Photo Credit: ANI

Critical Climate Change Concerns for the Road Sector in Colombia

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This paper is part of a larger effort funded by the Climate Development and Knowledge Network (CDKN), and conducted in cooperation with the Ministry of Transport and other Colombian government agencies. Entitled, “Mainstreaming Climate Change into the Transport Sector in Colombia,” the project’s objectives are to develop a greater understanding of climate change in Colombia and its impacts on transport systems, and to incorporate findings into the country’s transport planning and development. This paper provides data to inform the rest of the project, which includes development of a manual offering guidance on incorporating climate change concerns into the procurement process, and development of an adaptation plan for Colombia’s transport. The paper represents a synthesis of a larger, more comprehensive document outlining in detail the Colombian transportation system, the methodology used for this analysis, and the regional climate change impacts. For questions regarding the methodology, including assumptions made and the models used, please refer to the technical supporting document (ICF, 2013).

TABLE OF CONTENTS

1 CLIMATE, DEVELOPMENT, AND TRANSPORTATION

Reliable transportation infrastructure is paramount to successful and sustainable economic development in Colombia, where roads act as a primary conduit for commerce and connectivity to goods and services. Transportation infrastructure in Colombia is highly vulnerable to weather-related stressors, particularly floods and landslides, which routinely disrupt transportation services and damage transportation infrastructure. Climate change could exacerbate those impacts on transportation. The Colombian Government is proactively addressing these challenges, through the establishment of national climate change action policies and through mandating the adoption of adaptation strategies into sectors and local governments.[1] This paper is meant to inform the process of addressing climate change in the transportation sector, by identifying key associated climate-related impacts and issues.

Underinvestment in transport has led to a sub-optimal road network in Colombia. A 2007 survey[2] of Colombian roadways indicated that half of the country's road infrastructure was in 'bad to very bad' condition[3] (see Figure 1 for an example of road damage). Extreme weather events have played their part, damaging roadways, and disrupting critical services that can prevent people from reaching health care centers, transporting mining and agricultural products to market and/or transporting freight inland from the ports, for example. Overall, climate-related events including floods and landslides in Colombia have accounted for USD $2.2 million (about 4 billion Colombian pesos) in damages across all sectors (including transport) from 1970 to 2000.[4]

Figure 1: Road damage from erosion and scour between Cucuta and Pamplona. Source: Ministry of Transport, 2012a.

Planned efforts to tackle climate change in transportation investments presents Colombian transportation planners with both a development challenge and an opportunity. The development challenge is to build and maintain a transportation system that encourages economic and social development, protects fragile ecosystems, and is resilient to climate change impacts. The opportunity is to re-invent transport planning to more comprehensively address development needs in a climate-compatible manner that is better adapted to the current and future environment and reduces greenhouse gas emissions. The need to meet this challenge is immediate: with an investment of USD $24.5 billion being implemented by the government to build new roads and to improve the existing

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1 Colombia Policy Guidelines for Climate Change (CONPES No. 3700) (DNP, 2011), National Climate Change System (Sistema Nacional de Cambio Climático) (MADS, 2011), and Managing Climate Change in Colombia (Gestión del Cambio Climático en Colombia) (SINA, 2010).

2 Conducted by the Ministry of Transportation Highway in 2007.

3 Salin and Mello, 2009.

4 IDEAM, 2010.

roadway system, getting it right today is critical. By ensuring that the investments are resilient to future climate change, the economy can remain competitive, and important services can be sustained over the long term to support development needs.

The findings in this paper support the need to carefully consider climate change in Colombian transportation investments moving forward:

- Due to Colombia's high annual rainfall, mountainous topography, and frequent seismic and volcanic activities, floods and landslides are currently the major weather-related hazards to the Colombian transportation system. **Climate change suggests a potential increase in the intensity and frequency of floods and landslides, exacerbating the existing transportation vulnerability.**
- **Of particular importance is the potential increase in the intensity and frequency of floods and landslides in the environmentally, socially, and economically important Andean Region**, an area where critical roadways currently serve highly concentrated and growing populations.
- While a majority of current and projected climate-related impacts on transportation are rainfall-driven, **climate change may result in higher and more frequent thermal extremes, sea level and storm surge increases, which can damage and disrupt transportation infrastructure and services.**
- **Climate change is just one of many interlinked drivers that need to be taken into consideration by transportation planners**. For example, changes in land use/land cover (e.g., deforestation, increases in paved areas), reduced ecosystem services (e.g., linked to land use changes, or as a result of climate change), can lead to more frequent and intense floods and landslides.
- **When undertaking new investments, current and future climate risks should be taken into consideration, in all regions**, since climate change is expected to change risks in all regions; the service lifetime of transportation infrastructure is long; and the development of roadways often stimulates economic and population growth, creating new vulnerabilities.
- **Adaptation needs arising from climate changes will likely challenge Colombian transport and environmental agencies not only technically but institutionally, as well, requiring new coordination mechanisms.** The need for new data and tools and adaptation strategies will necessitate enhanced coordination between transport practitioners and climate scientists, requiring additional institutional capacity to address climate change, and raising resource and budget concerns.
- **Addressing climate change in transportation planning and development provides a critical opportunity to attune transport development and planning processes with social, economic and environmental goals.** A more inclusive transport development and planning process can contribute to quality of life improvements, economic competitiveness, and the preservation of the natural environment.

Fortunately, adaptation measures exist that can enhance the resilience of the Colombian road transport system. These can include changes in the planning and location, design, engineering, operations and maintenance of the roadways, as well as ecosystem-based adaptation approaches. Determining which adaptation measures need to be implemented will require context- and site-specific evaluations in light of their effectiveness, life cycle costs, difficulty of implementation, social impacts, and environmental consequences. Important considerations when prioritizing adaptation measures include (1) conducting vulnerability and risk assessments of transportation systems to identify key weaknesses in the systems, (2) understanding the optimal time to adapt within the lifetime of an asset, (3) considering both costs and benefits of adaptation, and (4) assessing the co-benefits of adaptation measures.

Successful adaptation in the transport sector of Colombia will likely require a holistic suite of policies, planning guidelines, procurement requirements, investment strategies, and education and outreach efforts that will need to be sustained over a long period of time. Climate resilience needs to be championed by all relevant stakeholders. The Ministry and other transport agencies will need to coordinate with other parts of the Colombian government, as well as with key stakeholder groups that make up the larger transport community. The purpose of this document is to summarize the key climate-related impacts on Colombian transportation for the Andean, Caribbean, Orinoquía, Pacific and Amazon Regions (see Figure 2) to help inform that process.

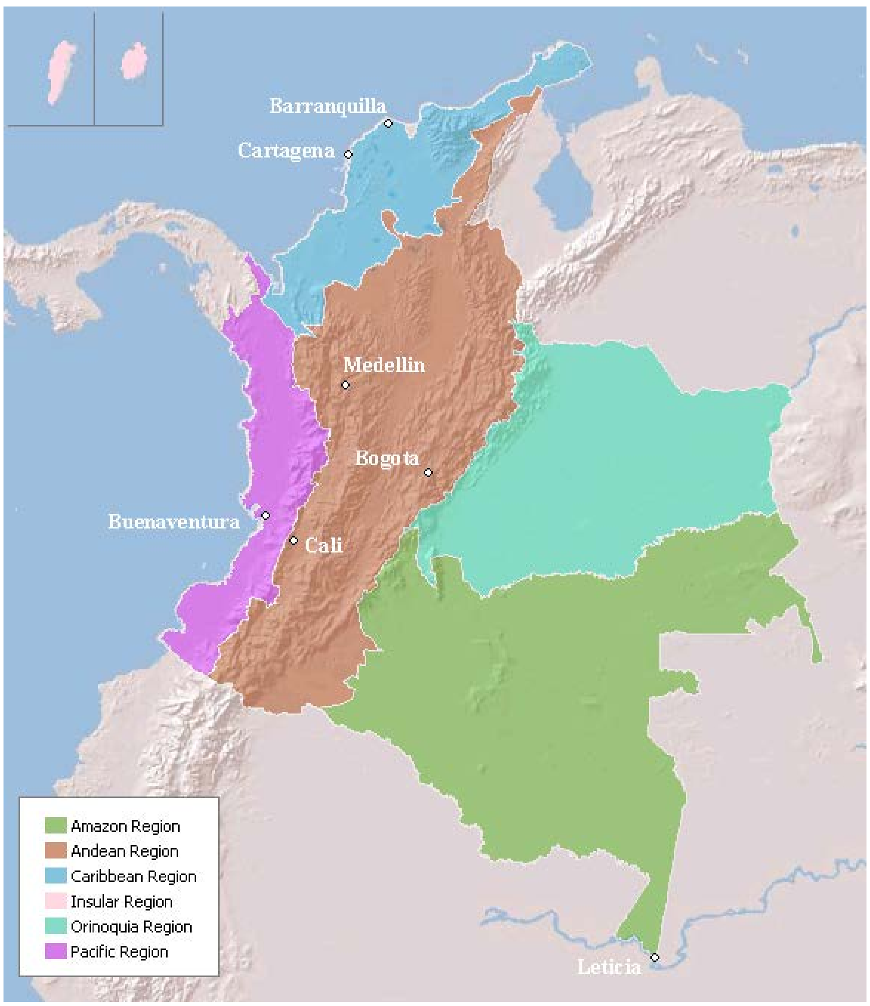


Figure 2: Natural Regions of Colombia

2 COLOMBIA'S TRANSPORT SYSTEM

Currently the Colombian transport network carries more than 200 million passengers and over 200 million tons per year over the different transport modes.[5] Roadways, which are the focus of this paper, consist of more than 214,000 km, allocated into primary, secondary, tertiary, and privately owned roads. Transport by road is the primary means for passenger and freight travel. Therefore, a reliable and efficient roadway transport system is essential for the functioning of the economy, as well as providing citizens with critical mobility. Some of the major corridors in Colombia are shown in Figure 3, while the distribution of transportation by cars, buses, passenger and cargo transport by major corridor is shown in Figure 4.

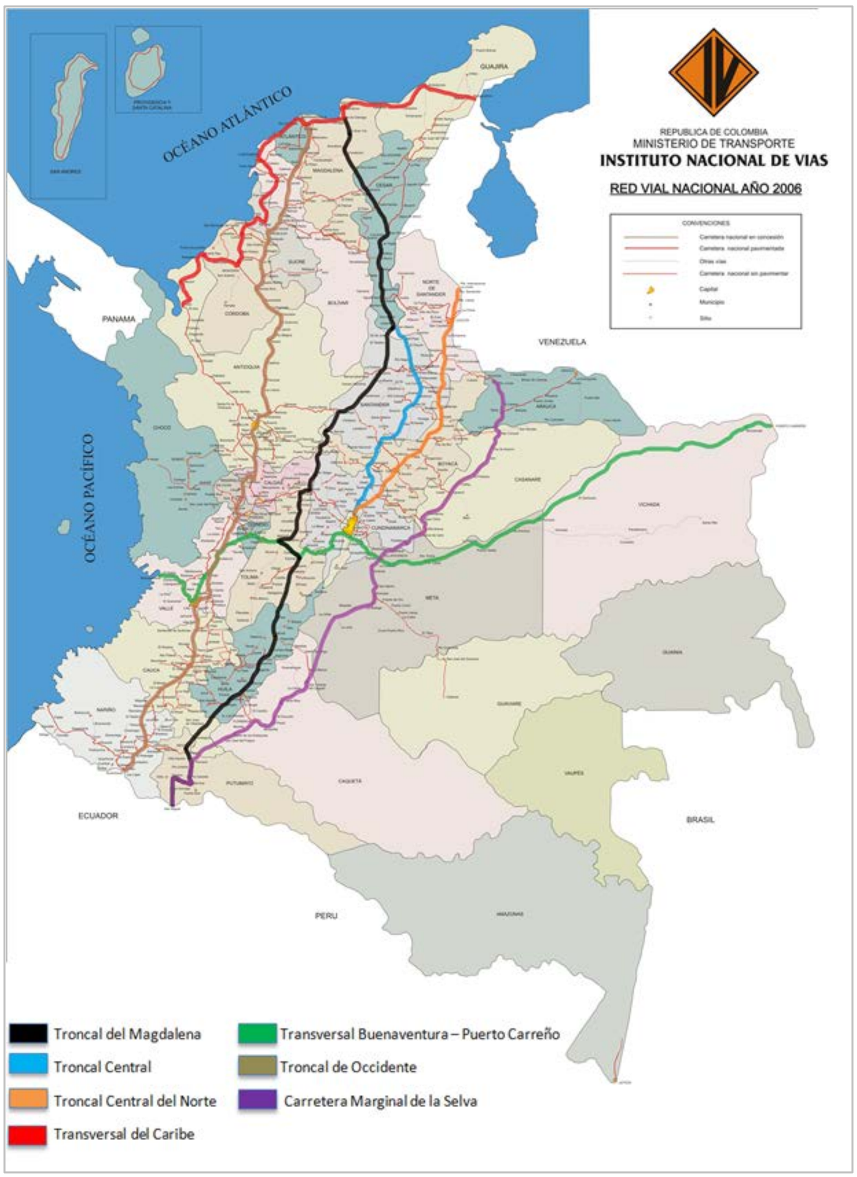


Figure 3: Principle Roadways of Colombia

[5] Ministry of Transport, 2012b.

