

CLIMATE RISK AND BUSINESS PORTS

Terminal Marítimo Muelles el Bosque
Cartagena, Colombia
Executive Summary



Acknowledgements

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Authored by

Vladimir Stenek, International Finance Corporation
Jean-Christophe Amado, Richenda Connell and Olivia Palin, Acclimatise
Stewart Wright, Ben Pope, John Hunter, James McGregor, Will Morgan
and Ben Stanley, WorleyParsons
Richard Washington and Diana Liverman, University of Oxford
Hope Sherwin and Paul Kapelus, Synergy
Carlos Andrade, EXOCOL
José Daniel Pabón, Universidad Nacional de Colombia

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Designer

Studio Grafik

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Foreword

The adverse effects of climate change on human welfare are becoming more apparent worldwide, particularly in developing countries. In the past year, climate related impacts caused economic damages amounting to tens of billions of dollars, displaced millions of people and contributed to the looming food crisis.

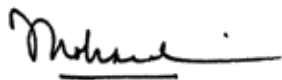
Scientists expect the physical impacts of climate change, along with its direct and indirect economic, social and environmental consequences, to continue increasing in intensity and frequency. Developing countries and the poorest populations are particularly vulnerable to temperature extremes, droughts, floods and storms. Unless the risks are addressed, climate change will reverse development progress and increase the hardship for the poor. Incorporating climate change concerns in current and future activities is not only about managing risks, but also about the necessity to create robust and resilient economic and social environments for the future.

Starting in 2008, IFC initiated a series of case studies that analyze climate risks to various sectors and projects located in different countries, while offering practical approaches for the assessment of relevant impacts and adaptation options. As no project or sector exists in isolation, they necessarily looked more broadly at a wider range of climate-related economic, social and environmental factors, with input from diverse national stakeholders.

Infrastructure and transport are among the sectors most exposed to climate change, which in turn are critical to national economic performance, growth and development. Ports in particular play a vital role in the world economy. More than 80% of goods traded worldwide are transported by sea. Ports in developing countries handle more than 40% of the total containerized traffic, of which a significant portion relates to materials and export of goods produced in the country. Hence, the impacts of climate change on ports will have much wider socio-economic ramifications.

This study analyzes climate related risks and opportunities facing IFC's client, Muelles el Bosque, and provides a quantitative assessment of climate impacts and related adaptation responses. While the work focuses on the impacts on this specific port and its surroundings, it also briefly explores how other ports in Colombia and elsewhere in the world can expect to be affected by climate change.

Through this study, the fifth in the Climate Risk series, IFC hopes to continue its contribution to the knowledge base for understanding the impacts of climate change and adaptation responses needed by our clients and the private sector in general. I would like to personally thank Muelles el Bosque for their cooperation and support in this important work.



Mohsen A. Khalil
Global Head
Climate Business Group
International Finance Corporation

Foreword

Many corporations and governments are concerned with climate change, however, individually we are not yet aware of the specific effects that global warming has or will have on our immediate surroundings.

Last year Colombia suffered the worst floods in 60 years with 2 million people displaced in a space of 3 months, a large part of this occurred in the coastal delta of the Magdalena River. Coincidentally, this study, which was carried out by the International Finance Corporation with a view towards understanding the effects of climate change in the region, will have an important impact on how future climate change studies will be made in Colombia, because it is one of the first, if not the first to analyze how businesses and commerce will be affected by the changing environment in our country.

The study has helped Muelles el Bosque develop its long term strategic planning and investment priorities and it is hoped that the discipline and content of the study will serve as a pilot model and guide for future efforts in our region.

One of the most important results of the study is the changes that will occur in commercial opportunities and agricultural products by region as a consequence of changes in weather patterns. This not only will affect the ports and Cartagena but also the country as a whole. It is urgent that Colombia undertake a long term view on how our lives will be affected and begin to plan accordingly. In this sense this study is just the beginning.

On behalf of Muelles el Bosque, its shareholders and employees, I would like to thank the International Finance Corporation for having taken the initiative to implement the study.



Gabriel Echavarría
President
Muelles el Bosque

This publication provides a summary of the findings of the climate risk study. The full report, available for download from IFC's website,¹ analyzes in depth the climate-related risks and opportunities facing Terminal Marítimo Muelles el Bosque (MEB). Wherever possible, the analyses include estimates of the financial impacts of climate change on MEB over the coming decades. For some of the more significant risks, the report also provides assessments of the costs and benefits of adaptation investments, and evaluates approaches to adaptation decision-making that are robust to uncertainties.

