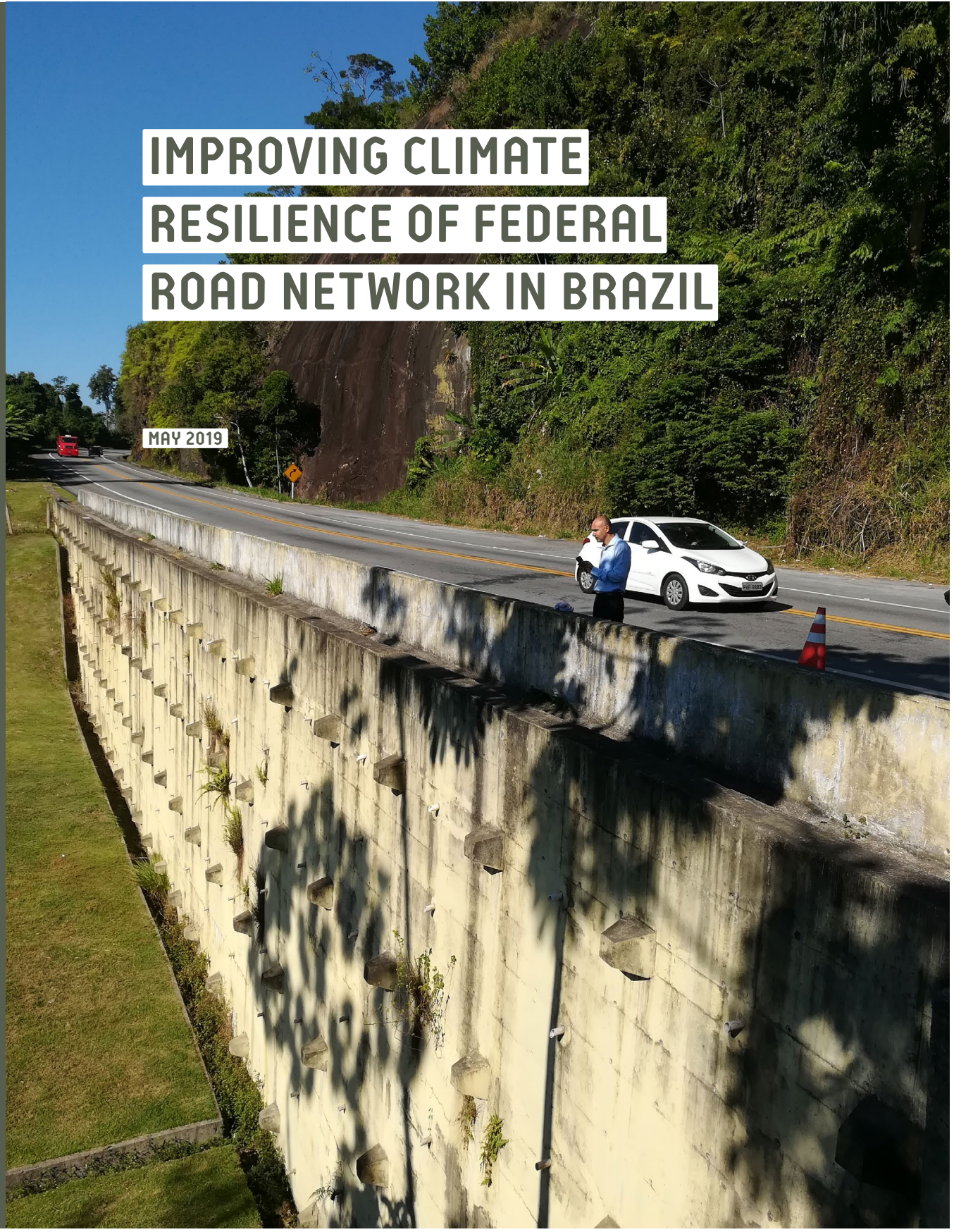


IMPROVING CLIMATE RESILIENCE OF FEDERAL ROAD NETWORK IN BRAZIL

MAY 2019



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TABLE OF CONTENTS

List of Figures and Tables	8
List of Abbreviations	12
1 Introduction	14
1.1 Objective and Scope	15
1.2 Terminology on disaster risk reduction	16
1.3 Brazil's Background	18
1.3.1 Background of Natural Disasters in Brazil	19
1.3.2 Geohazards on Roads in Brazil	24
2 Diagnostics of Road Geohazard Risk Management	26
2.1 Institutional Capacity and Coordination	27
2.1.1 Institutional Framework	27
2.1.2 Laws, Regulations, and Technical Standards	31
2.1.3 National Plans and Strategies	33
2.1.4 Funding Mechanisms	35
2.2 Systems Planning	36
2.2.1 Risk Identification, Assessment, and Evaluation	36
2.2.2 Risk Management Planning	39
2.3 Engineering and Design	39
2.3.1 Engineering Investigation and Study for Engineered Measures	39
2.3.2 Structural Measures and Design Considerations	40
2.4 Operations and Maintenance	40
2.4.1 Nonstructural Measures	40
2.4.2 Maintenance of Structural Measures	45
2.5 Contingency Programming	45
2.5.1 Pre-Disaster and Emergency Preparedness	45
2.5.2 Post-Disaster Response and Recovery	46
2.5.3 Post-Disaster Risk Funding and Management	47
2.6 Challenges in Road Geohazard Risk Management in Brazil	48
2.7 Identification of Pilot Study Methodologies	51

3	Methodologies for Road Geohazard Risk Assessment	52
3.1	Case Studies with Two Innovative Road Geohazard Risk Assessment Methodologies	53
3.2	Methodology for Mapping Landslide Risk Areas	55
3.2.1	Methodology	56
3.2.2	Applying this Methodology to a Pilot Area	59
3.2.3	Final Considerations on the Methodology	67
3.3	Unmanned Aerial Vehicles (Drones) for Monitoring	69
3.3.1	Introduction	69
3.3.2	Surveying	69
3.3.3	GIS Integration	73
3.3.4	Using Drones during Disasters	75
3.3.5	Case Study	77
3.3.6	Cost of implementation	80
3.3.7	Safe use of UAVs and user limitations	81
3.3.8	Conclusions	81
3.3.9	Recommendations	82
4	Economic Evaluation of Risk Mitigation Measures	84
4.1	Introduction to Economic Analysis under Deep Uncertainties (DMDU)	85
4.2	Accounting for Benefits	86
4.3	Methodology	88
4.3.1	Definition of a Baseline	88
4.3.2	Impacts of Road Interventions and Extra Maintenance	90
4.3.3	Dealing with Uncertainty	92
4.4	Cost-Benefit Analysis	98
4.5	Results	99
4.6	Conclusions	105
5	Suggestions and Next Steps	106
6	References	110

LIST OF FIGURES AND TABLES

FIGURES

Figure 1.1	Annual Rainfall and Registered Natural Disasters in Brazil, 1991–2010	20
Figure 1.2	Annual Natural Disasters and Cost of Damage to Infrastructure in Brazil, 1995–2014	21
Figure 1.3	Share by Region of Damage to Infrastructure in Brazil, 1995–2014	23
Figure 1.4	Total Annual Damages from Natural Disasters in Brazil, 1995–2014	24
Figure 2.1	Federal Organizations with Roles in Road Geohazard Risk Management in Brazil	27
Figure 2.2	DNIT Organizational Chart	28
Figure 2.3	DNIT Decision-Making Process for Work to Remedy Critical Spots	38
Figure 2.4	Launch Screens of DNIT Móvel	41
Figure 2.5	Warning Signs to Raise Road User Awareness	42
Figure 2.6	Emergency Inspection and Postdisaster Needs Assessment Process in Brazil	46
Figure 3.1	Rain/Landslide Curve Example	57
Figure 3.2	Flowchart of Aero Photogrammetric Surveying using UAVs	70
Figure 3.3	Ground Control Points Surveyed with GPS L1, L2	71
Figure 3.4	Illustration of the RTK System	71
Figure 3.5	Flight Plan for Aero Photogrammetric Surveying	72
Figure 3.6	Illustration of Aero Photogrammetric Survey with Overlapping Images	73
Figure 3.7	Map Generated in a GIS Environment, Containing the Image, MDS, and Isolines (aero photogrammetric survey data using an UAV)	74

Figure 3.8	Relief Map and Profiles Generated in a GIS Environment	74
Figure 3.9	Use of UAVs during Disasters	75
Figure 3.10	RGB Mosaic Point 3	79
Figure 3.11	Digital Surface Model Point 3	79
Figure 3.12	3D Model Point 3	80
Figure 4.1	Variables of the Economic Analysis Classified by Levels of Uncertainty	92

TABLES

Table 3.1	Limit Values by Rainfall Basin	65
Table 3.2	Recurrence of Rainfall above Limit Values per Rainfall Basin	66
Table 3.3	Flight Parameters	78
Table 3.4	Estimation of Cost of Implementation for the 155 km under Study	80
Table 4.1	Emergency Contracts by DNIT (2007–2015)	96
Table 4.2	Annual Number of Landslides	97
Table 4.3	Estimation of Needed Up-front Investment in Preventive Countermeasures	97
Table 4.4	Maximum regret for with and without project alternatives	102
Table 4.5	Variable Restrictions for NPV > 0 in 94.9 percent of the Cases	104

GRAPHS

Graph 2.1	Planned 2014 Investments of the National Plan for Risk Management and Response to Natural Disasters (R\$ million)	34
Graph 3.1	Limit Value for Angra dos Reis Rainfall Basin	64
Graph 3.2	Limit Value for Mangaratiba Rainfall Basin - Paraty Center (MCP)	64
Graph 3.3	Limit Value for São Roque- Patrimônio Rainfall Basin (SRP)	65
Graph 4.1	Conceptual investment schedule of the without-project scenario	87
Graph 4.2	Conceptual investment schedule of the with-project scenario	87
Graph 4.3	Reduced EAUL and Reduced EAD Range (R\$, millions)	99
Graph 4.4	Reduced Annual Losses	100
Graph 4.5	Benefit-Cost Ratio Range for the 1,500 scenarios (R\$, millions)	101
Graph 4.6	Regret of each alternative in all 1500 scenarios.	102
Graph 4.7	Variable Restrictions Applied to Different Scenarios	103

MAPS

Map 1.1	Regions of Brazil	18
Map 1.2	Distribution of Landslides in Brazil, 1994–2012	21
Map 1.3	Distribution of Damage to Infrastructure in Brazil, 1995–2014	22
Map 2.1	Screen Shot of DNIT Geographic Information Viewer (VGEO)	44
Map 3.1	Landslides Registered in the Pilot Section of the BR-101 (2007–2015)	53
Map 3.2	Section of the BR-101 under Study	54

Map 3.3	Location of the Pilot Area	59
Map 3.4	Pilot Area Susceptibility Map	60
Map 3.5	Map of Exposed Elements in the Pilot Area	60
Map 3.6	Map of the Degree of Susceptibility of the Exposed Elements in the Pilot Area	61
Map 3.7	Rainfall Basins in the Pilot Area	62
Map 3.8	Map of the Inventory of Mass Movement Points within the Area of Interest	63
Map 3.9	Risk Map of Exposed Elements by Climatological-Geological/Geomorphological Basin	68
Map 3.10	Locations of the Study Points	77
Map 4.1	Alternative Routes for the Pilot Area	93
Map 4.2	AADT in the Pilot Area	94

PHOTOS

Photo 1.1	Landslide in Angra dos Reis in 2018 in Rio de Janeiro State	25
Photo 2.1	Critical Spots Identified during a Field Visit, Angra dos Reis, Brazil	37
Photo 2.2	Local Traffic Sign: "Attention: Area Subjected to Flooding"	42
Photo 2.3	Local Traffic Sign: "Area Subjected to Flooding"	42
Photo 2.4	Variable Message Signs on Brazilian Roads Operated under Road Concessions	43
Photo 3.1	Aerial Photo by UAV, Bridge Collapse - Genoa, Italy	76
Photo 3.2	Aerial Photo by UAV, Bridge Debris - Genoa, Italy	76
Photo 4.1	Anchored Curtain	90
Photo 4.2	Deep Horizontal Drains	91

LIST OF ABBREVIATIONS

AADT	Annual Average Daily Traffic
ANAC	National Civil Aviation Agency
CEMADEN	National Center for Natural Disaster Monitoring and Alerts
CENAD	National Center for Risk and Disaster Management
CEPED UFSC	Centro Universitário de Estudos e Pesquisas sobre Desastres
CPRM	Mineral Resources Research Company
DENATRAN	National Department of Traffic
DMDU	Decision Making under Deep Uncertainty
DMU	Decision Making under Uncertainty
DNER	National Department of Roadways
DNIT	National Department of Transport Infrastructure
DOT	Department of Transportation (state)
DRM	Disaster Risk Management
GFDRR	Global Facility for Disaster Reduction and Recovery
GIDES	Integrated Risk Management in Natural Disasters

GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
NPV	Net Present Value
PPK	Post Processed Kinematic
RTK	Real Time Kinematic
SEDEC	National Secretariat for Civil Protection and Defense
SINDEC	National Civil Defense System
SINGREH	National Water Resources Management
SINPDEC	National Civil Protection and Defense System
SISNAMA	National Environmental System
UAV	Unmanned Aerial Vehicle
USGS	United States Geological Survey
VGEO	Geographic Information Viewer
VMS	Variable Message Sign
VOC	Vehicle Operating Cost

1

INTRODUCTION

1.1

OBJECTIVE AND SCOPE

The objective of the study is to strengthen capacity of geohazard disaster resilience of federal highway infrastructure in Brazil through reviewing disaster risk management (DRM) capacity for federal road infrastructure and case studies of applying innovative methodologies for assessing disaster risk and evaluating economic benefits of resilience countermeasures. Although floods and landslides are the most recurrent natural disasters in Brazil, this report focuses on the latter, leaving floods for future studies.

The report begins with diagnostics of the institutional capacities of geohazard risk management at the federal government level in Brazil. Chapters 1 and 2 include the backgrounds of natural disasters, road systems, and geohazards on roads in Brazil and a review of the road geohazard risk management with overviews of the following areas: institutional capacity and coordination, system planning, engineering designs, operation and maintenance, nonstructural measures, and contingency programming.

Then, Chapters 3 and 4 describe the case study of application of the three innovative DRM assessment methodologies. A section of 155 km of the federal road BR-101 in the State of Rio de Janeiro was selected as a case study for being a road noticeable exposed to landslide hazards. The methodologies applied include use of unmanned aerial vehicles (UAVs) to monitor landslide risk on roads, mapping of areas at risk for mass movements, and Decision Making Under Uncertainty (DMU) methodology for effective economic analysis. This report carefully describes how three innovative methodologies that, if properly applied, could improve the effectiveness of landslide risk management, thus reducing economic and human impacts.

Finally, Chapter 5 shows the suggestions and recommendations for the next steps.

1.2

TERMINOLOGY ON DISASTER RISK REDUCTION

Knowledgeable of the fact that some of the terms used throughout this report could lead the reader to misleading concepts, and in order to promote a successful understanding of the different sections presented in this report, some definitions used by the United Nations International Strategy for Disaster Reduction (UNISDR)¹ are described below:

Disaster. A serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts.

Disaster risk. The potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity.

Disaster risk management. Disaster risk management is the application of disaster risk reduction policies and strategies to prevent new disaster risk, reduce existing disaster risk and manage residual risk, contributing to the strengthening of resilience and reduction of disaster losses.

Disaster risk reduction. Disaster risk reduction is aimed at preventing new and reducing existing disaster risk and managing residual risk, all of which contribute to strengthening resilience and therefore to the achievement of sustainable development.

Early warning system. An integrated system of hazard monitoring, forecasting and prediction, disaster risk assessment, communication and preparedness activities systems and processes that enables individuals, communities, governments, businesses and others to take timely action to reduce disaster risks in advance of hazardous events.

Economic loss. Total economic impact that consists of direct economic loss and indirect economic loss.

- **Direct economic loss:** the monetary value of total or partial destruction of physical assets existing in the affected area. Direct economic loss is nearly equivalent to physical damage.
- **Indirect economic loss:** a decline in economic value added as a consequence of direct economic loss and/or human and environmental impacts.

Exposure. The situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas.

Hazard. A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation.

1

United Nations International Strategy for Disaster Reduction (UNISDR):
<https://www.unisdr.org/we/inform/terminology>

- **Geological or geophysical hazards originate from internal earth processes.** Examples are earthquakes, volcanic activity and emissions, and related geophysical processes such as mass movements, landslides, rockslides, surface collapses and debris or mud flows.
- **Hydrometeorological hazard are of atmospheric, hydrological or oceanographic origin.** Examples are tropical cyclones (also known as typhoons and hurricanes); floods, including flash floods; drought; heatwaves and cold spells; and coastal storm surges. Hydrometeorological conditions may also be a factor in other hazards such as landslides, wildland fires, locust plagues, epidemics and in the transport and dispersal of toxic substances and volcanic eruption material.
- **Natural hazards.** Hazards may be natural, anthropogenic or socionatural in origin. Natural hazards are predominantly associated with natural processes and phenomena.

Mitigation. The lessening or minimizing of the adverse impacts of a hazardous event.

Preparedness. The knowledge and capacities developed by governments, response and recovery organizations, communities and individuals to effectively anticipate, respond to and recover from the impacts of likely, imminent or current disasters.

Prevention. Activities and measures to avoid existing and new disaster risks.

Resilience. The ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management.

Response. Actions taken directly before, during or immediately after a disaster in order to save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of the people affected.

Structural and non-structural measures. Structural measures are any physical construction to reduce or avoid possible impacts of hazards, or the application of engineering techniques or technology to achieve hazard resistance and resilience in structures or systems. Non-structural measures are measures not involving physical construction which use knowledge, practice or agreement to reduce disaster risks and impacts, in particular through policies and laws, public awareness raising, training and education.

Vulnerability. The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards.

1.3**BRAZIL'S BACKGROUND**

Brazil covers approximately 8.5 trillion square kilometers, occupying 47 percent of South America's surface area. The country is divided into five geographic regions (**MAP 1.1**) with specificities that differentiate them from each other. It is made up of 26 states and the Federal District, whose capital is Brasília. Brazil has a total population of more than 208 million inhabitants and a 2017 gross domestic product (GDP) of approximately US\$2.1 trillion.

MAP 1.1**REGIONS OF BRAZIL**

1.3.1 BACKGROUND OF NATURAL DISASTERS IN BRAZIL

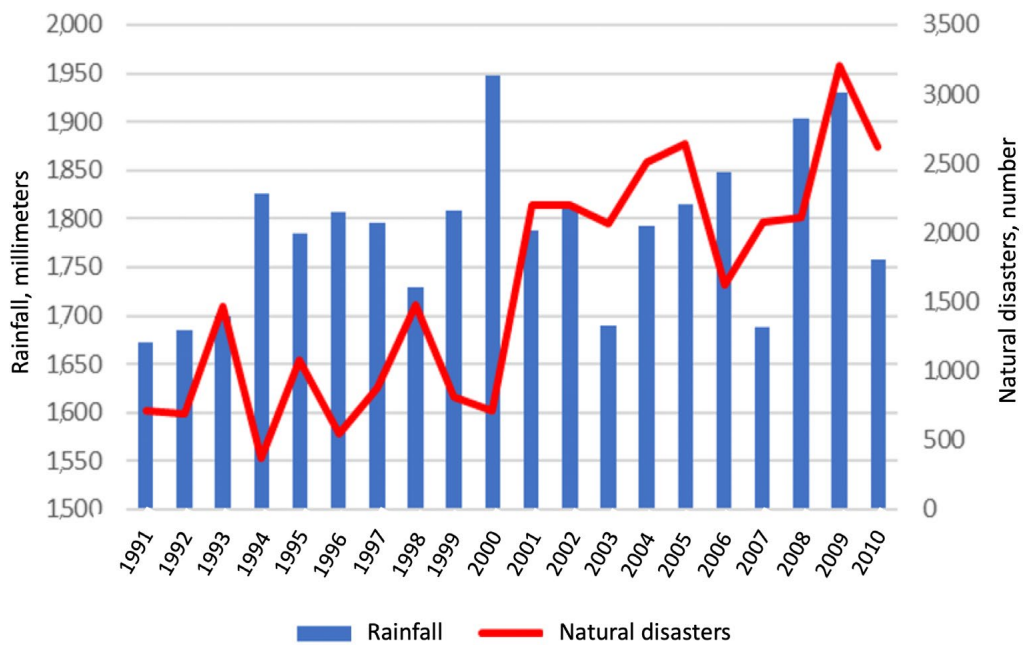
According to the “Disaster Losses in Brazil, 1995–2014” report, the events most frequently reported by the municipalities are related to droughts, followed by floods, flash floods, and windfalls (World Bank 2016). However, because of the country’s great territorial extension, each region presents different characteristics regarding the frequency and magnitude of these disasters.

In terms of intensity, natural disasters in Brazil can be classified into four distinct levels:

- **Level I:** Small-scale events with minor damages and minor losses that can be overcome by the affected community. Here the situation of normality is restored without great difficulty, using the resources of the municipality itself.
- **Level II:** Medium-size events with damage of some importance and significant losses, but surmountable by well-prepared communities. At this level, the situation of normality is reestablished with a special mobilization of local resources.
- **Level III:** Events of great proportions and with enormous impact on infrastructure and society. To restore normality, local resources are used, reinforced by state and federal contributions in the National Civil Defense System (SINDEC).
- **Level IV:** Events of very serious proportions with very large damages and losses that cannot be overcome without help from outside the affected municipality. When the disaster is of such intensity, the situation will return to normality only if there is an articulated action of the three levels of SINDEC and possible help from international organizations.

Brazilian law also distinguishes between “emergencies” and “public calamities.” An emergency situation is when the abnormal situation is caused by a disaster, with damages that can be overcome by the community; it is legally recognized as such by the government. A state of public calamity, in addition to being legally recognized as an abnormal situation caused by a disaster, seriously puts at risk the safety and life of the people of the community. The declaration of either an emergency situation or a state of public calamity must be approved by the state government, with this confirmation of the declaration having corresponding legal effects. Climate is directly related to natural disasters in Brazil, as it is in many other parts of the world. With the amount of rainfall varying from year to year, the number of registered natural disasters has increased dramatically since a record-breaking annual rainfall of 1,948 millimeters in 2000, closely followed by 1,930 millimeters in 2009. From 2011 to 2015, the amount of annual rainfall kept decreasing, but no reliable data is given regarding the number of registered natural disasters found by the time this report was published. **FIGURE 1.1** shows the sum of the annual rainfall in comparison with the number of registered natural disasters.

FIGURE 1.1
ANNUAL RAINFALL AND REGISTERED NATURAL DISASTERS IN BRAZIL, 1991–2010



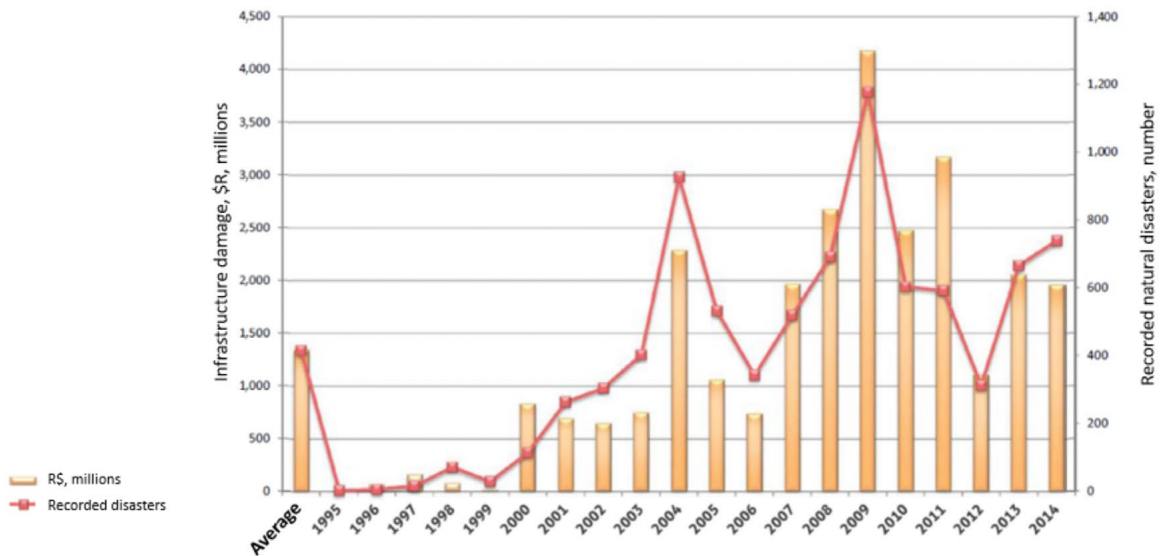
Source: World Bank Climate Change Knowledge Portal 2.0, <http://sdwebx.worldbank.org/climateportal/>.

Most of the disasters recorded in the North region are related to excess rainfall—the highest annual total in Brazil. The Northeast and South regions concentrate the highest occurrence of drought records (World Bank 2016). The semiarid region within the Northeast often faces long periods of drought. In the South, the western portion of the three states is more frequently affected by rainfall than the eastern portion. **FIGURE 1.2** shows the number of natural disasters in Brazil and the corresponding cost of damage to infrastructure from 1995 through 2014 (World Bank 2016).

Although floods and flash floods appear as the most recurrent phenomena in the South and Southeast regions, events related to wind, hail, and landslides are also responsible for significant damage. Finally, the West Central region presents a more frequent recurrence of flood-related disasters than drought.

Landslides due to heavy rains have a significant impact on roads across Brazil. **MAP 1.2** shows the distribution of landslides from 1994 through 2012, where a clear polarization of the events toward southeastern Brazil can be observed. Most of the events materialized in the states of Rio de Janeiro (RJ), São Paulo (SP), and Minas Gerais (MG). The states of Santa Catarina (SC), Paraná (PR), Espírito Santo (ES), and Bahia (BA) also suffered several landslides, although in smaller proportion.

FIGURE 1.2
ANNUAL NATURAL DISASTERS AND COST OF DAMAGE TO
INFRASTRUCTURE IN BRAZIL, 1995–2014



Source: World Bank 2016. Note: R\$ = Brazilian reais.