The main roads are located primarily in the Andean and Caribbean Regions. Analysis of traffic data carried out by INVIAS in 2010, shows that the Troncal de Occidente moves about 30% of the traffic on the seven national roads for passenger travel. This road is the westernmost of the major north-south highways in Colombia. The Troncal Central del Norte and the Transversal Buenaventura-Puerto Carreño, also represent a significant percentage with about 18% and 15% of annual average daily traffic, respectively. The Troncal de Occidente bears the highest proportion of freight vehicles with more than 27% of annual average daily traffic. The Transversal de Buenaventura-Puerto Carreño carries the second highest amount of traffic with more than 19% followed by the Troncal Central del Norte with more than 15% (see Figure 4).

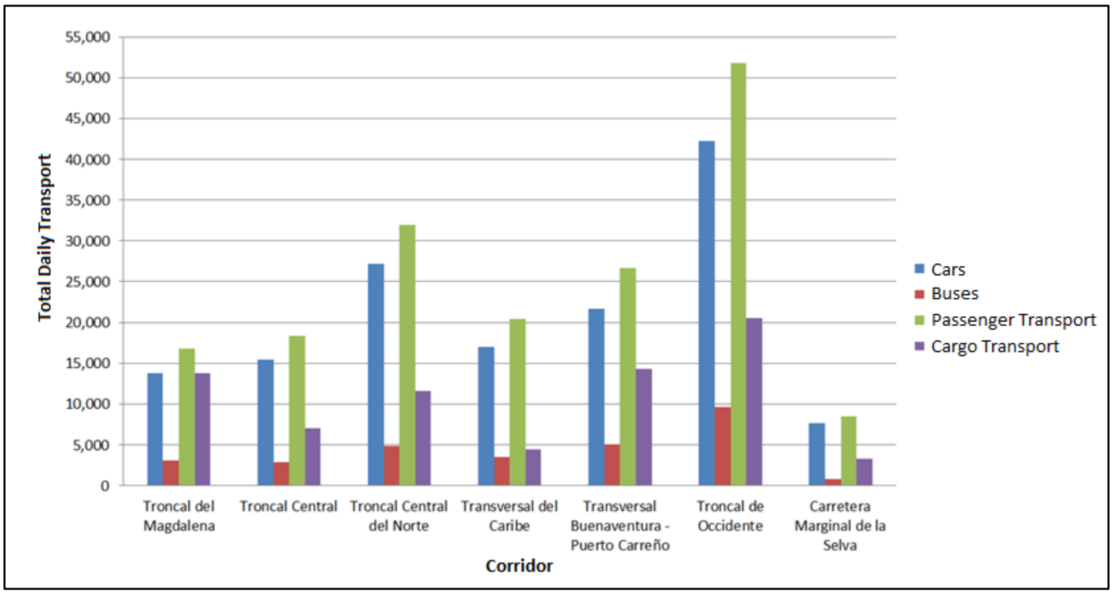


Figure 4: Annual average daily traffic along the main roads of Colombia.[6]

Although the main transport system in Colombia is the road network, it is considered to be of lower quality compared to the other transport modes in Colombia, while the airways system is considered to be the highest quality.[7] Studies suggest that in certain cases, it is less expensive to ship a ton of cargo internationally than domestically, due in part to the poor conditions of roads, and the amounts needed for tolls.[8] Transporting goods from the hinterlands of Colombia to the coastlines or bordering areas is not only costly, but it can also be impossible under certain climate conditions, such as the latest La Niña event (see textbox "Impacts of the 2010-2011 La Niña Event," later in this document).[9] The high costs of freight transport in Colombia reduce the competitiveness of Colombian businesses.

Many of the transportation issues that Colombia faces today stem from the many different populations scattered across rural, suburban, and urban areas. Urban populations have been rapidly increasing in Colombia as people move from rural areas toward cities. In 2005, urban populations made up 76% of

[6] Consultoría Colombiana, 2013a.
[7] Schwab and Sala-i-Martín, 2013.
[8] The Economist, 2011.
[9] Ministry of Transport, 2012b.

the total population of the country, compared to 39% in 1950. By 2020 it is estimated that more than 80% of the country's population will be concentrated in urban areas.[10] The functioning of transportation systems, particularly in urban areas, can affect the country's economic productivity.

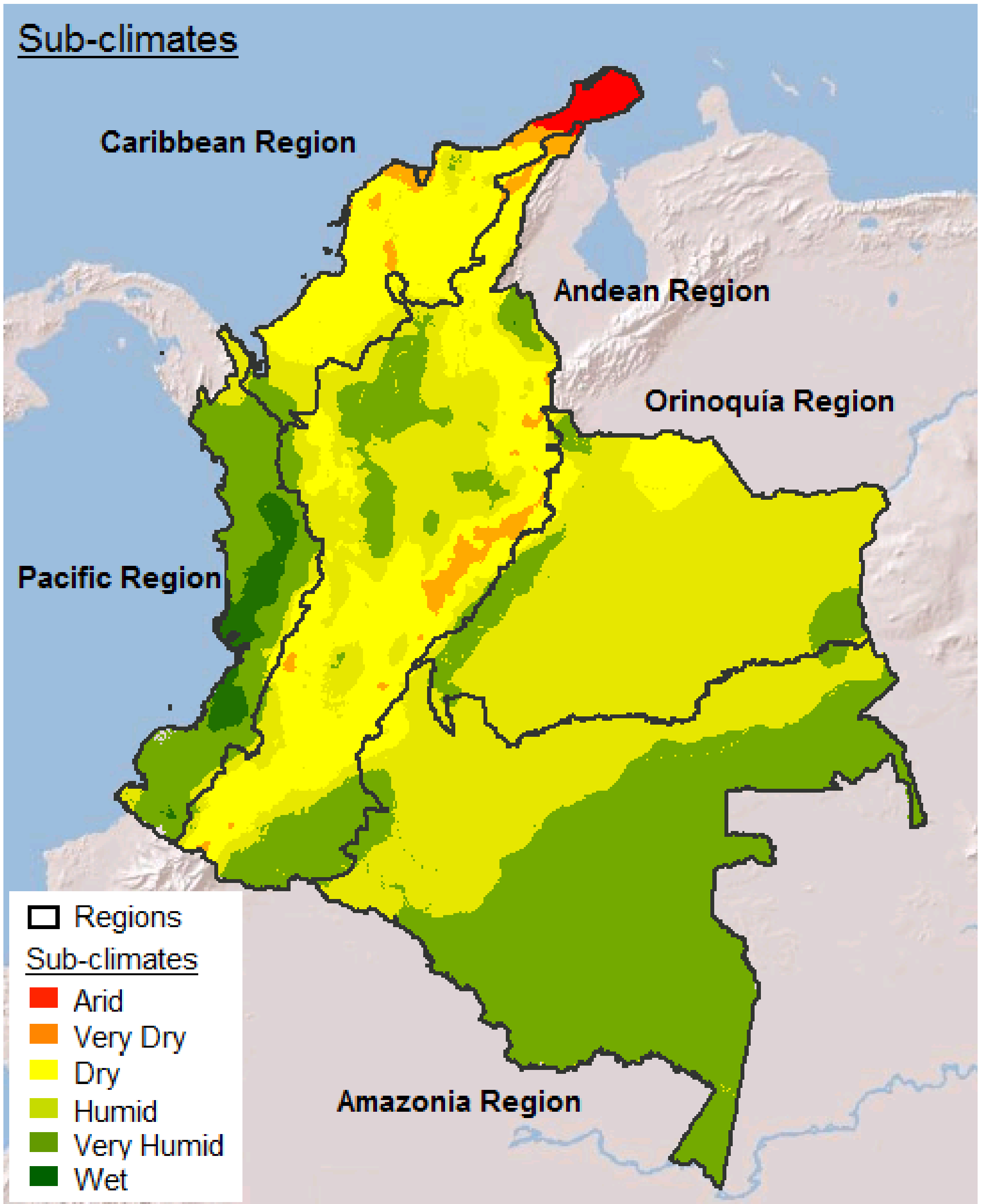
The decentralization of the Colombian government has impacted the way that transportation services are run. Many transportation services in cities have been traditionally provided by private operators and regulated by municipalities. However, some steps are being taken at the national level to address issues with the privatization of transportation and improve services within Colombian cities.[11] Limited financial resources within government agencies have also contributed to deteriorating road conditions in Colombia. As mentioned above, a survey was conducted by the Ministry of Transportation in 2007 of the country's road infrastructure, indicating that only approximately 15% of paved roads were in good to excellent condition, while 35% were in acceptable condition, and 50% ranged from bad to very bad condition.[12]

To address Colombia's previous underinvestment in roadways which was previously less than 1% of GDP per year, the government has released the 4th generation program of roads concessions (4G). The 4G Program, managed by the Agencia Nacional de Infraestructura (ANI), is aimed at investing USD $24.5 billion for 8,917 km of national roadways, benefiting over 22 departments in Colombia. Better understanding of how climate in Colombia impacts on the roadways, and of how this might change as a result of climate change, is critical to ensuring the sustainability of road investments.

3 COLOMBIA'S CLIMATE

Colombia's climate can be classified into 6 categories, spanning from arid to wet, which varies substantially across the 5 regions, (see Figure 5). Across Colombia, the topography varies substantially from the inner-mountainous regions of the Andean Region, to the forested area of the Amazon, to the coastal locations along the Pacific and Caribbean Regions, and the plains of the Orinoquía Region. There are wide differences in climate across the country; for example, quick comparisons of the Andean Region, and parts of the Caribbean and Pacific, show a large climactic diversity due primarily to the complex terrain.

[10] IDB, undated.
[11] IDB, undated.
[12] Salin and Mello, 2009.



Sub-climate	Temperature (˚C)	Precipitation (mm)
Arid	> 24	0 - 500
Very Dry	12 – 18	500 - 1000
Dry	1.5 – 6	1000 - 2000
Humid	> 24	2000 - 3000
Very Humid	> 24	3000 – 7000
Wet	> 24	> 7000

Figure 5: Colombia's climate, classified into 6 sub climates.[13]

[13] Source of data provided by IDEAM, 2013.

This section describes key phenomena that affect Colombia's weather and presents an overview of the historical conditions, current trends, and future projections for climate[14,15] including temperature, rainfall, and sea level. In addition, this section focuses on climate-related stressors that may lead to transportation impacts, such as temperature and rainfall extremes. This section also includes some discussion on flooding and landslide occurrence, particularly as it relates to rainfall extremes. It should be noted that there are strong regional components to some of these stressors. For example, some areas will be affected by drier, warmer conditions in the future, while others will be more prone to wetter conditions and more frequent flooding episodes. The Pacific and Caribbean Regions will contend with sea level rise and storm surge, while interior regions will not.

Temperature. Historically, average temperature has varied significantly across Colombia. For example, average temperatures in the mountainous regions can be less than 5°C while the hottest areas are close to 30°C. Year-to-year temperature variability across the country has been shown to be closely related to the occurrence of the El Niño and La Niña phenomena.[16] Strong El Niño events have been associated with notable increases in Colombia's annual average temperature in the country (e.g., of the ten warmest years over the period 1960 - 2011, eight were influenced by El Niño). Conversely, during La Niña events, average temperatures in the country also noticeably decreased.

From 1980 to 2011, Colombia's average annual temperature has experienced an increase of almost 0.2°C per decade.[17] Between 1960 and 2006, there has been a notable increase in the number of hot days[18] and hot nights[19] throughout the year.[20] The number of hot days per year has increased by 76 days (or 21% more hot days) and the number of hot nights has increased by 74 (or 20% more hot nights).[21] In addition, the number of cold days[22] has decreased by 26.6 days (or 7% of cold days) and the number of cold nights[23] has decreased by 27 days (or 7% of nights).[24]

In the near term (2011-2040) and under low and moderately-high emission scenarios, **annual temperatures are projected to increase across all regions** from 0.7 to 1.1°C under the low emission scenario and between 0.9 to 1.3°C under the high emission scenario. By mid-century (2041-2070), the

[14] For purposes of this report, weather is defined as day-to-day events and climate is defined as 20- to 30-year averages.
[15] This analysis used 9 climate models to consider future climate changes in Colombia. While the models broadly agree in temperature in terms of magnitude and direction of change, there are some disagreements in the magnitude and direction of change (i.e. positive or negative) for precipitation. As such, the results should be interpreted with caution. Please see the technical report for further description of the results, and the confidence in each of the precipitation projections presented here (i.e., agreement across models).
[16] IDEAM, 2012.
[17] IDEAM, 2012.
[18] Defined as the number of days in which the daily maximum temperature exceeds the 10 percent warmest days in the climate period (1970 to 1999).
[19] Defined as the number of days in which the daily minimum temperature exceeds the 10 percent warmest days in the climate period (1970 to 1999).
[20] McSweeney, 2010.
[21] McSweeney, 2010.
[22] Defined as the number of days in which the daily maximum temperature is below the 10 percent coldest days in the climate period (1970 to 1999).
[23] Defined as the number of days in which the daily minimum temperature is below the 10 percent coldest days in the climate period (1970 to 1999).
[24] McSweeney, 2010.

annual average is projected to increase across the regions by 1.2 to 1.6°C under the low emission scenario and between 1.6 to 2.2°C under the high emission scenario. With some exceptions, the months June through August are projected to experience the greatest increase in seasonal temperature across the regions.

