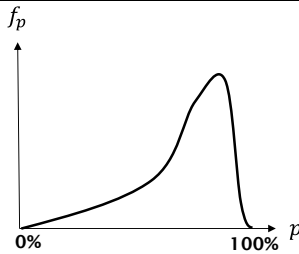
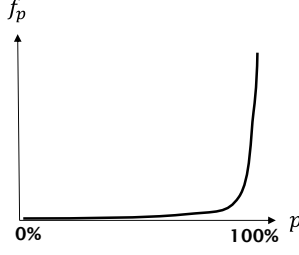
A.6 LIMITATIONS TO THE USE AND DEVELOPMENT OF VULNERABILITY MODELS

Vulnerability models are mathematical representations of the way in which damage and losses are caused to exposed elements when they are subjected to adverse natural phenomena that generate a given intensity at their location. Within the universe of possible approaches to modeling vulnerability, vulnerability functions stand out as the most appropriate method for capturing consequences in terms of economic losses within a catastrophic risk modeling framework.

In catastrophic risk modeling, losses are treated as random variables. This allows the inherent uncertainty in the loss amounts caused by one or another event of a given hazard to be directly incorporated into the calculations. In general terms, loss can be defined as a variable within the interval from 0 to 1, that is, from zero up to 100% of the exposed value of the element (i.e., its replacement value). The probability model most widely used to describe relative loss is the Beta distribution, proposed by Anne Kiremidjian and other authors in the development of the ATC-13 document and its commentary ATC-13-1 (ATC, 1985, 2002). Table 43 illustrates the shapes assumed by the Beta distribution under different combinations of expected value and variance for the loss.

Table 43. Illustration of the variation of the Beta distribution under events of different intensity levels.

Description	Probability Moments	Beta Distribution
<u>Very low intensity event:</u> Expected loss is low with low dispersion. That is, for very low intensity, losses are known to be small and with low variability. Exponential decay distribution; most probability density is concentrated near zero loss, as expected for low-intensity events.	$E(p)$  $Var(p)$ 	
<u>Low intensity event:</u> Expected loss increases along with variance (i.e., loss becomes more uncertain). Wider distribution, centered further to the right but still skewed toward low losses.	$E(p)$  $Var(p)$ 	
<u>Moderate intensity event:</u> Expected loss is significantly higher and variance reaches its maximum. Symmetrical, bell-shaped distribution, as wide as possible, indicating maximum variability.	$E(p)$  $Var(p)$ 	

Description	Probability Moments	Beta Distribution
High intensity event: <i>Expected loss continues to rise, but variance decreases as high damage levels become more certain.</i> <i>Distribution becomes skewed to the right, concentrated in higher loss values, with some density still in lower losses.</i>	$E(p)$  $Var(p)$ 	
Very high intensity event: <i>Expected loss is very high with low variance due to reduced uncertainty in damage severity.</i> <i>Distribution resembles an exponential rise, indicating high certainty of extreme losses.</i>	$E(p)$  $Var(p)$ 	

Vulnerability functions are a mathematical representation of physical vulnerability. They consist of two different functions: one that describes the variation of the expected value of loss with hazard intensity, and another that describes the variation of the variance. In other words, they combine into a single mathematical object the variation of loss as a function of hazard intensity. Figure 94 shows an illustration of a typical vulnerability function, composed of the two defining functions: $E(p)$, which is the expected value of loss, and $Var(p)$, which is its variance. Losses are always expressed in relative terms (i.e., p exists only within the 0–1 interval).

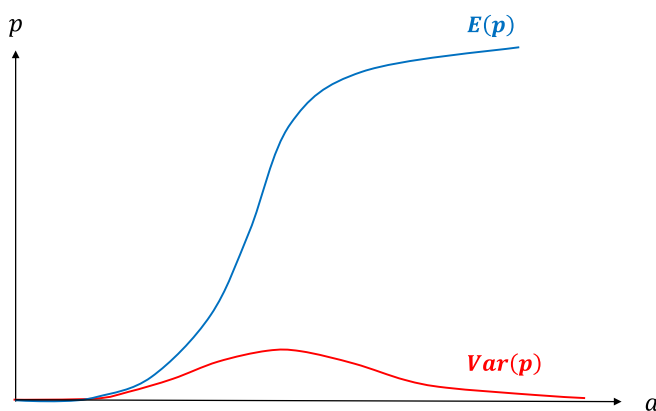


Figure 94. Illustration of a vulnerability function.

The shape of the expected value and variance functions is not entirely arbitrary. In general, they must satisfy the behavior illustrated in Table 43; that is, the expected value function must necessarily be increasing, while the variance function should first increase and then decrease in order to appropriately reflect its expected variability with hazard intensity.