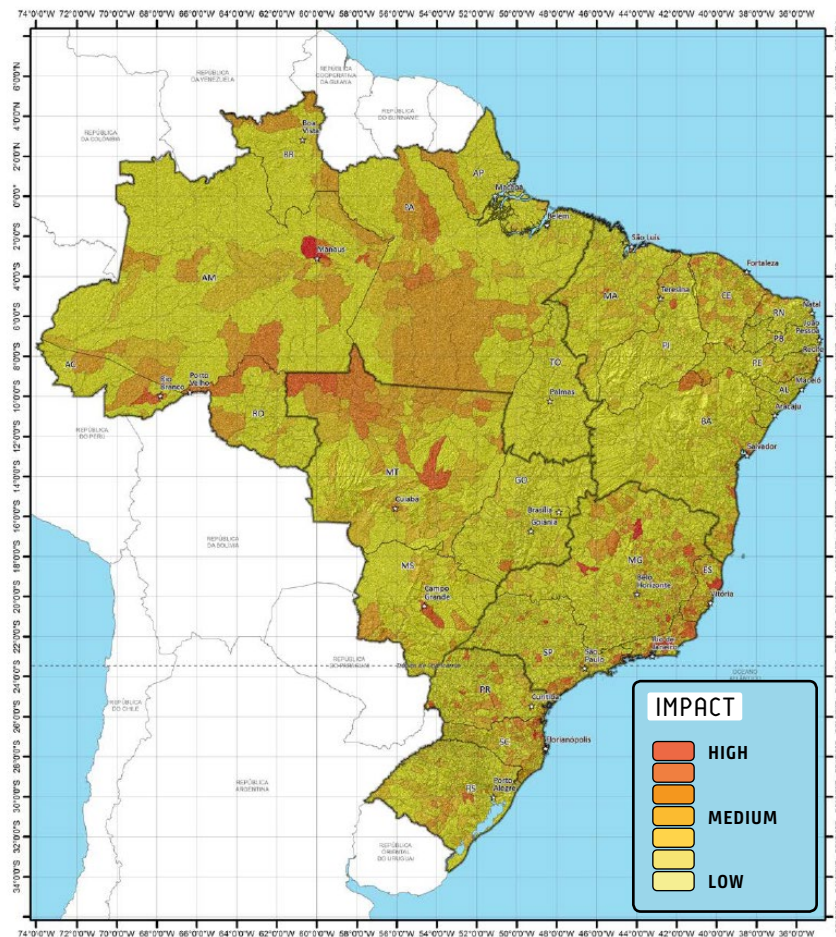
MAP 1.2
DISTRIBUTION OF LANDSLIDES IN BRAZIL, 1994–2012



Source: CEPED UFSC 2013. ©Center for Studies and Research in Engineering and Civil Defense, Federal University of Santa Catarina (CEPED UFSC). Reproduced, with permission, from CEPED UFSC; further permission required for reuse.

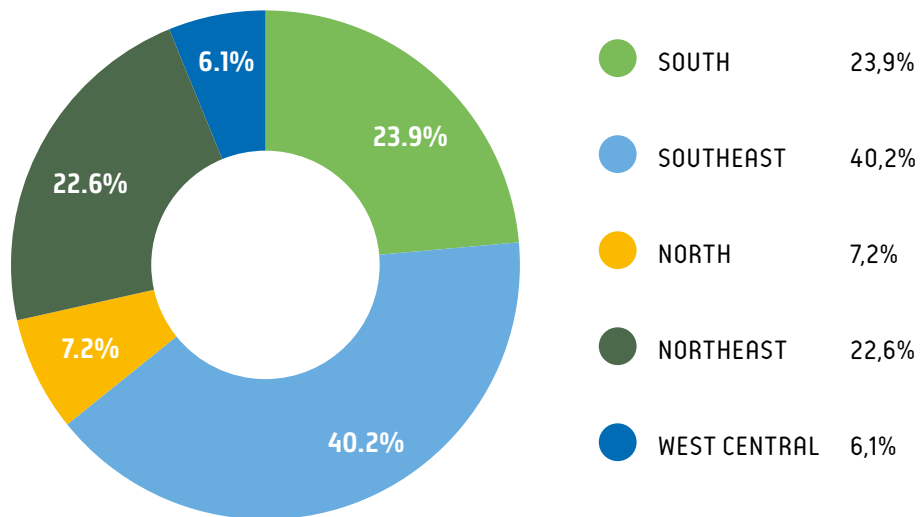
The way natural disasters are managed in Brazil has evolved throughout the years. The culture of monitoring and managing natural disasters has been ongoing since the 1940s, when Brazil implemented the first civil defense actions, structures, and strategies of protection and safety toward its citizens. Since then, the occurrence of numerous devastating natural disasters in the country has changed the way they are managed. **MAP 1.3** and **FIGURE 1.3** show the distribution and share of damage (R\$, millions) to infrastructure by region.

MAP 1.3
DISTRIBUTION OF DAMAGE TO INFRASTRUCTURE IN BRAZIL, 1995-2014



Source: World Bank 2016.

FIGURE 1.3
SHARE BY REGION OF DAMAGE TO INFRASTRUCTURE IN BRAZIL, 1995–2014



Source: World Bank 2016

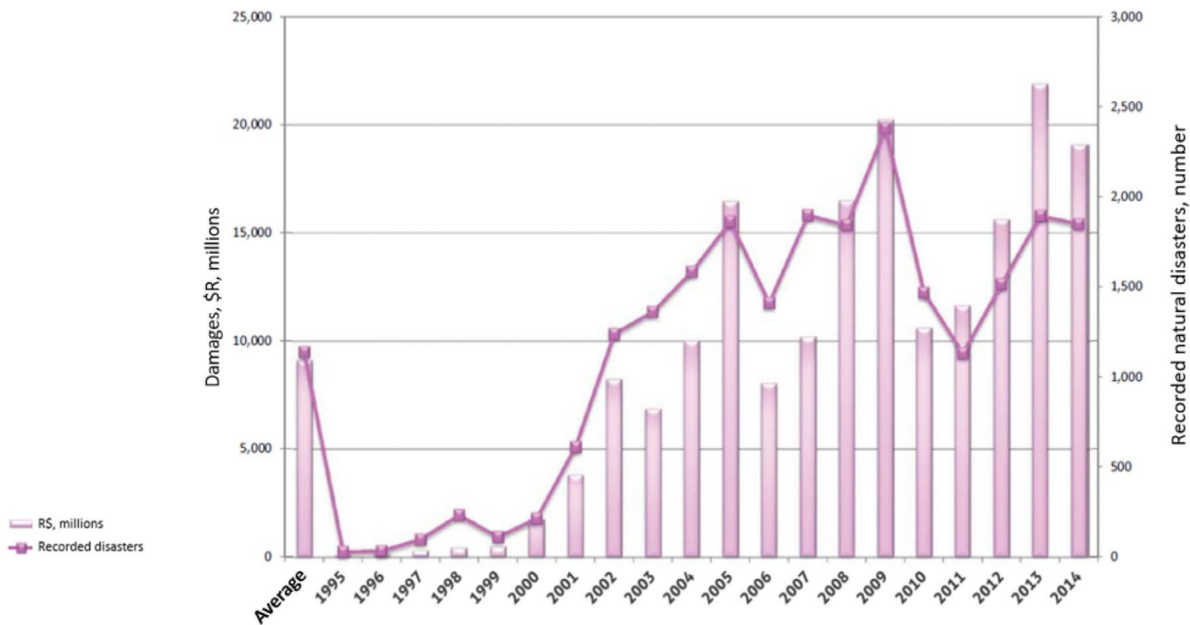
Although Brazil is the fifth largest country in the world, it has a relatively low number of natural hazards. However, its exposure to natural hazards has increased relative to other countries because of insufficient preventive actions in the past, resulting in more damage from natural hazards to both infrastructure and human lives than countries of comparable size would incur. For example, Brazilian building codes and maintenance of infrastructure are usually poor compared with other upper-middle-income countries, resulting in a disproportionately high amount of damage for a given severity of event.

Catastrophic floods and landslides occurred in Santa Catarina in 2008, Pernambuco and Alagoas in 2010, and the Serra region of Rio de Janeiro in 2011, resulting in combined estimated economic losses of about R\$15.5 billion (US\$4.2 billion). Even more worrisome, such results are partial in view of the limited data availability and the practical impossibility of evaluating all events recorded in a country (World Bank 2016).

More recently, the floods in the state of Paraná in 2016 affected 150,000 people; floods in Pernambuco and Alagoas in May 2017 forced a combined 69,000 people to leave their homes; and within the same week, floods in Rio Grande do Sul left more than 40,000 people homeless. This flooding is normally associated with intense and prolonged rainfall events during the rainy seasons: (a) summer in the South and Southeast regions, and (b) winter in the Northeast region. Figure 1.4 shows the total amount of damages and losses due to natural disasters from 1995 through 2014.

That economic losses were poorly accounted for in Brazil contributed to the idea that disasters were not a significant issue to be dealt with. Thus, Brazil has been considering floods and landslides as punctual problems that historically warranted a reactive approach, which consequently caused major setbacks for its regional and local sustainable development.

FIGURE 1.4
TOTAL ANNUAL DAMAGES FROM NATURAL DISASTERS IN BRAZIL, 1995–2014



Source: World Bank 2016. Note: R\$ = Brazilian reais.

1.3.2 GEOHAZARDS ON ROADS IN BRAZIL

Brazil faces an increasing risk of natural disasters, in particular floods and landslides (Photo 1.1). A recent Global Facility for Disaster Reduction and Recovery (GFDRR)-funded study showed that approximately US\$5 billion was lost in the four major flood and landslide disasters in the past five years, with damage to transport infrastructure amounting to 20 percent (US\$0.9 billion) of total costs (World Bank 2016).² Although insufficient data and studies prevent a complete understanding of disaster damages in the entire country, natural disaster incidents have increased for the past 10 years.

2

"Damage Report: Material Damages and Losses due to Natural Disasters in Brazil, 1995–2014" (World Bank 2016) intends to deepen the studies initiated by the World Bank and the Center for Studies and Research in Engineering and Civil Defense, Federal University of Santa Catarina (CEPED UFSC), organizing data on material damages and losses due to natural disasters in Brazil between 1995 and 2014 and based on the information reported by the municipalities to the states and the union.

PHOTO 1.1
LANDSLIDE IN ANGRA DOS REIS IN 2018 IN RIO DE JANEIRO STATE



Source: Javier Escudero Marroquin/ World Bank.

Although road infrastructure is the most important transport mode in Brazil—transporting 95 percent of passenger trips and 61 percent of cargo—the country’s disaster risk management (DRM) agenda is nascent, confined to a few specialized agencies (civil protection) and focusing only on emergency response.

Of the numerous transport projects that are developed in Brazil every year, few (if any) are strongly concerned about ensuring the application of DRM practices holistically. Some might consider common engineering approaches, such as the use of flood modeling information for the structural design of infrastructures, but a comprehensive approach under a DRM strategy is seldom observed.

Data sharing among institutions is key for an effective geohazard and disaster risk management. In Brazil, there is no integration of environmental and geohazard risk-related information with information from the transport sector. Each branch has been considered separately over the years without looking at each other’s data or information in an ad hoc manner.

Despite the fact that Brazil is a country with high human technical capacity within institutions and external contractors, institutional setup and coordination are rather limiting. In addition, budget constrains slow down every institutional effort to develop a more sophisticated DRM strategy and implementation.

The increasing frequency of natural disasters and their dramatic impact on infrastructure is slowly raising awareness on the DRM agenda, monitoring and prevention in particular, among transport infrastructure managers. Yet, there are strong needs to mainstream DRM practices at the planning and operating phases to deal with increasing natural disaster risks and thereby mitigate huge potential economic losses.

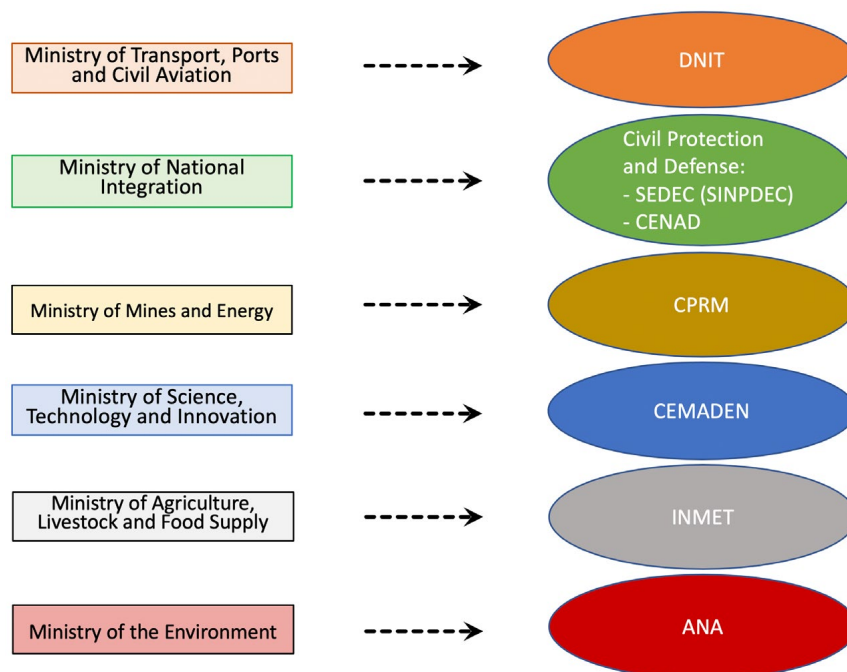
2

DIAGNOSTICS OF ROAD

GEOHAZARD RISK MANAGEMENT

2.1**INSTITUTIONAL CAPACITY AND COORDINATION****2.1.1****INSTITUTIONAL FRAMEWORK**

To understand the Road Geohazard Risk Management Framework in Brazil, there is a need to first map the different institutions involved in the process at the federal level. The federal government and its institutions are very different from the ones in any state. The key federal entities involved in geohazard management and response are outlined in **FIGURE 1.2**, with further explanation of their roles in the following paragraphs.

FIGURE 2.1**FEDERAL ORGANIZATIONS WITH ROLES IN ROAD GEOHAZARD RISK MANAGEMENT IN BRAZIL**

Note: ANA = National Water Agency. CEMADEN = National Center for Natural Disaster Monitoring and Alerts. CENAD = National Center for Risk and Disaster Management. CPRM = Mineral Resources Research Company. DNIT = National Department of Transportation Infrastructure. INMET = National Meteorological Institute. SEDEC = National Secretariat for Civil Protection and Defense. SINPDEC = National Civil Protection and Defense System.

National Department of Transport Infrastructure (DNIT). DNIT is a Brazilian federal authority under the Ministry of Transport, Ports and Civil Aviation. It was created by Law No. 10,233 of June 5, 2001, which restructured the land and water transportation system of Brazil and abolished the former National Department of Roadways (DNER).

The DNIT is responsible for the maintenance, expansion, construction, supervision, and preparation of technical studies for the resolution of problems related to the federal highway system, as well as for the multimodal traffic of people and goods in the modalities of roads, rails, and waterways.

There is a regional DNIT office in every state, including for the federal district where the DNIT headquarters is located, which is supported by the regional office from the state of Goiás. Each regional office is supported by strategically located local units throughout the state, where the number of units varies in accordance to the size of the federal road network. For example, the state of Sergipe has the smallest network with 319 kilometers and one local unit, while the state of Minas Gerais has the largest network with 8,711 kilometers and 18 local units throughout the state. These local units work as first responders to all transportation infrastructure issues under the DNIT's jurisdiction.

FIGURE 2.2
DNIT ORGANIZATIONAL CHART



Source: <http://www.dnit.gov.br/aceso-a-informacao/insitucional/organograma>

Note: DNIT = National Department of Transportation Infrastructure.

National Civil Protection and Defense System (SINPDEC). Civil protection and defense in Brazil, legally constituted by Law No. 12,608 of April 10, 2012, is organized in the form of SINPDEC, which comprises a set of multisectoral bodies that use a matrix concept with vertical and horizontal dynamics throughout the national territory.

National Secretariat for Civil Protection and Defense (SEDEC). SEDEC is the central body of SINPDEC, responsible for coordinating civil protection and defense actions throughout the national territory. Its aim is to reduce the risks of disasters. It also includes prevention, mitigation, preparedness, response, and recovery actions that take place in a multisectoral manner at the federal, state, and municipal levels of government, with broad community participation.

National Center for Risk and Disaster Management (CENAD). CENAD was created in February 2005, through Decree No. 5,376, to manage, with agility, strategic actions to prepare and respond to disasters in the national territory and, eventually, also internationally.

Coordinated by SEDEC within the Ministry of National Integration, the current structure of the organization has two work fronts: (a) "articulation, strategy, structuring, and continuous improvement"; and (b) "permanent action of monitoring, alert, information, mobilization, and response." The first is responsible for the preparation and response to disasters, and its main activity is the mobilization to care for the victims. The second work front corresponds to the constant monitoring of information about possible disasters in risk areas, with the objective of reducing impacts and preparing the population.

CENAD is responsible for consolidating information on risks in the country, such as maps of landslide and flood risk areas as well as data on the occurrence of natural and technological disasters and associated damages. Managing this information enables the center to support states and municipalities in disaster preparedness actions among the most vulnerable communities.

CENAD's operating dynamics consists of receiving information from various federal government agencies responsible for predicting time and temperature; assessing geological conditions in hazardous areas; monitoring the movement of tectonic plates; monitoring river basins; controlling forest fires; and transporting and storing hazardous products. CENAD evaluates and processes the information and forwards it to the civil protection and defense agencies of the states and municipalities under disaster risk.

CENAD is responsible for the federal coordination of disaster response actions within SINPDEC; its representativeness in committees and commissions related to risks and disasters has an important role in the planning and mobilization of response actions at the national level.

Mineral Resources Research Company (CPRM). CPRM is legally bound to act as Brazil's official agency for gathering data and information on Brazilian geology, minerals, and water resources. It manages a complex set of databases and theme-based georeferenced information systems as well as a vast collection of documents, maps, and images, which they put at the public's disposal.

The company was set up in 1969 with a mix of state and private ownership. With the onset of challenging circumstances in the nation, especially as of the second half of the 1980s, CPRM underwent deep-rooted institutional changes that culminated in Law No. 8,970, of December 27, 1994, which made it entirely state-owned. This changed things on a practical level because all private service provision ceased, and the company took on its current role as the nation's geological survey. The focus shifted to basic geology and hydrology, with the concomitant development of different applications, such as environmental geology, hydrogeology, and geological hazards. All corporate activities were halted, and institutional partnerships with other federal, state, and local government agencies became the order of the day.

CPRM has operational offices throughout Brazil. Eight regional offices are located where projects are carried out and where most of the institution's operations are centered: in Manaus (Amazonas), Belém (Pará), Recife (Pernambuco), Goiânia (Goiás), Salvador (Bahia), Belo Horizonte (Minas Gerais), São Paulo (São Paulo), and Porto Alegre (Rio Grande do Sul). Another three smaller operation facilities are in Porto Velho (Rondônia), Teresina (Piauí), and Fortaleza (Ceará). Three support centers, or small offices, provide representation and operational support in Natal (Rio Grande do Norte), Cuiabá (Mato Grosso), and Criciúma (Santa Catarina). The company's political headquarters is in Brasília, while the main administrative office and technical departments are in Rio de Janeiro. CPRM's three training centers are in Apiaí (São Paulo), Morro do Chapéu (Bahia), and Caçapava do Sul (Rio Grande do Sul).

National Center for Natural Disaster Monitoring and Alerts (CEMADEN). CEMADEN is responsible for the prevention of natural disasters in Brazil and the management of governmental action when they do occur. This center is linked to the Ministry of Science, Technology, Innovation and Communication (MCTI).

Created in 2011 and installed in the city of Cachoeira Paulista, in the state of São Paulo, this center is responsible for managing the information emitted by meteorological radars, rain gauges, and data from climate forecasts. By passing information to competent bodies throughout Brazil, it aims to anticipate possible occurrences of meteorological conditions that could lead to a natural disaster.

CEMADEN became effectively operational on December 2, 2011, and has since issued alerts to CENAD. CEMADEN's researchers and technologists work with high-resolution satellite imagery and a host of high-tech equipment such as weather radars, data collection platforms, and soil analysis equipment to prevent events such as floods and landslides.

National Institute of Meteorology (INMET). INMET, Brazil's meteorological institute, is part of the Ministry of Agriculture, Livestock and Food Supply. Its mission is to provide meteorological information to Brazilian society and to influence the decision-making process, contributing to the country's sustainable development. This mission is achieved through monitoring, analysis, and prediction of weather and climate, which are based on applied research, working in partnership, and sharing knowledge, emphasizing practical and reliable results³.

3

"About INMET," INMET website:

http://www.inmet.gov.br/portal/index.php?r=home/page&page=sobre_inmet.

National Water Agency (ANA). ANA is legally liable for implementing the National Water Resources Management System (SINGREH) and was created to ensure the sustainable use of Brazilian rivers and lakes for the current and future generations.

This mission implies the regulation of water use according to the mechanisms established by Law No. 9,433 of 1997, among which the following stand out: (a) the granting of rights to the use of water resources aimed at disciplining the use of water bodies in relation to the collection of water and discharging of effluents; (b) inspection to ensure that the grants are licenses effectively respected and not mere notarial formalisms; and (c) the charge for use of water, to ensure that the water bodies are used with parsimony, in addition to enabling the generation of the necessary financial resources to recover and conserve rivers and lakes.

These three mechanisms have been implemented in an articulated manner in each river basin, which requires harmony between ANA and the water managing bodies and entities of the state governments, because Brazilian rivers are under the domain of both the federal government and the states.

However, ANA's regulatory scope reaches other management tools that are also relevant to the effective performance of SINGREH and represent the grounds for the good water management in Brazil. In this regard, the agency carries out actions of management support, monitoring, and planning of water resources, in addition to offering Information for improvement of the performance of the water resources management agencies and of the sectors that use these resources⁴.

2.1.2

LAWS, REGULATIONS, AND TECHNICAL STANDARDS

There is not yet a law or plan that relates and directly integrates DRM with the transport sector in Brazil. However, there is a positive evolution in both branches that will facilitate their integration in the future. The key laws and regulations that changed the approach to handling natural disasters in Brazil and the ones that influenced directly on the transport sector, are discussed in the following paragraphs.

Transport institutions. In 1998, as part of a federal government effort to improve Brazil's transportation infrastructure, the National Department of Roadways (DNER) was authorized to contract, in the form of concession, the construction and conservation of roads. The same law (No. 10,233) that in 2001 replaced the DNER with the DNIT also created the National Agency for Ground Transportation (ANTT) and the National Agency for Waterway Transportation (ANTAQ) as regulating agencies under the Ministry of Transport, Ports and Civil Aviation.

National Environmental System (SISNAMA). SISNAMA was instituted by Law 6,938, dated August 31, 1981, and regulated by Decree 99.274 of June 6, 1990. The National Environmental Council (CONAMA) has representatives from five sectors: federal, state, and municipal agencies; business; and civil society. On December 19, 1997, through Resolution No. 237, CONAMA made it necessary for road constructions to have environmental licenses. In addition to road construction, this resolution applies to other modes of transportation and civil works in general, such as the following:

- Railroads, waterways, and metropolitan transport
- Dams and dikes
- Drainage channels
- Rectification of waterways
- Opening of channels and bars
- Transposition of watersheds.

To ensure that environmental impact will be minimal and consequently avoid road geohazards, the public agency responsible for issuing the licenses will do it in three stages:

1. Preliminary License (LP): In the preliminary phase of planning, approves the location and concept, attesting to its viability
2. Installation License (LI): Authorizes the installation of the works in accordance with the approved projects
3. Operation License (LO): Authorizes the operation of activities or works.

National Center for Risk and Disaster Management (CENAD). In 1988, the National System of Civil Defense (SINDEC) organized the civil defense in Brazil in a systemic way. SINDEC was reformulated in August 1993 and updated in February 2005 by Decree No. 5,376/05, with the creation of CENAD and the Disaster Support Group as well as the strengthening of civil defense in the municipalities. Decree No. 5,376/05 decentralized the actions of the civil defense. Responsibility began to be shared among federal, state, and municipal governments.

The current structure of the organization has two work fronts: "articulation, strategy, structuring and continuous improvement" and "permanent action of monitoring, alert, information, mobilization and response". The first is responsible for the preparation and response to disasters, and its main activity is the mobilization to assist the victims. The second work front corresponds to the constant monitoring of information about possible disasters in risk areas, with the purpose of reducing impacts and warning the population.

The establishment in 1994 of the National Council of Civil Defense (CONDEC) has broadened the scope of civil defense action in the country. In addition, in 2011, communities gained greater participation through Community Centers for Civil Defense (NUDECs), bringing about a cultural change in citizen awareness of the importance of increasing their own security.

National Policy on Climate Change (PNMC). The PNMC makes official Brazil's voluntary commitment to the United Nations (UN) Framework Convention on Climate Change to reduce greenhouse gas emissions by 36.1–38.9 percent of projected emissions by 2020, compared with the 2000 levels. Instituted in 2009 by Law No. 12,187, the PNMC seeks to ensure that economic and social development contribute to the protection of the global climate system.

Decree No. 7,390/2010, which regulates the PNMC, estimates the baseline greenhouse gas emissions for 2020 at 3,236 GtCO₂-eq (gigatons of carbon dioxide equivalent).

Thus, the corresponding absolute reduction was established between 1,168 GtCO₂-eq and 1,259 GtCO₂-eq, which amounts to 36.1 percent and 38.9 percent reduction of emissions, respectively. To help achieve the reduction targets, the law establishes the development of sectoral mitigation and adaptation plans at the local, regional, and national levels.

The goals achieved by the PNMC should be harmonized with sustainable development—seeking economic growth, eradicating poverty, and reducing social inequalities. To achieve these objectives, the law establishes some guidelines, such as promoting practices that effectively reduce greenhouse gas emissions and encouraging the adoption of low-emission activities and technologies as well as sustainable production and consumption patterns.

National Policy of Protection and Civil Defense (PNPDEC). Federal Law No. 12,608, dated April 4, 2012, establishes the National Policy of Protection and Civil and authorizes the creation of an information system and a disaster monitoring system. The law provides for articulated action between the federal level, states, and municipalities; a systemic approach; prioritization of preventive actions; the adoption of river basins as a unit of analysis; planning based on research and studies; and the participation of civil society. The act's provisions cover natural hazards of geological and hydrological origin as well as biological, nuclear, and chemical hazards.

PNPDEC must institute and maintain a national register of municipalities with areas susceptible high-impact landslides, sudden floods, or related geological or hydrological processes. States and municipalities should identify and map areas of risk and conduct studies to identify threats, susceptibilities, and vulnerabilities. This measure must be accompanied by meteorological, hydrological, and geological monitoring of risk areas.

It is compulsory for the registered municipalities to prepare geotechnical charts of suitability for urbanization, which would support the establishment of urban planning guidelines for the safety of new subdivisions and which will be a key element when the urban perimeter is expanded. These charts should be incorporated into the master plans of the municipalities, which should also contain the mapping of risk areas.

2.1.3 NATIONAL PLANS AND STRATEGIES

National plans and strategies have evolved together with the abovementioned laws and regulations. Every new plan tries to improve how natural disasters and the transport sector are treated. Even though there is still no broad integrated plan that embraces both the transport sector and natural disaster risk management together, the two branches are getting closer and closer with time. This subsection provides a description of the key plans and strategies carried out by the federal government⁵.

5

This report focuses on plans and strategies at the federal level and thus, subnational plans and strategies were not searched for, as they were not under the report's objective.

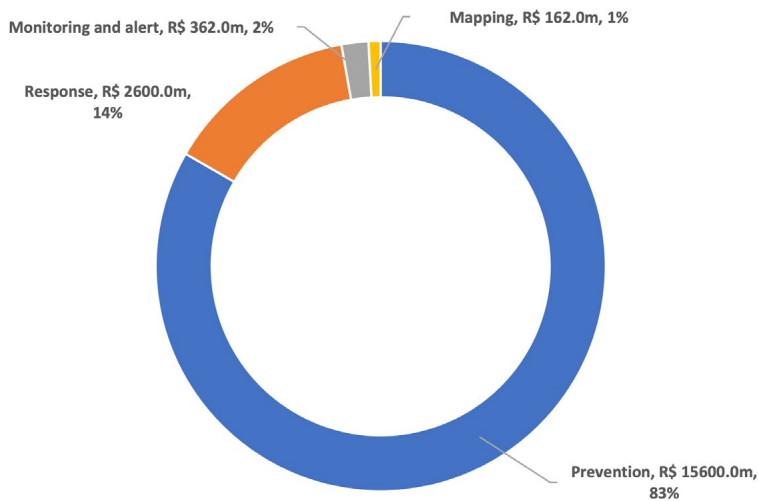
National Plan for Risk Management and Response to Natural Disasters. On August 2012, the president of the republic, Dilma Rousseff, launched the National Plan for Risk Management and Response to Natural Disasters 2012–2014, which provides for the identification of high-risk landslides, floods, and flash floods areas in 821 municipalities all over Brazil. The prioritization was made considering the areas that had suffered the most from natural disasters in the preceding 20 years.