Rainfall. **Since 1960, Colombia has become wetter in March through May, while June through August has become slightly drier. The total amount of rainfall has increased during extreme events**. From 1980 to 2011, Colombia's total annual precipitation has showed an increase of about 7 mm per decade.[25] Within Colombia, areas that have experienced an increase include: much of the Caribbean, Orinoco, Amazon, middle Magdalena valley, middle Cauca (most of Antioquia), the Coffee, northern and central Pacific, the foothills of Meta, central and southern Huila Tolima (see Figure 6).[26] The behavior of high-intensity rainfall tends to follow similar patterns as that for total annual precipitation described above.[27] Between 1960 and 2006, Colombia's March-May period has become wetter by 6.8 millimeters per month per decade (i.e., a 2.9% increase per decade).[28] This is offset by a smaller decrease in rain during the June-August months of 3.1 millimeters per month per decade (i.e., a 1.3% decrease per decade).[29]

[25] IDEAM, 2012.
[26] IDEAM, 2011a.
[27] IDEAM, 2011a.
[28] McSweeney, 2010.
[29] McSweeney, 2010.

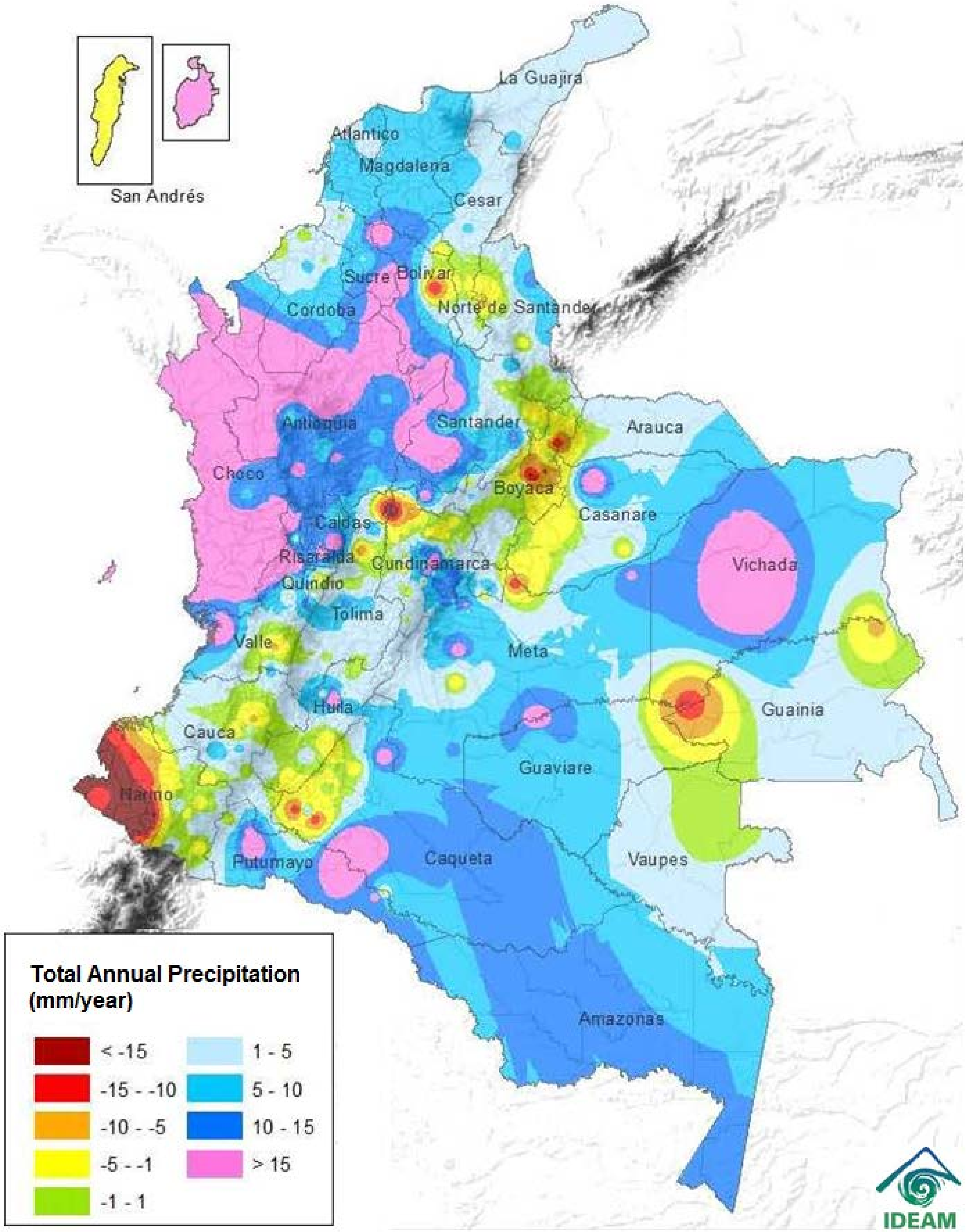


Figure 6: Trend of total annual rainfall from 1970 through 2010. The positive trend (shaded blue and fuccia) is an increase in precipitation and the negative trend is a decrease (shaded yellow, orange and red).[30]

[30] IDEAM, 2011a.

The amount of rain received during extreme rain events has increased. During the December-February months, the precipitation associated with a 1-day maximum event per year has increased by 3.5 millimeters per decade.[31] The precipitation associated with a 5-day maximum event per year has increased by 6.6 millimeters per decade during March-May and decreased by 6.5 millimeters per decade during June-August.[32] During a La Niña event, conditions across Colombia tend to experience normal to above normal precipitation.

Since the welfare of the transportation system is directly impacted by heavy rainfall events, it is useful to consider general precipitation indices shown in Table 1, which reflect the intensity and frequency of storm events, and can also act as proxies for changes in precipitation extremes that might impact floods and landslides.[33,34]

Table 1: Precipitation indices that describe the frequency and intensity of precipitation events

Index	Definition	Implications	Associated Hazard(s)
r10	Number of days with precipitation at or above 10 mm/day (days)	Direct measure of the number of very wet days, highly correlated with total annual and seasonal precipitation in most climates.	Flood, landslide
r5d	Maximum total 5-day precipitation received per year (mm)	A measure of short-term precipitation intensity.	Flood, landslide
r95t	Percent of annual total precipitation due to events exceeding the 1970-2000 95th percentile (%)	This index can be highly correlated with the number of extreme events per year.	Flood, landslide

As shown in Table 2, the intensity of heavy precipitation events tends to be greatest in the Pacific Region followed by the Orinoquía and Amazon Regions. These regions, though, do not experience quite as many heavy precipitation events per year compared to the Andean and Caribbean Regions. In other words, the Andean and Caribbean Regions appear to experience less intense but more frequent heavy precipitation events.

[31] McSweeney, 2010.
[32] McSweeney, 2010.
[33] For more in depth discussion of these indices, see ICF, 2013.
[34] Brazilian Foundation for Sustainable Development (FBDS), undated.

Table 2: Precipitation indices for five climate regions in Colombia (1970 to 2000), based on data provided by IDEAM (2013).[35]

Region	# of Stations in region	95-Percentile (mm)	r10 (days)	r5d (mm)	r95t (%)
Amazon	5	49	71	181	20
Andean	79	36	48	131	30
Caribbean	17	47	36	141	30
Orinoquía	14	53	70	191	20
Pacific	7	67	115	262	20

As for projections for future precipitation patterns, the **mid-term projections suggest a wetter climate compared to today for most of the country during December through May, and September through November**. Changes in precipitation are a concern as precipitation is considered a primary cause of landslides in Colombia.[36] The increase in precipitation can increase soil moisture affecting slope stability and causing landslides.[37] The June-August is generally projected to become drier – a pattern that strengthens the initial drying suggested by the near-term projections. In short, there appears to be a tendency for the wet periods becoming wetter and the dry periods to become drier.

The projected near-term and mid-century changes of the precipitation indices are provided in Table 3. For most regions and future time periods, these indices suggest the intensity and frequency of heavy precipitation events will increase. The Caribbean is a notable exception to this.

Table 3: Near-term projections of absolute and percent change of precipitation indices compared to 1970 to 2000 conditions, based on analysis of WCRP CMIP3 data.

Region	r10 (days)		r5d (mm)		r95t (%)	
Description	Number of very wet days per year		Short-term intensity of worst event per year		Number of extreme events per year	
B1						
	Historic	Projected Change	Historic	Projected Change	Historic	Projected Change
Amazon	71	4.9 (7%)	181	6.4 (4%)	20	2.4 (12%)
Andean	48	6.0 (12%)	131	6.6 (5%)	30	0.3 (1%)
Caribbean	36	3.5 (10%)	141	-1.4 (-1%)	30	-1.7 (-6%)
Orinoquía	70	1.2 (2%)	191	0.2 (<1%)	20	0.1 (<1%)
Pacific	115	7.4 (6%)	262	11.8 (5%)	20	1.5 (8%)
A2						
	Historic	Projected Change	Historic	Projected Change	Historic	Projected Change
Amazon	71	4.2 (6%)	181	5.0 (3%)	20	2.1 (11%)
Andean	48	1.4 (3%)	131	0.8 (1%)	30	0.4 (1%)
Caribbean	36	-3.7 (-10%)	141	-7.3 (-5%)	30	-2.3 (-8%)
Orinoquía	70	0.5 (1%)	191	1.4 (1%)	20	1.0 (6%)
Pacific	115	1.4 (1%)	262	4.8 (2%)	20	0.8 (4%)

[35] IDEAM, 2013.
[36] Khabarov et al., 2011.
[37] IFC, 2011.

Sea Level Rise and Storm Surge. During the 20th Century, global average sea level has risen by 170 millimeters (0.17 meters).[38] The rise in global average sea level has accelerated in recent decades to approximately 1.6 millimeters per year from 1961 to 2003.[39] However, sea level rise is not uniform across the globe due to local changes in such factors as salinity, ocean circulation, sediment and erosion, and geomorphology (uplift/subsidence).

In Colombia, sea level has risen along the coastal areas from 1 to 3 millimeters per year from 1960 to 1990 with an acceleration noted over the past decade.[40] The Cartagena tidal station reports a rise in sea level of about 5.6 millimeters per year over the last 40 years.[41] The Puerto Cristobal station in the northwest and the Buenaventura station in the Pacific Coast both recorded a rise in sea level of 2.2 millimeters per year over the same time period.[42] These tidal stations suggest that some of these coastal locations have experienced sea level rise faster rate than the global rate.

As sea level rises, infrastructure and other assets at or near sea level may be flooded more frequently or more severely. A number of studies suggest mean global sea level may rise within the range of 0.5 to 2.0 meters by 2100 with a general consensus of 1 meter.[43,44,45,46,47,48] This range demonstrates the large uncertainty associated with estimating sea level rise. Maurice et al. (2010) suggest that sea level rise for the Caribbean will be close to the global mean.[49] The findings available for our study suggest local sea level rise has occurred at or above the global mean. This suggests that the future projections of global mean sea level rise may be somewhat conservative regarding what may be experienced along the Colombian coastline.

Storm surge heights associated with various return periods, or recurrence intervals, have been developed for the Cartagena tidal station (see Table 4). For example, a 10 year storm surge height of 128 mm has a 10% chance of being exceeded in any one year and a 50 year storm surge of 151 mm has a 1/50 or 2% chance of being exceeded in any one year. Despite the connotations of the name return period, this does not mean that a 10 year storm event will happen regularly every 10 years, or only once in 10 years. In any given 10 year period, a 10 year event may occur once, twice, more, or not at all. The storm surge height is the incremental height associated with the storm surge (e.g., tidal variations would be an additional height). When compared to the tidal range of 360 mm experienced at this station, the storm surge height is not considered significant for causing coastal flooding, even with the storm surge associated with an event that has a 1% chance of occurring in any given year.[50]

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[38] Bindoff et al., 2007.
[39] Domingues et al., 2008.
[40] Magrin et al., 2007.
[41] IFC, 2011.
[42] Magrin et al., 2007.
[43] NRC, 2010.
[44] Nicholls et al., 2007.
[45] Rahmstorf, 2007.
[46] Pfeffer et al., 2008.
[47] Rohling et al., 2008.
[48] Grinsted et al., 2009.
[49] Maurice et al., 2010.
[50] IFC, 2011.

Table 4: Storm surge heights for return periods for the Cartagena tidal station.[51]

	Return Period			
	1	10	50	100
Height (mm)	83	128	151	159

With increasing sea level, the water height of the storm surge associated with tropical storms will correspondingly rise, allowing the surge and waves to travel farther inland. This will cause greater shoreline erosion and local damage, in effect magnifying the impact of storms. Though there is much debate regarding how tropical cyclones (e.g., hurricanes, tropical storms) may be affected by climate change, there is general consensus that these storms in the Atlantic basin may decrease in frequency but increase in intensity by the end of the century.[52] However, Colombia is not situated within the hurricane track and it is not clear if this track will change due to changes in climate.