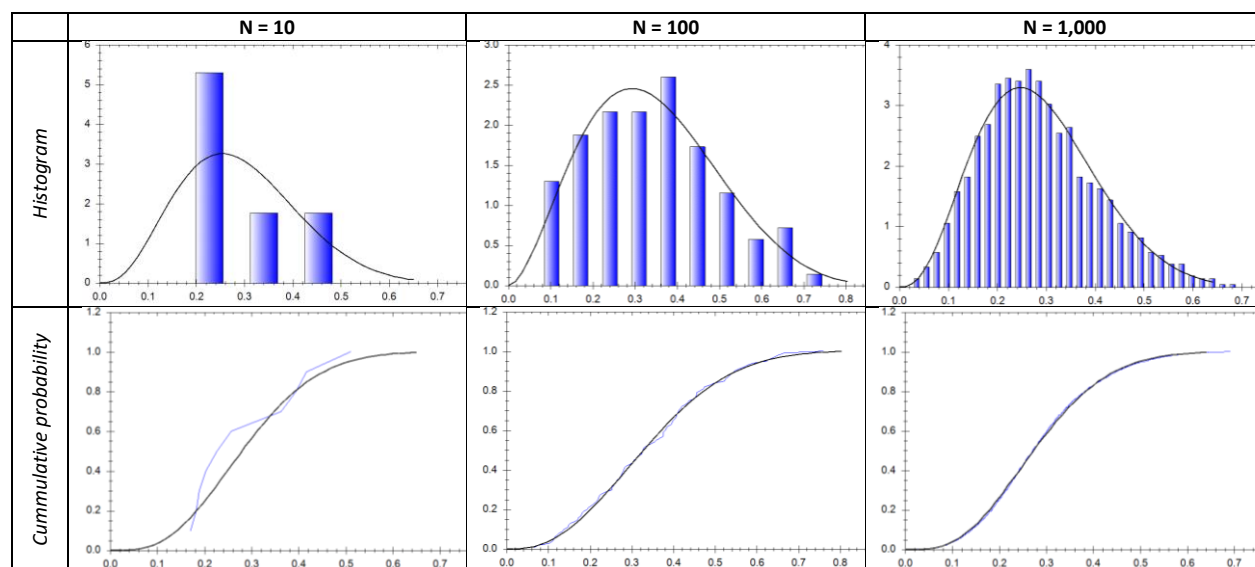
Table 43 clearly illustrates how the probability distribution of loss changes for each possible hazard intensity level. In other words, if a statistical validation process were to be carried out for the probability

model, it would be necessary to perform an independent analysis for a broad range of intensity values, covering the full domain of possibilities in a reasonable manner. Such validation is essentially a statistical goodness-of-fit process, through which it is possible to determine whether a given dataset is in fact distributed according to a specified probability model.

Goodness-of-fit methods assess the ability of a probability model to describe a collection of data by applying a hypothesis test. The outcome is a probability that the stated hypothesis holds. This probability is predefined through the selection of a significance level for the test, which is simply the complement of the probability that the hypothesis is true. In statistical practice, significance levels of 5% or lower are commonly adopted. The most widely used goodness-of-fit methods internationally can be categorized into two types: those that verify the fit using the data histogram, and those that do so using a cumulative probability function.

Statistical validation of a probabilistic loss model therefore requires a substantial number of data points at each intensity level. A large dataset allows for better approximation of the true probability model describing the data, whereas a limited number of observations prevents meaningful statistical verification. Table 44 illustrates the fitting process of a Beta distribution to three random datasets using the two principal fitting approaches previously mentioned. The datasets contain, respectively, 10, 100, and 1,000 observed values.

Table 44. Illustration of the impact of the number of data points on the application of statistical goodness-of-fit methods.



As can be observed, fitting a Beta probability model to describe loss would require a substantial amount of data, possibly more than 100 observations per intensity level, and ideally on the order of 1,000 observations per intensity level. In practice, this translates into having between 100 and 1,000 independent records of damage and loss for buildings or infrastructure of the same category at each intensity level. For example, in the case of flood vulnerability of single-story, informally constructed wooden buildings, if one wished to validate the vulnerability of such buildings for a flood height of 1 meter above ground level, between 100 and 1,000 records of relative loss for that specific building type at that

specific inundation height would be required. Furthermore, if the goal were to statistically validate a complete vulnerability function for these buildings, that same number of observations would be needed for multiple intensity levels—for instance, 0.1, 0.5, 0.7, 1.0, 1.5, 2.0, and 3.0 meters of inundation height¹⁶. In this example alone, this would imply at least 700 data points, and ideally 7,000 loss observations at different flood heights for that single construction type. Since building portfolios typically include a wide diversity of construction typologies, the statistical information requirements increase very significantly if all vulnerability functions in a flood risk model are to be validated. This challenge grows critically when incorporating different sectors of the built environment and different hazards, particularly those with much lower frequencies of occurrence, such as earthquakes or volcanic eruptions.

The example described above illustrates a broadly generalized situation. There is insufficient information on damage and losses caused by historical events to enable a validation process of loss models based on statistical estimation. This is not a problem exclusive to disaster risk in Costa Rica; rather, it is a fundamental condition that applies in any context and for any hazard anywhere in the world.

Due to this reality, the vast majority of vulnerability models available in the literature are based on computational simulations of asset response to hazard intensities, and only to a much lesser extent on studies of real structures or reduced-scale laboratory experiments. These approaches constitute the only reasonable means of obtaining an appropriate and sufficiently robust statistical basis to define a probabilistic loss model as a function of hazard intensity.

By way of example, Figure 95 presents the results of earthquake damage and loss simulations for seven-story reinforced concrete frame buildings conducted by Vargas (2013) as part of his doctoral research. In this work, Vargas defined a structural modeling archetype and applied a methodology known as Incremental Dynamic Analysis (IDA), which consists of determining the level of damage sustained by a structural model of the defined archetype through nonlinear time-history analysis under base excitation from a large collection of strong-motion accelerograms scaled to increasing intensity levels (see Vargas, 2013). Figure 95 includes the resulting intensity–loss pairs derived from the 24,000 nonlinear simulations carried out by Vargas over the course of a four-year research effort. Based on these results, Vargas proposed a single seismic vulnerability function for the structural archetype described above.