According to the government, this mapping would prevent natural disaster-affected regions and would contribute to the assessment of the investments needed to avoid more tragedies.

The plan included: (a) prevention, which includes works in more vulnerable municipalities, such as drainage; (b) mapping, surveying hazardous areas where landslides and floods could occur; (c) monitoring and alerting of climatic events; and (d) rescue, assistance, evacuation of areas.

In 2014, investments of nearly R\$18.8 billion (US\$4.8 billion) were planned in prevention works, purchase of equipment, monitoring of areas at risk, and issuing warnings about the proximity of a natural disaster (**GRAPH 2.1**). The plan foresaw the expansion of the observation network with the acquisition of nine radars, 4,100 rain gauges, 286 hydrological stations, 100 agrometeorological stations, 286 geotechnical assemblies, and 500 soil moisture sensors.

GRAPH 2.1
PLANNED 2014 INVESTMENTS OF THE NATIONAL PLAN FOR RISK MANAGEMENT AND RESPONSE TO NATURAL DISASTERS (R\$ MILLION)



Source: The World Bank based on data of Federal Government of Brazil 2012 ⁶

Note: R\$ = Brazilian reais.

In 2017, national efforts toward developing DRM continued. Twenty urban drainage projects were completed in critical municipalities, with a total value of R\$594.87 million. Together with the 19 projects completed in 2016, a total of 39 projects were completed between 2016 and 2017. In addition, 155 drainage projects were in progress, totaling R\$9 billion in investments.

As for alert and monitoring initiatives, CEMADEN made progress in identifying 98 percent of the triggering conditions of the natural disasters that had been recognized as emergency situations or states of public calamity by the Ministry of National Integration. In 2017, 151 maps were completed in support of natural disaster prevention.⁷

National Adaptation Plan (PNA). The purpose of the Brazilian Federal Government's National Adaptation Plan (PNA) is to guide initiatives for management and reduction of long-term climate risks, as established in the Ministry of Environment (MMA) Order No. 150 of May 10, 2016, published in the Official Diary of the Union (DOU) of May 11, 2016. The plan was drawn up by the Executive Group of the Interministerial Committee on Climate Change (GEx-CIM) between 2013 and 2016, as provided for in the National Policy for Climate Change (PNMC, Law No. 12,187/09) and its enabling decree (Decree No. 7,390/10). The PNA was drawn up in consonance with the PNMC, with sectoral mitigation and adaptation plans, and with decisions on adaptation undertaken by Brazil within the framework of the Conference of the Parties (COP 21) of the UN Framework Convention on Climate Change.

Sectorization of high and very high risk of landslides and floods. Starting in 2012, the national and federal risk reduction policy began to develop a "high" and "very high" risk sectorization. This action had the main objective of subsidizing the alarm and warning systems of the municipalities and meeting the demands of newly created federal agencies such as CEMADEN and CENAD.

2.1.4 FUNDING MECHANISMS

Public roads are state property and therefore constructed, managed, and maintained with the budget from government revenue. The federal roads are managed by DNIT under the Ministry of Transport. Besides regular managerial activities, DNIT is in charge of providing road geohazard risk evaluation, management, planning, implementing proactive measures, and putting in action contingency and post-disaster plans in respective jurisdictions.

The funds for these tasks are pulled from toll fees, financial loans, and the budget of the federal government of Brazil. As explained later in this case study, none or very few funds are destined for road geohazard risk activity before contingency and post-disaster.

Funding for road geohazard risk evaluation. The funding sources for road geohazard risk evaluation differ for new roads and existing roads. For new road projects, geohazard risk evaluation is often included in the engineering design preparation by road administrators (DNIT or the subnational governments) at the conceptual and design stages. For existing roads, the budget is generally included in the operation and maintenance cost of existing roads by each road administration authority. These are financed through the general budget, not any specific budget for geohazard risk evaluation.

Funding for road geohazard risk management planning. The funding for road geohazard risk management planning is similar to risk evaluation. Risk management planning is also usually included in the design preparation processes, which are funded through the general budget of the road administrators. In the case of urban areas, to support municipalities in reducing risks, the Ministry of Cities provides funding for the

7

This report focuses on plans and strategies at the federal level and thus, subnational plans and strategies were not searched for, as they were not under the report's objective.

elaboration of the PMRRs by municipalities. PMRR use has brought a breakthrough in DRM because it involves a number of actions linked to the mapping of risk areas. It includes a hierarchy of physical and financial needs for the implementation of structural and nonstructural measures in the risk areas, based mainly on the criticality of the risk.

Funding for proactive measures. Proactive measures refer to the implementation of structural and non-structural measures once risky areas for landslides have been identified, but disasters not occurred. Specific funding for preventive measures is almost nonexistent in the federal and state roads throughout Brazil. Road management authorities normally approve funds after a disaster event has already occurred or when the imminence of a disaster is evident.

Funding for postdisaster activities and recovery. When extremely severe disasters occur in the transport sector—such as the floods and flash floods in 2016 and 2017, where human lives were at high risk—civil defense takes action, and emergency funds are allocated to help the municipality and state in rescue and reconstruction activities.

2.2

SYSTEMS PLANNING

2.2.1

RISK IDENTIFICATION, ASSESSMENT, AND EVALUATION

i. Existing Roads

The operation and maintenance department of the National Department of Transportation Infrastructure (DNIT) lacks a standardized methodology for identifying critical spots that could cause or worsen a potential natural disaster on federal roads ([PHOTO 2.1](#)). It is the engineers of the local units themselves who supervise the stretches and identify the critical spots that would need rehabilitation, maintenance, or new investments within the DNIT's right of way.

PHOTO 2.1
CRITICAL SPOTS IDENTIFIED DURING A FIELD VISIT, ANGRA DOS REIS, BRAZIL



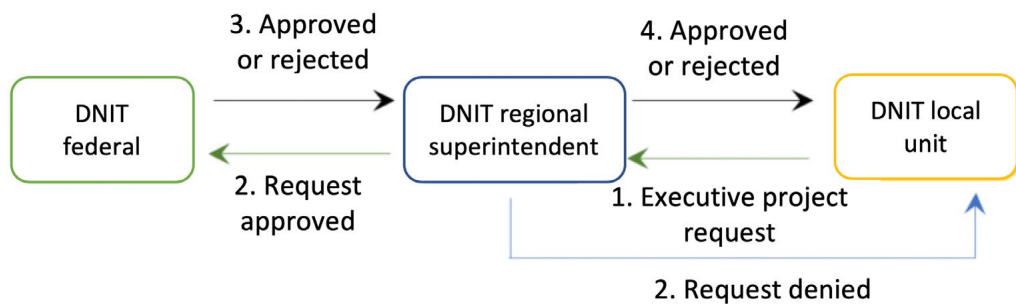
Source: Javier Escudero Marroquin/World Bank.

Note: "Critical spots" are places that could cause or worsen a potential natural disaster on roads. Clockwise (from left): deteriorated drainage pipe, anchored curtain and bumps on the road due to land movements.

After the identification of any critical spots, they are then prioritized and addressed within the existing road maintenance contract of the road agency when the budget permits. Because the road agency lacks a standardized evaluation methodology or checklist, these assessments are based on the experiences of the engineer of the local office or hired consultants (geologist) who evaluate a specific condition. If the existing road maintenance contract cannot address the risk, then the local unit prepares a preliminary evaluation report and a proposal to remedy the situation, which are used to request funding for preparing a detailed design to the regional superintendent of the DNIT. Once the request is approved and the detailed design is ready, the DNIT's regional superintendent sends the request to fund the work to DNIT headquarters of in Brasília.

The headquarters office, once it has received petitions from the different regional units, prioritizes the demands based on the relevance of the road (volume of traffic, logistical importance, and so on) and determines which of those demands are approved based on the available budget. Many of them will not be approved, and even identified critical spots of risk will not be remedied because of severe budget constraints. The federal unit informs the regional unit about the decision made, and the regional unit in turn forwards the decision to the corresponding local unit (FIGURE 2.3).

FIGURE 2.3
DNIT DECISION-MAKING PROCESS FOR WORK TO REMEDY CRITICAL SPOTS



Note: DNIT = National Department of Transportation Infrastructure. “Critical spots” are places that could cause or worsen a potential natural disaster on roads.

A lack of planning and network analysis on existing roads can lead road agencies to the impossibility to estimate real impacts of landslides on the system, as well as to project the most viable and cost-efficient alternative. Having a consistent and standardized systems planning both for new and existing roads in the federal road network is critical for a successful DRM.

ii. New Roads

The planning department of DNIT is responsible for and coordinates the construction of new federal roads. As part of any road engineering project in Brazil, experts in geology and hydrology engineering are consulted during the planning and design stages of a new road to evaluate the viability of the project. This will produce a ‘hazard-indicating map’, but it is not labeled as such and will be part of the preliminary studies of the project. Although ideally DNIT may also consider assessing the land out of the right-of-way (40 m to each side of the road) of the new road, juridically and budget wise there are complications as land does not belong the government and use of public funds in private land is not permitted by law.

A recent DNIT article—“Use of Small Drones as a Low-Cost Alternative for Topographic Characterization of the Transport Infrastructure in Brazil” (de Oliveira Borges et al. 2017)—evaluated the accuracy of using aerophotogrammetry with low-cost drones for the generation of models of terrain and the mosaic of orthorectified images compared with RTK (real-time kinematic) topographic surveys. As the authors mention, the results obtained from the pilot project are positive:

In general, the results obtained indicate an excellent cost-benefit ratio, given the low investment, fast processing time, and the reduction of the team required for its execution, as well as extremely consistent results for planning, monitoring, execution, and maintenance of road works in DNIT. Even with very promising results, inconsistent regions in the Digital Terrain Model (TDM) can be identified for the scale and accuracy achieved, a fact generally associated to the filtration of elevation points extracted in regions of dense vegetation and interpolation based on distant points, which can be complemented with GNSS/RTK points.

2.2.2 RISK MANAGEMENT PLANNING

The institution in charge of planning for interventions to reduce potential economic and social losses in federal roads is DNIT. For the time being, DNIT does not work with a list of potential roads' geohazard risk reduction- prioritized interventions. Because road maintenance is considered as part of the day-to-day activity of a road agency, potential economic loss due to road geohazard condition is not calculated. It falls into the general road fund for road maintenance contract within that given year.

To prioritize interventions based on both exposure and vulnerability to hazards and criticality (a trade corridor, a high traffic road, a road with no redundancy, etc.) is crucial for a successful geohazard risk management.

2.3 ENGINEERING AND DESIGN

2.3.1 ENGINEERING INVESTIGATION AND STUDY FOR ENGINEERED MEASURES

The initial engineering investigation is done by the road agency and included in the project as part of the proposal, which will go out for bids to be executed by an engineering firm. As part of the planning and design stages the engineering firm will be responsible for the respective studies, test, data collection, and analysis to be presented and evaluated by the road agency. This standard procedure is followed and needs to be approved before the beginning of construction.

The planning and design stages are usually composed by the following studies: traffic, geological and geotechnical, hydrology and hydraulics, topography and aerial photography, road layout and geometrics and earthwork. From these studies, different components are defined: land survey, drainage, paving, signage and environmental. For each of these components, structural measures and special structures are designed as needed.

For a new or existing road, all the appropriate phases regarding planning, design, and construction take place following the norms and specifications applicable to the project. The structural measures are part of the project as needed and are limited by available funds and thus not considered a priority, especially concerning works outside of the right-of-way. In other words, the structural measures become secondary to a project and are addressed only when issues arise.

2.3.2 STRUCTURAL MEASURES AND DESIGN CONSIDERATIONS

Before DNIT was created in 2002, the DNER operated as the national road agency for 65 years (1937 to 2002). Some of the DNER's pre-2002 specifications are still in use today including the following:⁸

- DNER-ES 039/71—Retaining Wall
- DNER-ES 044/71—Slope Stability with Soil/cement

Both technical specifications are from 1971 and are acceptable for their integrity, but they have not been updated with technology and materials information over the years.

Municipalities throughout Brazil use the technical specifications provided by DNIT and state Departments of Transportation (DOTs). The types of structural countermeasures depend on different parameters such as location, type of hazardous event and its magnitude, type of road section/construction threatened, and the geology and hydrology of the site.

The structural countermeasure design consideration in Brazil is based on the result of engineering investigations. While DNIT possesses a technical manual with countermeasures to apply, the reality is that this manual is barely used. Structural solutions for road geohazard risk are normally designed ad hoc or from first principles rather than from adopting a standard solution.

Anchored curtains, gabion walls, anchored grids, or slope restoration or berms are within the most common types of engineering interventions aimed at restraining (mitigating or preventing) mass movements (for example, translational landslides, rotational landslides, block plummeting, block running, and debris run) on Brazilian highways.

DNIT may also intervene out of the right-of-way (40 m to each side of the road) depending on the severity of the occurrence or the location of the potential geohazard. These interventions are not contemplated by the regular operation of DNIT but may take place after negotiations with the landowners or municipalities involved.

2.4 OPERATIONS AND MAINTENANCE

2.4.1 NONSTRUCTURAL MEASURES

i. Monitoring and Early Anomaly Detection

Except for road concessionaries that are obligated under contract to monitor roads and roadsides using cameras, the remaining road network in Brazil (over 1.5 million km) is monitored by visual inspection, which varies greatly as to how it is done on the federal, state, and municipal road networks. Depending on the size of the road network to be inspected, this visual inspection may take place daily, weekly, or

monthly. In some cases, if a road segment shows any uncommon behavior, especially during the rainy season, it is monitored 24 hours a day.

As mentioned earlier, the visual inspection is not exclusive to detect road geohazards, but also any distress or defect that occurs with the road's right-of-way. If a road geohazard is identified and poses a potential high risk to road users, a team of road engineers and geologists (sometimes with support from the civil defense) are dispatched to the location to evaluate the situation on foot and report with support of visual aids like photos and videos. No other detection devices like wired geofence, Closed-Circuit Television (known as 'CCTV'), or alarms are used.

ii. Emergency Information Collection

Today with the widespread use of cell phones, it is easy for road users to call an emergency number to report an abnormal situation on the road. Depending on the reported situation, the responsible agency attends to the emergency as a first responder.

Taking advantage of the evolution of smartphones, DNIT and other state DOTs like DER-SP have developed apps, for road users to inform about road conditions by uploading georeferenced pictures ([FIGURE 2.4](#)).

FIGURE 2.4
LAUNCH SCREENS OF DNIT MÓVEL



Source: National Department of Transportation Infrastructure (DNIT)

iii. Traffic Signs to Raise Awareness

Brazil's National Department of Traffic (DENATRAN) is the agency responsible for setting the norms and specifications for road signs, including regulatory, warning, identification and orientation, educational and auxiliary, tourist attraction, works, and other types of signs.

Two DENATRAN warning signs make road users aware of potential road geohazards and natural disasters (**FIGURE 2.5**):

- A. Area with Rockfall (Sign Code A-27); and
- B. Crosswind Area (Sign Code A-44).

FIGURE 2.5
WARNING SIGNS TO RAISE ROAD USER AWARENESS



Source: National Department of Traffic (DENATRAN).

In addition to using electronic variable message signs (VMS) to raise road user awareness of local conditions, road authorities at a local level create their own signs (**PHOTO 2.2** and **PHOTO 2.3**).

PHOTO 2.2
LOCAL TRAFFIC SIGN:
“ATTENTION:
AREA SUBJECTED
TO FLOODING”



Source: Stock photo.

PHOTO 2.3
LOCAL TRAFFIC SIGN:
“AREA SUBJECTED
TO FLOODING”



Source: Stock photo.

iv. Road Condition Emergency Information System Including Early Warning or Precautionary Road Closure

All traffic regulations that allow for road agencies to legally protect road users are listed in the Brazilian Traffic Code (CBT). The first CBT was published in 1941, but today it is based on the Federal Constitution and respects the Vienna Convention and Southern Common Market Agreement (Mercosur).

Because rainfall is the main indicator of potential road geohazards in Brazil, road agencies monitor meteorological conditions to first warn drivers about reducing travel speeds and later to focus on critical geohazard locations previously identified. However, rain gauges and automatic monitoring systems in general are not common in Brazil; thus, not every critical area in the country is covered.

Any early warning systems for road users, like VMSs—also known as changeable, electronic, or dynamic message signs—are found on roads operated under concessions. They can be placed on overpasses, bridges, and sometimes on trailers along the roadside, especially to warn drivers about construction zones ([PHOTO 2.4](#)).

PHOTO 2.4

VARIABLE MESSAGE SIGNS ON BRAZILIAN ROADS OPERATED UNDER ROAD CONCESSIONS



Source: Stock photos

Under their contracts, road concessionaires monitor their roads and roadsides 24 hours a day through video cameras and maintenance crews doing their day-to-day activities. Using VMSs they are able to warn drivers with emergency information and precautionary road closures, regardless of the reason that caused them.

Road agencies at the federal and state levels create seasonal campaigns to raise road users' awareness about the increased risk that heavy rainfalls carry, mostly in the four months of summer (November, December, January, and February). Prevention and

warning plans like “Plano Verão” (Summer Plan) in Petrópolis, Rio de Janeiro state, tend to reduce consequences and accelerate the response to potential natural disasters.

The Plano Verão includes a model called the “Family Contingency Plan,” which seeks to organize family members in advance—including domestic animals—in the event of a tragedy. This plan provides for an advanced civil defense office in Itaipava, which will operate at the Citizenship Center in a room provided by the Secretariat of Social Assistance. It will be possible, among other services, to find reports of occurrences and make requests for preventive surveys and emergency care. Five contingency plans were also developed by organizing the response to landslides, floods, rock blockages, gales, and lightning storms.⁹

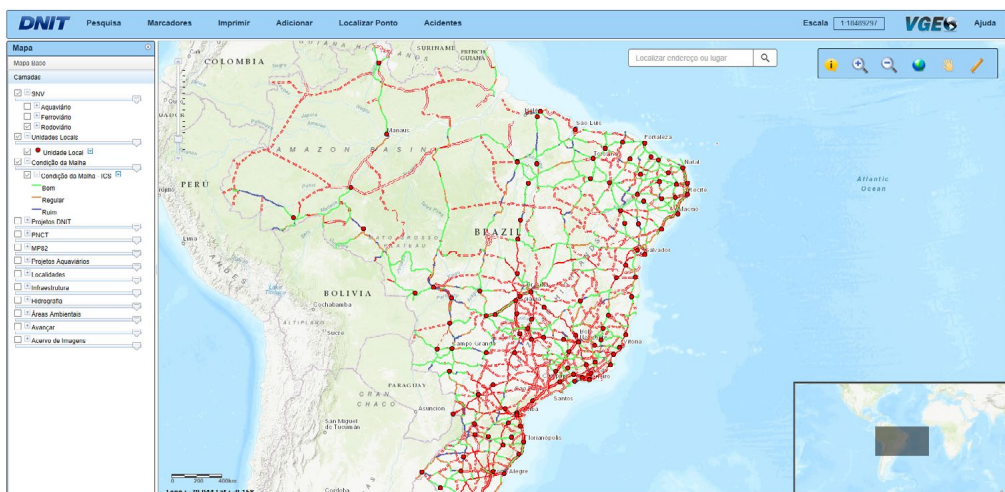
v. Development and Implementation of an Emergency Preparedness and Response Plan

Any Emergency Preparedness and Response Plan is part of the road agency’s scope of work, but since road agencies have lately reduced their equipment, machinery, and staff to attend to their road network, they do it through a contractor. Once again, this is specific to road maintenance within the right-of-way. Any other effort with regard to a major road disaster is coordinated by the Civil Defense.

vi. Road Asset Management

DNIT has created a road asset database that works as an interactive georeferenced inventory map. The Geographic Information Viewer (VGEO) uses layers that the user can superimpose depending on their interests. The VGEO (Map 2.1) shows information about DNIT local units, ongoing road projects, and the condition of the road network, among others. This tool, in spite of being essential for a successful road asset management, does not yet include road geohazard risk-related information which is critical for a timely identification of needs and an effective management of road maintenance.

MAP 2.1 SCREEN SHOT OF DNIT GEOGRAPHIC INFORMATION VIEWER (VGEO)



Source: Geographic Information Viewer (VGEO), National Department of Transportation Infrastructure (DNIT) <http://servicos.dnit.gov.br/vgeo/>. ©DNIT. Reproduced, with permission, from DNIT; further permission required for reuse.

2.4.2

MAINTENANCE OF STRUCTURAL MEASURES

In Brazil, road agencies have ongoing road maintenance contracts and are responsible for maintaining a certain level of service, including routine, preventive, and rehabilitation services. The existing road maintenance contracts with the private sector are limited to the width of the right-of-way, thus limiting the maintenance to the pavement surface, drainage, debris removal, and small-slope reinforcement.

Structural measures beyond routine maintenance and rehabilitation need to be constructed through a separate contract or emergency funding. This would preclude the road agency from starting a bidding process until funds are available. Therefore, this process is used only when major structural measure maintenance is needed after a natural disaster.

i. Local and Institutional Partnerships for Geohazard Risk Management

In general, the Brazilian population is well versed in reaching out to the civil defense at the municipal, state, and federal levels. Most calls concern urban populated areas, possibly involving a bridge or segment of road, because fewer people live outside of these areas and consequently a disaster's impact on human lives would be lower.

After a natural disaster has occur or is considered imminent, road agencies at the federal and state levels coordinate with civil defense, firefighters, ambulances, and any service that can contribute to a better recovery from the occurrence. This relationship of the road agency with the different bodies involved is normal throughout Brazil.

It could happen that damages to the infrastructure are so high that it could only be solved with the maintenance company. In these cases, the Civil Defense itself is also on notice to be able to respond as quickly as possible. This relationship of the road agency with the different bodies involved is normal throughout Brazil. Firefighters, ambulances, and any service that can contribute to a better recovery of the disaster will be on alert.

2.5

CONTINGENCY PROGRAMMING

2.5.1

PRE-DISASTER AND EMERGENCY PREPAREDNESS

When imminent emergencies are detected on either federal and state roads, road agencies lack a formal protocol for determining the appropriate action. Normally, they rely on their personal assessment of the situation to decide the actions to take. For example, in the municipality of Angra dos Reis (Rio de Janeiro state), when a road agency detects that the falling rain could trigger an natural disaster, it usually notifies the contracted maintenance company to be attentive and prepare to clear the road as soon as possible and thus restore normal operation. The civil defense itself is also on notice to be able to respond as quickly as possible in case the maintenance company

could not handle the situation on its own. Firefighters, ambulances, and any service that can contribute to a better recovery of the occurrence, will be on notice. It is worth mentioning that the procedures in the Angra dos Reis area cannot be extrapolated to every region in Brazil. With specific characteristics like accommodating the only two nuclear plants in Brazil, the region of Angra dos Reis is a good-practices example but does not show the real situation of Brazil.

2.5.2 POST-DISASTER RESPONSE AND RECOVERY

i. Emergency Inspection and Post-Disaster Needs Assessment

Post-disaster damage information is collected by visual inspection, usually by the same staff responsible for road maintenance. This information gathering process may vary greatly because each agency (federal, state, or municipal) is responsible for its own post-disaster activities and reactive measures on roads. In some cases, depending on the magnitude of the road geohazard, no further assessment takes place. In general, insufficient and unstandardized information is collected by road agencies after road geohazards.

If injuries or fatalities of road users (and surrounding communities) are involved, it is considered a natural disaster and Civil Defense procedures are followed to possibly warrant a police investigation. Depending on the results of this investigation, the road agency responsible may or may not be accountable for it and consequently, a judicial process takes place. For roads under concessions, the process of recovery works the same as a private business; insurance companies are also called to do an assessment.

Each agency, when dispatched to a road disaster, has its function based on what it has been trained to do. Of course, standard procedures will be followed to keep the victims and the area safe, but all the while under the coordination of the state's civil defense agency (**FIGURE 2.6**).

FIGURE 2.6
**EMERGENCY INSPECTION
AND POSTDISASTER
NEEDS ASSESSMENT
PROCESS IN BRAZIL**



Source: Quiroz, 2018.

ii. Emergency Traffic Regulation and Public Notice

Any emergency traffic regulation is executed by the police and the DOT, even if coordinated (or not) by the Civil Defense, because they have the appropriate equipment to set barricades to block off an area or lane until the situation is resolved.

In addition to the television, radio, and Internet, public notices can now be shared through in real time navigation devices, smartphone applications, and electronic logging devices for commercial vehicles. Some of these work with georeferences to alert drivers of potential road geohazard areas.

iii. Reactive Measures

Reactive measures are subdivided into emergency recovery, repair, rehabilitation, and reconstruction, as follows:

- **Emergency recovery:** Federal and state road agencies are no longer construction powerhouses, which in the past took care of day-to-day activities like removing debris and road rehabilitation. Today these agencies have three- to five-year road maintenance private contracts that need to maintain a level of service and be on call 24 hours a day. Local road management authorities—like the regional superintendents (for the National Department of Transportation Infrastructure [DNIT]) and state DOTs—coordinate these emergency recovery efforts on the road network under their jurisdictions. This network may vary greatly in extension, thus forcing the local road management authorities to prioritize among different road disasters.
- **Repair:** This is part of the emergency recovery, which could take place at the same time or be part of a routine or preventive maintenance.
- **Rehabilitation:** Rehabilitation is part of a road maintenance program, which is usually planned by the road agency and supervised by the local road authority but executed by the private sector under a specific contract.
- **Reconstruction:** Reconstruction works much the same way as rehabilitation, but because it requires more funds to be executed, it is part of a road maintenance program or qualifies for emergency funding if needed because of a natural disaster.

2.5.3

POST-DISASTER RISK FUNDING AND MANAGEMENT

The federal government can approve two types of funds: voluntary transfers and mandatory transfers. Voluntary transfers are funds that states request of the federal government if there is a need to rehabilitate or reconstruct infrastructure after a disaster. Mandatory transfers are funds that the federal government must approve through a provisional measure (MP) when an emergency is identified, and funds are requested by the affected state or municipality.

Under the Brazilian constitutional law, an MP is a one-person act of the president of the republic, with immediate force of law, without the participation of the legislative branch, which will be called upon to discuss and approve it later. The assumption of the MP, according to Article 62 of the Federal Constitution, is cumulative urgency

and relevance. The executive does not always respect this criterion of relevance and urgency when editing an MP.

The MP, therefore, although it has an immediate force of law, is not really a law in the strict technical sense of the term, because no legislative process preceded its formation; the legislative process occurs later.

In the face of a severe disaster, the civil defense is responsible for the coordination of all bodies (DNIT, police, firemen, and so on) to respond as quickly and efficiently as possible to disasters. Civil defenses at the state level respond to state emergencies. Some states have a fund linked to their civil defense where they put a percentage of the annual budget to cover future emergencies. Santa Catarina state's emergency fund is a good example.

2.6

CHALLENGES IN ROAD GEOHAZARD RISK MANAGEMENT IN BRAZIL

Based on the abovementioned diagnostics, the following challenges in the DRM framework are identified.

No systematic approach to road geohazard risk management. There is no comprehensive approach to road geohazard risk management, including risk identification and assessment, planning measures, and contingency programming to protect road infrastructure from geohazard events. Such an approach should be coordinated and implemented by relevant stakeholders. However, road administrators and other relevant institutions often work individually and any official coordination mechanism on geohazard risk does not exist. The integrated and multi-institutional approach is essential to enhance geohazard risk management on road infrastructure.