The methodologies employed to undertake the assessments for MEB are spelt out in detail in the full report, with the aim of facilitating similar assessments being conducted for other ports. Finally, the report identifies the gaps and barriers constraining action on adaptation, and discusses the work on adaptation underway within the public sector in Colombia.

Supplementary material is also provided in a set of annexes, and includes a detailed analysis of climate change projections for Colombia as a whole and Cartagena specifically.

Introduction

In general, the physical infrastructure at ports, and port activities, may be highly vulnerable to changes in climate. For instance, the risks could manifest through changes in the level or patterns of shipping, increased flooding affecting movements within ports and causing damage to goods stored, reduced navigability of access channels and business interruption. Some ports will also see opportunities as a result of climate change. A port's reputation for reliability is key to its success, so ports that are more resilient to disruption from climate events should fare better. Higher temperatures may benefit ports in cold regions where navigation is currently restricted by ice, through increasing the length of the shipping season.² Changes in trade flows driven by climate change will also see winners and losers. To understand the significance of these risks for a given port, it is necessary to analyze the factors affecting the success of that port and evaluate climate-related impacts, taking account of existing vulnerabilities, critical climate-related thresholds and climate change projections.

Recognizing the potential significance of climate change to ports, the IFC Adaptation Program commissioned a study to assess the risks and opportunities for ports in general, and specifically for a private port company, Terminal Marítimo Muelles el Bosque (MEB),

in Cartagena, Colombia. Where possible, the study estimated the financial impacts of climate change for MEB and evaluated actions that the company can consider to manage them.

The analysis undertaken for the study found that the materiality of climate change impacts will vary greatly from one port to another, though there are some key risk areas that all ports should consider. Due to climate change, the oceans are expanding as they warm and land-based ice is melting into the sea. Around the globe, mean sea levels are rising as a result, and this will affect vulnerable ports in low-lying coastal locations. In some areas, it is also expected that storm intensities will increase. The combined effects of mean sea level rise, high tides, extreme waves and storm surges could overwhelm a greater number of coastal ports and disrupt operations, unless actions are taken to increase their resilience. Climate change will lead to changes in the areas suitable for producing certain goods (such as agricultural products) and in demand for goods (such as fuel for heating), and will thus affect trade flows. Wider impacts of climate change on the global economy, as noted in the Stern Review on the Economics of Climate Change,³ will affect overall trade and hence port revenues.

¹ www.ifc.org/climatechange

² USTRB (U.S. Transportation Research Board). 2008. Potential Impacts of Climate Change on U.S. Transportation. Committee on Climate Change and U.S. Transportation. Transportation Research Board Special Report 290 and USEPA (U.S. Environmental Protection Agency). 2008. Planning for Climate change Impacts at U.S. Ports. White Paper. Fairfax, p. 16.

³ Stern, N. 2006. *The Economics of Climate Change: The Stern Review*. Cambridge University Press. [Online]. Available at: http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/sternreview_index.cfm (accessed 2/03/10).

Climate change risks to ports

Climate change will increasingly affect public and private sector organizations, especially those reliant on long-lived fixed assets and complex supply chains. Port facilities are likely to be particularly at risk for a number of reasons:

- Due to their long lifetimes, they will face several decades of accelerating climate change,
- By virtue of their locations on coasts, rivers or lakes they are often exposed to a range of climate-related hazards such as sea level rise, storm surges, extreme wind and waves and river flooding, and
- Ports rely for their success on economic stability and growth, as well as on third party infrastructure (such as inland transportation networks), both of which are sensitive to changes in climate conditions.

Clearly, there will be considerable differences in the nature and level of climate change risks and opportunities between ports depending on the characteristics of their locations – be they in regions prone to tropical or extra-tropical cyclones, in areas where permafrost is thawing, or on lakes or rivers whose levels are changing.

Further, ports vary considerably in the functions they perform. Climate change will have different implications for ports with cargo handling and warehousing functions compared to those providing exclusively pilotage, navigation and dredging services, or for cruise/passenger ports.