¹⁶ These seven flood intensity values are presented as an example and do not constitute a standard.

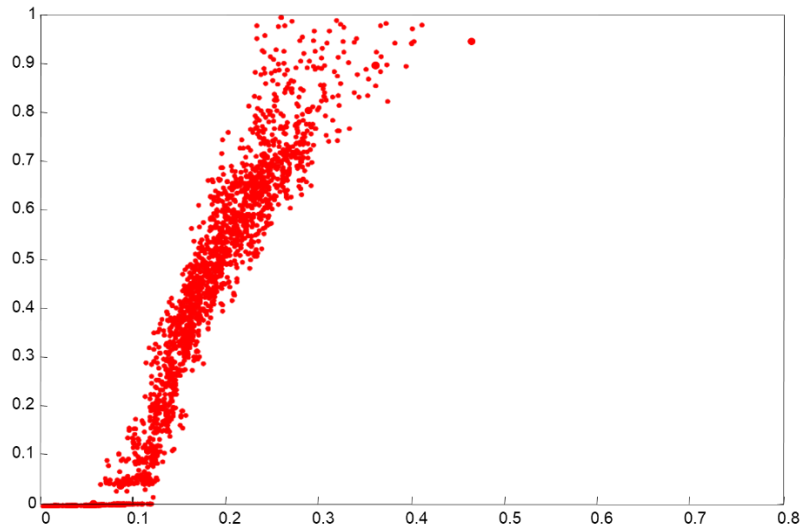


Figure 95. 24,000 modeled intensity–loss pairs by Vargas (2013) for a structural archetype.

The above constitutes an example of what is involved in the development of new vulnerability models. As can be observed, this is a highly demanding activity, generally confined to the academic and research sphere at the international level. Clearly, the selection of one vulnerability model over another from among those available in the literature, for practical applications in catastrophic risk modeling, is a modeling decision that cannot be validated using either local data or global records, as such information simply does not exist.

Moreover, the process of constructing these functions is far more rigorous than any subsequent verification procedure could be. This implies that vulnerability models are effectively validated by their own authors, based on the best available information—namely, that generated synthetically through computational simulations or controlled laboratory experiments.

A.7 DATASET OF EXPOSURE AND VULNERABILITY MODELS

As part of the products included in this deliverable, a web repository (Drive) was established to host the models from the Strategic Project and Operational Projects 1, 2, and 3 for Costa Rica. Below is the list of the files included in this dataset.

The link to access the dataset is:

<https://1drv.ms/f/c/9f6f548dad075343/IgCGf6yf9s0HT54pSOBjr9ANAfRG4NLwY3k4cWA2Eky7McE?e=4ghig3>

Strategic Project: Demonstration of Risk Assessment Methods for Critical Infrastructure in Heredia

Building exposure model

This directory contains the files corresponding to the building datasets for the canton of Heredia.

File	Format
Edificaciones_Heredia_CR-SIRGAS	.shp
Edificaciones_Heredia_WGS84	.shp
Exposicion_Heredia	.csv

Files in *.shp format contains the identifier fields for each of the buildings in the canton of Heredia. All layers are projected in the CRTM05 and WGS 84 coordinate systems.

The file in *.csv format contains the required fields for the exposure file, which are necessary for risk assessment.

Building vulnerability models

This directory contains the files corresponding to the building vulnerability for the canton of Heredia, including the vulnerability curves for both flood and earthquake hazards.

This directory contains the following files:

Flood Vulnerability Curves

File	Format	
FL_A_1	.csv	.fvu
FL_C_1	.csv	.fvu
FL_C_2	.csv	.fvu
FL_C_3	.csv	.fvu
FL_C_4	.csv	.fvu
FL_C_5	.csv	.fvu
FL_C_6	.csv	.fvu

File	Format	
FL_C_7	.csv	.fvu
FL_C_8	.csv	.fvu
FL_C_9	.csv	.fvu
FL_CB_1	.csv	.fvu
FL_CB_2	.csv	.fvu
FL_CB_3	.csv	.fvu
FL_CB_4	.csv	.fvu
FL_CB_5	.csv	.fvu
FL_HS_ARQ_1	.csv	.fvu
FL_HS_ARQ_2	.csv	.fvu
FL_HS_ARQ_3	.csv	.fvu
FL_HS_ARQ_4	.csv	.fvu
FL_HS_ARQ_5	.csv	.fvu
FL_HS_ARQ_6	.csv	.fvu
FL_W_1	.csv	.fvu
FL_W_2	.csv	.fvu
Vul_inunda_Heredia	.dat	

Earthquake Vulnerability Curves

File	Format	
EQ_A_1	.csv	.fvu
EQ_B_1	.csv	.fvu
EQ_B_2	.csv	.fvu
EQ_C_1	.csv	.fvu
EQ_C_2	.csv	.fvu
EQ_C_3	.csv	.fvu
EQ_C_4	.csv	.fvu
EQ_C_5	.csv	.fvu
EQ_C_6	.csv	.fvu
EQ_C_7	.csv	.fvu
EQ_C_8	.csv	.fvu
EQ_C_9	.csv	.fvu
EQ_CB_A_1	.csv	.fvu
EQ_CB_A_2	.csv	.fvu
EQ_CB_A_3	.csv	.fvu
EQ_CB_A_4	.csv	.fvu
EQ_CB_A_5	.csv	.fvu
EQ_CB_B_1	.csv	.fvu
EQ_CB_M_1	.csv	.fvu
EQ_CB_M_2	.csv	.fvu
EQ_CB_M_3	.csv	.fvu
EQ_CB_M_4	.csv	.fvu
EQ_CB_M_5	.csv	.fvu
EQ_HS_ARQ_1	.csv	.fvu