4 CLIMATE IMPACTS ON ROAD TRANSPORT IN COLOMBIA

This section presents an examination of the implications of climate stressors for the country's road network, considering both observed and projected impacts. Understanding the damage that has already been incurred on Colombia's road network due to climate-related stressors can help assess the scale of potential damage in future years. Given the distinct characteristics of each of Colombia's regions, it is imperative to assess the risks to the country's road transport system on a region by region basis. Before delving into a detailed regional analysis, an overview is provided of the current and projected impacts of key climate related stressors on Colombian roadways.

4.1 OVERVIEW OF IMPACTS

Climate-related impacts have already been the cause of substantial and costly destruction in Colombia. As most Colombians would know intuitively, the two hazards that are most significant to the roadway system are landslides and floods[53] – the projections discussed above demonstrate that the severity of each of these hazards is likely to become more intense in the coming years as climate changes – suggesting a potential increase in costs and damages.

In Colombia, six reported hazards are related to weather events: landslide, erosion, forest fire, flood, storm surge, and drought. ***Of these, only landslides and floods are recorded as a demonstrated impact on the roadway system.***

In this section an overview of impacts is provided for the following climate stressors: heavy rainfall events (and associated flooding and landslides), sea level rise and storm surge (and associated flooding), and temperature increases and extremes. Other climate-related stressors are discussed in the regional

[51] IFC, 2011.
[52] Knutson et al., 2010.
[53] Other hazard categories in the database include flash flood (only two incidents were recorded with impacts on the roadway system), storm surge, erosion, avalanche, gale, hail, thunderstorm, earthquake, volcanic eruption, fire, accident, explosion, collapse, and various unspecified hazards.

analysis. In addition, the combined effects of climate change and other drivers are highlighted, as multiple stressors can interact to result in impacts on transportation infrastructure.

Heavy Rainfall, Flooding and Landslides. More extreme rainfall and severe storm activity – including La Niña events – trigger a number of impacts that affect roads (see example, below). In particular, flooding and landslides caused by heavy precipitation have serious consequences both for human safety and infrastructure conditions (Figure 7). These hazards are also exacerbated by anthropogenic stressors such as development, deforestation, and population growth. Understanding current risk to these hazards provides a lens through which to view future risks as they may change with climate. Figure 8 presents the number of floods and landslides each year that have affected the roadway system across the country.[54] Recent years indicate a correlation between high rainfall La Niña years with a greater number of damaging landslides and floods.[55]

Figure 7: Collapse of "El Mochilero" bridge near San Jose del Fragua by scour on the abutments. Source: Ministry of Transport, 2012a.

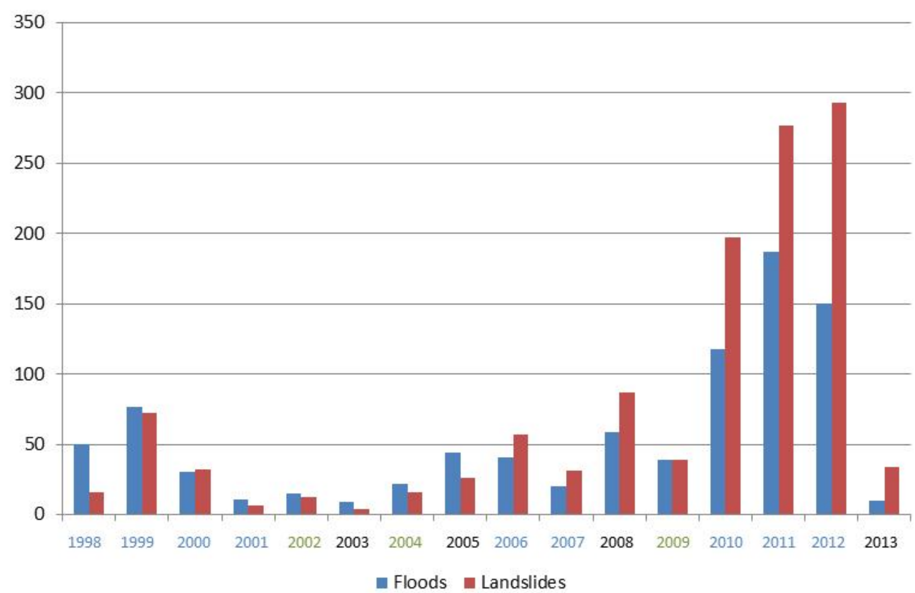

Figure 8: The number of floods and landslides affecting roadway segments each year in Colombia. Years in blue indicate La Niña years, years in red indicate El Niño years. Based on ICF data analysis of the UNGRD database.[56]

[54] Damages to the roadway system are constrained to impacting a road or bridge.

[55] This first order approach labeled years as La Niña or El Nino if at least three months where considered abnormal in the oceanic nino index using the NOAA climate prediction center website (cpc.ncep.noaa.gov/products.analysis_monitoring/ensostuff/ensoyears.html).

Impacts of the 2010-2011 La Niña Event

The 2010-2011 La Niña Event in Colombia illustrates how damaging an unusually extreme rainy period can be to Colombia's transportation system and the most vulnerable locations. This event impacted 4 million people, caused 491 deaths, and destroyed or damaged 562,000 homes. A total of 98 major roadways were damaged, causing delays in distribution and driving up commodity prices. The Caribbean and Andean Regions of the country were the hardest hit and saw precipitation levels exceeding historical records.

Deforestation exacerbating floods and landslides. In the Magdalena-Cauca river basin, deforestation led to increased erosion and sedimentation, further exacerbating the impacts caused by flooding. While the flooding was extensive and dramatic, the damage done to infrastructure such as roads and aqueducts was caused by major landslides and mass movement.

Economy. Natural disasters (e.g., floods and landslides) caused by the severe December to February months during the 2010-2011 La Niña event resulted in total economic losses of more than USD $6.2 billion, of which USD $1.9 billion were allocated to the transport sector. Cargo transport was badly affected and the resulting detours and stoppages of traffic flows caused loss of about USD $222 million. Table 5 shows the share of departments in national losses of cargo on roads caused by natural disasters in the transport sector.

Table 5: Summary of damages by sectors (millions of USD $) caused by the 2010-2011 December-February period.[57]

Sector	Damages	Percentage	
		Total	By Sectors
TOTAL	**6.240,63**	**100,00%**	
Habitat	**2.726,41**	**43,69%**	**100,00%**
Environment	43,91	0,70%	1,61%
Housing	2.390,35	38,30%	87,67%
Water and sanitation	292,15	4,68%	10,72%
Social services and public management	**695,06**	**11,14%**	**100,00%**
Education	428,16	6,86%	61,60%
Health	107,14	1,72%	15,41%
Family welfare	11,28	0,18%	1,62%
Culture	32,08	0,51%	4,61%
Sports facilities	95,65	1,53%	13,76%
Police force	19,28	0,31%	2,77%
Law enforcement	1,47	0,02%	0,21%
Infrastructure	**2.371,00**	**37,99%**	**100,00%**
Transport	1.883,97	30,19%	79,46%
Power	487,03	7,80%	20,54%
Productive	**448,16**	**7,18%**	**100,00%**
Agribusiness	422,16	6,76%	94,20%
Non-Agribusiness	26,00	0,42%	5,80%

Impact on transport. The loss in the transport sector alone requires an investment of more than 0.5% of GDP. When compared with previous investment levels of less than 1%, the impact of the 2010-2011 La Niña event is clear. The departments that suffered the greatest losses in cargo transport are shown in Figure 9. The department of Otros was most severely impacted, experiencing a disproportionate loss of more than 43%.

[56] UNGRD, 2013.
[57] Consultoría Colombiana, 2013b.

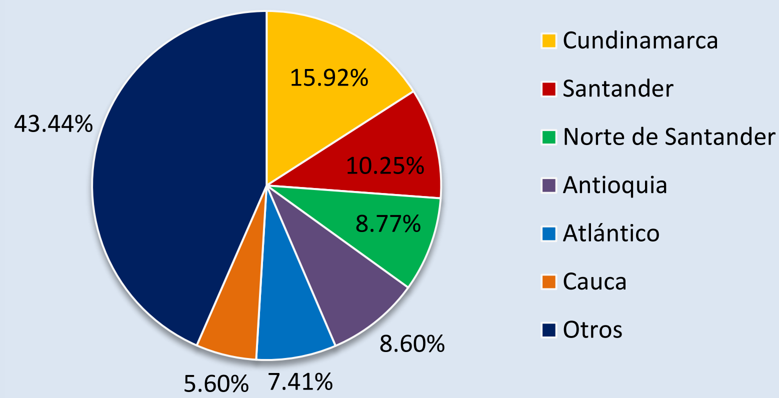

Figure 9: Share by departments in losses in cargo transport, caused by December-February disasters in the 2010-2011 La Niña event.[58]

Increases in heavy precipitation events can lead to an increase in weather-related accidents and disruptions during downpours, and associated flooding. Currently, about 45% of the road network infrastructure is highly vulnerable to flooding.[59] Flooding of roadways can lead to increased mortality and injury, disrupt commerce and lead to economic losses, and damage roads, bridges, and drainage systems (Figure 10).[60] Flooding risk is compounded in coastal areas, where flooding can be more severe due to sea level rise. Figure 11 shows the number of floods and flood-affected roadway segments and bridges by region. From 1998 to 2013, the majority of floods (about 70%) and associated damages to the roadway system occurred in the Andean Region.

Figure 10: Flooding from the Bogotá River on the road north to Chía. Source: Ministry of Transport, 2012a.

[58] Consultoría Colombiana, 2013c.
[59] IDEAM, 2010.
[60] CDKN, 2013.

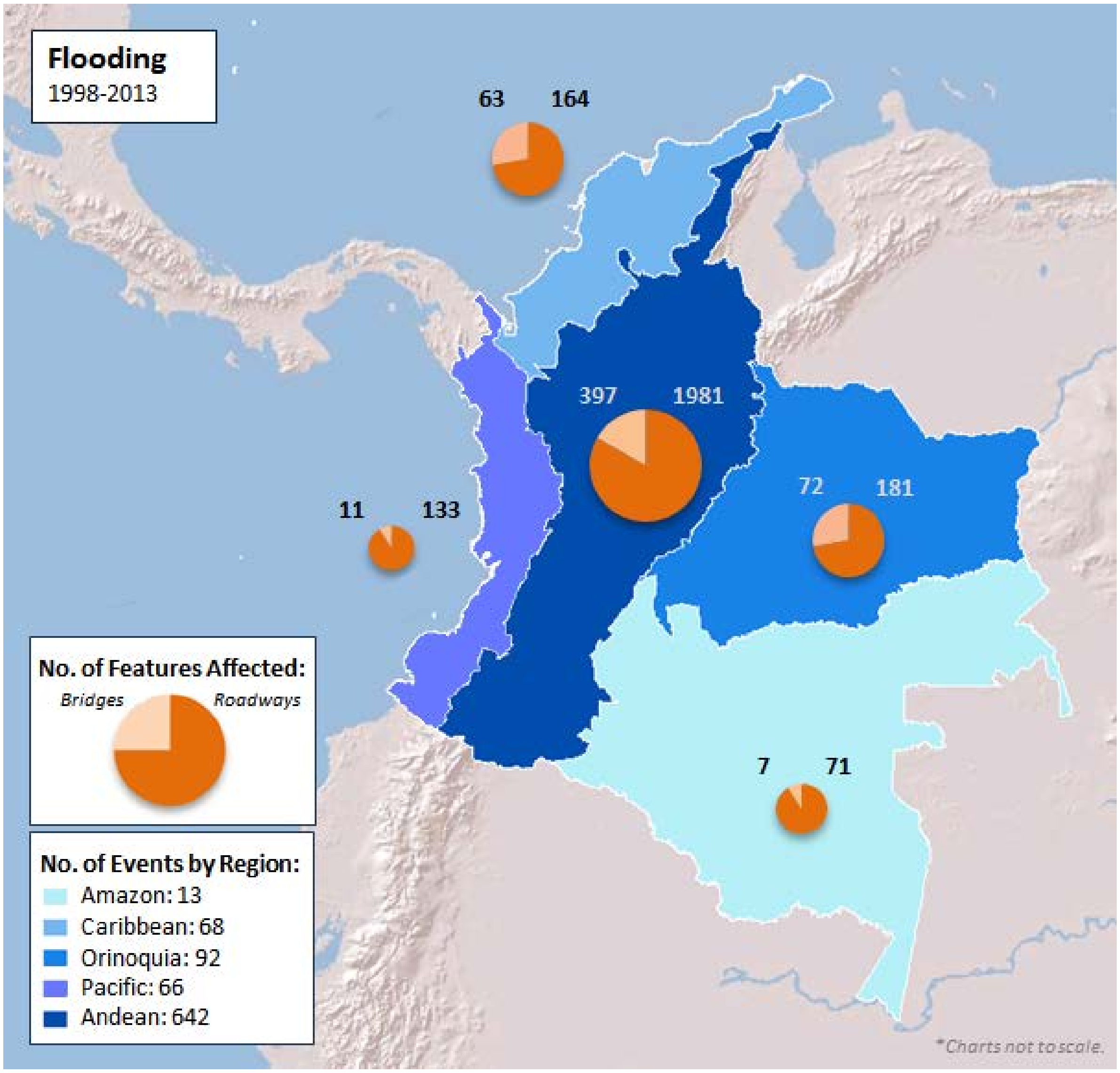

Figure 11: Number of floods and affected roadway segments and bridges by climate region, based on ICF analysis of data from UNGRD database.[61]

Figure 12 provides an overlay of areas historically susceptible to flooding with regional projections of areas vulnerable to heavy precipitation through 2040 for the months March through May. Corridors exposed to this risk include the Monteria-Coveñas and the Caucasia-La Apartada corridors located in the Departments of Córdoba and Antioquia, respectively. The Bogotá metropolitan area is also vulnerable, as demonstrated by the 2010-2011 floods: many of the roads east of the mountain and adjacent to the capital were flooded causing significant damage as described above.