MEB consists of two separate legal entities. Terminal Marítimo Muelles el Bosque, S.A. (TMMEB) holds the concession (expiring in 2032) from the Government of Colombia to develop and manage Cartagena's second largest port. Its sister company, Muelles el Bosque Operadores Portuarios, S.A. (MEBOP), provides the port operations.⁴

MEB currently employs approximately 250 people and handles four types of cargo: containers, grain, bulk materials and coke (in decreasing order of average throughput for the period 2005–2009). Between 2005 and 2010, containers represented the largest share of MEB's revenue. In 2008, MEB moved 1% of Colombia's international trade (in tonnage).

MEB's 10 ha terminal is located in a mixed industrial and residential zone of Cartagena. It is composed of two sites, an island named *Isla del Diablo* (shown in Figure 1) and an adjacent mainland area linked via a causeway road.

Cartagena is too close to the Equator to be prone to tropical storms, and MEB is located in the natural harbor of the Bay of Cartagena, which is one of the most secure on the Caribbean coast of Colombia. It is sheltered from high winds, waves and storm surges. This natural resilience brings advantages compared to its competitor ports in Colombia and the Caribbean.

MEB's competitor ports in Colombia

The port system in Colombia currently has 122 facilities, including five regional port societies, or *Sociedades Portuarias Regionales* (SPRs), which are MEB's principal competitors. Of these, Buenaventura SPR took the greatest share (8%) of the international trade by tonnage in 2008, followed by Santa Marta SPR (6%), Cartagena SPR (3%) and Barranquilla SPR (3%). Buenaventura on the Pacific coast benefits from being the closest port to the main Colombian production and consumption centers, which favors its use, despite it being one of the rainiest places in the world, with around 6,000 to 7,000 mm of rainfall annually. Santa Marta, east of Cartagena on the Caribbean coast, exports mainly coal and has a deep natural access channel suitable for Post-Panamax vessels. The port of Barranquilla handles mostly grain, steel and coal and is approximately 22 km from the Caribbean Sea, in the Magdalena River. Limited depth causes navigation limitations for Barranquilla, and dredging and construction works are ongoing to improve access by larger vessels.

⁴ For simplicity, both entities together are referred to as *MEB* in this report.

Figure 1 – Aerial photograph of MEB's Isla del Diablo (island site).

On the photograph, the following elements of the port can be seen: A) Quays 4, 1 and 2 (from top to bottom); B) Quay 3; C) Grain silos; D) Coke storage area; E) Patio for containers; F) Part of the causeway that connects to the mainland site; and G) the mangrove around the causeway.



Climate variability, climate change, adaptation and businesses

Climate change is underway. Increased global average temperatures and rising sea levels have been observed and droughts, floods, heat waves and storms are becoming more common. Even if emissions of greenhouse gases are significantly reduced, the world faces inevitable changes in temperature and precipitation for decades to come, and sea levels will continue to rise for centuries. The climate is also naturally variable and man-made climate change will superimpose on natural climate variability.

If the risks are left unmanaged, the implications of climate variability and change for businesses, their investors, customers, workforce, local communities and the environment could be significant.

Adaptation is the general term used to describe the range of actions that can be taken to reduce vulnerability to climate change. For instance, adaptation can include increasing a port's

In Cartagena, average temperature varies little from month to month, generally lying in the range of 27 to 29°C. Projections from 10 General Circulation Models (GCMs) for three greenhouse gas emission scenarios (A2, A1B and B2) point at future increases between 0.7–1.2°C and 1.2–2.2°C from the 1961–1990 baseline to the 2020s and 2050s respectively.⁵ However, empirical downscaling of 14 GCMs for the A2 greenhouse gas emission scenario shows possible temperature increases of 6°C by the 2050s in all seasons.⁶ For this study, a broad set of climate models and greenhouse gas emission scenarios were considered, to capture the range of uncertainty in future climate change.

Average precipitation on wet days has increased by 0.6% per year in Cartagena between 1941 and 2009. There is also evidence that precipitation is becoming more intense in some parts of Colombia.⁷

Making resilient decisions in the face of uncertainty requires managing gaps in knowledge and data. For example, there is

⁵ GCMs are climate models that provide global climate change projections with coarse resolutions of hundreds of kilometers (typically 2.5o x 2.5o). The A2, A1B and B2 greenhouse gas emission scenarios were developed by the Intergovernmental Panel on Climate Change (IPCC) in 2001 to represent different plausible future pathways for greenhouse gases. While all scenarios are considered equally sound by the IPCC, some scientists have warned that greenhouse gas emissions are currently rising at a rate above the highest scenario trajectory (the A1FI scenario).