Road asset management system is not used for geohazard risk management. Although some road agencies own basic road inventory systems, the detailed data of road structures, such as bridges, culverts, and protection walls, are not in the inventory. Having such an inventory will improve management capacity of the geohazard mitigation measures and make it possible to maintain these structures more efficiently.

Little data sharing among stakeholders in geohazard management. There is no integration of environmental and geohazard risk-related information with information from the transport sector. Each branch has been considered separately over the years without looking at each other's data or information in an ad hoc manner. With regard to a successful road geohazard risk management, data are one of the most valuable assets and, as such, it is fundamental that every institution involved in the area is aware and knowledgeable about all the available data.

A more developed collaboration among the different stakeholders involved in the road geohazard risk management would increase the impact of preventive countermeasures on roads while reducing the response time after a natural disaster event happens. As successful example is the State of Sao Paulo, where there is an integrated and coordinated relationship between the Geological Institute and the Civil Protection and Defense. Sharing key information and being aware of other institution's actions and plans keeping a fluid and continuous relationship is fundamental for effective prevention and a rapid response to natural disasters.

Lack of norms and technical specifications for preventing geohazard risks. Brazil road sector has its own construction norms and specifications, many of which are based on North American and European standards. Good-quality technical specifications are widely available for the transport infrastructure in Brazil. However, most of these norms and specifications have been designed solely for the construction of engineering structures (pavement and so on), lacking norms and specifications specifically designed for natural disaster prevention on roads. Having a wide variety of natural disaster prevention norms and technical standards would support the use of preventive structural measures, thus reducing the number of natural disasters.

Inefficient data collection of disaster events. The collection, by road agencies, of standardized and more complete set of data after road geohazards is key to ensure a consistent database. Road agencies and Civil Defense lack a digital standardized database to keep record of previous road geohazards. Data is key when assessing road geohazard risks or when developing economic analysis. To overcome this issue, a more complete, standardized, and easily shareable road geohazard occurrence database would help manage risks and provide important information regarding the efficient allocation of government funds.

Ad hoc methodology for geohazard risk assessment. Road administrators identify and assess road geohazard risks substantially depending on the experiences of local engineers, normally through visual inspection from roads. Though the experiences in the local situations helps them identify problems, this has certain limitations as this is not based on any geological or statistical assessments. For example, it is difficult for the local unit of road administrators to conduct a proper geological survey or inspection of risky slopes. Many of the occurrences often start out of the right-of-way or inaccessible areas where human eye cannot reach.

This obstacle could be overcome by using an advanced technology, for example, the use of UAVs to supervise the terrain and identify critical spots. Furthermore, an additional assessment made by experts in geology with the support of local geological institutes would enrich the engineers' evaluation and provide a better solution as a combination of the transport and geological points of view.

No strategic contingency program. While a certain protocol exists at the local unit level of road agencies for preparing geohazard events, no official and written procedures or contingency plan is developed, which is key to reduce potential losses of life or asset under a natural disaster threat. Such a contingency plan should include preparedness and early warning system and define the roles and responsibilities of every stakeholder, including road agencies, local municipalities, Civil Defense, police, and so on, and the required preparatory actions for effective and quick response to disasters. For example, the plan needs to clarify under what condition a road agency needs to close a road considering risk for human lives.

A more standardized and protocolized contingency plan is recommended to establish clear guidance and criteria of the preparedness actions based on the historical data of disaster events. The plan will be able to promote close coordination between the involved stakeholders to carry out appropriate actions in the most efficient way possible.

Lack of monitoring and maintenance. A regular monitoring and maintenance of roads is fundamental for lengthening the useful life of road assets. In federal and state roads in Brazil, routine monitoring and maintenance of the roads is common practice; however, the inspections and actions taken are limited to the main road structures such as pavements. In the process of road geohazard prevention, a continuous monitoring and maintenance of the surroundings of roads, for example, retaining walls or drainage

systems on slopes are needed to avoid or minimize the occurrence of natural disasters. In some cases, even monitoring and performing maintenance works beyond the right-of-way of a road would dramatically reduce the probability of a natural disaster occurrence and thus prolong the lifecycle of the road agency's assets.

To enhance monitoring and maintain the key structures to mitigate geohazard risk for road, the scope of the road routine maintenance can be broadened. Normally, roads in Brazil are maintained under one-year or longer routine maintenance (conservation) contracts or CREMA (performance-based road rehabilitation and maintenance) contract. These contracts, as stated earlier, mainly deal with pavement structures. To reduce geohazard risk, broadening the scope of maintenance contracts to structures for geohazard mitigation, including containment or slope protections or so on, is recommended.

No cost-benefit assessment for geohazard mitigation measures is conducted.

While geohazard mitigation could bring a substantial economic benefit by preventing chronic recuperation roadworks after disasters, economic assessment of geohazard mitigation measures from a lifecycle viewpoint has rarely been conducted, and as a result, such benefits are not clearly demonstrated. This often leads to low priority of these works under serious budget constraints. The implementation of an economic analysis for DRM on roads generates valuable information that can be analyzed and compared.

2.7**IDENTIFICATION OF PILOT STUDY METHODOLOGIES**

Considering the above challenges, this study aims at establishing the geohazard risk assessment methodologies which can be incorporated as a part of geohazard risk management for roads. As described in Section 2.6, the geohazard risk assessment has been conducted not in a systemic manner with statistical data, but largely relying on individual engineers in the sites. Accordingly, the study analyzed the historical landslide and rainfall data in a pilot section and tried to establish a statistical methodology of a geohazard risk for roads which could be used for other regions in Brazil and even in other countries. Also, the pilot study proposed a use of innovative drone technology for site survey so that the geohazard risk can be assessed more accurately and cost effectively.

In addition, the study also conducted a pilot economic evaluation study for risk mitigation measures. As pointed out above, the economic evaluation has not been conducted and the economic justification for geohazard risk mitigation measures has not been very clear. Under such a circumstance, it is difficult for road administrators to prioritize risk mitigation measures compared to more “usual” interventions such as road rehabilitation or improvement. Based on the recent World Bank experiences in Mozambique, the study introduced the Decision Making under Uncertainty (DMU) so that the methodology can cope with substantial uncertainty associated with natural disaster event and damage.

The study focused on the above two topics and does not deal with other challenges identified in Section 2.6, as other World Bank financed project is currently working on some issues and the study has a certain limit of the budget. The ongoing World Bank financing operation: Sao Paulo Sustainable Transport Project (P127723), is assisting the Sao Paulo State Government in developing a contingency plan and Geo-referenced IT system for disaster event database. Together with this study, the results of these activities will be good practices for improving geohazard risk management for roads in Brazil.

3

METHODOLOGIES FOR ROAD

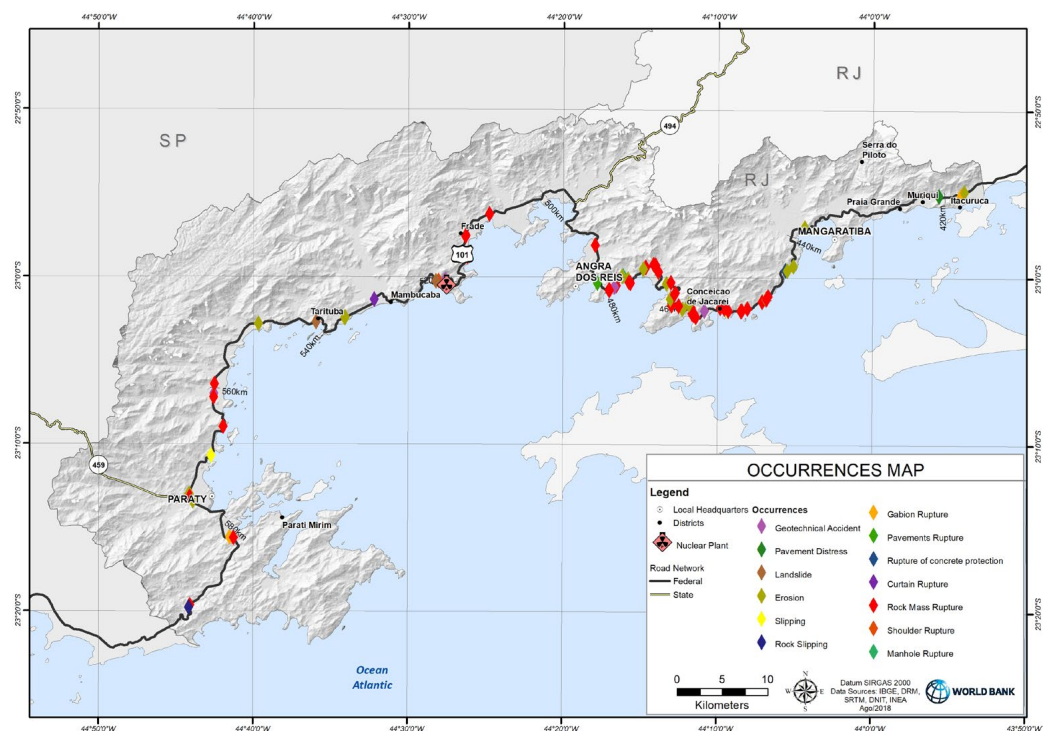
GEOHAZARD RISK ASSESSMENT

3.1 CASE STUDIES WITH TWO INNOVATIVE ROAD GEOHAZARD RISK ASSESSMENT METHODOLOGIES

This chapter describes a case study of the application of two innovative DRM assessment methodologies: (a) mapping landslide risk with historical event and rainfall data and (b) monitoring and assessment of landslide risk using drone. One of the challenges identified in the diagnostics in the previous chapter is that there is no systematic approach to road geohazard risk management. The study conducted the risk assessments on a pilot basis and examined benefits of the application of these innovative methodologies.

A section of 155 km of the federal road BR-101 in the State of Rio de Janeiro was selected as a case study as it is a road exposed to landslide hazards. The road for case study was in particular the section connecting the municipalities of Angra dos Reis, Mangaratiba, and Paraty in the State of Rio de Janeiro. Due to recurrent landslides over the years, this section becomes worthy of analysis. Between 2007 and 2015, as many as 79 landslides were registered in this section of the BR-101 if we only account for those occurrences that needed an emergency contract to be issued by DNIT¹⁰ (MAP 3.1).

MAP 3.1
LANDSLIDES REGISTERED IN THE PILOT SECTION OF THE BR-101 (2007-2015)

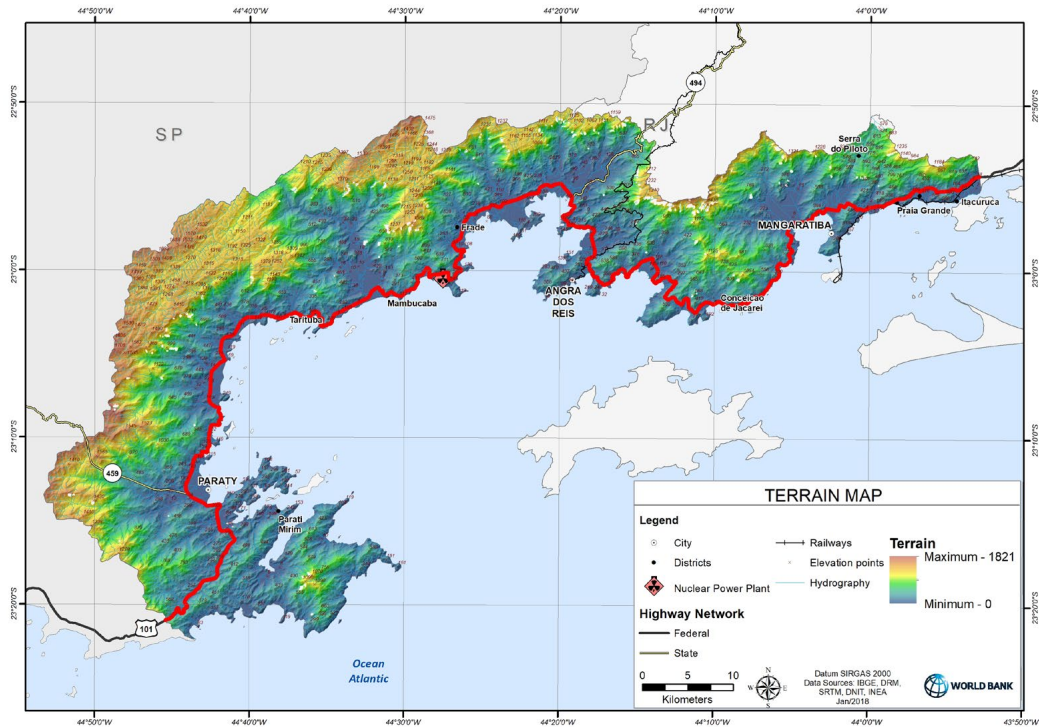


Source: World Bank.

The most unique characteristics of the selected BR-101 stretch are the Angra I and Angra II nuclear power plants which are Brazil's only nuclear power plants. Due to the high disaster risk associated with the power plants, additional security

measures are taken on the BR-101. In addition, tourism has an important impact on the economy of the Municipalities of Angra dos Reis, Mangaratiba, and Paraty, thus increasing vehicle traffic flow on the BR-101 particularly during the peak season, from December to February. See the section of the BR-101 under study in **MAP 3.2**.

MAP 3.2
SECTION OF THE BR-101 UNDER STUDY



Source: World Bank.

A local unit of DNIT in Angra dos Reis is responsible for maintaining infrastructure of this pilot section of the BR-101. Along with other personnel, the local unit is composed of two engineers in charge of monitoring and detecting risky critical spots along the road. As addressed in the previous chapter, there is a lack of systematic monitoring system and thus a very high dependency on human subjectivity, considering the huge social and economic costs at risk.

In the following paragraphs, two different methodologies are presented to overcome the above exposed barriers. The first one simulates calculation of the risk of mass movement events based on historical events and rainfall statistics looking at the rainfall/landslide correlation. The second of the methodologies shows how the use of UAVs to supervise the terrain and identify critical spots can reduce costs and improve accuracy when monitoring a road. Both methodologies have been applied to the case study and present pilot-specific conclusions and recommendations for scaling up.

3.2**METHODOLOGY FOR MAPPING LANDSLIDE RISK AREAS**

This section aims at establishing a methodology to calculate the risk of mass movement events to the Brazilian federal road transport system based on event recurrence and using rainfall statistics and the observed rainfall/landslide correlation.

First, besides the definitions presented at the beginning of this report, two terms must be clarified to avoid any doubts about the definitions herein.

Risks are losses and/or damages (human, material, or cultural, tangible or intangible) that can be caused by a dangerous process (hazard) within a geographical space and in a certain period. To put it simply, to calculate risks we have to identify potential losses that the dangerous process can cause, establishing what are the exposed elements in a danger area and the recurrence of this dangerous process in time. Examples of risk measurement units are the number of deaths per year due to landslide events or value of losses (in Brazilian real) per decade due to lightning. Note that this measurement can also be qualitative when relative to a standard, for example, high, medium, and low risk.

Susceptibility is an environment with a natural predisposition to certain dangerous processes. For example, areas with a high slope and a thick soil layer are naturally predisposed to mass movements, or areas at low altitudes and low slope are more likely to be flooded. The onset of dangerous processes depends additionally on a triggering factor, which in both examples is high intensity rainfall. Susceptibility can also be defined as a measure of how natural characteristics of an area can favor the actual occurrence of a hazard and usually is measured qualitatively, for example, high, medium, and low susceptibility.

In the case of a set of dangerous processes known as mass movements,¹¹ calculating the likelihood of a hazard actually materializing is a complex problem because of the kind of physical phenomenon involved, which relates the physical characteristics of a usually very heterogeneous environment (soil) and the intensity of a triggering factor with great spatial variability (rainfall).

A simplified way to develop a tool—aimed at helping manage disaster risk reduction—in case of mass movement events is to establish an association between exposed elements and the susceptibility of their environment. In this case, the map of the degree of susceptibility of exposed elements to mass movements is an important piece of information for managing risks.

A possible way of establishing the likelihood of a mass movement event is to relate its occurrence to a triggering factor, which in this case is a precipitation limit value. This limit value is specific for basins that share similar characteristics, both climatological and geological-geomorphological. Thus, by calculating the probability of reaching this limit value, we can also infer the likelihood of a mass movement event for the whole basin. The determination of this limit value relies on two different databases, an inventory of mass movements (with event location, day, and time) and a historical meteorological database. The outcome will be the likelihood of a mass movement event for the whole climatological/geological-geomorphological basin.

11

Gravitational processes with movement of different materials, such as soil, rocks, and other debris, that may or may not have waterlogging as a triggering factor are generally called mass movements. These processes can be classified as different physical phenomena that have specific names such as planar landslides, rotational landslides, wedge landslides, mud run, block run out, debris run, crawl, and so on.

3.2.1 METHODOLOGY

i. Map of susceptibility to mass movement events

To draw a susceptibility map, it is necessary to spatially combine information on the relevant region's susceptibility to mass movement events with information on the spatial positioning of the exposed elements within the same area. The outcome will show exposed elements' degree of susceptibility to mass movements. Based on this map, decision makers can prioritize investments in infrastructure and works of art in the federal road transport system according to the degree of susceptibility of the terrain where exposed elements are located.

Several methodologies can be used to establish susceptibility to mass movements. As the main client for this methodology is the DNIT, we adopted the mapping methodology used by the Brazilian Geological Service, CPRM, a DNIT institutional partner from the same level of government (federal).

To map susceptibility to mass movements, CPRM uses the Integrated Risk Management in Natural Disasters (GIDES) methodology, developed in a partnership between CPRM and Japan International Cooperation Agency (JICA) in 2013. This methodology divides areas into sectors based on inherent characteristics of the environment that can lead to mass movement events and determines areas potentially affected by the movement of mobilized materials.

The identification of exposed elements relies on an inventory of potential losses in susceptible areas. In Brazil, the Brazilian Institute of Geography and Statistics (IBGE) is in charge of regional scale mapping (up to 1: 25,000), whereas larger-scale cartographic basis is under the responsibility of municipal governments or of stakeholders themselves. Larger-scale maps show more details. However, mapping of infrastructure and works of art in the federal road transport system (exposed elements) is not systematized by DNIT and is not available in a digital and georeferenced medium. The best national systematized database available is the IBGE's, whose scales vary, according to the region, between 1: 100,000 and 1: 25,000.

ii. Map of risk sectors in the road transport system

As mentioned earlier, establishing the likelihood of a mass movement event is a complex process because of the heterogeneity of the environment where these take place, that is, soil. Moreover, several types of physical processes are clustered as 'mass movements' that have different development mechanisms.

The proposed methodology, aimed at establishing the likelihood of a mass movement event in a given region, is based on the following assumptions:

- Factors that led to mass movement events in the past are the same factors as today, that is, the characteristics that caused susceptibility in the past are the same that cause susceptibility in the present.
- The (future) likelihood of a mass movement event is the same as the recurrence rate (past).

- Each sector/area is a basin that shares the same climatological (rainfall regimes) and geological-geomorphological characteristics (types of rocks and relief forms) evenly distributed throughout the basin.

iii. Climatological / geological-geomorphological sectorization

A meteorological statistical analysis of the region should be conducted before carrying out its climatological/geological-geomorphological sectorization. Based on historical data from weather stations within the region, the area is divided into basins sharing the same climatological regime (seasonal rainfall profile). This sectorization must take into account geological characteristics (type of rocks) and geomorphology (form of relief), considering the limits of the basins and sub-basins in the region. Each region should share the same rainfall regime, the same types of rock, and the same relief forms.

Previous experiences with this methodology failed due to a lack of compliance with these guidelines.

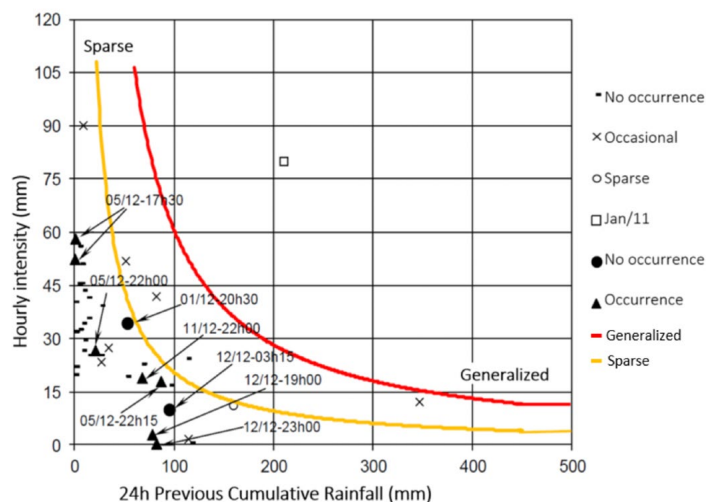
iv. Calculating precipitation limit value

Using a database including information on the location of mass movement events and their triggering factors (rainfall in a given time), a mathematical curve can be derived to determine the precipitation limit value above which mass movement events start. The precipitation limit value must be calculated for each basin delimited during the climatological/geological-geomorphological sectorization.

Drawing this curve requires **(a)** a database that includes the history of mass movement events in the region and provides data on spatial location, date, and time of each recorded event and **(b)** a meteorological database covering the same period.

Using a data-plotting software (for example, Microsoft Excel or Google Spreadsheets), cumulative rainfall versus accumulation time data are plotted on graphs. Based on a representative data population, trend curves are calculated above which mass movement events can occur. As in the following example (**FIGURE 3.1**), this trend line can establish limits as values below or above which movements become sparser or more generalized. A trend line could also be calculated below which mass movement events cannot occur. Decisions concerning the construction of these graphs, periods of accumulation, number of trend lines, and so on are made according to the experience of the technicians involved in the work.

FIGURE 3.1
RAIN/LANDSLIDE
CURVE EXAMPLE



Source: DRM-Rio de Janeiro technical report.

Curves relating rainfall with mass movement events should be established for each area sharing the same geological-geomorphological characteristics (for example, relief form and slope, composition, degree of alteration, and soil mineralogy). The adoption of a single general rain/landslide curve for areas with different susceptibilities has induced technically ill-informed users to make management mistakes that have undermined the credibility of the methodology.

v. The probability of reaching the rainfall limit value

The next step is to calculate the likelihood of rainfall reaching limit value in each delimited basin. In some cases, a combination of cumulative precipitation limit values such as 20 mm per hour and 85 mm per 24 hours, and 150 mm per 48 hours, and 350 mm per 96 hours is chosen. For this proposal, future recurrence rate is taken to be the same as past recurrence rate. Therefore, the probability that we will consider is the combined recurrence rate of the limit values available in meteorological database.

In this proposal, the first step is finding, in the meteorological database for each basin, how many times the precipitation limit with the shortest accumulation time has been exceeded (using the abovementioned example of 20 mm per hour). The next step is finding in this data subgroup how many times cumulative rainfall exceeded the second shortest accumulation time (85 mm per 24 hours) and so on (150 mm per 48 hours and 350 mm per 96 hours). The result will be the number of times the combination of cumulative precipitation values has been exceeded in relation to the basin limit value (in this example, the combined cumulative values of at least 20 mm per hour and 85 mm per 24 hours and 150 mm per 48 hours and 350 mm per 96 hours occurred 45 times).

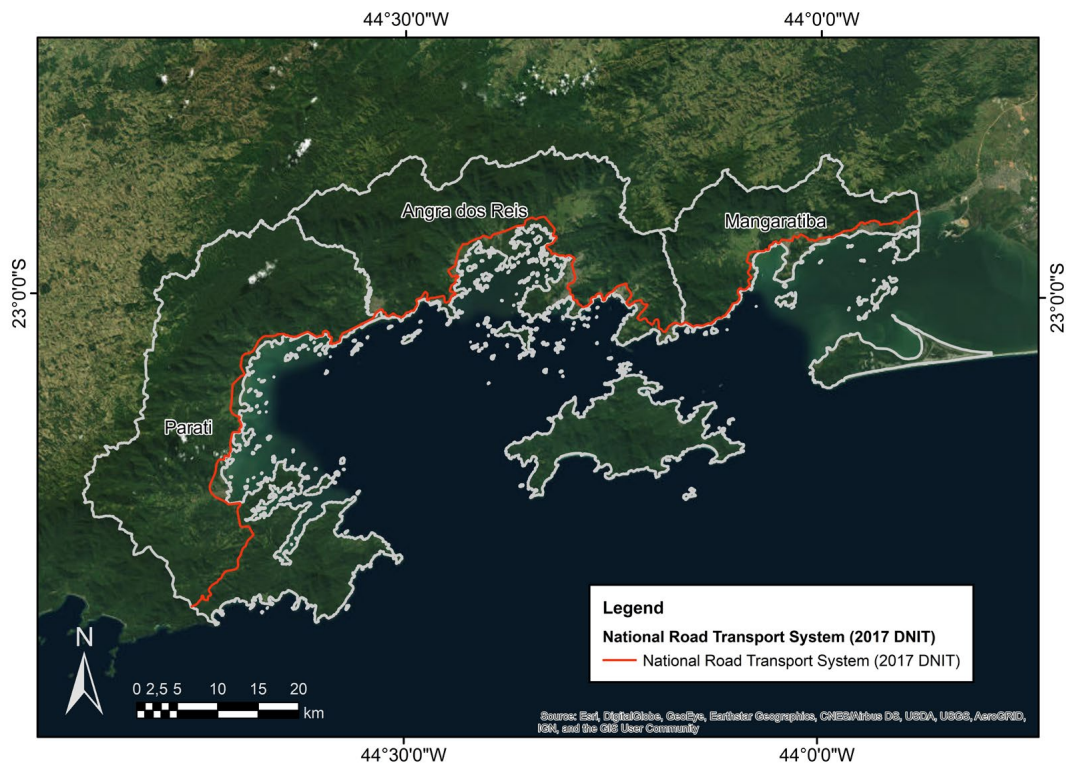
To calculate the recurrence interval for this combination of cumulative and combined precipitations for the relevant basin, the number of events identified in the previous step is divided by the total time in the meteorological database. Continuing the previous example, suppose we identify 45 occurrences on a 30-year meteorological monitoring time. Therefore, the recurrence rate is, on average, 1.5 events a year in which the combined precipitation limit value is exceeded. Thus, for this particular basin, we consider that the likelihood of an event causing mass movements is 1.5 times a year.

To calculate this recurrence rate, only the rain gauges from meteorological stations within the relevant basins should be considered.

3.2.2 APPLYING THIS METHODOLOGY TO A PILOT AREA

The section between the municipalities of Mangaratiba and Paraty (including Angra dos Reis), in the State of Rio de Janeiro ([MAP 3.3](#)), was selected to evaluate the routine proposed for calculating the risk of mass movement events and susceptibility to mass movements of the exposed elements in the federal road transport system. These municipalities are served by federal highway BR-101, previously known as Rio-Santos (184 km, between 414.5 km and 598.5 km).