[61] UNGRD, 2013.

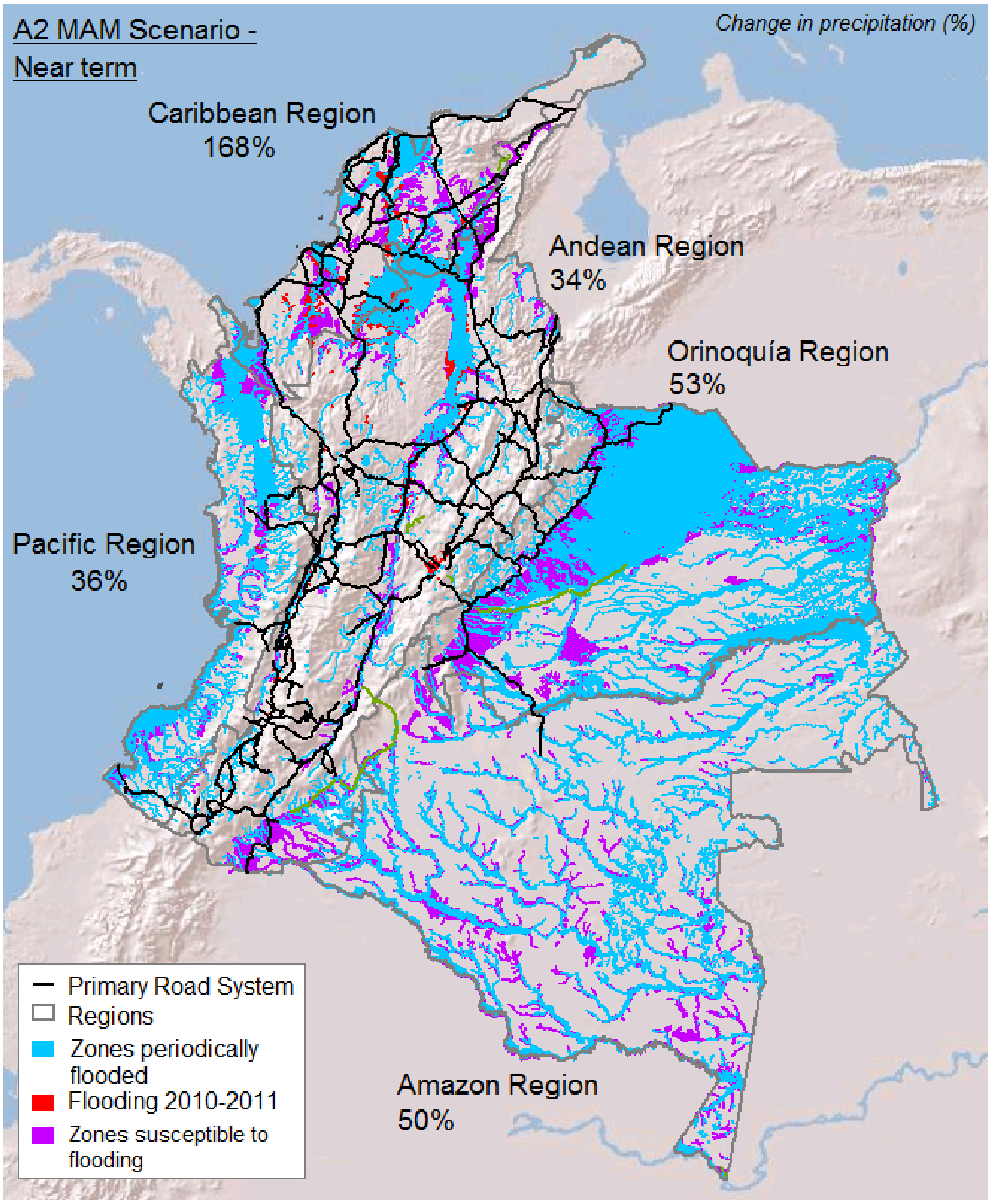

Figure 12: Primary roadway system overlaying the flooding susceptibility and near-term precipitation change in March-April-May for each of the five natural regions for the moderately-high (A2) emission scenarios. (Sources: Flood data--IDEAM, IGAC, and DANE. Precipitation percentages are based on analysis of WCRP CMIP3 data).

Due to Colombia's high annual rainfall, mountainous topography, and frequent seismic and volcanic activities, landslides are frequent hazards in the country[62] and pose significant risks to the roadway system. Landslides may become more predominant with an increase in heavy precipitation events, leading to an increase in roadway closures and delays and costly infrastructure damage. Overall, most of the floods and landslides with impacts to the roadway system historically have taken place in the

[62] Schuster and Highland, 2001.

Andean Region, with a third of all hazard events in that region occurring in March through May. In contrast, the Caribbean Region experiences more landslides and flooding in the September through November. Similar to flooding, most of the landslides (about 90%) and associated damage to roadways and bridges from 1998 to 2013 occurred in the Andean Region (see Figure 13).

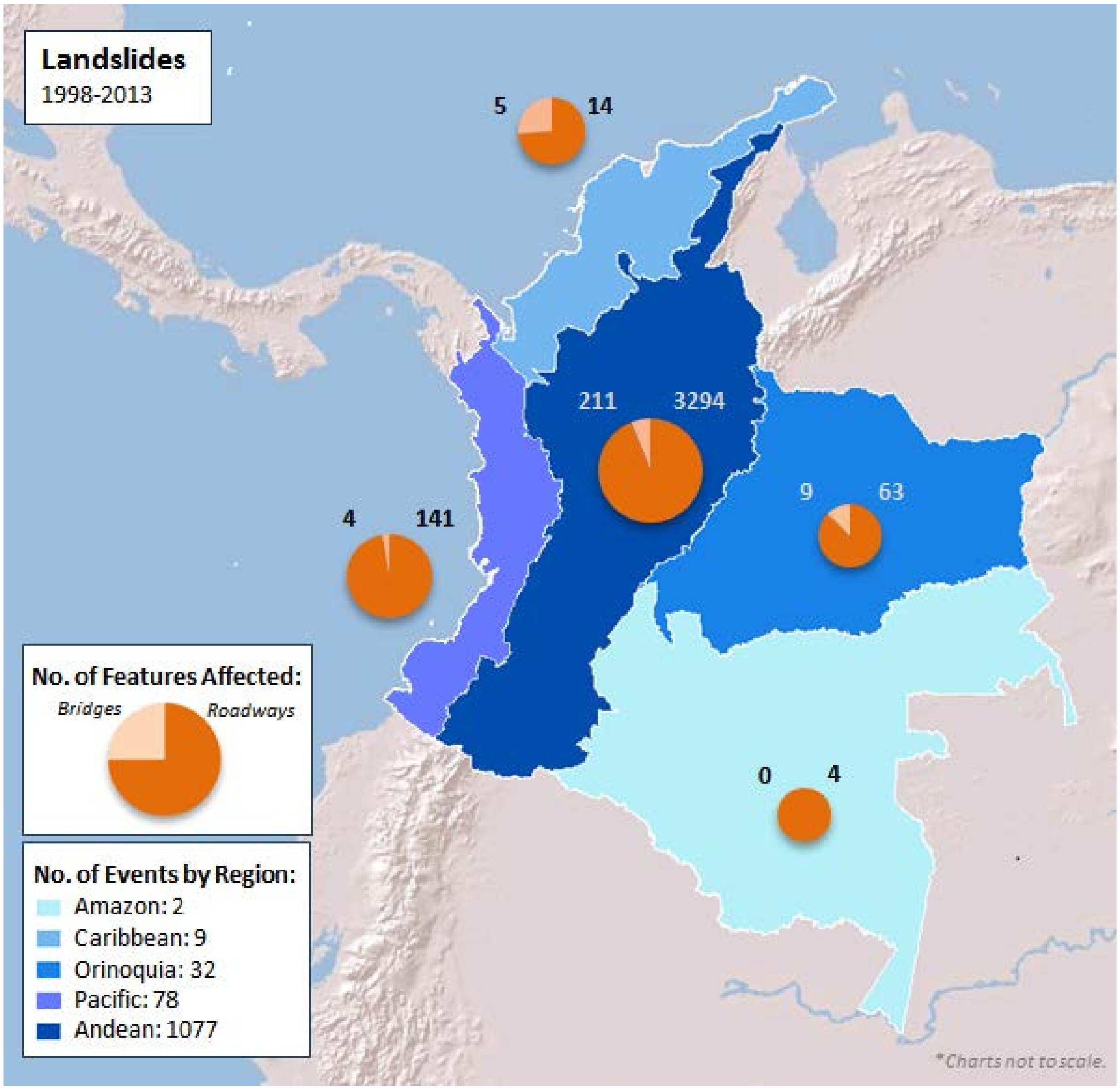

Figure 13: Number of landslides and affected roadway segments and bridges by climate region, based on ICF analysis of data from UNGR database.[63]

As landslides are a natural hazard to the primary roadway system, it is important to consider how landslides may change under a changing climate. Figure 14 provides an overlay of areas historically-susceptible to landslides with regional projections of areas vulnerable to heavy precipitation events and flooding through 2040 (under the A2 scenario). Note that while all regions under this scenario are projected to experience greater precipitation which could theoretically increase the threat of landslides, rainfall may not be the limiting factor, other critical factors such as topography and land cover must be

[63] UNGRD, 2013.

in place. That said, given the Andean Region is at greatest risk from landslides this qualitative analysis indicates that landslide risk may increase.[64] The roadway Honda-Villeta, located between Bogotá and the Magdalena River, is one of the most exposed corridors to this natural hazard. Other highly susceptible corridors include the Silvana-Girardot corridor and the Villavicencio-Granada corridor located south and east of the capital, respectively.

[64] See ICF (2013) for description and caveats associated with this analysis.

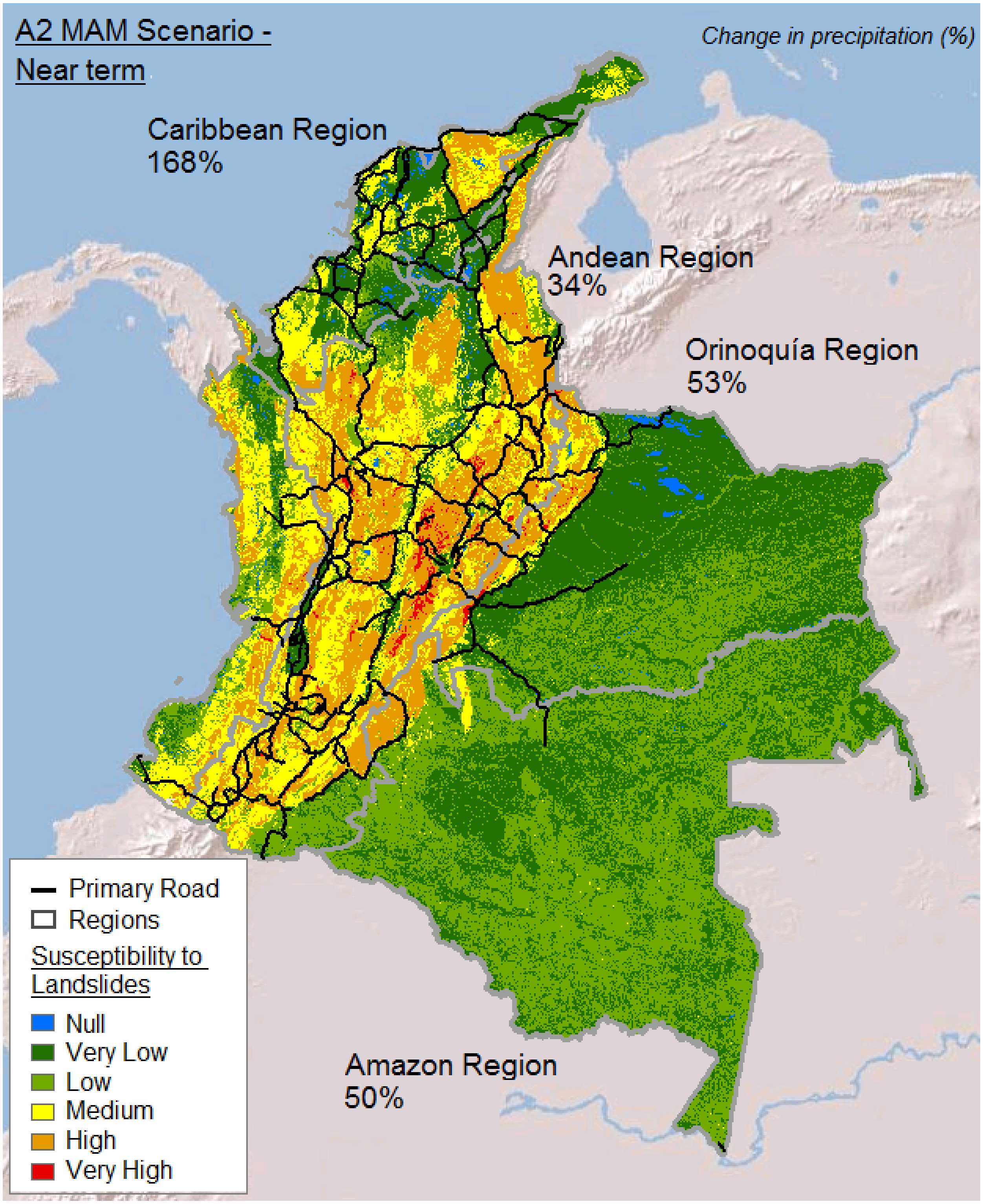

Figure 14: Primary roadway system overlaying the landslide susceptibility and near-term precipitation change (%) in March-April-May for each of the five natural regions for the moderately-high (A2) emission scenarios. (Sources: Landslide data—jointly developed by IDEAM and the Colombian Geological Service (SGC). Precipitation percentages are based on analysis of WCRP CMIP3 data).