File	Format	
EQ_HS_ARQ_2	.csv	.fvu
EQ_HS_ARQ_3	.csv	.fvu
EQ_HS_ARQ_4	.csv	.fvu
EQ_HS_ARQ_5	.csv	.fvu
EQ_HS_ARQ_6	.csv	.fvu
EQ_PRE_1	.csv	.fvu
EQ_PRE_2	.csv	.fvu
EQ_PRE_3	.csv	.fvu
EQ_PRE_4	.csv	.fvu
EQ_PRE_5	.csv	.fvu
EQ_PRE_6	.csv	.fvu
EQ_PRE_7	.csv	.fvu
EQ_PRE_8	.csv	.fvu
EQ_PRE_9	.csv	.fvu
EQ_S_1	.csv	.fvu
EQ_S_2	.csv	.fvu
EQ_S_3	.csv	.fvu
EQ_S_8	.csv	.fvu
EQ_W	.csv	.fvu
Vul_sismo_Heredia	.dat	

Files in .fvu format are text files with a specific format adapted to the CAPRA-GIS platform and its computational engine, RiskOne. These files allow the integration of vulnerability models to estimate how exposed elements may experience physical damage in response to natural hazards. The *.fvu file stores the vulnerability function by organizing the values that define the curve line by line (point by point).

Files in .dat format, is a plain text file with a *.dat extension that can be viewed and edited using any text editor. It is recommended to use the FileCAT program, which provides information management tools for the entire CAPRA software suite. These .dat files contain and organize the library of vulnerability functions associated with a specific hazard.

Infrastructure exposure models

This directory contains the files corresponding to the infrastructure exposure for the canton of Heredia, including the road network, rail sector, electric power sector, telecommunications sector, hydrocarbons sector, drinking water, and wastewater systems.

This directory contains the following files:

Road Network

File	Format
Puentes_CRTM05	.shp
Puentes_WGS84	.shp
Vias_CRTM05	.shp
Vias_WGS84	.shp

Rail Sector

File	Format
Ferreo_CRTM05	.shp
Ferreo_WGS84	.shp

Electric Power Sector

File	Format
Electrico_Distribucion_Circuitos_CRTM05	.shp
Electrico_Distribucion_Circuitos_WGS84	.shp
Electrico_Distribucion_Postes_CRTM05	.shp
Electrico_Distribucion_Postes_WGS84	.shp
Electrico_Distribucion_Transformadores_CRTM05	.shp
Electrico_Distribucion_Transformadores_WGS84	.shp
Electrico_Generacion_CRTM05	.shp
Electrico_Generacion_WGS84	.shp
Electrico_Transmision_Circuitos_CRTM05	.shp
Electrico_Transmision_Circuitos_WGS84	.shp
Electrico_Transmision_Subestaciones_CRTM05	.shp
Electrico_Transmision_Subestaciones_WGS84	.shp
Electrico_Transmision_Torres_CRTM05	.shp
Electrico_Transmision_Torres_WGS84	.shp

Telecommunications Sector

File	Format
Antenas_CRTM05	.shp
Antenas_WGS84	.shp

Hydrocarbons Sector

File	Format
Poliducto_CRTM05	.shp
Poliducto_WGS84	.shp

Drinking Water

File	Format
Acueducto_Fuentes_CRTM05	.shp
Acueducto_Fuentes_WGS84	.shp
Acueducto_Hidrantes_CRTM05	.shp
Acueducto_Hidrantes_WGS84	.shp
Acueducto_Sist-Bombeo_CRTM05	.shp

File	Format
Acueducto_Sist-Bombeo_WGS84	.shp
Acueducto_Tanques_CRTM05	.shp
Acueducto_Tanques_WGS84	.shp
Acueducto_Tuberias_CRTM05	.shp
Acueducto_Tuberias_WGS84	.shp

Wastewater

File	Format
Alcantarillado_Colectores_CRTM05	.shp
Alcantarillado_Colectores_WGS84	.shp
Alcantarillado_Pozos_CRTM05	.shp
Alcantarillado_Pozos_WGS84	.shp
Alcantarillado_PTAR_CRTM05	.shp
Alcantarillado_PTAR_WGS84	.shp

The *.shp files used in this project are available in vector format (point or line) and require a Geographic Information System (GIS) for visualization.

Infrastructure vulnerability models

This directory contains the files corresponding to the infrastructure vulnerability for the canton of Heredia, including the vulnerability curves for both flood and earthquake hazards.

This directory contains the following files:

Flood Vulnerability Curves

File	Format	
FL_AP_FUENTE	.csv	.fvu
FL_BRIDGE_0	.csv	.fvu
FL_BRIDGE_1	.csv	.fvu
FL_BRIDGE_2	.csv	.fvu
FL_BRIDGE_3	.csv	.fvu
FL_BRIDGE_4	.csv	.fvu
FL_BRIDGE_5	.csv	.fvu
FL_BRIDGE_6	.csv	.fvu
FL_BRIDGE_7	.csv	.fvu
FL_BRIDGE_8	.csv	.fvu
FL_HID-EMB	.csv	.fvu
FL_No-damage	.csv	.fvu
FL_PPPS	.csv	.fvu
FL_PTAR1	.csv	.fvu
FL_PTAR1_mod	.csv	.fvu
FL_R1_S1	.csv	.fvu
FL_R1_S2	.csv	.fvu