⁶ Empirical downscaling is a method through which high resolution climate change projections are derived from a statistical model which relates large-scale climate variables obtained from global climate models to regional and local variables, based on site-specific observed data.

⁷ Aguilar, E., et al. 2005. "Changes in precipitation and temperature extremes in Central America and northern South America, 1961–2003", J. Geophys. Res., 110, pp. 1–15.

coping ranges related to climatic conditions, such as raising the height of a quay exposed to rising sea levels, or diversifying port income streams away from those which are highly climatically-vulnerable.

A checklist of climate risks and adaptation actions for ports is provided at the end of this Executive Summary.

Scientists and practitioners have developed approaches to decision-making on climate change adaptation that take into account the varying levels of uncertainty about climate change risks. For example, for risks which are highly uncertain (e.g., those related to changes in extreme climatic events), it can be useful to apply an *adaptive management* approach. This involves adapting incrementally over time in light of experience of how risks are changing, rather than undertaking expensive *one-off* up-front adaptation investments.

poor agreement between climate models over future precipitation changes in Colombia, due to the complex topography and the lack of understanding of how tropical cyclones might change in the future. No credible daily or peak rainfall projections are available.

Thermal expansion of the oceans due to higher temperatures, and increased melting of glaciers, ice caps and the Arctic and Antarctic ice sheets all contribute to sea level rise. To capture the range of possible future sea level rise over the 21st century, this study considered:

- An observed sea level rise scenario of 5.6 mm per annum,⁸ and
- An accelerated sea level rise scenario (of up to 1.3 m by 2100), starting from the current rate of sea level rise (5.6 mm) and following a quadratic equation that approximates the exponential sea level increase projected by many studies.

Winds are predominantly from the north and north east in Cartagena and are either calm (21% of the time) or between 1.6 and 13.9 m/s (69% of the time). These wind speeds are below the operating thresholds of MEB's cranes. However, no data is available on observed wind gusts.

Cartagena is located south of tropical cyclone tracks and is protected by its location in the northeastern corner of the South American land mass. No significant change in wind speeds and storminess are projected by climate models, though this is an area of uncertainty.

In countries such as Colombia, where climate models perform poorly, there is a role for the public sector to support development of improved high resolution climate change projections. For instance, the Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM, the Colombian Institute of Hydrology, Meteorology and Environmental Studies) has been working with scientific experts to develop regional climate projections using the PRECIS modeling system.⁹

For a summary of the climate information used in this study, see Table 1.

⁸ Sutherland, M., Dare, P and Miller, K. 2008. "Monitoring Sea Level Change in the Caribbean". *Geomatica*, 62 (4), pp. 428–436.

⁹ Precipitation projections for Colombia obtained from PRECIS are quite different from the projections of the majority of the other global climate models. PRECIS is a regional climate model developed by the UK Met Office's Hadley Centre that provides high resolution climate data (at a 25 kilometer square spatial resolution).

Table 1 – Summary of present-day conditions and future projections for the key climate variables considered in this study

Climate and climate-related variables	Observed conditions recorded by meteorological stations and tidal gauges in Cartagena	Future scenarios from climate model projections
Mean temperature	Between 26.7°C and 28.5°C (average monthly) No obvious trend in temperature over the last 70 years	Increases of 0.7 to 1.2°C by the 2020s, 1.2 to 2.2°C by the 2050s and 1.7 to 3.7°C by the 2080s (projected by an ensemble of GCMs) ¹⁰ Potential increases up to 6°C by the 2050s (projected by an ensemble of downscaled GCMs) ¹¹
Mean precipitation	Annual average rainfall was about 600 mm per year in the 1940s and has risen steadily, to about 1100 mm per year in the last decade Increase of 6 mm per year in 1941–2009; corresponding to a 0.6% increase per year on wet days	Assumed yearly increase of 0.6% on wet days, based on continuation of observed trends ¹² Climate models perform poorly at projecting future rainfall in Colombia
Sea level rise	Rising at 5.6 mm per year (± 0.008 mm)	<i>Observed sea level rise scenario:</i> 5.6 mm per year, i.e., 504 mm by 2100 <i>Accelerated sea level rise scenario:</i> 1,300 mm by 2100
Wind	Calm or between 1.6 and 13.9 m/s for most of the time	Increases by up to 0.2 m/s by the 2020s and 0.5 m/s by the 2050s and 2080s (projected by an ensemble of GCMs) ¹³ Winds in the range 3 to 10 m/s could become more frequent (projected by the regional climate model PRECIS) ¹⁴
Storminess and storm surges	Not affected by tropical cyclones Storm surge height up to 171 mm for a 1 in 300 year event	Little to no change