Impacts associated with sea level rise and storm surge. As sea level rises, infrastructure and other assets at or near sea level may be flooded more frequently or more severely. It is estimated that a sea level rise of 1 meter could affect 1.4 to 1.7 million people in Colombia.[65] Sea level rise is a concern along both the Pacific and Caribbean Region coastlines. As sea levels rise, some coastal and low-lying roadways and underground tunnels may be affected by flooding that could cause shut downs and traffic delays. In addition, the infrastructure may be damaged by erosion of road bases and undermining of bridge supports.[66] Further, with increasing sea level, the water height of the storm surge associated with tropical storms will correspondingly rise, allowing the surge and waves to travel farther inland. This will cause greater shoreline erosion and local damage to existing roadways, and may affect the siting and design of future roads, bridges, and tunnels.

Impacts associated with rising temperatures and thermal extremes. Rising temperatures and thermal extremes can affect roadway systems by affecting the pavement materials and environmental conditions impacting roadways. Hot temperatures can cause the pavement slabs to shift and can adversely soften materials.[67] Increasing temperatures can also alter vegetation patterns that affect road infrastructure. For example, vegetation used for erosion control may not thrive under hotter temperatures; invasive aquatic vegetation can clog drainage systems.

Human operations (road repairs and maintenance, traffic control) can be impacted by high temperatures—often, limitations are placed on the amount of time operations staff can work in high temperature conditions (for example, over 32°C). In cases for which heat events occur after heavy precipitation events, local humidity can exacerbate the "feel" of temperatures on people—an 31°C day with 70% relative humidity can impact the human body as much as a low humidity, 37°C day. In addition to affecting transportation infrastructure directly, climate change will also have implications for ecosystem services that are supported by transportation. For example, climate change impacts on the páramos could result in adverse effects on Colombia's road network (see box).

Multiple stressors and vulnerabilities. The combined effects of climate change are important to recognize as plans are developed for the location, design, construction, operation and maintenance of the nation's roads. The combination of heavier precipitation events and rising sea level can result in even more severe coastal flooding. In the case of coastal storms involving a storm surge, sea level rise can exacerbate impacts of surge. Immediate impacts include inundation of infrastructure, rendering it unusable temporarily until flooding recedes or until repaired/replaced. The long-term impact of saltwater flooding can include corrosion of structural supports and of electrical operating equipment. In any type of flooding (fresh or saltwater), scour and erosion can destroy natural and manmade support structures.

[65] IDEAM, 2010.
[66] IFC, 2011.
[67] INVIAS, 2006.

The Páramos, Climate Change and Transportation Services

One of Colombia's most vital natural areas is 'the páramos', which is a generally cool and humid Andean ecosystem that is found in areas between the timberline (~3,600 meters elevation) and the frost line (~4250 meters elevation)[68] (See Figure 15). Approximately 60% of the vegetation in the páramos is unique to the area; these include giant rosette plants, shrubs, and grasses.[69] Together, these plants serve a vital function as water regulators for areas at lower elevation, including the major metropolitan areas of Colombia: the Chingaza páramo, for example, provides 80% of Bogota's water.[70] Consequently, protecting these fragile ecosystems is considered a necessity by the government.

Figure 15: Páramos Location Map (Source: T. Consiglio, MBG)

According to IDEAM, recent years have witnessed various climate change-related impacts in the páramos. IDEAM analysis of climate data from selected weather stations located in or near the páramos shows a decline in annual precipitation totals[71] and an increase in average temperatures, explaining an observed increase in glacial melting. The average temperatures in these areas could increase between 2.5˚C and 3˚C and precipitation could reduce between 10% and 20%.[72] As a result, scientists expect that the páramos will have less water storage capacity. This would bring new challenges not only to the ecosystem, but to cities such as Bogota, Cali, and Medellin, which rely on the páramos for their water needs.[73]

Further research is needed to improve the understanding of the hydrological cycle and water budget in these areas, including the effects of receding glaciers on the hydrology of páramos and of future climate variability and change on streamflow. However, reduced water storage capacity in combination with intense precipitation events or increased glacial melt could result in increases in runoff . Resulting in potential increases in erosionand flooding downstream, affecting the transport system. range), these climate-related risks to the páramos are concerning.

In addition, the combined effects of climate change and other drivers of change are important for transportation planning. For example, demographic and land use changes, in combination with climate change, could exacerbate existing vulnerabilities. The loss of vegetation through deforestation can increase the susceptibility of soil to erosion (Figure 16), 'encouraging' landslides and increasing sedimentation in the rivers. In addition, as population increases, cities may continue to grow, increasing impermeable surfaces and placing increased pressures on the existing drainage system. In combination

[68] Greenpeace, 2009.
[69] Greenpeace, 2009.
[70] Greenpeace, 2009.
[71] These observed reductions are specific to the páramos stations and are contrary to the increased trend recorded at observation stations throughout much of Colombia.
[72] IDEAM, 2011a.
[73] Greenpeace, 2009.

with increases in rainfall extremes a result of climate change, floods and landslides may also increase in frequency and severity, exacerbating impacts on transportation infrastructure.

Figure 16: Caved-in roadway due to erosion between Bucaramanga and Barrancabermeja. Source: Ministry of Transport, 2012a.

The significance of climate-related impacts will increase as travel increases. The degree to which a roadway segment is critical to travel – and to system connectivity – is a vital factor when considering the relative importance of climate impacts to Colombia's overall road transport system. As travel demand increases, so does the impact of delays, closures, and accidents that may result from climate impacts. The roadways that may be in most need of adaptation are the ones in which two stressors exist: (1) the roadway serves municipalities with high (and growing) populations, and (2) the roadway is located in a region that is projected to experience an increase in heavy precipitation events.

4.1 REGIONAL ANALYSIS

In this section, the information is presented in a regional context. This provides transportation planners with relevant summaries and concisely discusses the key findings to assist them in focusing their future vulnerability assessment and adaptation efforts. For each region, the analysis begins with an overview of the area's geography, economy, and population. This is followed by a brief description of the region's key transportation infrastructure and services, focused on the road network but also mentioning other significant modal infrastructure, such as airports, rail lines, and ports. Then the analysis summarizes the key climate-related impacts on road transportation, first addressing current risks, and then turning to the potential future impacts of climate change and variability.

4.1.1 Andean Region

As the region with the largest population and economy, the Andean Region is also home to the majority of Colombia's built transportation system. The hazards of landslides and flooding associated with heavy precipitation events are already common in the Andean Region and cause damage to the transportation system. These events occur throughout the year, but are most common in the March-May months, followed by the December-February, September-November, and June-August.[74]

Flooding and landslides cause costly repairs, and also disrupt passenger travel and movement of goods (see box). For example, the road between Bogota and the port of Buenaventura experiences recurring landslides and is often unable to operate at full capacity.[75] These disruptions cause infrastructure damage and also require extensive detours, which are estimated to cause commercial losses of USD $5

[74] These three month comparisons are used for a consistent analysis between past and future conditions and impacts. One of the ways the climate community analyzes future conditions is through three month averages and totals; these three month comparisons do not represent Colombia's wet/dry seasons which vary by region.

[75] Agrimoney.com, 2011.

million per day. Flooding from intense rainfall in December 2010 caused nine road closures and 26 roadway restrictions in Caldas.[76] The disruptions in Caldas and other departments disrupted logistics for Colombian industries and affected the movement of goods across all modes of transportation.

Snapshot of Repair Costs in the Department of Antioquia

Flood, landslide, and erosion hazards can be costly and affect traffic patterns for months. Table 6 presents selected financial impacts of 2008 hazard events in Antioquia that affected roadways in Colombia. The costliest repairs in 2008 were associated with landslides where erosion had occurred.

Table 6: Corridors that were impacted in 2008 by various hazard events (TPD = average daily traffic).[77]

Corridors	TPD 2008	% TPD trucks	km	% km affected	Type of work	Terms in months	Estimated investment (millions of pesos)
Floods							
Los llanos - Taraza - Caucasia 2511, 2512 (Medellín – Caucasia)	2779	59%	188	20%	Walls, erosion control, embankments, hydraulic structures	8	8000
Landslide							
La Mansa – Primavera 6003 (Medellín - Quibdo)	1175	20%	94	70%	Stability of slopes, drainage work	6	25000
Landslides/erosion							
Chogorodo - Dabeiba – Santa Fe de Antioquia 6202, 6203 (Medellin - Turbo)	599	42%	223	40%	Walls, drainage, stability of slopes	6	33000
Bolombolo – Santa Fe de Antioquia 25B02	405	18%	73	90%	Walls, slope stability, hydraulic structures for erosion control	3	35000
Erosion, undermining of bridges							
Cisnero Cruce Ruta 45 Puerto Olaya 6206 (Medellín – Puerto Berrio)	1776	31%	153	20%	Walls, drainage work, erosion control	8	18000

[76] Coifman, 2010.
[77] INVIAS, 2013.

Overall, the Andean Region is projected to experience a climate that is warmer and wetter in the future, particularly in the March-May time period**.** This raises important concerns for transport in this populous and economically-active region:

- **Planning for construction and operations of the concession and public roads through 2040 will need to take into consideration potential increases in intensity and frequency of floods and landslides.** Our analysis projects that rainfall for low and high emission scenarios will likely increase in periods when floods and landslides are already very prevalent. In addition, the intensity of the heaviest rainfall events is also projected to increase by one to five percent. These impacts warrant consideration in the location, design, and operations of road transport in the Andean Region.[78] This could also potentially disrupt riverine transportation in the Magdalena and Cauca rivers, if bridge heights do not provide sufficient clearance, or are not designed to withstand higher runoff.
- **Continued deforestation in the Andean Region could contribute to greater erosion and destabilization of slopes, contributing to landslides.** While data indicate that the rate of deforestation has slowed, some 435.000 hectares of land were deforested in the 2005 – 2010 period. Forest preservation, particularly in areas where new roads are planned, could help reduce the potential for landslides and reduce costs of construction. In addition, restricting human development from these susceptible areas may reduce the effects of landslides on both the population and the assets.
- **Given the very large population and economic importance of the Andean Region, more detailed examination of these impacts in the planning, development, and operations of current and future transport facilities, especially the road system should be a high priority.** Unless addressed, climate change impacts through 2040 may cause severe disruptions to the transport system, reducing economic activity and quality of life.

Potential development changes in the Andean Region could both exacerbate and mitigate some of the risks posed by climate change. For example, unregulated development on mountainsides could further destabilize slopes and contribute to landslides. Population growth could continue to stress watersheds and drainage systems and increase flood frequency, all the while putting more people in flood-prone areas. Future development in susceptible areas would increase the amount of roadway segments exposed to these hazards. However, development could also alleviate some of the stresses posed by natural hazards. For example, development of new roadways could introduce redundancy into the transportation system and would allow for goods and people to continue to move even if certain components of the system are closed.

4.1.2 Caribbean Region

The Caribbean Region is the second most important transportation hub in Colombia, after the Andean Region. It is home to some of the most important sea ports in Colombia, including the ports of Cartagena, Barranquilla, Bolivar, Mamonal, Santa Marta, and Coveñas. Roads and railways connect the

[78] These quarterly periods overlap with the 'wet' season in the Andean Region (i.e., April through June; September through November).

Caribbean region with the hinterland of the country, facilitating the movement of goods to and from the sea ports.

Transportation infrastructure in the Caribbean region is vulnerable to a variety of natural hazards, including floods, storm surges, and erosion. There is some occurrence of landslides, but overall landslides are not a major risk since the region's topography largely consists of lowland plains. Floods are a major concern in the region. Between 1998 and 2013, there were 68 floods that caused damage to road infrastructure.[79] Most of the floods in this region occur from September-November which overlaps with the last 3 months of the rainy season.