File	Format	
FL_R1_S3	.csv	.fvu
FL_R1_S4	.csv	.fvu
FL_R3_S1	.csv	.fvu
FL_R3_S2	.csv	.fvu
FL_R3_S3	.csv	.fvu
FL_R3_S4	.csv	.fvu
FL_R4_S1	.csv	.fvu
FL_R4_S2	.csv	.fvu
FL_R4_S3	.csv	.fvu
FL_R4_S4	.csv	.fvu
FL_SUBSTA	.csv	.fvu
FL_TR-PED	.csv	.fvu
FL_WLS	.csv	.fvu
Vul_FL_Acueducto	.dat	
Vul_FL_Alcantarillado	.dat	
Vul_FL_Carretero	.dat	
Vul_FL_Electrico	.dat	
Vul_FL_Ferreo	.dat	
Vul_FL_Poliducto	.dat	
Vul_FL_Telecom	.dat	

Earthquake Vulnerability Curves

File	Format	
EQ_AP_FUENTE	.csv	.fvu
EQ_DL-UM	.csv	.fvu
EQ_Edif-Telecom	.csv	.fvu
EQ_HID-EMB	.csv	.fvu
EQ_HRD1	.csv	.fvu
EQ_HRD2	.csv	.fvu
EQ_HRD3	.csv	.fvu
EQ_HV-SUB	.csv	.fvu
EQ_HWB10	.csv	.fvu
EQ_HWB12_NC3	.csv	.fvu
EQ_HWB15	.csv	.fvu
EQ_HWB16	.csv	.fvu
EQ_HWB22	.csv	.fvu
EQ_HWB22_NC2	.csv	.fvu
EQ_HWB26	.csv	.fvu
EQ_HWB28	.csv	.fvu
EQ_HWB3	.csv	.fvu
EQ_LT1	.csv	.fvu
EQ_LT2	.csv	.fvu
EQ_LTCAB-UMB	.csv	.fvu
EQ_No-damage	.csv	.fvu

File	Format	
EQ_PIPE	.csv	.fvu
EQ_POLE_C1_H1_STA	.csv	.fvu
EQ_POLE_C1_H1_STB	.csv	.fvu
EQ_POLE_C1_H1_STC	.csv	.fvu
EQ_POLE_C1_H2_STA	.csv	.fvu
EQ_POLE_C1_H2_STB	.csv	.fvu
EQ_POLE_C1_H2_STC	.csv	.fvu
EQ_POLE_C1_H3_STA	.csv	.fvu
EQ_POLE_C1_H3_STB	.csv	.fvu
EQ_POLE_C1_H3_STC	.csv	.fvu
EQ_POLE_C1_H4_STA	.csv	.fvu
EQ_POLE_C1_H4_STB	.csv	.fvu
EQ_POLE_C1_H4_STC	.csv	.fvu
EQ_POLE_C1_H5_STA	.csv	.fvu
EQ_POLE_C1_H5_STB	.csv	.fvu
EQ_POLE_C1_H5_STC	.csv	.fvu
EQ_POLE_C2_H1_STA	.csv	.fvu
EQ_POLE_C2_H1_STB	.csv	.fvu
EQ_POLE_C2_H1_STC	.csv	.fvu
EQ_POLE_C2_H2_STA	.csv	.fvu
EQ_POLE_C2_H2_STB	.csv	.fvu
EQ_POLE_C2_H2_STC	.csv	.fvu
EQ_POLE_C2_H3_STA	.csv	.fvu
EQ_POLE_C2_H3_STB	.csv	.fvu
EQ_POLE_C2_H3_STC	.csv	.fvu
EQ_POLE_C2_H4_STA	.csv	.fvu
EQ_POLE_C2_H4_STB	.csv	.fvu
EQ_POLE_C2_H4_STC	.csv	.fvu
EQ_POLE_C2_H5_STA	.csv	.fvu
EQ_POLE_C2_H5_STB	.csv	.fvu
EQ_POLE_C2_H5_STC	.csv	.fvu
EQ_POLE_M1_H1_STA	.csv	.fvu
EQ_POLE_M1_H1_STB	.csv	.fvu
EQ_POLE_M1_H1_STC	.csv	.fvu
EQ_POLE_M1_H2_STA	.csv	.fvu
EQ_POLE_M1_H2_STB	.csv	.fvu
EQ_POLE_M1_H2_STC	.csv	.fvu
EQ_POLE_M1_H3_STA	.csv	.fvu
EQ_POLE_M1_H3_STB	.csv	.fvu
EQ_POLE_M1_H3_STC	.csv	.fvu
EQ_POLE_M1_H4_STA	.csv	.fvu
EQ_POLE_M1_H4_STB	.csv	.fvu
EQ_POLE_M1_H4_STC	.csv	.fvu
EQ_POLE_M1_H5_STA	.csv	.fvu
EQ_POLE_M1_H5_STB	.csv	.fvu
EQ_POLE_M1_H5_STC	.csv	.fvu