¹⁰ See footnote 5.¹¹ See footnote 6.¹² Due to the lack of good agreement between climate models on future precipitation changes, the study considered a future scenario whereby the yearly trend in average precipitation observed between 1941 and 2009 continues in the future.¹³ See footnote 5.¹⁴ See footnote 9.

Port success criteria at risk from climate change

It is useful to take a generic view of the various success criteria for ports which can potentially be affected by climate change, as presented in Figure 2.

These relate to the chain of external systems and internal assets and activities on which a port's commercial success relies:

- Trade levels and patterns and the consequent demand for port's services,
- Navigation in and out of ports and ship berthing,
- Goods handling inside ports,
- Movements of goods, vehicles and people inside ports,
- Goods storage in ports, and
- Inland transportation beyond ports' fence lines.

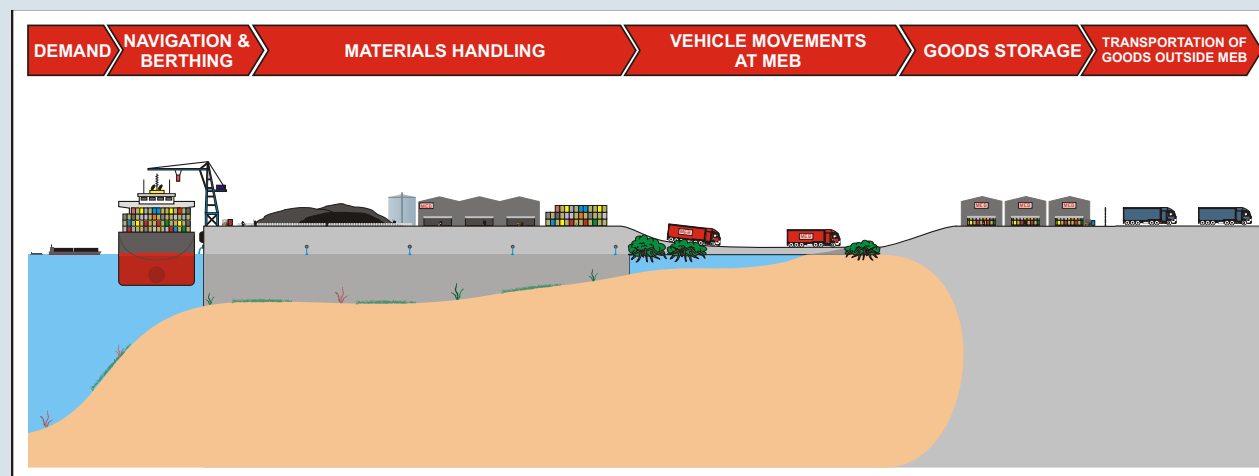
In the case of MEB, the climate change risk analysis found that only a small number of these success criteria are likely to be significantly affected by climate change. These include:

- Reduced vehicle movements inside MEB due to increased seawater flood risk,
- Decreased global trade and U.S. grain exports and associated shipping movements, with consequences for MEB's revenues,
- Increased risk of damage to goods stored inside ports due to seawater flooding, with potential reputational consequences, and
- Degradation of the mangroves located around the causeway due to sea level rise.

In the case of materials handling and surface flood risk, climate change does not appear to challenge the operational threshold of MEB's cranes or its drainage capacity, though there is some uncertainty about this. For instance, while precise data was available on the operational limits of MEB's cranes, information on observed extreme winds was uncertain and there were no credible future extreme wind projections. However, given that the climate models do not project significant changes in winds, and because Cartagena lies too close to the Equator to be significantly at risk from hurricanes, the study discarded this as a significant risk to MEB.

The absence of risk to navigation and berthing relates to MEB's favorable location on the Bay of Cartagena, where extreme climatic hazards are limited. The generally low risk of social or environmental issues driven by climate change (with the exception of impacts on the mangrove, see Figure 1) can primarily be explained by MEB's existing management systems.