In addition to climate-related factors, natural hazard risks in the Caribbean region are influenced by a number of anthropogenic stressors. There has been high population growth along the region's coastline from 1993 to 2005. Population increase and associated economic growth have led to the removal of natural buffers against flooding and erosion such as mangroves. In addition, population and economic growth have stressed the drainage systems in urban areas, resulting in increased damage from flooding. Most of the Caribbean coastline has experienced some degree of erosion. The Caribbean region has also experienced some deforestation between 1990 and 2010; however, this region is not as heavily forested compared to the Andean and Amazon regions and hence may be more relevant as a localized stressor.[80] A review of the issues associated with climate change impacts in the Caribbean Region shows the following:

- **Sea level rise, particularly in combination with storm surge, and mangrove destruction, can increase the number, intensity, and impact of coastal flooding events on roads and ports in the already flood-prone areas of the Caribbean Region.** Sea level rise will vary by locality, but is expected to rise on average globally by 0.5 to 2.0 meters by the end of the century. Colombia's First National Communication to the UNFCCC indicates that 45% of the road networks on the Caribbean coast are highly vulnerable, 5% are moderately vulnerable, and 23% are slightly vulnerable to sea level rise of one meter.[81] Flooding will also exacerbate coastal erosion, especially in areas where natural buffers such as mangroves have been removed.[82] Flooding events from storm surge in combination with sea level rise could result in greater inundation. Ports, including road and rail connections for inland transport, have been shown to be already vulnerable to flooding which over the long term could threaten the economic vitality of port operations and reduce economic activity. Careful examination of existing and planned roads and ports to this hazard should be done. Continued monitoring of sea levels, flooding events, road conditions and port operations will help identify critical thresholds where intervention may be necessary.
- **Elevated temperatures from climate change may raise road and bridge maintenance costs and could cause some assets to fail**. In the near term, climate models project that temperature will increase about 1°C throughout the year in the Caribbean region where annual average

[79] UNGRD, 2013.
[80] IGAC, 2013.
[81] IDEAM, 2010.
[82] Cardoso and Benhin, 2003.

temperatures are already among the highest in Colombia at >24°C. With increasing average temperatures, increases in the intensity of high heat events as well as their number are expected to increase. While temperature is currently not an identified hazard to the transportation system in the region, extreme heat events in the future may cause paving materials to warp, expand and crack, resulting in disruption in service. Furthermore, bridge materials that were not designed to withstand extended periods of intense heat may weaken or fail. Additional maintenance of road surfaces and bridge components may be required as a result. Monitoring of pavement condition, as well as maintenance costs, may be warranted in this region.

- **Changes to the incidence and intensity of inland flooding events are not clear in the Caribbean Region and warrant further monitoring.** Historically, flooding has occurred primarily in the September – November period, where rainfall I expected to increase, along with the March – May period. Based on this information, the Caribbean region could experience more flooding in March-May and potentially also in the September-November period. However, the number of extreme precipitation events and the short-term intensity of the worst event per year are projected to decrease, thus potentially reducing susceptibility to extreme flood and landslides in the region. Further monitoring appears warranted.
- **Population increases combined with loss of mangroves and other natural protections against the impacts of climate change due to development pressure could worsen erosion, increase flooding, and disrupt some transport services.** The population in the Caribbean is projected to continue to increase by 2020. The northern areas have experienced severe erosion in the past decades, partly due to mining activities, and are likely to see increased erosion due to sea level rise. Currently, there is only one primary road in these areas, but more roads may be constructed to accommodate the population growth, therefore increasing the number of roads that are vulnerable. Moreover, if development continues to encroach on mangroves, which are increasingly threatened by sea level rise, this can further exacerbate the vulnerability of the coastal Caribbean to the effects of erosion and flooding. Efforts to lessen these impacts due to population and development can be explored for this region.

4.1.3 Orinoquía Region

The relative lack of infrastructure in the Orinoquía region has limited economic development by making it difficult to transport and trade goods, particularly cattle and agricultural products. For many years, the majority of roads in this region have been unpaved, making road transport nearly impossible during the rainy season.[83] Poor road conditions and low road density have led to river ports and waterways serving as the key form of transportation.

[83] Viloria de la Hoz, 2009.

Natural hazards, such as riverine flooding and drought, pose a major challenge for the Orinoquía region. The main types of natural disasters experienced in this region are wildfires, floods, erosion, and windstorms. Flooding and drought are both part of the natural wet and dry seasons of the region.[84]

From 1998 to 2013, the region's road and bridge infrastructure was impacted by flooding 90 times and by landslides 31 times. Flooding and landslides in this region are most common during June-August and March-May (the rainy season), which is when the majority of destruction to road infrastructure occurs.

In the foothills , expansion of agriculture has led to deforestation. Slash-and-burn agriculture occurs from December to February and is a major cause of forest fires; most of the fires in the Los Llanos region are caused by slash-and-burn agriculture.[85] Several socioeconomic and institutional factors may also exacerbate natural hazard risks in the Orinoquía region.

Analysis of data supplied by the Government of Colombia and other sources indicates the following:

- **Increased heat events in the Orinoquía could lead to increased need for maintenance and disrupt road operations.** Average yearly temperatures in the Orinoquía are typically higher than 24°C and can reach 30°C. Annual average temperatures in the Orinoquía region are projected to increase in both the near-term and mid-century. Very hot days can increase the strain on asphalt paved roads, resulting in rutting and other damage to the road surface. Very hot days during the dry season could also increase the risk of wildfires, which could potentially delay road travel. Detailed examination of heat extremes in this region, along with routine monitoring of road conditions and pavements, would assist assessment of the need for direct intervention.
- **Road transport disruptions in the Orinoquía Region could worsen due to increased floods and landslides, disrupting freight transport of oil and gold, as well as other goods.** Rainfall during floods and landslide-prone months (March – August) is projected to increase, indicating a potential intensification of floods and landslides. In addition, heavy rain events are projected to become more frequent, potentially rising by as much as 8 percent. A more severe rainy season is likely to result in higher number of road closures due to landslides and flooding. Strong floods can washout unpaved roads, particularly if the roads are located in an area with poor drainage. In addition, unpaved roads may need to be closed following heavy rains to avoid damage to the road surface from traffic. If flood waters infiltrate the road substrate, they can severely damage asphalt road surfaces.
- **Severe bridge scour due to riverine flooding could necessitate extensive repairs, road closures, and even bridge replacement**. While the road and bridge infrastructure in the Orinoquía is limited compared to most other Regions, the bridges that do exist across rivers across rivers may face a future of increased runoff from increased precipitation and heavy rain events.

[84] Dry period ranges from 2 to 5 months, generally between November and March and the wet period ranges from May through October (Armenterasa, 2005).
[85] Armenterasa, 2005.

4.1.4 Pacific Region

The Pacific region has some of the most important ports in Colombia, including Buenaventura, Tumaco, and Quibdo, among which Buenaventura is the most critical as a gateway to Asia. However, inland modes of transport are sparse in the Pacific. Overall, the region represents only 4% of the country's total primary roadways, 3% of railways, 9% of airports, 7% of ports, and 3% of bridges[86], and yet the major road in the area, the Troncal Occidente, carries 29.7 and 27.9 percent of the passenger and freight transport, respectively, making its smooth operation a strategic objective.

As a coastal region with one of the world's highest rainfalls, the Pacific region is vulnerable to a variety of natural hazards, including landslides, floods, sea level rise, and storm surge. Between 1998 and 2013, 78 landslides with impacts on the roadway system were recorded in the region. Landslides are most common in March through May, followed by September through November, December through February, and June through August. Meanwhile, a total of 66 floods that damaged road infrastructure were recorded from 1998 to 2013. Floods are most common from March through May. High levels of annual precipitation (6,000-7,000 mm per year) have also limited hours of operation at the port of Buenaventura. Rainy conditions have caused delays in unloading ships and impacted the port's reputation, leading to losses of business.[87]

Due to its relatively lower population and economic growth, the Pacific region faces less pressure from anthropogenic stressors compared to other regions of Colombia. Population growth was minimal for most of the region between 1993 and 2005, except for the areas around Buenaventura and Tumaco.[88] There was some deforestation between 1990 and 2010, but overall the region remains heavily forested. There is little or no indication of erosion along the Pacific coastline.[89]

- **Flooding and landslides will continue to disrupt road operations unless corrective action is taken.** As the Pacific Region already has one of the highest rainfalls in the world, projected precipitation increases to those disruptions significantly. In September-November and March-May, which are when the large majority of floods and landslides already occur, quarterly precipitation in the near term could more than double in the September – November period, and by as much as 36 percent in March - May. Furthermore, this increased tendency could be exacerbated by an increase in the frequency and intensity of heavy precipitation events. The number of heavy rain events per year could increase by 4 to 8 percent. Intensity of the worst events could increase by 1 to 5 percent. Given the likely strategic importance of maintaining service on the Troncal Occidente, addressing these issues could be key.
- **Sea level rise could increasingly pose a threat to transport to and from the important ports and connecting roadways in the Pacific**. It is estimated that sea levels will rise by 0.6 meters along the Pacific coast by 2050 to 2060 compared to the 1961-1990 average.[90] Of the estimated 462,457 inhabitants on the Pacific coast, IDEAM projects that 41% would be at direct risk from

[86] IGAC, 2013.
[87] IFC, 2011.
[88] DANE, 2011.
[89] IGAC, 2013.
[90] Catarious and Espach, 2009.

flooding due to sea level rise. Port facilities, including inland road connections should be closely examined for vulnerabilities to better assess the need for corrective action.

While the Pacific is currently a sparsely inhabited region, population is projected to continue to grow. Moreover, as Colombia further develops its trading activities with Asian countries, the Pacific may experience an economic boom in the future, with potential consequences for the natural environment. If natural buffers such as mangroves are removed, for example, the region will be at greater risk to coastal flooding and erosion from sea level rise and storm surges.

4.1.5 Amazon Region

The population of the Amazon is supported by very limited road transportation, making air and river travel more important. The conditions in the region – including high humidity, complex river basins, and fragile ecosystems – make road construction extremely difficult. The region contains only 2% of the country's primary roadways, no railways or bridges, 11% of its airports, and 28% of its ports. These figures highlight the dependence of this region on river and air travel.

Though this region has some susceptibility to landslides and floods, it has a minimal number of recorded flood and landslide events that have affected roads and bridges. In part, this is because there are limited roads and bridges in the region. Floods appear to be a greater risk to the roadway system than landslides.

Issues and concerns related to climate change impacts on transport include the following:

- **Flooding events, though they currently have limited impacts on the road transport system, will likely increase.** There were just 9 recorded flooding events affecting roadways in the 1998 – 2013 period. Precipitation during the flood-prone period of March – May could increase by 50 percent in the near term. In addition, the number of extreme weather events could rise more than 10 percent, and the intensity of the worst events could increase by 3 to 5 percent. Taken together, these precipitation changes could lead to more flooding of the roads in the Amazon. Overall, seasonal precipitation is projected to shift, with September-November experiencing the greatest increase in rainfall after a potentially drier June-August. This may increase the chance of floods and landslides during this time of year.
- **Flooding impacts on the Region's 20 ports and 20 airports could be significantly greater**. These facilities may be affected, in particular, if the drainage system is inadequate to withstand heavy precipitation events. Further study may be warranted.

Anthropogenic stressors are significant in the Amazon region with an increasing trend of deforestation. From 1990 to 2010, the land covered by forests reduced from about 41.9 million hectares (ha) of forests in the region to about 39.8 million ha, representing about a 5% reduction over a 20 year period.[91] Continued activities of deforestation could affect the region's natural protection against landslides. If deforestation continues at the present rate, then by 2040 there may be an additional reduction in the forest land area of about 2.9 million hectares from 2010 conditions and by 2070 a reduction of about 2.8

[91] IDEAM, 2011b.

million hectares. This reduction in vegetation can reduce the stability along the limited slopes of the Amazon region, increase erosion, and increase runoff thereby increasing the threat of floods and landslides, but the region is largely unpopulated compared to other regions in Colombia which suggests that human development has played a relatively minor role in contributing to the impact of landslides and floods. An exception is in the northwest section, where the most populated departments are located.

5 INSTITUTIONAL ARRANGEMENTS

The impacts of climate change will require changes in the way planning, programs, and projects are developed and implemented in Colombia. Given the magnitude of the existing vulnerabilities, and the potential for more and more intense adverse impacts, the challenge is just too great to be addressed by incremental actions. The Department of National Planning has recognized this need to expand institutional capacity in its *Estrategia Institucional pare la Articulacion de Politicas y Acciones en Materia de Cambio Climatico en Colombia* (CONPES No. 3700) [92] which states that in light of significant climate impacts, "the creation of a system of institutional arrangements that define the requirements for the generation of information for decision making and risk management … is a priority."

New ways of working together, of building capacity, and of finding the resources necessary to address climate impacts will be necessary. The key Colombian transport agencies (Ministry of Transport, ANI, and INVIAS) are taking major steps to begin to address the institutional needs identified below, including through working with IDEAM, MinAmbiente, DNP and UNGRD to assist this process. In advance of a more thorough examination of institutional coordination in Colombian, several lessons from international experience may be identified.

Adaptation needs arising from climate changes will likely challenge Colombian transport and environmental agencies not only technically but institutionally, as well as, requiring new coordination mechanisms. Other transport agencies and country governments are struggling with the critical question of how to address the impacts of climate change. It is clear that new institutional arrangements will be necessary in many places and that the key capacities may not reside in any single agency. New information needs and new tools are necessary to assist the Ministry of Transport in addressing climate change. And perhaps most importantly, the resistance to change must be overcome.