MAP 3.3
LOCATION OF THE PILOT AREA



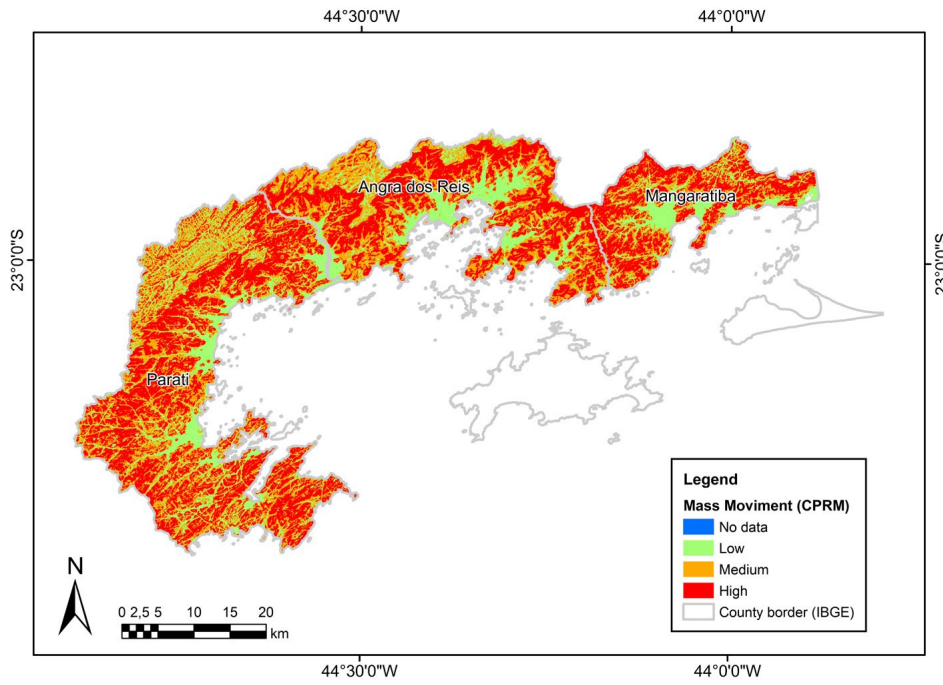
Source: World Bank.

i. Map of exposed element susceptibility to mass movements

Using the GIDES methodology, CPRM mapped the pilot area for areas of susceptibility to mass movements ([MAP 3.4](#)). For the purpose of this work, we took into account danger areas, defined pursuant to a qualitative classification of the susceptibility to mass movements, and exposed elements, that is, the infrastructure and the works of art identified in the IBGE cartographic base of the region ([MAP 3.5](#)) that is available on a 1:25,000 scale.

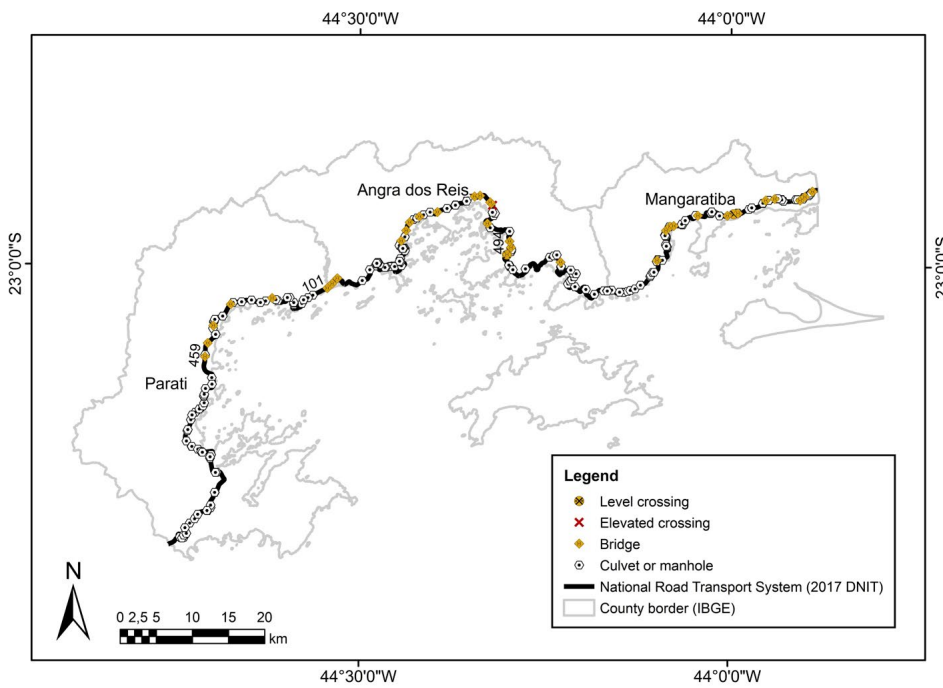
The outcome of combining these two kinds of information is a map of the exposed elements based on the susceptibility of their locations ([MAP 3.6](#)).

MAP 3.4
PILOT AREA SUSCEPTIBILITY MAP

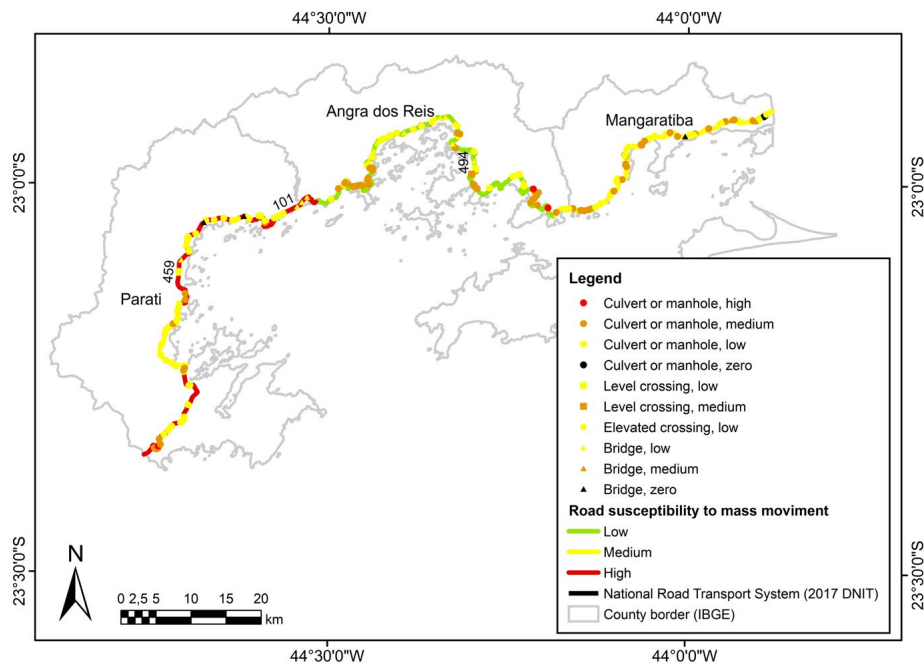


Source: World Bank.

MAP 3.5
MAP OF EXPOSED ELEMENTS IN THE PILOT AREA



Source: World Bank.

MAP 3.6**MAP OF THE DEGREE OF SUSCEPTIBILITY OF THE EXPOSED ELEMENTS IN THE PILOT AREA**

Source: World Bank.

ii. Map of mass movement risk to the road transport system

Mass movement risks to the road transport system were calculated based on publicly available data from INMET meteorological stations and on an inventory of mass movement events in the study region made up of DNIT and Geological Service of the State of Rio de Janeiro (DRM-RJ) data.

The outcome is a map of the exposed elements categorized by their annual probability of exposure to a cumulative precipitation that may start a mass movement.

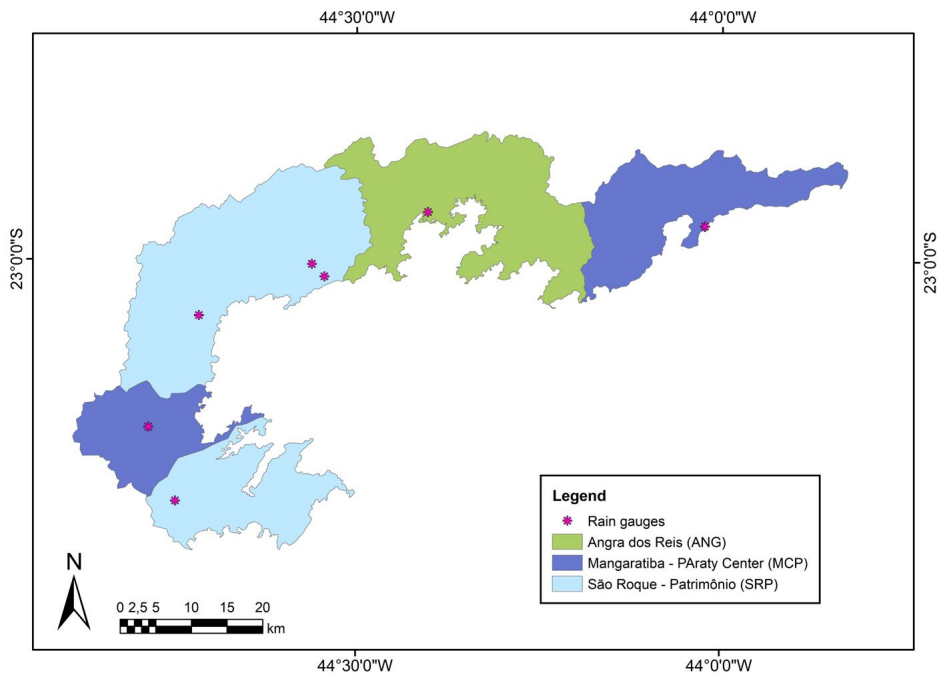
iii. Climatic / geological-geomorphological sectorization of the pilot area

To establish the precipitation limit value and the recurrence rate of rainfall that would reach these limit values, a climatological study of the pilot area was conducted that defined regions with shared average annual rainfall regimes. Each of these regions was designated as a rainfall basin. We considered that the entire pilot area shares the same geological-geomorphological characteristics.

Our climatological survey established the climatic pattern of the region using data from seven rain gauges for 1995–2016. Five rainfall basins were delimited. Two pairs of these basins, although not continuous, shared the same average annual rainfall regimes and, therefore, were merged into two basins. Accordingly, the pilot area was subdivided into three rainfall basins ([MAP 3.7](#)).

Further details are presented in a specific report on the climatological survey of the pilot area.

MAP 3.7
RAINFALL BASINS IN THE PILOT AREA

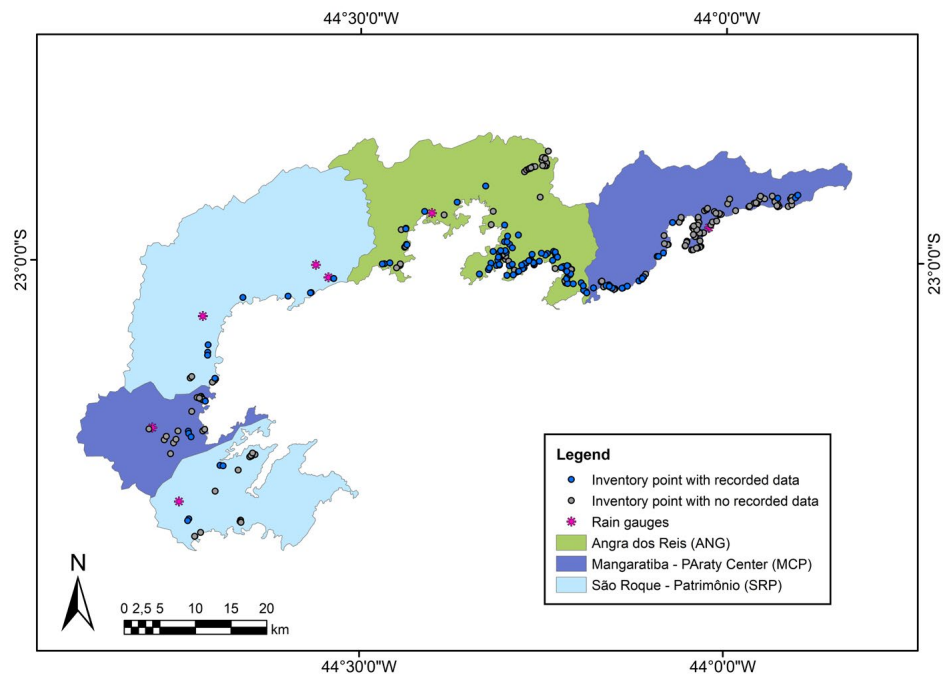


Source: World Bank.

iv. Calculating the rainfall limit value for the pilot area

The rainfall limit value was determined based on the inventory of mass movement events compiled at an earlier stage of this project using data from 347 points provided by the DRM-RJ and DNIT ([MAP 3.8](#)).

MAP 3.8
MAP OF THE INVENTORY OF MASS MOVEMENT POINTS WITHIN THE AREA OF INTEREST



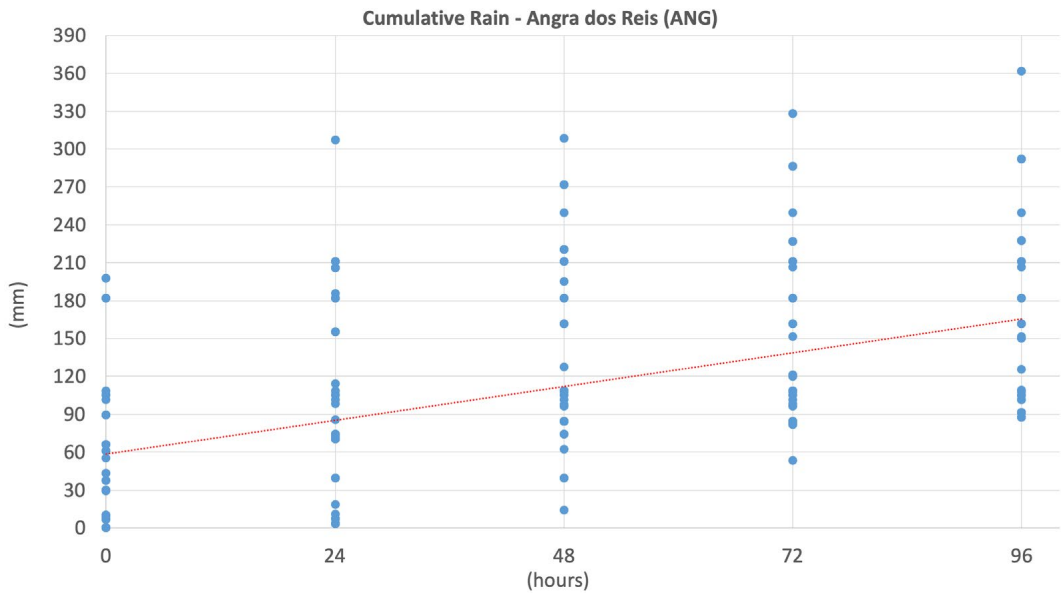
Source: World Bank.

Out of the 347 points in the inventory, 141 events had a recorded date of occurrence. Using the database produced by the climatological survey described earlier and with event dates as references, a table was compiled that included the cumulative precipitation information for event days and 24, 48, 72, and 96 hours before the recorded event dates.

References for capturing cumulative precipitation values were event dates and precipitation values recorded by the rain gauge closest to each event site within the same rainfall basin.

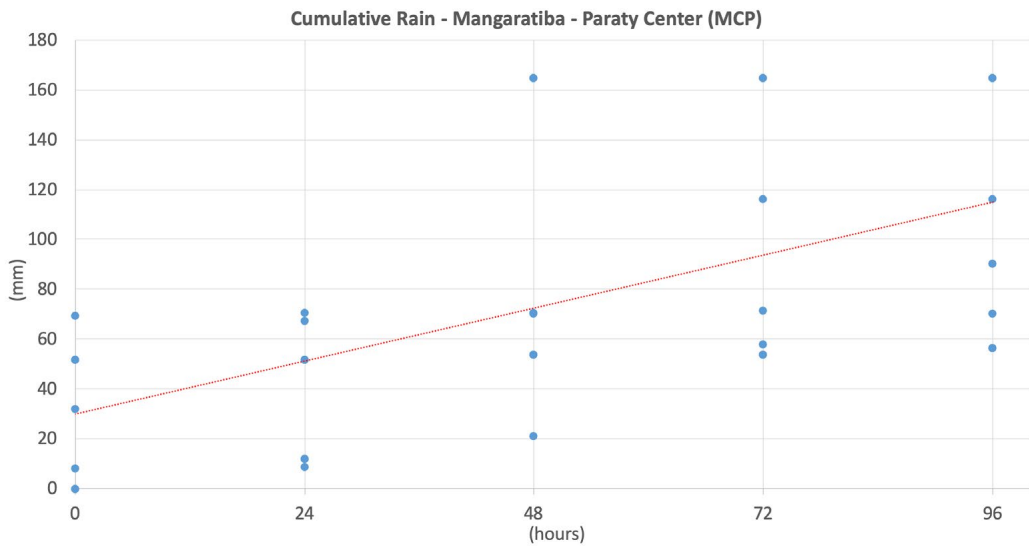
It was not possible to calculate cumulative rainfall for 23 of these 141 events due to data gaps in the historical rainfall series recorded by the rain gauge closest to those event sites. For a few events in this database, the cumulative precipitation in the event day and the hours leading to the event was zero or very low, not justifying hydrographically a mass movement event. This anomaly may stem from the fact that the date recorded as the event date is actually the date when the event was recorded. In case the event is recorded a few days after it occurred, cumulative precipitation during the first few hours will be very low or even zero. Therefore, a further 37 events were excluded from the calculation of the precipitation limit value. The 81 event records were clustered by rainfall basin and plotted on graphs where the X-axis represents the hours of cumulative rainfall (0, 24, 48, 72, and 96 hours) and the Y-axis, the cumulative precipitation value. A linear trend line was calculated and established as the limit value for the rainfall basin ([GRAPH 3.1](#), [GRAPH 3.2](#), and [GRAPH 3.3](#)). For limit values by rainfall basin, see [TABLE 3.1](#).

GRAPH 3.1
LIMIT VALUE FOR ANGRA DOS REIS RAINFALL BASIN



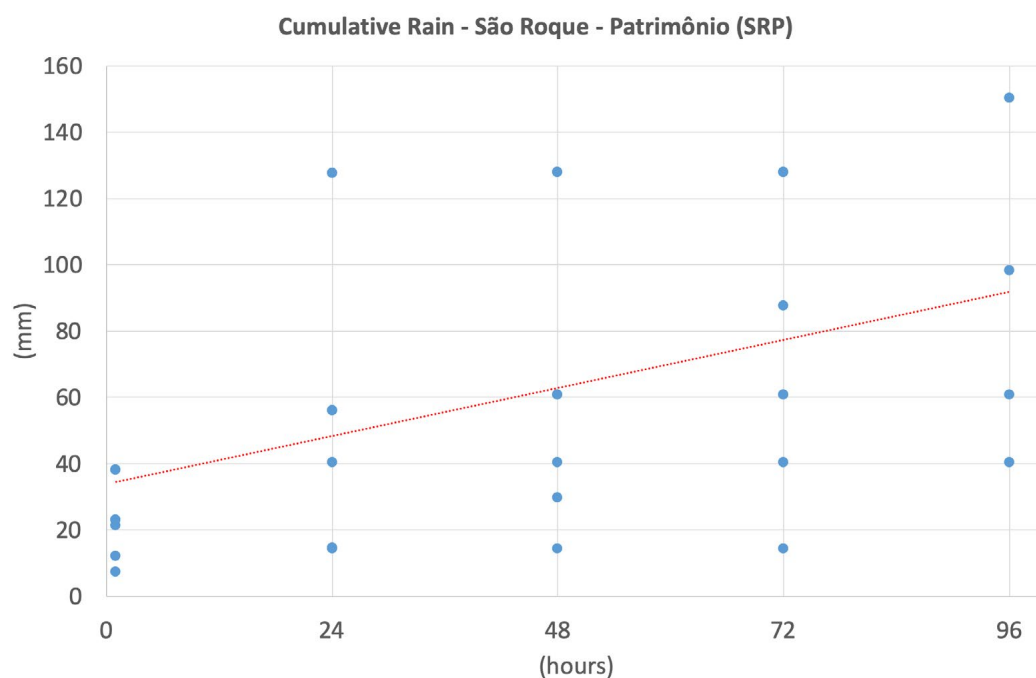
Source: World Bank.

GRAPH 3.2
LIMIT VALUE FOR MANGARATIBA RAINFALL BASIN - PARATY CENTER (MCP)



Source: World Bank.

GRAPH 3.3
LIMIT VALUE FOR SÃO ROQUE- PATRIMÔNIO RRAINFALL BASIN (SRP)



Source: World Bank.

TABLE 3.1
LIMIT VALUES BY RAINFALL BASIN

BASIN	NUMBER OF EVENTS CONSIDERED FOR THE CALCULATION	CUMULATIVE RAINFALL (MM)				
		1 DAY	24 HOURS	48 HOURS	72 HOURS	96 HOURS
ANGRA DOS REIS	65	60	85	112	140	165
MANGARATIBA - PARATY CENTER	9	30	52	73	94	115
SÃO ROQUE - PATRIMÔNIO	7	35	48	63	72	91

Source: World Bank.

v. Calculating the recurrence rate of the limit value for each basin

A statistical study using information from the database produced by the climatological survey established the recurrence rate of the limit value for each basin (TABLE 3.2). The recurrence rate was calculated in three steps:

1. Selection of events with daily rainfall above the limit value for the rainfall basin
2. Selection, among these events, of those whose cumulative rainfall over 96 hours was higher than the limit value for the relevant rainfall basin
3. Counting of the number of selected events

The recurrence rate of rainfall exceeding the cumulative precipitation limit values that may start mass movements in their basins was calculated based on the number of events selected per basin (whose values exceeded the calculated limit values) and on the temporal extent of the historical series used.

TABLE 3.2
RECURRENCE OF RAINFALL ABOVE LIMIT VALUES PER RAINFALL BASIN

BASIN	CUMULATIVE RAINFALL (MM)					HISTORICAL SERIES (YEARS)	NUMBER OF RAINFALL EVENTS ABOVE THE LIMIT VALUE	RECURRENCE RATE (EVENTS/ YEAR)
	1 DAY	24 HOURS	48 HOURS	72 HOURS	96 HOURS			
ANGRA DOS REIS	60	85	-	40	165	27.4	37	1.4
MANGARATIBA - PARATY CENTER	30	52	-	-	115	55.3	138	2.5
SÃO ROQUE - PATRIMÔNIO	35	48	-	-	91	50.2	358	7.1

Source: World Bank.

vi. Risk map of exposed elements by climatological-geological/geomorphological basin

Data on exposed elements (works of art identified in the IBGE 1: 25,000 base), federal transport system (provided by DNIT), and climatological-geological / geomorphological basins were combined to establish the recurrence rate of the limit value for each basin. The limits of qualitative classification—high – medium - low—were subjective and users or clients can establish new limits. For this case study, the methodology adopted has been explained in the following paragraphs.

Climatological-geological/geomorphological basins are delimited considering hydrographic basins, regional geomorphology, geology and the spatial pattern of rainfall. Different hydrographic basins could belong to a same climatological-geological/geomorphological basin if these basins are under the same geomorphological compartment. The same geological unit can be divided on different climatological-geological/geomorphological basins based on similar patterns of rainfall (considering the spring, summer, autumn and winter stations as different analysis periods).

Landslide events (from a historical database) under the same climatological-geological/geomorphological basin are correlated to the historical database of precipitation (based on the spatial position, date and hour of the occurrence). Based on previous correlation, rainfall limit values for which landslides have historically occurred are determined. According to the historical database of precipitation, the recurrence of the previously determined rainfall limit values is calculated.

The risk of exposed elements is calculated based on the recurrence of the rainfall limit value obtained for each of the climatological-geological/geomorphological basins. In order to improve the correlation between landslide events and rainfall limit values some improvements to databases would be necessary.

Regarding the rainfall database, there is a need to improve the spatial sampling of rainfall. This does not mean to decrease the space between weather stations but to improve their spatial representation. Other important parameter to that could improve the quality of this type of analysis is the sampling time resolution. The rainfall rate can be very volatile by changing dramatically within a few minutes and thus, smaller sampling time resolutions when collecting rainfall data could improve accuracy when predicting its behavior.

For the landslide database, it is important to register as many events as possible (statistic population). As important mentioned earlier in this report, the quality of the recorded data is also critical. A standardized and complete data collection has enormous consequences on the quality of this kind of analysis. For instance, registering real date/time of events (it is common to register the date/time when emergency services attend rather than the real date/time of the landslides event); and registering events that did not cause any material loss (usually it is registered only events that caused losses or call to emergency services, in other cases it is no registered) could drastically improve the accuracy of events-rainfall correlation analysis.

3.2.3

FINAL CONSIDERATIONS ON THE METHODOLOGY

As it is difficult to calculate the probability of mass movement events due to the heterogeneous environment where these occur, we decided to propose a methodology associating the probability of a mass movement event (dangerous process) with the recurrence rate of rainfall (triggering factor) patterns (limit value) that can cause this kind of event.

A few assumptions have to be made to obtain results that are consistent with our proposal (**MAP 3.9**): **(a)** past susceptibility is the same as current susceptibility, **(b)** the likelihood of a mass movement event is the same as its recurrence rate, and **(c)** each delimited risk sector is a basin that shares the same climatological and geological-geomorphological characteristics.

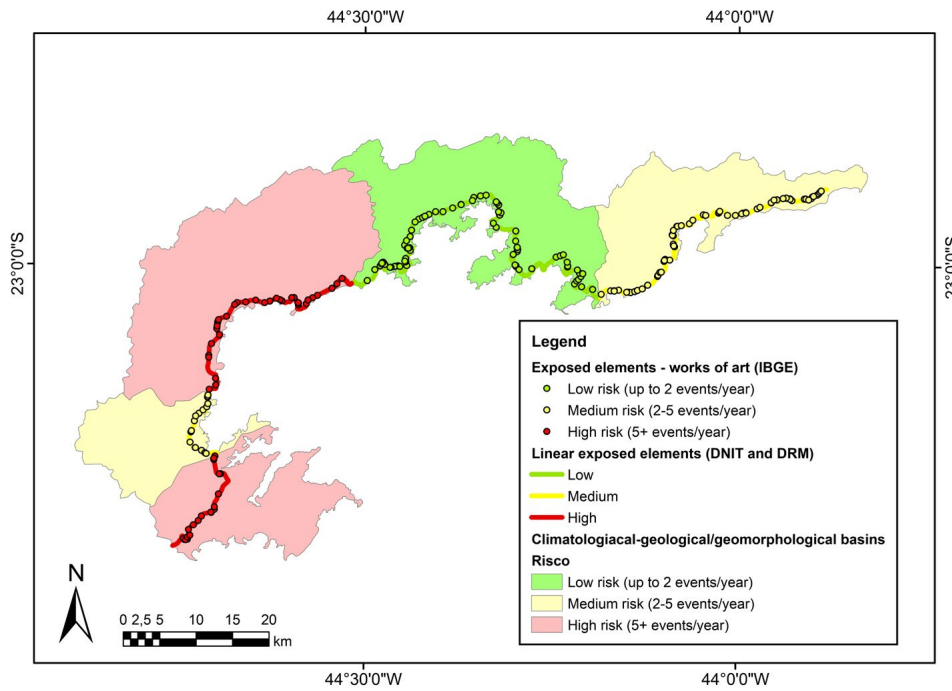
The main difficulties this methodology poses are the following:

- In the few existing mass movement inventories, there usually are data gaps, such as those concerning event date and time (time of response and type of mass movement are more commonly recorded). The lack of a proper inventory makes it impossible to calculate the rainfall limit value that can start mass movement events. Likewise, a small data population can lead to result inconsistency for statistical reasons.
- Spatial distribution of rain gauges is still precarious in Brazil—small number and poor distribution of rain gauges (clustered in a few regions) can lead to low-efficiency calculation of regional climatological profiles. In addition, historical data series cover limited periods; when available, these include less than 10 years of recorded data.