In some cases, the available information was too limited to assess risk accurately. This was the case for assessing climate change impacts on the transportation network outside MEB. Quality elevation data for the city of Cartagena could not be obtained, which led the study to consider potential sea level thresholds above which flood risk of the roads used by MEB and its customers increases.

Figure 2 – Conceptual model of a cargo handling port and the main success criteria that can be affected by climate change

Demand, trade levels and patterns

Commercial ports rely on the vitality and growth of the shipping industry, which is very sensitive to fluctuations in world and country gross domestic product (GDP), as shown by the recent economic downturn.

For some products, climate change will influence market conditions which can translate either into risks of decreased trade through ports or opportunities for new exports or imports. For example, the supply of agricultural and forest products is very sensitive to climatic conditions.

Demand for a port's services can also be affected by population movements and changes in the locations of industrial centers, as well as by the way port customers perceive its reliability in the face of extreme weather events. Those that suffer major disruptions during storms or other climatic events may experience decreased throughput. For example, following Hurricane Katrina some customers shifted to alternative ports on the U.S. East Coast.

The potential impacts of climate change on international trade are difficult to quantify with confidence over coming decades, due to the interactions between future climate change impacts, economic performance and trade, the number of other factors that significantly influence trade and the unstable nature of trade itself. However, trade is a potentially significant climate-related risk area for ports, and merits further research.

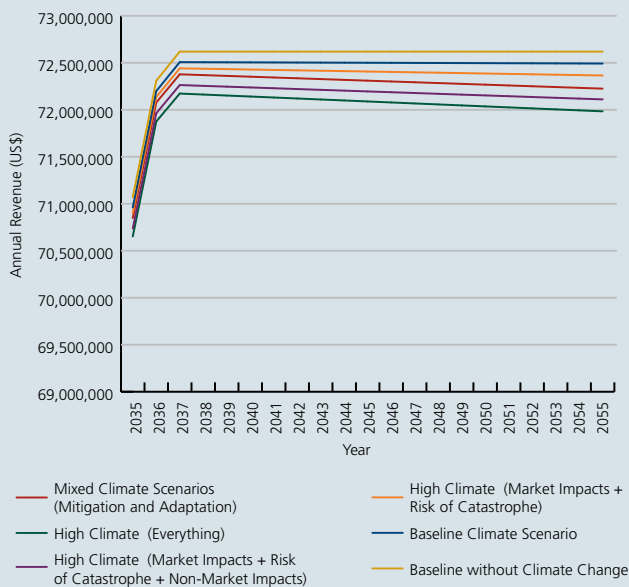
The study adopted a practical approach to assessing the potential implications of climate change for MEB's imports and exports, aiming to provide insights into these potentially significant impacts to MEB.

For the period 2005–2010, MEB's revenue and world GDP appear closely related: on average, a 1% change in world GDP is correlated with a 0.7% change in MEB's revenue. The study acknowledges that this relationship could be different in the future.

The Stern Review on the Economics of Climate Change estimated that the average costs of climate change could be up to 1.25% of global per capita consumption by the 2050s. The implications of such global GDP reductions for MEB could amount to an annual revenue loss of about US\$640,000 by 2055. The effect on MEB's annual revenue under different climate change scenarios is shown in Figure 3.

Projected increases in imported grain prices and impacts on land suitability for the Colombian crops that are exported through MEB are not expected to affect MEB's revenue significantly.

Figure 3 – Potential global economic impacts of climate change on MEB's annual revenue between 2035 and 2055 (in US\$)



Customer demand for MEB's services could benefit from climate change:

- When tropical cyclones disrupt other ports in the Caribbean, MEB has observed a 2% increase in its total income on average, due to its reputation as a safer hub than other Caribbean ports. Research has shown that tropical cyclone intensity may increase in the Caribbean (though not at Cartagena, which is too close to the Equator to be at significant risk).
- Compared to other major Colombian ports, MEB is not vulnerable to disruption from intense precipitation and fluctuations in water depth. In contrast, Buenaventura is known to face operational restrictions due to heavy rainfall, and shipping from Barranquilla is limited by depth. Therefore, future climate change could create a competitive advantage for MEB if it exacerbates existing problems in these competing ports.

Navigation and berthing

In general, as a result of sea level rise, navigable water depths are likely to increase in many coastal ports and shipping channels. The increased available draft also generally equates to decreased dredging maintenance requirements.