File	Format	
EQ_POLE_M2_H1_STA	.csv	.fvu
EQ_POLE_M2_H1_STB	.csv	.fvu
EQ_POLE_M2_H1_STC	.csv	.fvu
EQ_POLE_M2_H2_STA	.csv	.fvu
EQ_POLE_M2_H2_STB	.csv	.fvu
EQ_POLE_M2_H2_STC	.csv	.fvu
EQ_POLE_M2_H3_STA	.csv	.fvu
EQ_POLE_M2_H3_STB	.csv	.fvu
EQ_POLE_M2_H3_STC	.csv	.fvu
EQ_POLE_M2_H4_STA	.csv	.fvu
EQ_POLE_M2_H4_STB	.csv	.fvu
EQ_POLE_M2_H4_STC	.csv	.fvu
EQ_POLE_M2_H5_STA	.csv	.fvu
EQ_POLE_M2_H5_STB	.csv	.fvu
EQ_POLE_M2_H5_STC	.csv	.fvu
EQ_POLE_W1_H1_STA	.csv	.fvu
EQ_POLE_W1_H1_STB	.csv	.fvu
EQ_POLE_W1_H1_STC	.csv	.fvu
EQ_POLE_W1_H2_STA	.csv	.fvu
EQ_POLE_W1_H2_STB	.csv	.fvu
EQ_POLE_W1_H2_STC	.csv	.fvu
EQ_POLE_W1_H3_STA	.csv	.fvu
EQ_POLE_W1_H3_STB	.csv	.fvu
EQ_POLE_W1_H3_STC	.csv	.fvu
EQ_POLE_W1_H4_STA	.csv	.fvu
EQ_POLE_W1_H4_STB	.csv	.fvu
EQ_POLE_W1_H4_STC	.csv	.fvu
EQ_POLE_W1_H5_STA	.csv	.fvu
EQ_POLE_W1_H5_STB	.csv	.fvu
EQ_POLE_W1_H5_STC	.csv	.fvu
EQ_POLE_W2_H1_STA	.csv	.fvu
EQ_POLE_W2_H1_STB	.csv	.fvu
EQ_POLE_W2_H1_STC	.csv	.fvu
EQ_POLE_W2_H2_STA	.csv	.fvu
EQ_POLE_W2_H2_STB	.csv	.fvu
EQ_POLE_W2_H2_STC	.csv	.fvu
EQ_POLE_W2_H3_STA	.csv	.fvu
EQ_POLE_W2_H3_STB	.csv	.fvu
EQ_POLE_W2_H3_STC	.csv	.fvu
EQ_POLE_W2_H4_STA	.csv	.fvu
EQ_POLE_W2_H4_STB	.csv	.fvu
EQ_POLE_W2_H4_STC	.csv	.fvu
EQ_POLE_W2_H5_STA	.csv	.fvu
EQ_POLE_W2_H5_STB	.csv	.fvu
EQ_POLE_W2_H5_STC	.csv	.fvu
EQ_PPPS	.csv	.fvu

File	Format	
EQ_PSTGC	.csv	.fvu
EQ_PSTGS	.csv	.fvu
EQ_PWTS	.csv	.fvu
EQ_PZ_M1_H0	.csv	.fvu
EQ_PZ_M1_H1	.csv	.fvu
EQ_PZ_M1_H2	.csv	.fvu
EQ_PZ_M1_H3	.csv	.fvu
EQ_PZ_M1_H4	.csv	.fvu
EQ_PZ_M2_H0	.csv	.fvu
EQ_PZ_M2_H1	.csv	.fvu
EQ_PZ_M2_H2	.csv	.fvu
EQ_PZ_M2_H3	.csv	.fvu
EQ_PZ_M2_H4	.csv	.fvu
EQ_PZ_M3_H0	.csv	.fvu
EQ_PZ_M3_H1	.csv	.fvu
EQ_PZ_M3_H2	.csv	.fvu
EQ_PZ_M3_H3	.csv	.fvu
EQ_RWY1	.csv	.fvu
EQ_TR-PED	.csv	.fvu
EQ_WLS1_H1	.csv	.fvu
EQ_WLS1_H2	.csv	.fvu
EQ_WLS1_H3	.csv	.fvu
EQ_WLS2_H1	.csv	.fvu
EQ_WLS2_H2	.csv	.fvu
EQ_WLS2_H3	.csv	.fvu
EQ_WLS2_H4	.csv	.fvu
EQ_WLS2_H5	.csv	.fvu
Vul_EQ_Acueducto	.dat	
Vul_EQ_Alcantarillado	.dat	
Vul_EQ_Carretero	.dat	
Vul_EQ_Electrico	.dat	
Vul_EQ_Ferreo	.dat	
Vul_EQ_Poliducto	.dat	
Vul_EQ_Telecom	.dat	

OPERATIONAL PROJECT 1: DISASTER AND CLIMATE RISK ASSESSMENT FOR ROAD INFRASTRUCTURE – NATIONAL ROUTE 2 PANAMERICAN HIGHWAY (RN2)

Exposure models

This directory contains the files corresponding to the exposure models for the National Route 2 (RN2)

File	Format
Puentes_CRTM05	.shp
Puentes_WGS84	.shp
Via_CRTM05	.shp

Via_WGS84	.shp
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Vulnerability models

This directory contains the files corresponding to the infrastructure vulnerability for the RN2, including the flood, earthquake, and volcanic ash vulnerability curves.