- The outcomes of this methodology—susceptibility map and risk map—should be used as indications for prioritizing maintenance and prevention investments aimed at minimizing potential losses in federal transportation system renovation and reconstruction works.

MAP 3.9

**RISK MAP OF EXPOSED ELEMENTS BY CLIMATOLOGICAL-
GEOLOGICAL/GEOMORPHOLOGICAL BASIN**



Source: World Bank.

3.3**UNMANNED AERIAL VEHICLES (DRONES) FOR MONITORING****3.3.1****INTRODUCTION**

Unmanned Aerial Vehicles (UAVs), commonly known as drones, are unmanned aircraft operated by remote control or through a computer. UAVs emerged in the United States in the 1950s for military use in espionage missions. The U.S. military began testing UAVs fitted with weapons only in the 1990s.

Civilian use of UAVs started to gain traction in 2000. Many industries adopted UAVs as work tools because of their quick deployment, low operating costs, and more affordable prices compared to traditional techniques.

This platform has become a viable alternative for capturing images for monitoring purposes as it provides significant benefits in terms of flexibility, affordability, and spatial and temporal resolution, among others. It is, however, just another mapping tool, to be used in conjunction with other proven, well-known methods.

In this sense, UAVs are gaining ground as a new technology in risk and disaster management, as a tool that contributes to prevention during (and after) disasters. This feature of the UAVs is linked to four key aspects:

1. Captured aerial images enable identification, measurement, and quantification.
2. 3D models constructed from the images can be used to three-dimensionally locate a disaster site and estimate volumes, slopes, and morphological features
3. Ease of flight and programmable coverage provides users with plenty of data in a short period, thus enabling continuous monitoring.
4. UAVs have lower operating costs compared to similar methods.

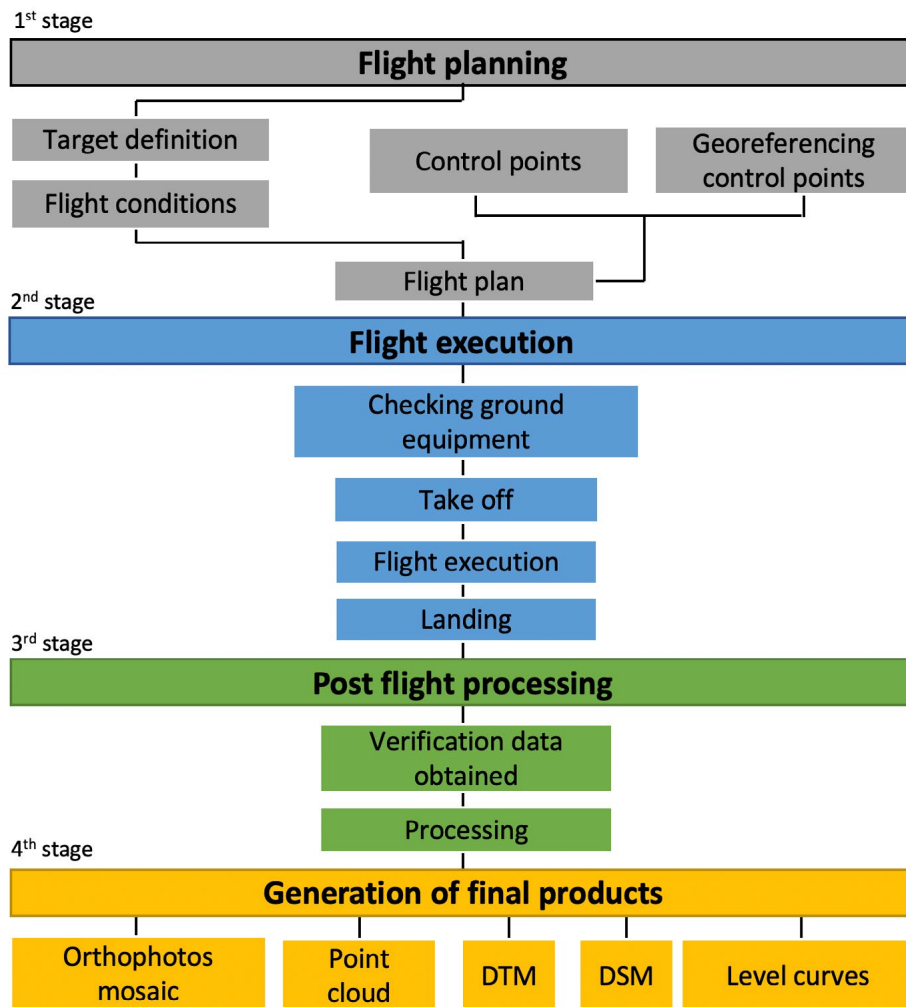
3.3.2**SURVEYING**

UAVs can capture images at various angles, altitudes, and speeds during flight. For aerial surveying purposes, however, image capturing should be sequential and nadiral.

The methodology used to acquire, and process captured data can be divided into four stages (**FIGURE 3.2**).

- Flight planning
- Flight execution
- Post-flight processing
- Output generation

FIGURE 3.2
FLOWCHART OF AERO PHOTOGRAMMETRIC SURVEYING USING UAVS



Source: World Bank.

Note: DSM = Digital Surface Models.

i. Flight Planning

As with any aerial vehicle, missions should be preceded by a plan. The plan includes prior knowledge of the flight area, the target coverage area for the flight, and a weather condition check.

The vast majority of UAVs available on the market feature only Global Navigation Satellite System (GNSS) navigation receivers, with geographic accuracy of 1–5 m of positioning error. However, in terms of altimetric accuracy, the error often ranges from 30 m to 100 m.

Control points on the ground (by means of a high-precision global positioning system [GPS]) are needed to correct such inaccuracies. Ground control points (GCPs) must

be identifiable and visible in the photographs, so they may be connected based on spatial coordinates. Natural or artificial targets—such as signs painted on the ground, buildings, landmarks, and so on—can be used as references for such points (**FIGURE 3.3**).

FIGURE 3.3
GROUND CONTROL POINTS SURVEYED WITH GPS L1, L2

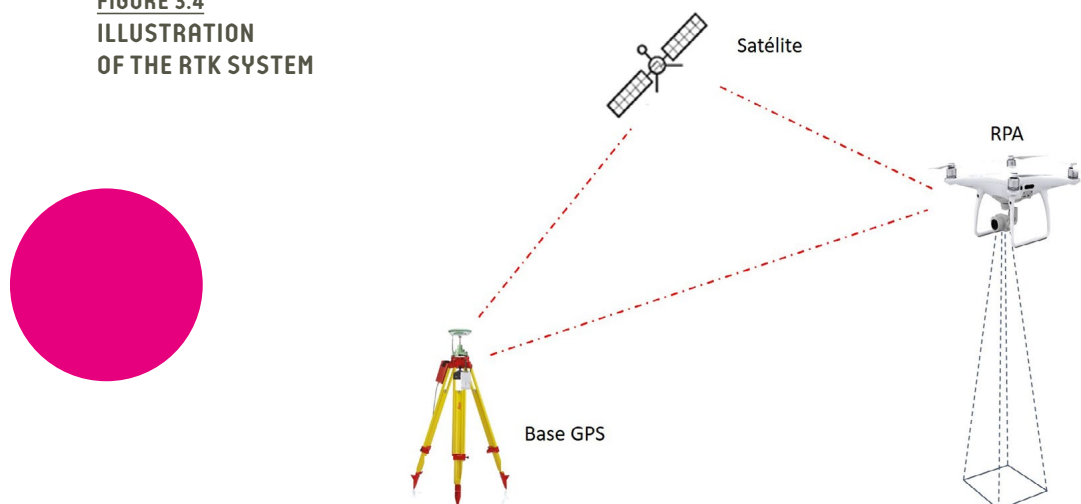


Source: World Bank.

Certain UAV models in the market use aircraft-mounted RTK or Post Processed Kinematic (PPK) systems, which can adjust the position of the UAV in real time or post flight, thereby eliminating the need for control points.

The RTK system can correct the data collected by the aircraft's GPS system in real time, using a special ground base with a precision geodetic GPS. The base serves as a static geographic reference for the UAV in motion, allowing the position to be corrected (**FIGURE 3.4**).

FIGURE 3.4
ILLUSTRATION
OF THE RTK SYSTEM



Source: World Bank.

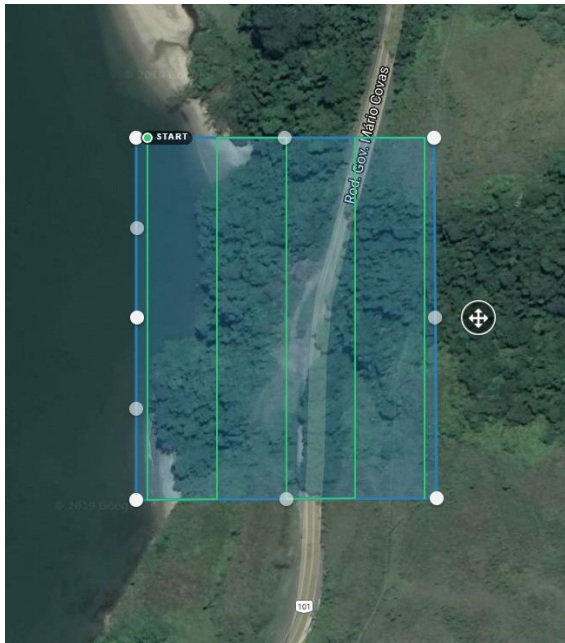
The PPK system is very similar to the RTK system but does not require a telemetry link and stores all geographic data on the aircraft's on-board computer. This means that the information collected can be processed post flight.

Once the flight area has been set and control points have been allocated, a flight plan must be set, which basically consists of determining take-off and landing locations, flight altitude, speed, the UAV's route when capturing images, and the battery power needed.

ii. Flight Execution

This stage begins by checking the equipment on the ground. After this check, the aircraft takes off and lifts to flight height, at which point the flight plan is executed. The aircraft flies over the area of interest in parallel flight paths, capturing images every 3 seconds until the area of interest has been fully covered. The UAV then proceeds to land (FIGURE 3.5). This phase can be automated by software, with operators able to intervene at any point.

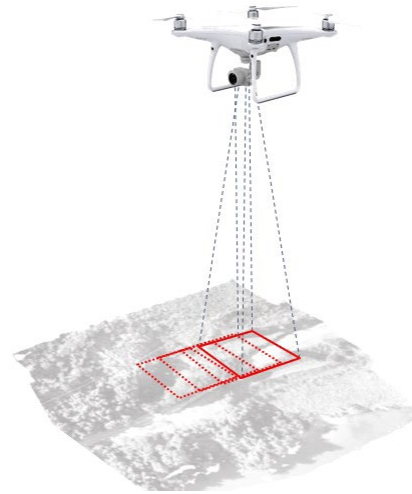
FIGURE 3.5
FLIGHT PLAN FOR AERO PHOTOGRAMMETRIC SURVEYING



Source: DronEng, 2018.

Aircraft stability and the rate of overlap are factors that directly influence the quality of the final output; the optimal overlap percentage is usually 70 percent lateral and 80 percent frontal, as shown in FIGURE 3.6.

FIGURE 3.6
ILLUSTRATION OF
AERO PHOTOGRAMMETRIC
SURVEY WITH
OVERLAPPING IMAGES



Source: World Bank.

iii. Post-Flight Processing

Once the images are obtained, they are checked and filtered. This preliminary assessment is carried out manually. Images that are distorted for whatever reason and may affect the quality of the final product are discarded.

The remaining images are uploaded to a software which identifies similar areas, groups them together, and compiles a single image of the entire area of interest.

Images can be processed using software available on the market, such as Agisoft Photoscan, Pixel4D, and Drone2Map.

iv. Output Generation

Post-flight processing draws on computational procedures to produce outputs such as point clouds, orthophotos, digital terrain models (DTMs), DSMs, contours, heights of objects and volumes, among others. The output can be exported by the software into matrix and vector formats, which can then be inserted into and/or edited in a geographic information system (GIS) environment.

3.3.3 **GIS INTEGRATION**

A GIS is designed to collect, store, manipulate, relate, and present all types of geographic data.

It enables users to view, query, and interpret data from a given location and identify patterns and trends. It functions as an integrated information platform, generating results and outputs to aid in decision making.

One of the GIS tools is photographic data interpretation, which involves an analysis of aerial photographs from satellites, airplanes, and UAVs. These interpretive analyses can be used to generate various outputs, such as isolines, classifications of elements, measurements, and so on.

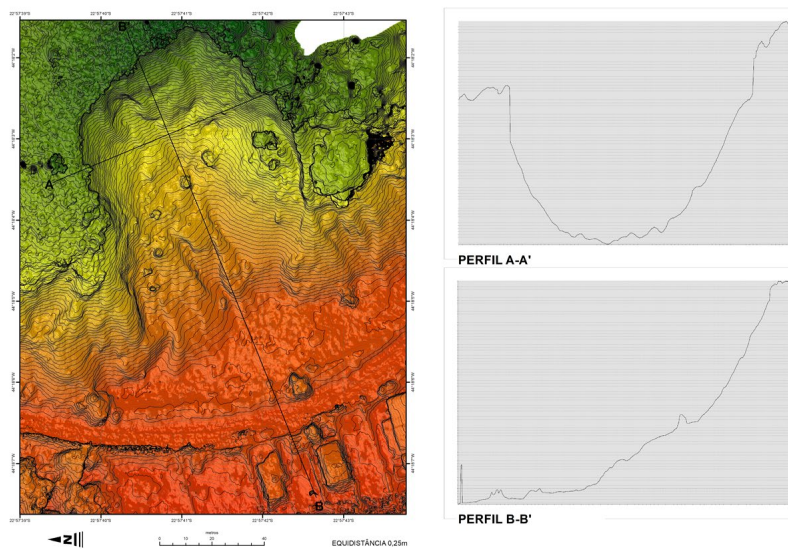
In addition to editing and working on the collected data, the GIS also allows users to overlay multiple information layers and create thematic maps to graphically depict information collected by aerial vehicles (satellites, airplanes, and UAVs). **FIGURE 3.7** and **FIGURE 3.8** show the outputs generated from data collected in an aero-survey carried out with an UAV.

FIGURE 3.7
MAP GENERATED IN A GIS ENVIRONMENT, CONTAINING THE IMAGE, MDS, AND ISOLINES (AERO PHOTOGRAMMETRIC SURVEY DATA USING AN UAV)



Source: World Bank.

FIGURE 3.8
RELIEF MAP AND PROFILES GENERATED IN A GIS ENVIRONMENT



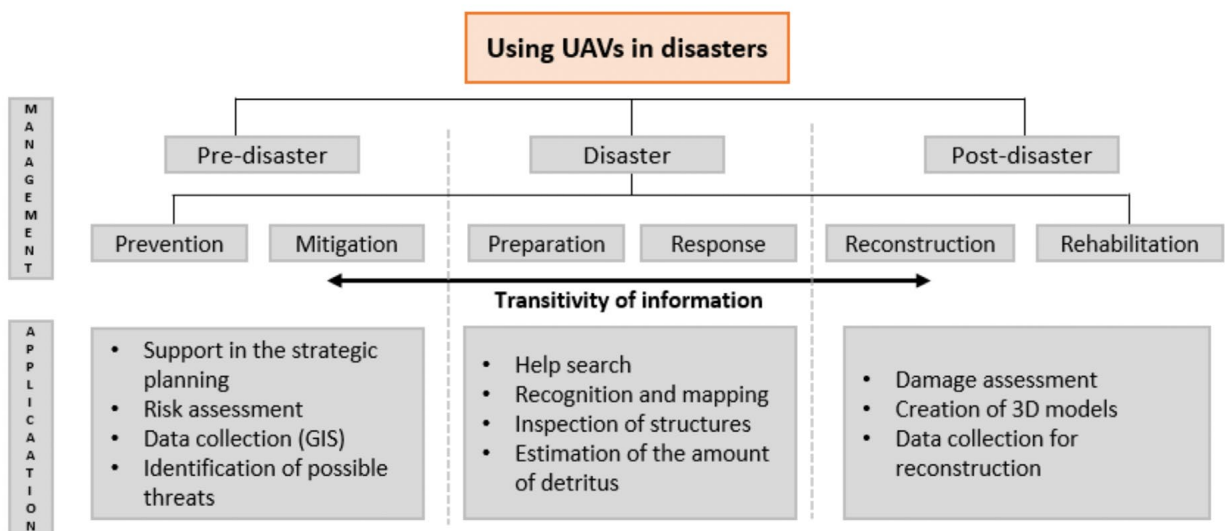
Source: World Bank.

3.3.4 USING DRONES DURING DISASTERS

The use of UAVs in disaster prevention, monitoring, and management has become commonplace around the world. Their low operating cost has allowed UAVs to be used in poor and rich countries alike.

According to Ludwig et al. (2016), such UAV use is subdivided into three main categories (Pre-Disaster, Disaster, and Post-Disaster), as shown in **FIGURE 3.9**. As such, each management phase and the applications of UAV use can be better understood, as the potential contribution of each phase is highlighted, and the technology is structured in such a way as to enable regular and systematic use.

FIGURE 3.9
USE OF UAVS DURING DISASTERS



Source: Adapted from Ludwig et al. (2016).

Post-disaster UAV use is meant to prevent and mitigate possible disasters. Based on macro and historical studies, UAVs can be used to aid in more detailed studies of risk areas. This new technology can be used in support of strategic action planning and as input for geographic information systems.

The use of UAVs in disasters has become commonplace around the world. One such example took place in August 2018 in Italy. 'Vigili del Fuoco' firefighters employed UAVs at a collapsed bridge in Genoa to conduct searches amidst the debris and pinpoint risk areas (**PHOTO 3.1** and **PHOTO 3.2**).

PHOTO 3.1
AERIAL PHOTO BY UAV, BRIDGE COLLAPSE - GENOA, ITALY



Source: Vigili del Fuoco.

PHOTO 3.2
AERIAL PHOTO BY UAV, BRIDGE DEBRIS - GENOA, ITALY



Source: Vigili del Fuoco.

In addition to not putting more lives at risk, the equipment is often more agile than humans, can operate in hard-to-reach areas, and conduct sweeps faster and at lower operational costs. However, captured images must still be analyzed by human specialists.

In the post-disaster phase, high-resolution aerial images captured by UAVs can aid in accurate damage assessment and reconstruction planning, as well as in mapping affected areas.

In DRM, UAVs have a bright future in terms of providing remote sensing data with high planimetric resolution (data are typically obtained at between 3 cm and 5 cm), far surpassing the resolutions of both orbital and traditional aerial systems. When it comes to altimetric resolution, the superabundance characteristics described above provide DRM results with altimetric definitions above the necessary parameters, although at lower operating costs.

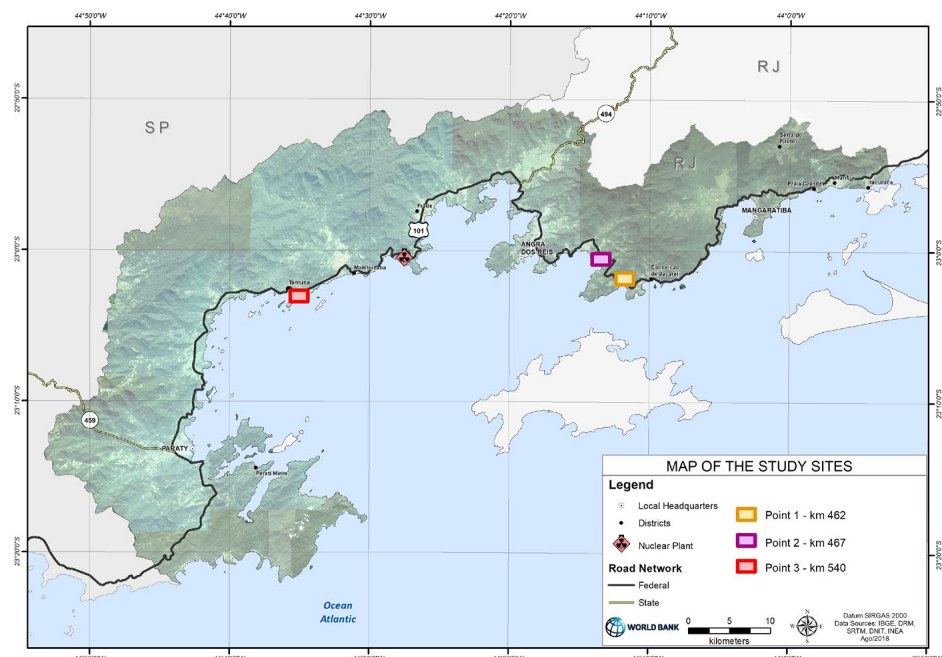
In this context, however, the main advantage of using UAVs in DRM is flight autonomy. Barring adverse weather conditions, UAVs can operate for long periods in the event of floods, flash floods, landslides, earthquakes, and other disasters.

Future developments—such as fitting UAVs with multispectral sensors or active sensors such as Lidar—will surely complement these lines of operation, currently at peak implementation.

3.3.5 CASE STUDY

As a case study for this report, a flight was carried out over three points of Highway BR-101 in the State of Rio de Janeiro, which have had landslides in the past and are currently being monitored by local DNIT teams. **MAP 3.10** shows the geographical locations of the study points.

MAP 3.10
LOCATIONS OF THE STUDY POINTS



Source: World Bank.

The UAV flew over the three points and the images were captured at the nadiralangle and under the flight parameters shown in **TABLE 3.3**.

TABLE 3.3
FLIGHT PARAMETERS

PARAMETERS	POINT 1	POINT 2	POINT 3
EQUIPMENT	DJI PHANTOM 4 PRO	DJI PHANTOM 4 PRO	DJI PHANTOM 4 PRO
AVERAGE SPEED (KM/HOUR)	9.0	5.1	3.1
TIME (MINUTES)	6	4	7
HEIGHT (METERS)	120	120	100
NUMBER OF PHOTOGRAPHS	50	48	76
CAMERA RESOLUTION	5472 × 3078	5472 × 3078	5472 × 3078
COURSE (METERS)	900	340	365
FLIGHT TRACKS	2	2	3
LATERAL COVERAGE	70%	70%	70%
LONGITUDINAL COVERAGE	90%	90%	90%

Source: World Bank.

The altimetric component was determined using the conventional parallax method (relative positions of elements in the observed area, according to a central conic projective system).

The advantage of UAV-generated images compared to conventional surveying is the significant number of common points for determining parallaxes which, due to simplified digital coverage, can be achieved by small aircraft.

Furthermore, advances in digital processing (particularly in signal processing and automatic feature detection through multivariate correlation) and in processing power enable analyses of this magnitude, with clouds of several hundred thousand points often derived from even relatively small areas.

Point cloud densification (enabled by the superabundance of common elements) also increases the number of parallax calculations, which translates into improved morphological features and higher parallax accuracy.

The angle of view and coverage of the images used to obtain the parallaxes for elements situated on the observed surface must be integral; otherwise, areas outside the lines of sight will not be included in the equation and their planialtimetric attributes will not be calculated, resulting in areas with no data, as shown in [FIGURE 3.10](#), [FIGURE 3.11](#), and [FIGURE 3.12](#).

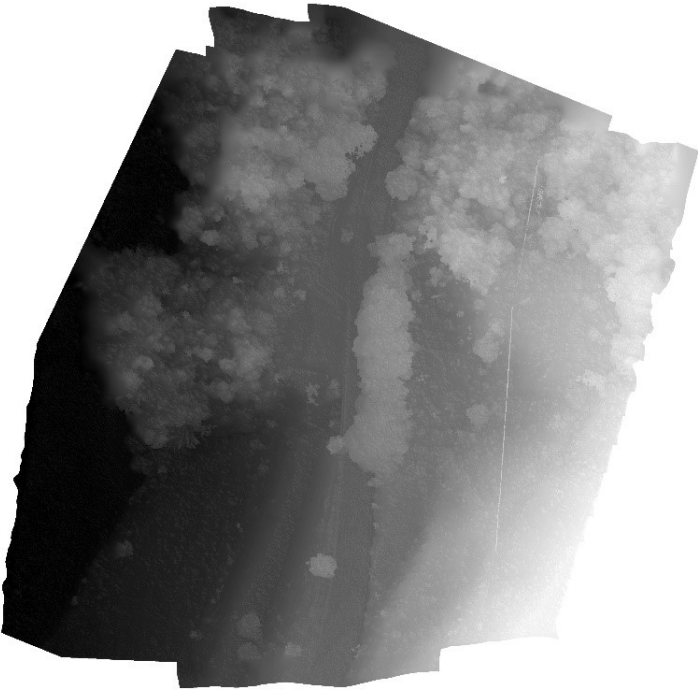
Finally, the point cloud and its X, Y, Z coordinates are translated into matrix representations such as digital surface models.

FIGURE 3.10
RGB MOSAIC POINT 3



Source: World Bank.

FIGURE 3.11
DIGITAL SURFACE MODEL POINT 3



Source: World Bank.

FIGURE 3.12
3D MODEL POINT 3



Source: World Bank.

3.3.6 COST OF IMPLEMENTATION

TABLE 3.4
ESTIMATION OF COST OF IMPLEMENTATION FOR THE 155 KM UNDER STUDY

SURVEY			
SERVICE (UNIT)	UNIT PRICE	QUANTITY	TOTAL PRICE
Aerial Survey (Hectare)	R\$30,00	1.860	R\$55,800,00
Collection of control points GNSS (By point)	R\$500,00	155	R\$77,500,00
POST PROCESS			
SERVICE (UNIT)	UNIT PRICE	QUANTITY	TOTAL PRICE
Georeferencing (Hectare)	R\$15,00	1.860	R\$27,900,00
Mosaic generation RGB (Hectare)	R\$10,00	1.860	R\$18,600,00
Generation of DSM and DTM (Hectare)	R\$10,00	1.860	R\$18,600,00
Generation of point cloud and 3D (Hectare)	R\$10,00	1.860	R\$18,600,00
TOTAL			R\$217.000,00

Source: World Bank.

The values shown in Table 3.4 are to be considered as a reference in a preliminary budget analysis based on 155 km in length and 60 m strip on both sides from the center of the road.

In case of a competition for the contracting of the services presented in this section, the contracting unit should carry out a more detailed designation for the case, considering these values and other additional updated ones that are specific to the case. Local characteristics of relief and displacement in the field as well as scaled market values should be specifically taken into account.

3.3.7 SAFE USE OF UAVS AND USER LIMITATIONS

Safe use and limitations of UAVs are oriented mainly to the radio-controller waves range, radioelectric interferences and restricted guarded areas.

Radio-controller waves range affects how fast an UAV can be controlled in a safe mode, including real-time observation of surveyed areas by means of a tablet-based device. Tendencies show that the more channels are used in radio-controller devices, the safer the connection is. New UAV models are provided with redundant radio channels in order to keep operating in case of loss of signal.

In addition, radioelectric interferences can be more complex to be controlled due to their variation as the aircraft flies. They can produce losses of signal and can even make the UAV falling. Cell towers, TV or radio antennas and high voltage lines must be avoided.

Finally, restricted guarded areas (including private areas) should be avoided. Devices oriented to interrupt communication between the UAV and the radio controller are being tested in buildings to avoid aerial photographing or filming of these areas.

3.3.8 CONCLUSIONS

This case study focuses on obtaining massive planialtimetric and photographic data with levels of density and precision that surpass the current monitoring needs for landslides associated with highways.

There is also a cost-savings component. In addition to providing highly cohesive results, the UAVs are an extremely affordable alternative to similar conventional surveys and are able to produce the same results and compatible data volumes.