However, changes in rates of coastal erosion and deposition will affect the depths of some navigation channels, and lead to increased dredging costs.

Furthermore, capital expenditure may be necessary in ports where sea levels rise above the operability range of infrastructure and equipment. For instance, reduced clearance under some bridges will restrict the low water level windows available to large vessels.

Climate change will lead to reduced river flows or lake levels in some areas with severe implications for navigation and port access. Increased shipping or improved inland transportation in areas where higher temperatures will increase ice-free periods is likely to benefit some ports. For instance, the opening of the Northwest Passage could provide a commercial alternative to using the Panama Canal, which would decrease shipping movements in Central America.

The Bay of Cartagena has limited openings to the sea via two sea channels: Bocachica and Bocagrande (Bocachica is the only entrance for commercial shipping) (see Figure 4). Seawater flows in and out of the bay through these two channels and there is a freshwater input from the Canal del Dique (see Figure 4). The bay offers protection against waves and storms surges; it is also characterized by low tidal ranges and little congestion or navigation difficulties.

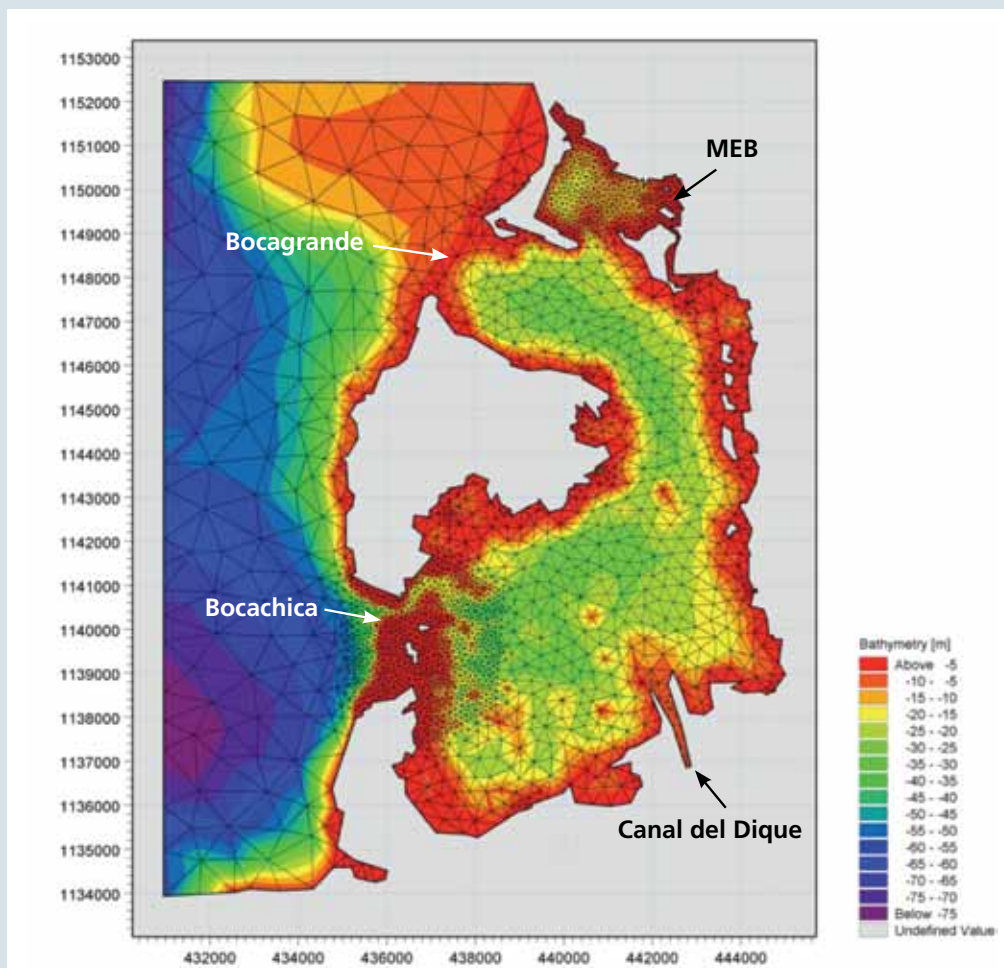
Because of the characteristics of the Bay of Cartagena, climate change is not expected to represent a considerable risk. A number of issues were considered during the assignment:

- The top of MEB's quays and the operability range of cranes and fenders are able to cope with the rise in sea levels projected this century in both the observed and accelerated sea level rise scenarios.
- MEB only dredges two short channels every five years approximately. The increased draft caused by higher sea levels is likely to reduce maintenance dredging requirements. A gross estimate of the total savings to the end of the century is from US\$325,000 to US\$400,000. MEB has no plans to accommodate vessels with a draft above 12 m.