Flood Vulnerability Curves

File	Format	
FL_BRIDGE	.csv	.fvu
FL_BRIDGE_3	.csv	.fvu
FL_RN_S2	.csv	.fvu
FL_RN_S3	.csv	.fvu
FL_RN_S4	.csv	.fvu
Vul_FL_RN2	.dat	

Earthquake Vulnerability Curves

File	Format	
EQ_HWB1_NC3	.csv	.fvu
EQ_HWB1_NC4	.csv	.fvu
EQ_HWB10	.csv	.fvu
EQ_HWB10_NC3	.csv	.fvu
EQ_HWB10_SK30	.csv	.fvu
EQ_HWB11	.csv	.fvu
EQ_HWB12	.csv	.fvu
EQ_HWB12_NC2	.csv	.fvu
EQ_HWB12_NC2_SK19	.csv	.fvu
EQ_HWB12_NC3	.csv	.fvu
EQ_HWB12_NC3_SK15	.csv	.fvu
EQ_HWB12_NC4	.csv	.fvu
EQ_HWB12_NC4_SK55	.csv	.fvu
EQ_HWB15	.csv	.fvu
EQ_HWB15_NC3	.csv	.fvu
EQ_HWB15_NC4	.csv	.fvu
EQ_HWB17	.csv	.fvu
EQ_HWB17_NC2	.csv	.fvu
EQ_HWB17_NC2_SK40	.csv	.fvu
EQ_HWB17_SK40	.csv	.fvu
EQ_HWB23	.csv	.fvu
EQ_HWB28	.csv	.fvu
EQ_HWB5_NC3	.csv	.fvu
EQ_HWB5_NC4	.csv	.fvu
EQ_RN_S2	.csv	.fvu
EQ_RN_S3	.csv	.fvu
EQ_RN_S4	.csv	.fvu

File	Format
Vul_EQ_RN2	.dat

Volcano Ash Vulnerability Curves

File	Format
ASH_RD	.csv .fvu
Vul_ASH_RN2	.dat

OPERATIONAL PROJECT 2: FLOOD AND DROUGHT RISK FOR SMALL AND MEDIUM-SCALE AGRICULTURAL PRODUCERS

Exposure models

This directory contains the files corresponding to the exposure models for small and medium scale agricultural producers, including coffee sugarcane and livestock.

Coffee

File	Format
Cafe_puntos_CRTM05	.shp
Cafe_puntos_WGS84	.shp

Sugarcane

File	Format
Cana_puntos_CRTM05	.shp
Cana_puntos_WGS84	.shp

Livestock

File	Format
Ganaderia_puntos_CRTM05	.shp
Ganaderia_puntos_WGS84	.shp

The *.shp files used in this project are available in vector format (point) and require a Geographic Information System (GIS) for visualization.

Vulnerability models

This directory contains the files corresponding to the vulnerability of small and medium scale agricultural producers, including flood curves, water response models, and soil texture.

Flood Curves

File	Format	
FL_D_3	.csv	.fvu
FL_D_4	.csv	.fvu
FL_D_5	.csv	.fvu
FL_D_6	.csv	.fvu
FL_D_7	.csv	.fvu
FL_D_8	.csv	.fvu
Vul_FL_Cultivos	.dat	

Water response models

File	Format
Cafe	.txt
cazucar	.txt
Pastos	.txt

The *.txt files present the parameters that characterize the water response model for each product.

Soil texture

File	Format
suelo	.shp

OPERATIONAL PROJECT 3: EXPOSURE AND RISK ASSESSMENT OF SMALL AND MEDIUM-SIZED HOTELS AND HOSTELS UNDER THE FU-TURISMO PROGRAM

Exposure models

This directory contains the files corresponding to the exposure characterization of hotels.

File	Format
Hoteles_CR-SIRGAS	.shp
Hoteles_WGS84	.shp

Vulnerability models

This directory contains the files corresponding to the infrastructure vulnerability for the hotels, including the flood, coastal flood, and earthquake curves.

Flood Vulnerability Curves

File	Format	
FL_H_C_B1_2_1	.csv	.fvu
FL_H_C_B1_2_10	.csv	.fvu
FL_H_C_B1_2_11	.csv	.fvu
FL_H_C_B1_2_12	.csv	.fvu

File	Format
FL_H_C_B1_2_2	.csv .fvu
FL_H_C_B1_2_3	.csv .fvu
FL_H_C_B1_2_4	.csv .fvu
FL_H_C_B1_2_5	.csv .fvu
FL_H_C_B1_2_6	.csv .fvu
FL_H_C_B1_2_7	.csv .fvu
FL_H_C_B1_2_8	.csv .fvu
FL_H_C_B1_2_9	.csv .fvu
FL_H_C_B3_1	.csv .fvu
FL_H_C_B3_10	.csv .fvu
FL_H_C_B3_11	.csv .fvu
FL_H_C_B3_12	.csv .fvu
FL_H_C_B3_2	.csv .fvu
FL_H_C_B3_3	.csv .fvu
FL_H_C_B3_4	.csv .fvu
FL_H_C_B3_5	.csv .fvu
FL_H_C_B3_6	.csv .fvu
FL_H_C_B3_7	.csv .fvu
FL_H_C_B3_8	.csv .fvu
FL_H_C_B3_9	.csv .fvu
FL_H_C_B4_1	.csv .fvu
FL_H_C_B4_10	.csv .fvu
FL_H_C_B4_11	.csv .fvu
FL_H_C_B4_12	.csv .fvu
FL_H_C_B4_2	.csv .fvu
FL_H_C_B4_3	.csv .fvu
FL_H_C_B4_4	.csv .fvu
FL_H_C_B4_5	.csv .fvu
FL_H_C_B4_6	.csv .fvu
FL_H_C_B4_7	.csv .fvu
FL_H_C_B4_8	.csv .fvu
FL_H_C_B4_9	.csv .fvu
FL_H_C_B5_1	.csv .fvu
FL_H_C_B5_10	.csv .fvu
FL_H_C_B5_11	.csv .fvu
FL_H_C_B5_12	.csv .fvu
FL_H_C_B5_2	.csv .fvu
FL_H_C_B5_3	.csv .fvu
FL_H_C_B5_4	.csv .fvu
FL_H_C_B5_5	.csv .fvu
FL_H_C_B5_6	.csv .fvu
FL_H_C_B5_7	.csv .fvu
FL_H_C_B5_8	.csv .fvu
FL_H_C_B5_9	.csv .fvu
FL_H_CB_A1_2_1	.csv .fvu
FL_H_CB_A1_2_2	.csv .fvu