Flight autonomy and independence make this technique a suitable alternative for massive photographic data surveys, with planialtimetric potential for use in monitoring tasks.

With regard to risk assessment itself, it provides successive temporal snapshots and can integrate and compare digital models obtained over time (monitoring). Procedures such as matrix algebra—for example, to extract digital surface models—may be used to generate information on relief changes and issue landslide alerts. It should be noted that the precision and differential accuracy in this experimental phase is 3 cm to 5 cm, which could be further improved upon.

In summary, the traditional concepts of photogrammetry and remote sensing applied here (homogeneous coverage, digital restitution) are combined with ease of flight and multitemporal and even multispectral use. If these factors are put to use responsibly and with technical and institutional efficiency, they can be a powerful strategy for assessing the risk of landslides from both a quantitative and a qualitative perspective.

3.3.9 RECOMMENDATIONS

As with any technology, UAVs have their strengths but also issues that need more work or improvement. In the case of this particular technology, these points may vary depending on use. Based on our research, we have identified the following strengths and issues UAVs might have:

Strengths

- Ease of flight and programmable coverage
- Geographic location of images
- Digital camera with high planimetric resolution
- Nadiral view
- Superabundance of longitudinal and transversal coverage
- Vector stability under basic conditions
- Real-time survey control
- Simple National Civil Aviation Agency (ANAC) licensing process
- Low operating cost

Points in need of further improvement

- Restricted range
 - Battery life
 - Camera still limited by geometric constraints
 - Vector instability in critical conditions
 - Subject to electromagnetic interference
 - Needs control points
 - Ground cover
-

4

ECONOMIC EVALUATION OF

RISK MITIGATION MEASURES

4.1**INTRODUCTION TO ECONOMIC ANALYSIS
UNDER DEEP UNCERTAINTIES (DMDU)**

This chapter demonstrates an economic evaluation of risk mitigation measures for uncertain geohazard events and shows the economic benefits of such preventive interventions through reducing geohazard disaster risk on the road network.

The benefits of the reduced risk of disaster events on the road network has not been taken into consideration when traditional economic evaluation studies of road projects are conducted. The benefits of transport investments are normally defined as saving in transport costs, for example, shorter travel time or lower vehicle operation costs due to interventions. Meanwhile, economic benefits associated with reduction of disaster risks need to include economic loss of traffic interruptions and additional reconstruction/repair costs under extreme and unexpected disaster events.

One of the biggest barriers preventing governments from investing sufficiently in preventive countermeasures that can mitigate risk to natural disasters is that economic benefits of such measures are not very clear and visible until disaster events happen. Thus, other investments with more visibility immediately after interventions, such as paving rehabilitation and so on, are widely preferred by decision makers than preventive measures.

Meanwhile, such evaluation for natural disasters normally involves dealing with high levels of uncertainty, which prevents traditional economic evaluation from dealing with natural disaster risks and risk mitigation measures. Concretely, probability of landslide occurrence and reduction of landslide probability after an intervention play a major role in the analysis and are uncertain and fluctuant during the lifecycle of the intervention. Furthermore, climate change is also major factor in the economic impact analysis and embraces a deep uncertainty.

This study applies a new approach of economic evaluation which can tackle a high level of uncertainty during natural disaster events. Researchers have been developing a set of new methods and techniques to support decision makers under situations of deep uncertainty. All these techniques fall under the umbrella of Decision Making under Deep Uncertainty (DMDU or sometimes simply DMU). These methods have been applied to different types of infrastructure projects but mostly used in the water management context. There are still very few examples of DMDU applied to transport infrastructure projects even though transport planning is facing most of the same challenges and issues.

Decision making under uncertainty techniques are particularly useful in dealing with high uncertainty associated with natural disasters. DMDU identifies the combinations of factors that would make the interventions economically viable and identify the most robust interventions. As a result, the DMU methodology will help in the following way:¹²

- Identify and characterize uncertainties that shape a decision
- Communicate the levels of uncertainty and risk to stakeholders
- Improve decision making by clarifying options and potential outcomes

Thus, the economic analysis with DMU will support decision making of the road agency through providing a quantitative analysis of the impact of future interventions and prioritization of preventive interventions. A major driver for decision makers to invest in preventive interventions will be the amount of economic costs (losses) that that intervention will be able to reduce, or in other words, the economic benefit (savings) that is expected to create. Benefits or savings are obtained as a reduction of costs in the 'with-project' scenario compared to the 'without-project' scenario.

The case study introduces the innovative DMU methodology to help understand the enabling conditions that return a positive economic benefit for potential preventive interventions on roads. For this exercise, the same section as the previous chapter, that is, 155 km segment of the BR-101 in the region of Angra dos Reis, Paraty, and Mangaratiba in the State of Rio de Janeiro, was selected as a pilot road.

The following sections explain a methodology to assess economic benefits of preventive risk mitigation interventions under deep uncertainty of geohazard disaster events.

4.2

ACCOUNTING FOR BENEFITS

The objective of this economic analysis is to identify the economic benefits of investing in new preventive interventions that mitigate the risk of landslides. As in any economic analysis, benefits or savings are obtained as a reduction of costs or losses in the 'with-project' scenario compared to the 'without-project' scenario. As benefits come from the reduction of costs, the two types of benefits or savings that can be identified in this analysis are defined in the following paragraphs:

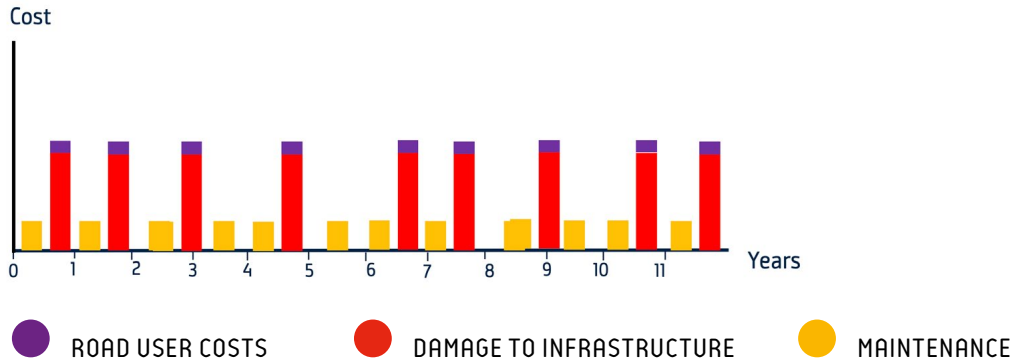
- **Expected annual user losses (EAUL).** The EAUL refers to the increased cost that users must assume when they are forced to make a detour or wait for the disruption to be fixed after a landslide.
- **Expected annual damage to infrastructure (EAD).** The EAD is the cost of repairing or rebuilding the damaged infrastructure after a landslide.

As shown in [GRAPH 4.1](#) and [GRAPH 4.2](#), benefits will appear from the difference in cost between the 'without-project' and the 'with-project' scenario.

In the base or without-project scenario, there is a high economic cost incurred every year after landslides in repairing the damaged infrastructure and the disruption it causes for users. These two facts materialize in expensive emergency contracts by DNIT and road users having to wait for long periods until the road is reopened. In the with-project scenario, while there is a higher up-front investment in preventive interventions and higher annual maintenance costs, the reduction of annual number of landslides causes a lower expenditure for repairing the infrastructure and lower user costs.

GRAPH 4.1
CONCEPTUAL INVESTMENT SCHEDULE OF THE WITHOUT-PROJECT SCENARIO

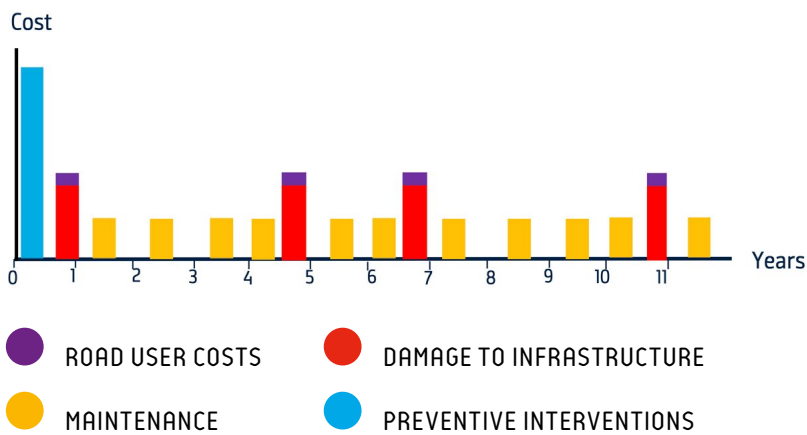
Without-project scenario:



Source: World Bank.

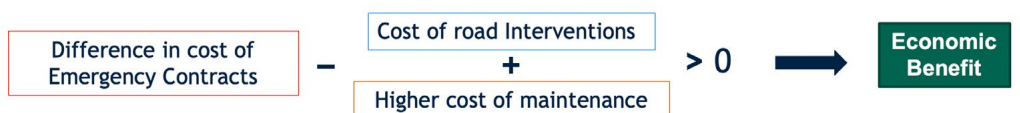
GRAPH 4.2
CONCEPTUAL INVESTMENT SCHEDULE OF THE WITH-PROJECT SCENARIO

With-project scenario:



Source: World Bank.

When the investment in preventive measures is lower than the saved economic cost derived from having less landslides in the future and thus, less emergency contracts, there is an economic benefit.



4.3 METHODOLOGY

The economic analysis performed in this section applies to existing federal roads in Brazil. For new road designs, a broader assessment of the hydraulics of water basins should be incorporated so drainage infrastructure and landslide mitigation works could be considered, designed and budgeted for. As mentioned previously, the economic analysis carried out in this study applies only to existing federal roads in Brazil.

The road interventions that are being analyzed in this study aim to lower socioeconomic costs derived from natural disasters and to adapt the Brazilian road network to climate change. Although the main impact of climate change on the roads is through landslides and floods, this study will focus solely on landslides, leaving the floods for future analysis. The cost-benefit analysis presented in the following sections includes landslide risk reduction as a benefit.

To assess the benefit, this study first estimates landslide risk for the analyzed road in a baseline or without-project scenario with no interventions. Then the impacts of investing in road interventions and extra maintenance are described with a definition and classification of all the variables or parameters involved in the economic analysis. Variables are classified as certain, assumable uncertainty, and deep uncertainty, and their values are defined and explained.

Only for the most uncertain variables the value ranges are calculated out of randomized normal or uniform distributions. To have a wide result spectrum, 1,500 different scenarios are created for each of the variables and thus, 1,500 different results are obtained. Finally, an exhaustive analysis of the results is carried out.

4.3.1 DEFINITION OF A BASELINE

In the baseline, it is assumed that no intervention is made, and the right-of-way receives low or no maintenance and monitoring besides what is done to the infrastructure itself (pavement). The existing interventions are poorly maintained or rehabilitated. That translates to an annually incrementing risk of landslide occurrence due to a more deteriorated infrastructure.

The road under analysis is exposed and vulnerable to landslides, and we can estimate landslide risk as the expected annual losses (EAL) caused by this kind of natural disaster. The EAL has two components: the EAD and the EAUL. While the EAD is the cost of repairing or rebuilding the damaged infrastructure, the EAUL refers to the increased road user cost that users must assume when they are forced to make a detour or wait for the disruption to be fixed after a landslide.

Formula for EAL:

$$\mathbf{EAL = EAUL + EAD}$$

To calculate the annual infrastructure losses (EAD) for the BR-101 road section under study, historical data for emergency contracts are considered from the federal road agency, DNIT. These emergency contracts, besides providing information about the

costs of repairing the infrastructure after a landslide, provide valuable information about the when, where, and what happened in a particular section of the road. To calculate the annual cost of repairing the infrastructure (EAD) after a landslide occurs, the next two variables are considered:

- Average number of landslides per year
- Average cost of repairing the infrastructure after a landslide

As we will show later in this section, due to the high level of uncertainty around these two variables, a value range will be defined for these variables before running the economic analysis. The formula to calculate the EAD for a single year would be

$$EAD = \text{Average Number of landslides per year} \times \text{Average cost of repairing the infrastructure after a landslide}$$

To calculate the EAUL, the road under study has been split in two separate sections based on the existing alternative routes. One section is from Mangaratiba to Angra dos Reis (62 km) while the second one links Angra dos Reis with Paraty (93 km). It is assumed that only a percentage of the affected users will take the best alternative route while the rest will wait for the disruption to end. The rerouting is assumed to happen until the original route is reopened to traffic. Therefore, road repair time is a major driver of user losses. Traffic growth has not been used to calculate the EAD in this study due to the low impact that it has on the final result and the difficulty in making a reasonable estimation of the variable. For the calculation, the following variables are considered:

- Average number of landslides per year
- Vehicle Operating Cost (VOC)
- Extra kilometers traveled taking the alternative route
- Annual average daily traffic (AADT)
- Value of time
- Time of traffic interruption
- User behavior

All the variables used to calculate annual user losses (EAUL) but the average number of landslides per year can be either calculated or estimated with certain level of accuracy. This will be further explained later in this section. The formula to calculate the EAUL for a single year would be

$$EAUL = \text{Average Number of landslides per year} \times \left[\begin{array}{l} \text{Users taking an alternative route} \times \text{Vehicle Operating Cost (VOC)} \times \text{Extra kilometers traveled taking the alternative route} \\ + \\ \text{Users waiting} \times \text{Time of traffic interruption} \times \text{Value of time} \end{array} \right]$$

■ Cost of users taking an alternative route

■ Cost of users waiting

4.3.2 IMPACTS OF ROAD INTERVENTIONS AND EXTRA MAINTENANCE

New investments in road interventions and extra maintenance by DNIT will reduce the risk to landslides and thus, the expected annual losses (EAL).

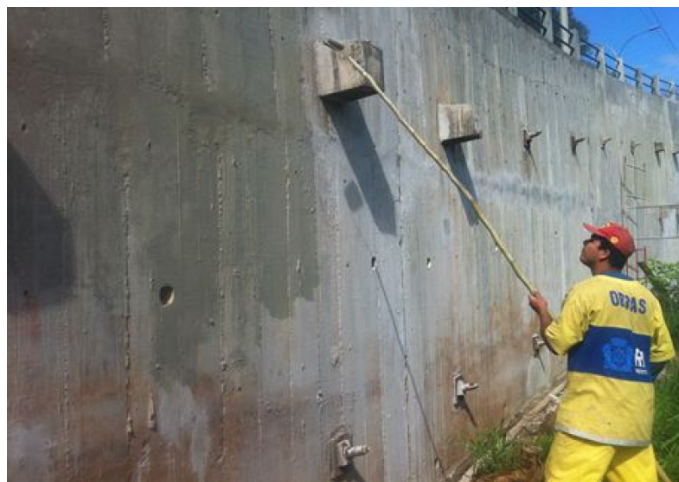
The decrease in landslide risk for the road agency is calculated as the difference between EAD in the baseline scenario and EAD with the interventions and extra maintenance. Following interventions, the repair and rehabilitation cost (after landslides) will be reduced, as damage will be lowered or avoided in some cases. In this new scenario, the EAUL will be reduced as well due to having fewer occurrences and thus, less users waiting and/or taking the alternative route.

Road Interventions

Road interventions can certainly reduce landslide risk on roads. However, it seems difficult to estimate the prioritization of the type of interventions needed and where these interventions should be implemented to best reduce landslide risk. For this study, this information has been taken from local representatives of DNIT in the local unit of Angra dos Reis. They have registered more than 130 critical spots along the road under study. For many of these critical spots, a detailed design of the most appropriate type of intervention needed has been identified. Interventions include different type of containment measures and drainage to prevent a landslide from occurring. Every intervention identified has an estimated cost associated. The average cost of fixing a critical spot is close to R\$500,000. Two common examples of infrastructure interventions used in Brazil are described in the following paragraphs.

Anchored curtain (PHOTO 4.1). Anchored curtains are containment structures that use tie rods. They are formed of a wall of reinforced concrete, generally 20–30 cm thick (depending on the loads on the rods) fixed to the ground through pretensioned anchors. This provides a structure with sufficient stiffness to minimize shifting of the terrain.

PHOTO 4.1
ANCHORED CURTAIN



Source: Collection of Fundação Geo-Rio. Reproduced, with permission, from Fundação Geo-Rio; further permission required for reuse.

Deep horizontal drains (PHOTO 4.2). Deep horizontal drains (DHPs) are devices along the body of slopes or hills, which aim to provide flow for infiltrated or groundwater, to alleviate the existing pore pressure, thereby improving the stability conditions of slopes or hills.

PHOTO 4.2
DEEP
HORIZONTAL
DRAINS



Source: Collection of Geoconcret. Reproduced, with permission, from Geoconcret; further permission required for reuse.

Based on this data from the local unit of Angra dos Reis and for this study, the estimation of the total investment needed for interventions is considered as a key element for the simulation of new scenarios where the landslide risk is reduced. However, due to the huge uncertainty around this variable and because of the enormous difficulty to work with a unique number, this is one of the variables for which a range with a uniform distribution of probabilities has been estimated.

Maintenance

As mentioned earlier in this report, there is a lack of maintenance besides what is undertaken for the sole infrastructure of the road. The right-of-way of the road is not appropriately maintained or monitored, and this turns into a more deteriorated infrastructure that increases the risk of landslides over time. Although it is easy to agree on the fact that a higher investment in maintenance reduces risk, it seems difficult to determine how much higher it should be to really have a noticeable impact in the landslide risk reduction.

The extra investment in maintenance is a very uncertain variable. Due to this uncertainty, it is complicated to select a unique number representative of the reality. Thus, this is another variable for which the study assumes a value range that will be combined with other variables to obtain a wider range of results.

Cost of interventions and maintenance will be further discussed and analyzed in the following section and so will the uncertainty around the achieved reduction in landslide risk after carrying out extra investments.

4.3.3 DEALING WITH UNCERTAINTY

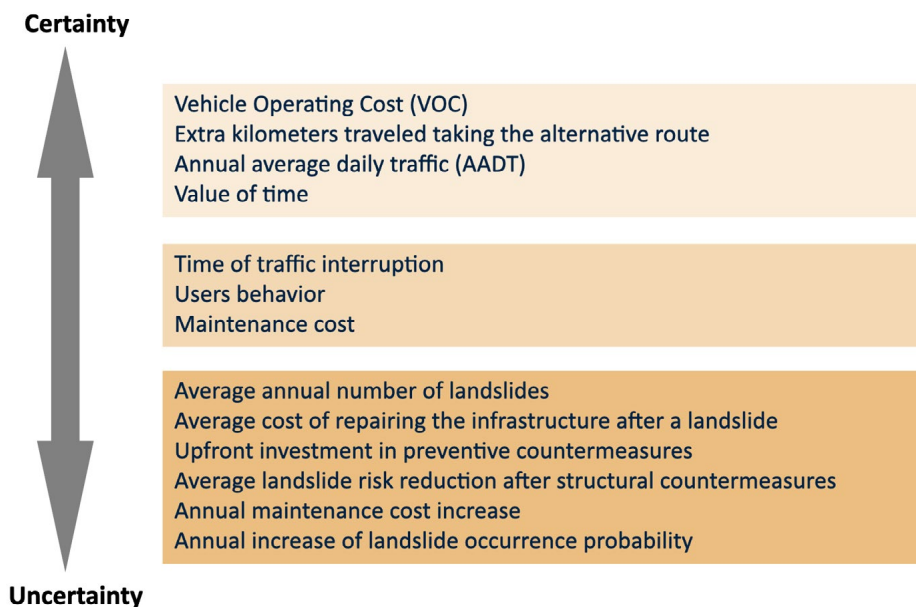
Once the baseline and the potential interventions have been defined, we have to deal with the uncertainty around some of the variables when modelling the economic analysis.

As stated in the previous sections in this report, some of the variables are easier to estimate than others. This study classifies the variables under three different categories depending on the uncertainty involved in their estimation. These categories differentiate between variables that are relatively easy to estimate due to previous analysis or studies carried out, from those that are more difficult to estimate because of continuous fluctuation or uncertainty, and finally parameters that do not depend directly on human actions or that are completely uncertain to decision makers.

It is to mention that this section of the report uses available data for the calculation of variables and final results. For some of the variables, the lack of available data can act as a limiting factor for the perform of the DMU analysis. A potential improvement of datasets in the future could improve the accuracy of the results obtained in the economic analysis.

FIGURE 4.1 shows the summary of the parameters used in the economic analysis. These parameters will be described later in this section.

FIGURE 4.1
VARIABLES OF THE ECONOMIC ANALYSIS CLASSIFIED BY LEVELS OF UNCERTAINTY

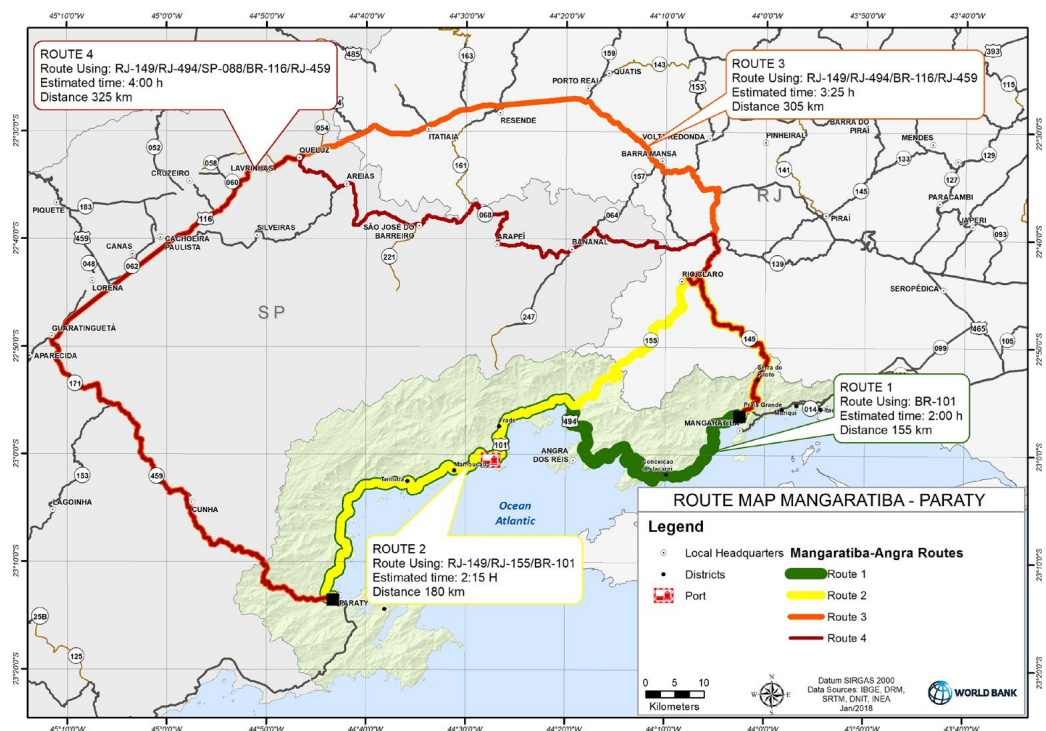


Certain

Variables considered as certain are those for which it is possible to calculate a specific number from the investigation or analysis. The following are under this category:

- **VOC.** Defined as R\$ per km, operating cost of a vehicle type is a function of several variables including road condition, travel speed, road geometry, and many other parameters. Based on existing economic evaluation studies of road projects in Brazil, the VOC has been set as R\$1.5 per km in this study for the entire section of the road under analysis. This value already includes the additional time needed to complete the alternative route.
- **Extra kilometers traveled taking the alternative route.** The road section under study has been divided in two sections based on the available alternative routes (**MAP 4.1**). Each alternative route represents the extra kilometers travelled by any user who decides to take the alternative route instead of waiting for the disruption to be fixed and normal traffic restored. Thus, extra kilometers travelled is the difference between the kilometers when taking the original route and the kilometers when taking the alternative one.

MAP 4.1
ALTERNATIVE ROUTES FOR THE PILOT AREA



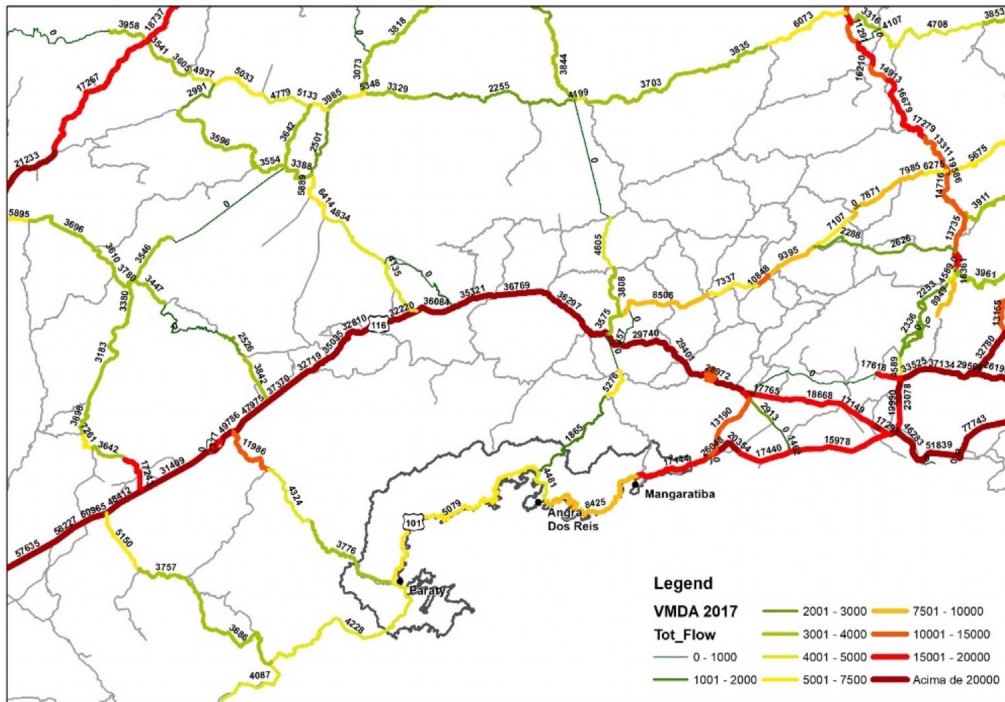
Source: World Bank.

The road under study has been split into two different sections based on the location of the available alternative routes. One of the sections is from Mangaratiba to Angra dos Reis, while the other section links Angra dos Reis with Paraty. This is a calculation of the extra kilometers travelled after a disruption of the traffic has taken place.

DISRUPTION IN: MANGARATIBA – ANGRA DOS REIS	DISRUPTION IN: ANGRA DOS REIS – PARATY
ORIGINAL ROUTE (MANGARATIBA - PARATY): 155 KM	ORIGINAL ROUTE (MANGARATIBA - PARATY): 155 KM
ALTERNATIVE ROUTE: 180 KM	ALTERNATIVE ROUTE: 305 KM
EXTRA KM: 25 KM	EXTRA KM: 150 KM

- **AADT.** It is calculated as the total volume of vehicle traffic of the road for a year divided by 365 days. Based on traffic count analyses, traffic volume has been estimated for each of the sections, Mangaratiba to Angra dos Reis and Angra dos Reis to Paraty. The traffic volume for the first section (Mangaratiba - Angra dos Reis) has been set as 8,000 vehicles per day while the traffic volume estimated for the second section (Angra dos Reis - Paraty) is 6,000 vehicles per day in 2017 ([MAP 4.2](#)).

MAP 4.2
AADT IN THE PILOT AREA



Source: World Bank.