One lesson from international experience is that addressing climate impacts on transport will require a mutual understanding between transport practitioners and climate modelers. Transport practitioners need to understand what climate information is available and relevant to their needs. At the same time, climate modelers need to understand what practitioners need and work to develop it. All parties need to recognize the limits of the information as it relates to transport decision making. IDEAM has produced a variety of analyses that has been very useful for Ministry planners, including climate projections and overlays of landslide and flooding vulnerabilities, but more will likely be needed.

[92] DNP, 2011.

Project-specific analysis requires a detailed understanding of how climate change will interact with the existing environment and alter existing vulnerabilities.

It will also require new tools based on longer time frames, probabilities, and risk management rather than relying on existing standards and practice. Transport planners do not typically look 40 years in the future when developing infrastructure, yet climate change will affect those assets over that time frame and needs to be addressed to provide robust and resilient service over the long term. Many best practices in transport planning rely on engineering standards that have been developed through analysis of past trends. According to the IPCC, however, the past is no longer a good predictor of the future as climate change occurs. Models can help develop future climate projections but the uncertainties associated with those future conditions often prove challenging for transport decision makers. New analytical methods and data are needed and will require close collaboration between the Ministry of Transport, ANI, INVIAS and the environmental agencies, on the one hand, and with DNP and UNGRD on the other.

Institutional changes may be needed to reduce resistance to change. Transport agencies have well defined processes for decision making. They typically favor incremental over radical change and tend toward proven methods and practices because they are building costly infrastructure, designed to last for decades. But this way of thinking can hamper the development and implementation of adaptation measures that are needed both in the short-, and long- term.[93] Those processes and decision support tools need to be amended, and transport agencies must adopt new protocols that recognize climate change. Efforts will likely be required by the Colombian transport, environmental and planning agencies to not only raise awareness on the importance of addressing climate change among the broader transport community but to reduce any resistance that may prevent timely action.

Efforts to build institutional capacity on climate change adaptation may be necessary in Colombia. International transport and other agencies have realized that existing institutional capacity on transport and climate change adaptation is severely lacking. This is understandable since the modern study of such impacts stems only from 2008 when studies were first able to relate changes in global climate to transport infrastructure plans and projects in a meaningful way.[94] Since that time, transport agencies, including those in Colombia, have held numerous conferences, workshops, and training sessions to raise awareness on the topic and build institutional capacity. The Inter-American Development Bank and World Bank have focused heavily on transport and climate change adaptation through research efforts, publications, and workshops.

Still more needs to be done. Addressing climate change impacts will require transport officials to consider climate impacts, and where appropriate take action to adapt appropriately. Each decision to expand, rehabilitate, or maintain the transport network in vulnerable areas should take climate impacts into account. This requires that all transport decision makers at the planning and project levels at the Ministry, ANI and INVIAS – as well as the concessionaires who construct and operate many of the country's roads -- be well versed in working with the climate specialists in IDEAM to understand the risks

[93] NRC, 2008.
[94] CCSP, 2008.

and identify adaptation measures that will assure resilience. Furthermore, capacity building may be necessary at IDEAM and MinAmbiente on working with transport agencies to better understand help meet their needs. Training and other forms of capacity building will almost certainly necessary if this goal is to be attained.

Resource constraints will need to be addressed. Effective adaptation measures in the form of new designs, longer lasting materials, and eco-based systems will require additional resources. How costly they will be has been the subject of intense discussion within the international community. Certainly some cost savings can be realized by adopting a strategic approach to adaptation by considering climate impacts and measures to address them when planning and designing infrastructure either in new construction or during planned rehabilitation rather than retrofitting existing facilities or addressing disasters. But costs are likely to go up to meet current and future needs, and resources will be necessary.

In Colombia, resource requirements need to be viewed within the context of both public and private roads. For publicly-owned roads, the issue of resources is straightforward; the additional costs must be covered if additional resilience in the face of climate change is to be achieved. For roads under the concessions programs, additional costs will be borne by the contractors building the roads. These costs could either be passed on to the road users in the form of increased tolls or be borne by the government through risk sharing measures with the concessionaries or direct subsidies to them. If borne by the users, additional consideration should be given to the added traffic risk that could be incurred by raising prices to them and to the potential for reduced economic development opportunities.

Additional resources will also be necessary for the enhanced coordination and capacity building noted above. The necessary resources could be either human or financial. Training and other forms of capacity building in addition to simply filling more requests for information in the case of IDEAM could be addressed through enhanced human capital or through additional budget and funding.

6 SOCIAL AND ECONOMIC CONSIDERATIONS

Providing equitable, affordable, clean, safe, and accessible transportation is essential for contributing to sustainable development, including poverty reduction. People rely on transportation to access resources and opportunities including employment, health care, and education. Maintaining well- functioning transportation systems is critical for contributing to the welfare of individuals and households and supporting economic development.[95]

In Colombia, 18% of the population lives on incomes of less than USD $2 per day, and the country's social inequality is among the highest in Latin America. Many people have been displaced from their homes because of violence or other issues, which has contributed to increasing urban populations.

[95] World Bank, 2010.

Colombia's internally displaced population is estimated to be between 3 and 4 million, or roughly 10% of the country's entire population.[96]

Many of these displaced people move into low income communities that may be poorly linked to transportation systems. Transportation services are often costly to provide to peripheral low income areas, which has resulted in fewer transport choices to get to employment opportunities in the urban areas.[97] Bus rapid transit systems have become a major focus for improvement of transportation in urban areas within Colombia, such as in the cities of Curitiba and Bogotá. The implementation these bus systems have socioeconomic benefits, providing access and mobility for populations in different parts of urban and suburban areas.[98]

Populations within cities rely heavily on multiple modes of transportation, particularly for lower income groups, who often depend on public or non-motorized transportation (such as walking) for at least part of their daily trips. In Bogotá, for example, 58% of all daily trips are made by public transportation, while private cars are responsible for 14%, taxis 5%, and bicycles and pedestrians 17%.[99] Gender issues are also important to consider, as women may access important resources via transportation and deserve to benefit from the economic opportunities that construction and operation of the transport system affords. For example, women rely on transportation for access to employment, childcare, education, health, and political processes. Walking serves as the main mode of travel for many women in developing countries because other transport modes may be too expensive, too far away, unsafe, etc.[100]

The poor and disenfranchised populations of Colombia will likely experience the worst impacts of climate change due to their reduced capacity to address them. Climate changes in Colombia will threaten the services enabled by infrastructure—just as weather affects these services today. For example, storms and flooding makes roads impassable, preventing people from reaching health care centers or jobs. As climate change worsens, service disruptions will become more intense and more frequent, and society as a whole will suffer increasingly negative impacts. Coastal populations are particularly at risk from sea level rise. In coastal cities like Cartagena, poor neighborhoods are often located in low-lying areas, which will be vulnerable to flooding and erosion.[101] In addition, climate change is a particular concern for the growing of coffee beans, which is an essential part of Colombia's economy. Not only will changing temperatures and precipitation directly impact the growing of coffee, but climate changes will also affect the infrastructure required for transporting and exporting the coffee (such as roads, freight operations, and ports) that is grown in more rural regions of the country, likely harming agricultural workers who rely on this trade.[102] Since the poor have limited resources in savings, job security, and mobility options, they will be disproportionately affected by climate disruptions to transportation.

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[96] Catarious and Espach, 2009.
[97] World Bank, 2010.
[98] Duarte and Rojas, 2012.
[99] Duarte and Rojas, 2012.
[100] World Bank, 2010.
[101] CDKN, 2013.
[102] Armenteras et al., 2004.

7 MOVING TOWARD MORE SOCIAL, ENVIRONMENTAL, AND CLIMATE COMPATIBLE TRANSPORT PLANNING PROCESS IN COLOMBIA

Colombia is poised to invest significantly in its transport infrastructure in the coming years. With the existing transport network already vulnerable to flooding, landslides, and other climate stressors, it is important to ensure that new investments are resilient to current and future climate-related stressors. The findings of this analysis indicate that flooding and landslides, the primary existing climate related stressors on Colombian transportation infrastructure today, may become more frequent and intense over the coming decades. These impacts will particularly affect the Andean region, where the majority of the population resides and depends on critical transportation services to access goods and services. Other impacts associated with climate-related stressors include flooding of critical ports and roads as a result of rising sea levels in the Pacific and Caribbean, as well as potential road damages as a result of higher temperatures and associated extremes.

Given the long service lifetime of most transportation infrastructure, current and future climate risks should be taken into consideration when undertaking new investments in all regions, because climate-related risks are expected to change over time, across, and within each region. In addition, since the development of roadways often stimulates economic and population growth, new vulnerabilities may arise that should be considered in transportation planning. The vulnerability of the transportation system to future drivers of change is not limited to climate–related stressors, other drivers of change, including land use/land cover, and demographic changes, can interact to exacerbate or reduce potential impacts on the transportation system. For example, the combination of deforestation, urbanization, and increased frequency and intensity of rainfall events, can result in more damaging flooding, that will affect the mobility and health of goods and people.

Addressing climate change presents a unique opportunity to attune transport development and planning processes with social, economic, and environmental development goals. A more inclusive transport development and planning process can contribute to quality of life improvements, economic competitiveness, and the preservation of the natural environment. By emphasizing social inclusion (education, employment, public services, social and recreational activities), transport development and planning efforts can achieve two important goals: *equity* and *economic development*. Transport development can improve a particular group or individual's social inclusion through a variety of methods, including land use accessibility (encouraging the development of transit stations that reach various populations, including rural areas), affordability (improving access from lower-income housing areas to urban centers), and mobility options and substitutes (transit service improvements and providing the delivery of goods to more remote areas).[103]

It is not sufficient to address climate risk with *only* engineering solutions, or *only* policy solutions. Climate risk must be comprehensively addressed within government policy, such that the transport

[103] Litman, 2003.

planning process is consistent with development goals. Adaptation needs will likely require new ways for transport, environment and planning agencies to interact. The need for better information and methods will necessitate enhanced coordination between transport practitioners and climate scientists, require additional institutional capacity to address climate change, and raise resource and budget concerns. It is clear that the Ministry and the other transport agencies will need to coordinate with other parts of the Colombian government responsible for national planning, environment, and risk management. They will also need the cooperation of key stakeholder groups who make up the larger transport community, including concessionaires and road builders/operators, academic institutions and transport associations, key users of the transport system, and local communities.

Within this larger policy context, project-level adaptation measures will need to be identified. There are many different ways to approach adaptation, and most fall within the following general categories, identified by the IPCC:[104]

- **Protect**: Transportation assets can be protected from climate change impacts through design features or actual protective structures.
- **Accommodate**: Climate-related challenges can be addressed by accommodating increased needs for maintenance/repair and service disruptions.
- **Retreat**: At some point, transportation officials may decide that the risks or costs of climate change impacts are too great, and transportation assets should be moved to other less risky locations.

These strategies will need to be evaluated in light of their effectiveness, life cycle costs, difficulty of implementation, social impacts, and environmental consequences before decision makers can determine a course of action. But before adaptation measures can be evaluated a more complete assessment needs to be accomplished at the project level. Vulnerability and risk assessments of transportation systems provide insight into key weaknesses in the system. Not all transportation assets are equally important, and their degree of "criticality" can help prioritize locations where efforts are most needed. Understanding *when* to adapt is equally as important as selecting a feasible set of adaptation options. Climate change happens over time, and there is often an optimal time to align adaptation strategies within the lifetime of an asset. Both costs *and* benefits of adaptation must be considered. While it is easy to focus on immediate costs of adaptation, there are also costs of *not* adapting (costs of inaction). Finally consideration of co-benefits, strategies that will help meet other safety, environmental or social goals should be accomplished.

There are a number of barriers to adaptation, as well as strategies for overcoming them, including:

- **Institutional Barriers**. Regulations and acceptable practices within institutions must be designed to be compatible with climate-resilient development. The ability of these organizations to collaborate and coordinate approaches will be vital to successful adaptation.

[104] Burkett et al., 2011.

- **Financial Barriers.** Lack of funding is frequently cited as a barrier to implementing adaptation strategies. In Colombia, resources such as the Adaptation Fund are available. A specific goal of this fund is to mitigate risks to natural hazards in the future.
- **Technical Barriers**. Frameworks are emerging, and being tested, to systemically guide transportation stakeholders through adaptation planning processes. These frameworks already provide a good starting point for adaptation planning, and will gradually be improved over time.
- **Political Barriers.** Unless there is adequate support among the general public and among elected officials, it may be difficult to mobilize resources to adequately address climate change. Education and outreach are therefore vital components of adaptation strategies.
- **Uncertainty in Climate Projections and Expected Impacts.** Uncertainty is unavoidable when dealing with climate change. Fortunately, there are ways to take action in the face of uncertain futures and imperfect data, including scenario planning, developing strategic approaches to adaptation planning and identifying "no-regrets" strategies to maximize resilience.

Adaptation strategies will be critical given the potential increase in climate impacts on the transportation system, as well as on people, livelihoods and environment. These strategies will need to be developed and evaluated given broader development goals. A well planned transportation system can help to foster not only a safe and reliable transportation system, but also a healthy environment, higher quality of life, and a stronger economy. All of these goals can be threatened by climate change impacts on the transportation system, but a more sustainable transportation network can be developed by transforming it within the principles of climate compatible development. By mainstreaming adaptation into these normal planning processes, funding and political support can become more accessible.

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