File	Format	
FL_H_CB_A3_1	.csv	.fvu
FL_H_CB_A3_2	.csv	.fvu
FL_H_CB_A4_1	.csv	.fvu
FL_H_CB_A4_2	.csv	.fvu
FL_H_CB_A5_1	.csv	.fvu
FL_H_CB_A5_2	.csv	.fvu
Vul_FL	.dat	

Coastal Flood Vulnerability Curves

File	Format	
CFL_H_C_B1_2_1	.csv	.fvu
CFL_H_C_B1_2_10	.csv	.fvu
CFL_H_C_B1_2_11	.csv	.fvu
CFL_H_C_B1_2_12	.csv	.fvu
CFL_H_C_B1_2_2	.csv	.fvu
CFL_H_C_B1_2_3	.csv	.fvu
CFL_H_C_B1_2_4	.csv	.fvu
CFL_H_C_B1_2_5	.csv	.fvu
CFL_H_C_B1_2_6	.csv	.fvu
CFL_H_C_B1_2_7	.csv	.fvu
CFL_H_C_B1_2_8	.csv	.fvu
CFL_H_C_B1_2_9	.csv	.fvu
CFL_H_C_B3_1	.csv	.fvu
CFL_H_C_B3_10	.csv	.fvu
CFL_H_C_B3_11	.csv	.fvu
CFL_H_C_B3_12	.csv	.fvu
CFL_H_C_B3_2	.csv	.fvu
CFL_H_C_B3_3	.csv	.fvu
CFL_H_C_B3_4	.csv	.fvu
CFL_H_C_B3_5	.csv	.fvu
CFL_H_C_B3_6	.csv	.fvu
CFL_H_C_B3_7	.csv	.fvu
CFL_H_C_B3_8	.csv	.fvu
CFL_H_C_B3_9	.csv	.fvu
CFL_H_C_B4_1	.csv	.fvu
CFL_H_C_B4_10	.csv	.fvu
CFL_H_C_B4_11	.csv	.fvu
CFL_H_C_B4_12	.csv	.fvu
CFL_H_C_B4_2	.csv	.fvu
CFL_H_C_B4_3	.csv	.fvu
CFL_H_C_B4_4	.csv	.fvu
CFL_H_C_B4_5	.csv	.fvu
CFL_H_C_B4_6	.csv	.fvu
CFL_H_C_B4_7	.csv	.fvu

File	Format	
CFL_H_C_B4_8	.csv	.fvu
CFL_H_C_B4_9	.csv	.fvu
CFL_H_C_B5_1	.csv	.fvu
CFL_H_C_B5_10	.csv	.fvu
CFL_H_C_B5_11	.csv	.fvu
CFL_H_C_B5_12	.csv	.fvu
CFL_H_C_B5_2	.csv	.fvu
CFL_H_C_B5_3	.csv	.fvu
CFL_H_C_B5_4	.csv	.fvu
CFL_H_C_B5_5	.csv	.fvu
CFL_H_C_B5_6	.csv	.fvu
CFL_H_C_B5_7	.csv	.fvu
CFL_H_C_B5_8	.csv	.fvu
CFL_H_C_B5_9	.csv	.fvu
CFL_H_CB_A1_2_1	.csv	.fvu
CFL_H_CB_A1_2_2	.csv	.fvu
CFL_H_CB_A3_1	.csv	.fvu
CFL_H_CB_A3_2	.csv	.fvu
CFL_H_CB_A4_1	.csv	.fvu
CFL_H_CB_A4_2	.csv	.fvu
CFL_H_CB_A5_1	.csv	.fvu
CFL_H_CB_A5_2	.csv	.fvu
Vul_CFL	.dat	

Earthquake Vulnerability Curves

File	Format	
EQ_H_C_B_10	.csv	.fvu
EQ_H_C_B_11	.csv	.fvu
EQ_H_C_B_12	.csv	.fvu
EQ_H_C_B_3	.csv	.fvu
EQ_H_C_B_4	.csv	.fvu
EQ_H_C_B_5	.csv	.fvu
EQ_H_C_B_6	.csv	.fvu
EQ_H_C_B_7	.csv	.fvu
EQ_H_C_B_8	.csv	.fvu
EQ_H_C_B_9	.csv	.fvu
EQ_H_CB_A_1	.csv	.fvu
EQ_H_CB_A_2	.csv	.fvu
Vul_EQ	.dat	

RDLS Metadata

This directory contains metadata compliant with the *Risk Data Library Standard*, providing structured information to describe, organize, and ensure the consistency of the datasets used in the project.

File	Format
Exp_Agriculture	.json
Exp_Heredia_Buildings	.json
Exp_Heredia_Infrastructure	.json
Exp_RN2	.json
Exp_Tourism	.json
Vul_Agriculture	.json
Vul_Heredia_Infraestructure	.json
Vul_RN2	.json
Vul_Tourism	.json

The *.json file may contain information related to hazard, exposure, vulnerability, or loss, depending on the type of data being represented within the project.