- **Value of time.** It is defined as the opportunity cost of the time that a traveler spends on his/her journey (R\$ per hour). In essence, this makes it the amount that travelers would be willing to pay to save time or the amount they would accept as compensation for lost time. Based on previous studies and analysis of the World Bank in Brazil, it is estimated that the value of time is R\$15 per hour for the users crossing the road under analysis.

Assumable uncertainty

Under this category fall those variables for which, despite being uncertain in essence, it is possible to rely on local authorities' information and wide experience to estimate them.

- **Time of traffic interruption.** It is the average time needed to restore the traffic flow to business as usual after a disruption. Based on interviews with the local representatives of DNIT in Angra dos Reis, it is estimated that an average time for traffic disruptions is three hours.
- **Users behavior.** After a landslide blocks the road and the traffic flow are stopped, there are two options that users can consider. They can wait until the road is opened again or they can take the alternative route. Based on interviews with the local representatives of DNIT in Angra dos Reis, it is estimated that 90 percent of the users opt to wait until the traffic is restored, while 10 percent of the users decide to take the alternative route.
- **Maintenance cost.** It is defined as the average annual cost for the road agency (DNIT) to maintain the section of the road under analysis. Based on the historical data and current maintenance contract costs assumed by the local unit of DNIT in Angra dos Reis, an average annual cost of road maintenance of R\$5,250,167 is estimated for the 155 km under study. This variable will be useful when estimating the additional (percentage) annual cost of maintenance needed to reduce the risk of landslides; this variable is classified as a variable with deep uncertainty, and it will be later analyzed.

Deep level of uncertainty

These are the most uncertain variables. Even with existing historical data or interviewing local authorities, it would be difficult to estimate a unique number for these variables. For this reason, the DMU methodology proposes an alternative way of introducing these variables in the cost-benefit analysis, with value ranges. Faced with the impossibility to assign a representative number for the variables described under this category, a range of values the variable could adopt is estimated. This range of values is combined with the rest of the variables involved in the cost-benefit analysis that create multiple scenarios associated with multiple results. The variables under this category are described in the following paragraphs:

- **Annual average number of landslides¹³**. This is explained as the expected average number of landslide occurrences that damage the infrastructure per year, along the roads under analysis. Every time a landslide damages the infrastructure or immediate action is needed in a federal road, DNIT activates the protocol for an emergency contract to restore the situation to business as usual. The estimation of the value range for this variable is thus based on historical data on issued emergency contracts by DNIT from 2007 to 2015.

13

The methodology presented in the section 3 for mapping landslide risk areas presents some limitations due to the small amount of available data and the distribution of the same (many events registered in Angra dos Reis while very few in Mangaratiba or Paraty). It is believed that this data varies depending on the rigorousness with which events were tracked by local units of DNIT in different municipalities and not so much on the real number of events occurred.

Although the methodology presented in section 3 of this report will be a very valid methodology to use in the near future, a different approach is considered for the calculation of the annual probability of landslides in the economic analysis performed in this study.

By tracking the number of this type of contract over the years, a normal distribution of probabilities of annual landslide occurrences has been assumed. The parameter of the distribution is based on the historical emergency contract data for the nine years between 2007 and 2015. The real data for the annual number of landslides and the parameters used for the calculation are detailed in [TABLE 4.1](#).

TABLE 4.1
EMERGENCY CONTRACTS BY DNIT (2007–2015)

YEAR	NUMBER OF EMERGENCY CONTRACTS	AVERAGE	8.8
2007	19		
2008	5	Standard deviation	13.6
2009	1	MIN value	1.0
2010	44	MAX value	44.0
2011	1		
2012	1		
2013	5		
2014	2		
2015	1		
TOTAL	79		

Source: World Bank based on data from DNIT.

For each of the scenarios, an annual average number of landslides has been calculated. The 1,500 averages obtained have been used to run the economic model.

- **Average cost of repairing the infrastructure after a landslide.** It is defined as the average cost of an emergency contract after a landslide occurred on the road under study. To estimate the range of this variable—as it has been done with the average-number-of-landslides-per-year estimation—the historical data collected by DNIT on emergency contracts between 2007 and 2015 have been used.

By tracking the cost of this type of contract over the years, a normal distribution of probabilities has been defined for a period of 20 years for the 1,500 scenarios. [TABLE 4.2](#) provides the real data for annual number of landslides.

TABLE 4.2
ANNUAL NUMBER OF LANDSLIDES

AVERAGE COST	2,373,621
STANDARD DEVIATION	2,893,756
MIN VALUE	11,259
MAX VALUE	18,021,239
TOTAL NUMBER OF CONTRACTS (2007–2015)	79

Source: World Bank based on data from DNIT.

For each of the scenarios, an annual average cost of emergency contracts has been calculated. The 1,500 averages obtained have been used to run the economic model.

- **Up-front investment in preventive countermeasures.** The up-front preventive interventions or investments in countermeasures are the cost of protecting the infrastructure from potential landslides in the future by applying structural countermeasures. The local unit of DNIT in Angra dos Reis regularly identifies critical spots with higher landslide risk along the road as well as the most appropriate countermeasure to tackle the problem. The value range of this variable has been estimated based on the cost of the proposed countermeasures for each of the critical spots identified. The parameters used to generate a uniform distribution are shown in [TABLE 4.3](#).

TABLE 4.3
ESTIMATION OF NEEDED UP-FRONT INVESTMENT IN PREVENTIVE COUNTERMEASURES

YEAR	NUMBER OF IDENTIFIED SPOTS
2014	15
2015	12
2016	37
2017	0
2018	66

AVERAGE COST PER SPOT	TOTAL NUMBER OF SPOTS IDENTIFIED
R\$558,505.18	130

CURRENT INVESTMENT NEEDED		
R\$72,605,674.03		
VALUE RANGE	MIN Value	R\$ 30,000,000
	MAX Value	R\$ 100,000,000

Source: World Bank based on data from DNIT.

- **Average landslide risk reduction after structural countermeasures.** The landslide risk reduction after having implemented preventive countermeasures and after having increased the cost of maintenance is a completely uncertain variable. Given this lack

of certainty, a value range has been estimated based on the personal experience of different experts in transport and DRM. The values used in the economic model for this variable range from 5 percent to 50 percent landslide probability reduction after interventions. Values have been randomly generated using a uniform distribution.

- **Annual maintenance cost increase.** As explained before in this report, to reduce the risk of landslides, investing in structural measures is not enough. A more intensive maintenance on the right-of-way of the road is needed to ensure good condition of the infrastructure over the years. This variable accounts for the increase in cost of the current maintenance expenditure needed to reduce landslide risk. Based on the personal experience of different experts in transport and DRM, the values used in the economic model for this variable range from 10 percent to 40 percent increase of maintenance cost. Values have been randomly generated using a uniform distribution.
- **Annual increase of landslide occurrence probability.** The landslide risk tends to naturally increase with time if no measure is implemented. This variable is defined as the annual increase in probability of having more landslides in the future considering that no structural countermeasure or maintenance intensification has been done. Climate change and normal deterioration of the infrastructure are the two main reasons for the incremental risk to landslides. For this study, only the natural deterioration of the infrastructure has been taken into account. Based on the personal experience of different experts in transport and DRM, the values used in the economic model for this variable range from an annual 0 percent to 2.5 percent increase of landslide occurrences. Values have been randomly generated using a uniform distribution.

4.4

COST-BENEFIT ANALYSIS

A net present value (NPV) is calculated for each of the scenarios generated. The NPV is the present value of the difference between the total economic cost in the 'without-project' scenario and the total cost in the 'with-project' scenario. The considered period is 20 years and the discount rate used is 6 percent.

With $EAL = EAUL + EAD$;

With $EAL = EAUL + EAD$;

$$NPV^i = \left(\sum_{y=1}^{20} \frac{EAL_y^0}{(1+d)^{y-1}} - \sum_{y=1}^{20} \frac{EAL_y^i}{(1+d)^{y-1}} \right) - CI^i$$

Where, EAUL is the Estimated Annual User Losses, EAD is the Estimated Annual Damage to the Infrastructure, CI is the Capital Cost of Interventions, d is the discount rate, and y the years from 1 to 20. The cost of interventions is divided between the first three years of analysis.

To capture the uncertainty around some of the variables, the NPV is calculated for 1,500 scenarios, combining values on the following:

- Average number of annual landslides, 4.45 to 18

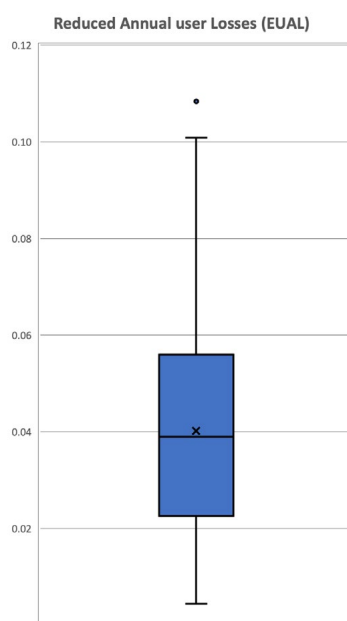
- Average cost of repairing the infrastructure after a landslide, R\$1,008,953 to R\$4,719,439
- Up-front investment in preventive countermeasures, R\$30,000,000 to R\$100,000,000
- Average landslide risk reduction after structural countermeasures, 5 percent to 50 percent
- Annual maintenance cost increase, 10 percent to 40 percent
- Annual increase of landslide occurrence probability, 0 percent to 2.5 percent

Once the NPV for each of the 1,500 scenarios has been calculated, the conditions under which the NPV returns a value higher than 0 are identified and further analyzed.

4.5
RESULTS

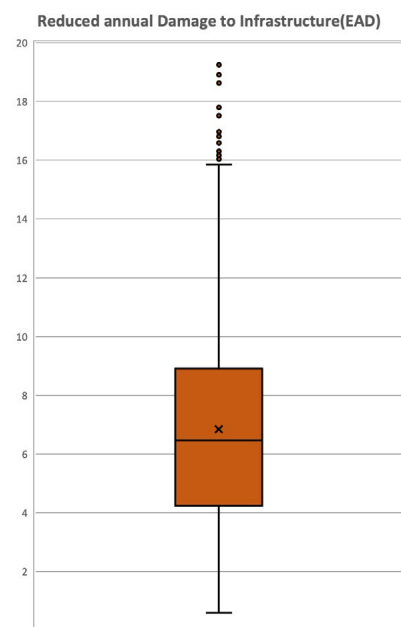
The combination of all the parameters for the proposed 1,500 scenarios returned interesting results that were carefully analyzed. With the implementation of new road interventions and the extra investment in maintenance, a reduction of the annual infrastructure and user losses are expected. In **GRAPH 4.3**, the range of both variables is represented for all of the 1,500 different scenarios.

GRAPH 4.3
REDUCED EAUL AND REDUCED EAD RANGE (R\$, MILLIONS)



EAUL:

AVERAGE	MINIMUM	MAXIMUM
0.04	0	0.1



EAD:

AVERAGE	MINIMUM	MAXIMUM
6.8	0.59	22.1

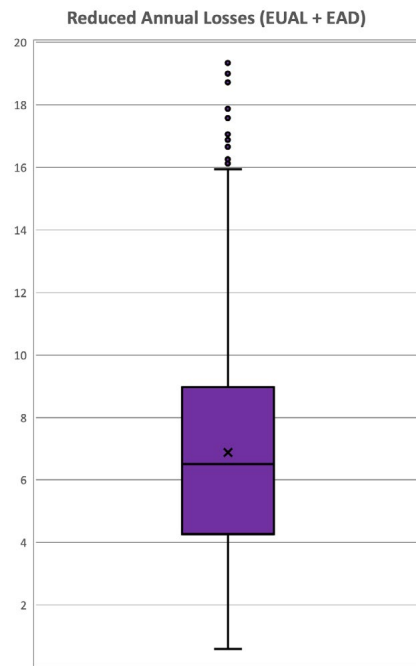
The EAUL ranges from almost 0 to more than R\$0.1 million per year, with the average value being close to R\$0.04 million. The EAD ranges from R\$0.59 million to more than R\$22 million per year. The average of the EAD for all the scenarios combined is R\$6.8 million reduction annually. These numbers translated to a 20-year period result in an average annual savings of R\$0.8 million for EAUL and R\$136.8 million for EAD, both in constant prices of 2018.

When we account for the two variables shown above combined, total reduced annual losses (EAL) are obtained. In Graph 4.4, the reduced EAUL and reduced EAD combined are displayed. Because EADs are much higher than EAULs, the figure is very similar to the EAD figure shown earlier.

GRAPH 4.4
REDUCED ANNUAL LOSSES

EAL:

AVERAGE	MINIMUM	MAXIMUM
6.8	0.59	22.2



The reduced EAL ranges from R\$0.59 million to more than R\$22.2 million per year. The average of the EAL for all the scenarios combined amounts for R\$6.8 million reduction annually. These numbers translated to a 20-year period result in an average total annual savings (EAL) of R\$137.6 million in constant prices of 2018.

The figure shows the benefit-cost ratio range for all the scenarios after interventions. It has been calculated by aggregating all benefits shown in **GRAPH 4.5** and dividing by the additional costs. The costs include initial interventions and periodic extra investment in maintenance.

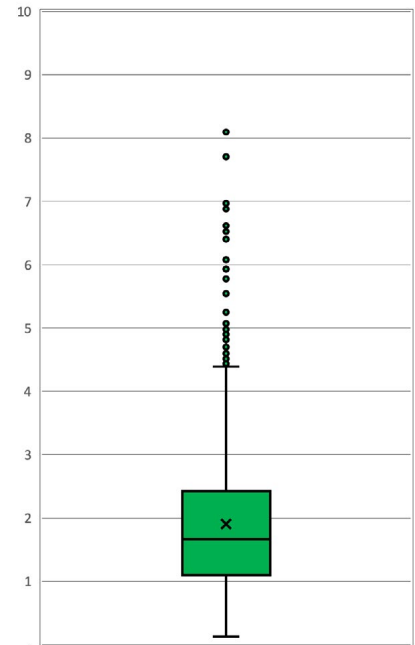
GRAPH 4.5
BENEFIT-COST RATIO RANGE
FOR THE 1,500 SCENARIOS

EAL:

AVERAGE	MINIMUM	MAXIMUM
1.90	0.1	8.1

EAL:

BENEFIT-COST RATIO > 1	$0 \leq$ BENEFIT-COST RATIO < 1
79% of the scenarios	21% of the scenarios



The values of the benefit-cost ratio range from almost 0 to more than 8. The average value of the benefit-cost ratio for all the 1,500 scenarios presented is close to 2. The general interpretation of the results of the benefit-cost ratio is that, on average, the benefit obtained after investing on preventing natural disasters in that particular road will double the cost in a 20-year period. In 79 percent of the cases, the benefits obtained will be higher than the costs invested in preventive measures.

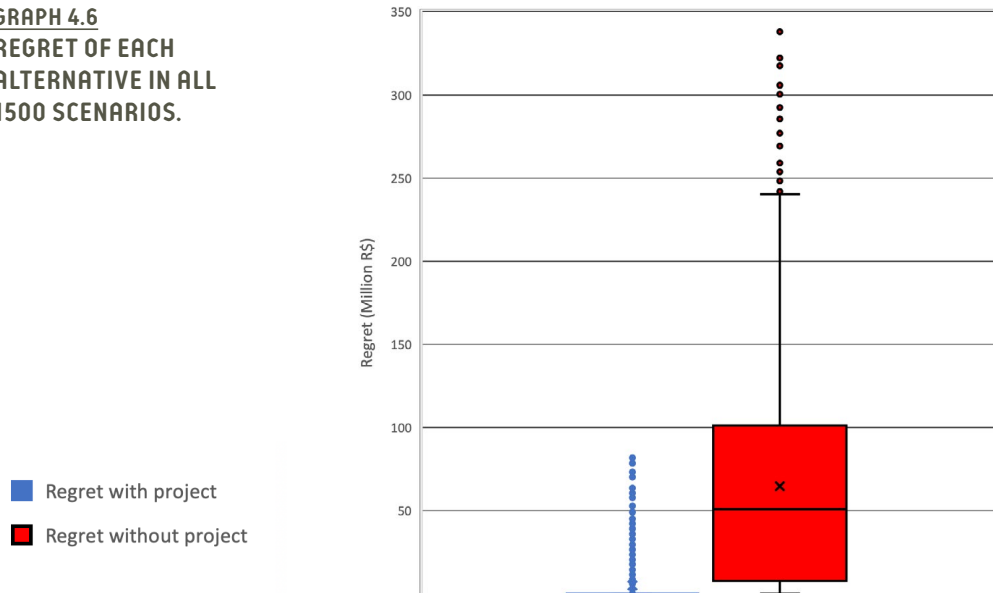
Another approach is to minimize the maximum regret that each alternative can lead to. The choice of this metric assumes a risk averse client, who wants to avoid the worst-case scenario. The regret is defined as the difference in performance of that option compared to the best option, for that scenario.

If i' are all the options considered, and using NPV of the option as the performance criteria, the regret of an option i in the future state of the world is defined by:

$$\text{regret}(i, s) = \max_{i'} (NPV(i', s) - NPV(i, s))$$

The regret is calculated as the difference between the NPV of one alternative and the NPV of the best alternative under this particular scenario. As this study only compares two different alternatives, with and without-project, the regret will be calculated from the difference of these two for the 1,500 different scenarios, as is shown in **GRAPH 4.6**:

GRAPH 4.6
REGRET OF EACH
ALTERNATIVE IN ALL
1500 SCENARIOS.



GRAPH 4.6 shows that regret values for the without-project alternative are higher than for the with-project alternative all scenarios considered. We can then identify the option that minimizes the maximum regret across a wide range of possible futures. The most robust option therefore is the one that solves:

$$\text{mini}(\text{maxs}(\text{regret}(i, s)))$$

TABLE 4.4
MAXIMUM REGRET FOR WITH AND WITHOUT PROJECT ALTERNATIVES

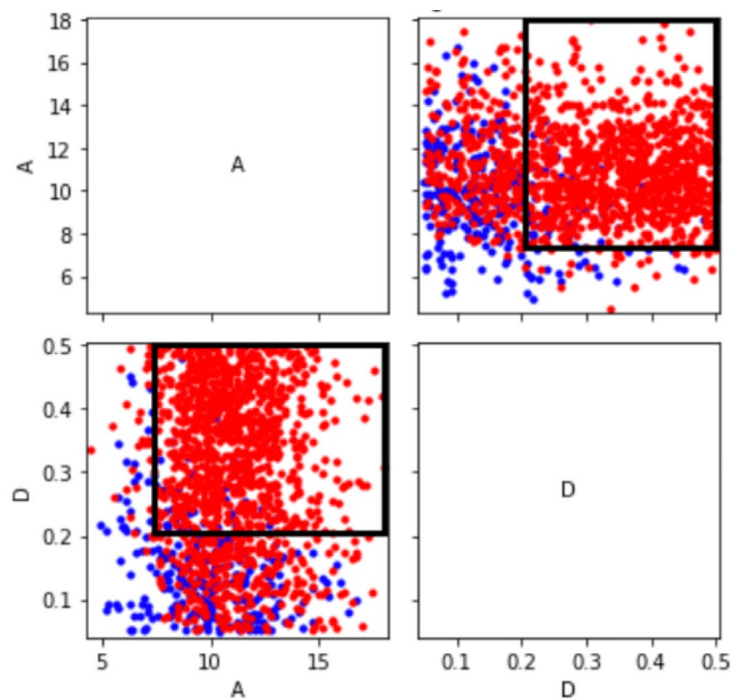
	WITH PROJECT	WITHOUT PROJECT
MAXIMUM REGRET - OVER 20 YEARS IN MILLION R\$	8.23	388.43

TABLE 4.4 shows that the with-project alternative brings the lowest maximum regret, meaning that even when it is performing less well than the without-project alternative the loss is minimal. The maximum regret of the without-project alternative is higher because it misses the potentially very high benefits of with-project alternative in terms of avoided risk (reduction of EUAL and EAD) under some scenarios. The analysis above therefore suggests that investing in countermeasures and maintenance is the most robust alternative for the analyzed pilot project.

One of the main takeaways from the DMU methodology is the availability to analyze the used variables to evaluate which of them have a higher impact on the desired result, in case of this study, NPV greater than 0. The following scatter plot (**GRAPH 4.7**) presents all the 1,500 scenarios. Red dots represent the scenarios where the resulted NPV is higher than 0, while blue dots represent the scenarios with a negative NPV.

Black-bordered boxes hold the scenarios once the variable restrictions have been applied. Density represents the percentage of red dots to the total inside the box. A density of 94.9 percent means that under the selected conditions, NPV is greater than 0 in 94.9 percent of the cases.

GRAPH 4.7
VARIABLE RESTRICTIONS APPLIED TO DIFFERENT SCENARIOS



A: Average number of annual landslides

D: Average landslide risk reduction after structural countermeasures

Density 94.9%

The restrictions are presented in [TABLE 4.5](#) as well, to make the results more understandable. The benefit-cost ratio will be higher than 1 when the uncertain variables stay between the ranges shown in [TABLE 4.4](#).

TABLE 4.5
VARIABLE RESTRICTIONS FOR NPV > 0 IN 94.9 PERCENT OF THE CASES

		MIN	MAX
A	AVERAGE NUMBER OF ANNUAL LANDSLIDES	7.37	18
B	AVERAGE COST OF REPAIRING THE INFRASTRUCTURE AFTER A LANDSLIDE	1,008,953	4,719,439
C	UPFRONT INVESTMENT IN PREVENTIVE COUNTERMEASURES	30,112,504	100,000,000
D	AVERAGE PROBABILITY REDUCTION OF LANDSLIDE OCCURRENCE AFTER INVESTMENTS	20.4%	50%
E	ANNUAL MAINTENANCE COST INCREASE	10%	40%
F	ANNUAL INCREASE OF LANDSLIDE OCCURRENCE PROBABILITY	0.00%	2.50%

Restricted Variables

In this study, the analysis of the variable restriction shows that with an average number of annual landslides greater than 7.37 and an average landslide risk reduction after structural countermeasures greater than 20.4 percent, the scenarios where the NPV is positive are close to 95 percent of the cases.

4.6 CONCLUSIONS

The objective of the DMDU analysis is to assess under which conditions the interventions would make sense or not regardless of the NPVs obtained. However, due to the difficulty for readers not familiarized with DMDU methodology to fully interpret some of the obtained results leading them to a misinterpreting of the whole study, the team tried to improve how to present results in a way that don't generate unjustified doubts of the economic justification. In terms of the objective of identifying conditions under which the interventions would make sense or not, the team emphasizes that the final conclusions of the DMDU analysis remain the same regardless of the distribution of values used in the model.

After carrying out the economic analysis using the DMU methodology for the pilot road in the region of Angra dos Reis (Rio de Janeiro), the following important conclusions could be drawn:

- A. The implementation of well-developed economic analysis for DRM on roads generates valuable information that can be analyzed and compared. The application of economic analysis to a whole road network can provide road agencies with critical information for efficient budget allocation.
- B. The main cost reduction after investing in preventive countermeasures and extra maintenance is shown in the cost related to repair the infrastructure (emergency contracts) after a landslide occurs. The average cost reduction is close to R\$135 million in 20 years.
- C. In the road section under study, 79 percent of the scenarios create an economic benefit when invested in preventive countermeasures and increases in maintenance.
- D. In the road section under study, the average benefit-cost ratio of all the created scenarios is 1.9.
- E. The maximum regret of the without-project alternative is higher because it misses the potentially very high benefits of with-project alternative in terms of avoided risk (reduction of EUAL and EAD) under some scenarios.
- F. When the average number of annual landslides is greater than 7.37 and an average probability reduction of landslide occurrence after investments is greater than 20.4 percent, the scenarios where the benefit-cost ratio is higher than 1 will be 94.4 percent.
- G. Investing in preventive countermeasures and extra maintenance will substantially reduce DNIT's operation costs in the mid and long term. Using average values from this study as an example, with an average initial investment in countermeasures of R\$65,000,000 and an average increase of 25 percent on annual maintenance (current R\$5,250,000), DNIT could save an average R\$137,000,000 in a 20-year period, which is around R\$6,800,000 yearly.

5

SUGGESTIONS AND NEXT STEPS

The objective of the study is to strengthen capacity of geohazard disaster resilience of federal highway infrastructure in Brazil through reviewing DRM capacity for federal road infrastructure and case studies of applying innovative methodologies for assessing disaster risk and evaluating economic benefits of resilience countermeasures. The structure and content of the report has been oriented to provide DNIT with valuable tools, ideas and recommendations that support the transition towards a successful management of geohazard disasters on federal roads.

This study gives greater emphasis to presenting easily implementable methodologies and recommendations than to developing complex techniques that are difficult to understand and implement by the federal road agency. Therefore, although some of the methodologies presented in this report could be further developed, the authors of this report believe that the way they are explained fit the needs of DNIT and other institutions related to DRM in the most appropriate manner.

Based on the above reviews, the following section summarizes the findings and recommendations to enhance geohazard risk management in the road sector in Brazil and thereby, open a path for future actions.

Investing in preventive countermeasures and extra maintenance will substantially reduce DNIT's operation costs in the mid and long term. This study proves the positive economic benefits of investing in the reduction of landslide risk. This has clearly been demonstrated in the analyzed pilot case study. Using average values from the case study as an example, with an average initial investment in countermeasures of R\$65,000,000 and an average increase of 25 percent on annual maintenance (current R\$5,250,000), DNIT could save an average R\$137,000,000 in the next 20-year period, around R\$6,800,000 yearly. With these numbers resulting from a 155 km stretch, the potential savings for the whole federal road network are definitely worth examining in the future.

Calculating the probability of mass movements based on the recurrence rate of rainfall patterns could successfully inform investment decisions. However, lack of consistent data is still an enormous obstacle that needs to be overcome. Spatial distribution of rain gauges is still precarious in Brazil: small number and poor distribution (clustered in a few regions), which can lead to low-efficiency calculation of regional climatological profiles. Historical data series cover limited periods; when available, these include less than 10 years of recorded data. Even though estimating probability of mass movements from rainfall seems a very logical and valuable approach, the lack of a proper data inventory makes it impossible to calculate the rainfall limit value that can start mass movement events. Likewise, a small data population can lead to result inconsistency for statistical reasons. The outcomes of this methodology—susceptibility map and risk map—should be used as indications for prioritizing maintenance and prevention investments aimed at minimizing potential losses in federal transportation system renovation and reconstruction works.

Introduction of drones would be a cost-effective way to monitor potential landslide risks and could be included into existing routine maintenance contracts. The pilot test showed that the drone technology can be used for monitoring slopes or structures effectively where it is difficult to access and detect potential risk through frequent monitoring of slight slope movements. This can be introduced at a cheap cost compared to routine maintenance of road pavements. One recommendation would be that the monitoring of slopes situation at risk locations be included into routine maintenance contracts to guarantee periodical assessment.

The systematic and standardized approach of geohazard risk assessment for road infrastructures should be established and these methodologies applied in this study would help develop such an approach. DNIT does not have any standardized approach for geohazard risk assessment and relies on site engineers' visual inspections, which have a certain limitation in capturing all the risks properly. The methodology mentioned here, the risk assessment approach of historical events and rainfall, together with drone monitoring technology, will significantly contribute to assess geohazard risks more properly and effectively. Furthermore, the DMU economic evaluation method can help DNIT justify economic benefits of risk mitigation investments and prioritize them among other competing interventions.

6

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IMPROVING CLIMATE RESILIENCE OF FEDERAL ROAD NETWORK IN BRAZIL