- There is no evidence that sedimentation in the bay will change. Further, because other port terminals located in the bay (Sociedad Portuaria Regional de Cartagena and Contecar) are in charge of dredging the channels closest to the mouth of the Canal del Dique and have plans to accommodate Post-Panamax ships, the depth in the bay will be maintained at a level significantly greater than that required by MEB.
- Since wave height is limited in the Bay of Cartagena, any increases in wave height due to greater water depths (driven by sea level rise) is unlikely to have a significant effect on MEB.

The municipality of Cartagena has been reviewing options to reduce the volume of sediment discharged by the Canal del Dique into the bay.

Figure 4 – The 2D hydrodynamic model grid of the Bay of Cartagena developed for this study



Goods handling and storage

High winds, extreme rainfall and lightning can restrict port operations. For instance:

- Cranes cannot be moved or used above certain wind speeds and heavy rain can affect crane's electrical systems.
- Some operations cease in times of strong winds, including tugboat and ferry movements.
- During heavy rainfall, the loading or unloading of weather-sensitive goods or material also ceases. Usually rainfall limits are set by ports on a case-by-case basis.

Higher temperatures are expected to lead to some improvements in port operating conditions in cold regions.

Risk of spoilage of goods stored is likely to increase because of increased temperature and changing rainfall and their effect on pests, diseases, rust and mold, as well as increased flood risk.

Changing climate conditions can also have implications for port energy and water requirements. At the same time, electricity and water supplies may become increasingly unreliable due to climate change. Countries heavily reliant on hydropower may be most vulnerable to power shortages, but thermal power plants cooled by river or lake water can also be affected.

Risks of dust explosions associated with grain handling and storage may increase in areas which become hotter and drier.

The study assessed future surface flood risk on MEB's island site considering both changes in surface water runoff and sea level rise which can lead to seawater surcharge of drainage pipes.

When rainfall is considered alone, the amount of rainfall required to overwhelm MEB's drainage pipes on the quay is 639 mm per day. The maximum daily rainfall recorded between 2000 and 2008 in Cartagena was 158 mm and daily rainfall only exceeded 50 mm for about 1% of this time. Future precipitation changes in Cartagena are uncertain, so to assess the capacity of the drainage system to cope with future rainfall changes, the observed rate of increasing rainfall was extrapolated into the future and applied to the maximum daily rainfall observed between 2000 and 2008. Thus, considering a possible future scenario in which the observed 0.6% yearly increase in average rainfall during wet days continues, and peak rainfall increases by as much as average rainfall, no risk to MEB's required drainage capacity is expected, unless the future maximum daily rainfall calculated for 2100 (of 245 mm in a day) falls within less than 9 hours.

When the additional effect of seawater ingress is considered, surface flood risk could increase. For instance, mean sea level during the highest spring tide is expected to reach the critical limit above which the drainage system cannot cope with both seawater ingress and increased rainfall towards the end of the century in the accelerated sea level rise scenario (estimated to be 1.7 m above the port plan datum). If the effect of storm surges is added, seawater ingress is expected to be critical to drainage earlier in the century in the accelerated sea level rise scenario.

No adaptation action appears to be necessary to prevent an increase of surface flood risk due to climate change. However, because of the uncertainty of future precipitation changes and the possibility of occasional flooding due to heavy rainfall events, a few steps are recommended including: regular maintenance, inspections and fitting valves to all drainage sea outlets. Towards the end of the century, it could be necessary to raise the drainage outlets to avoid seawater surcharge, which would be best done when quays are replaced.

Water-sensitive storage areas at MEB (namely the warehouses and the storage area on the mainland site) are likely to be flooded under the compound effect of rising sea levels and storm surges between 2040 and 2050, and 2030 and 2040 in the observed and accelerated sea level rise scenarios respectively (see Figure 5 and Figure 6.) Without knowing the value of the goods stored on the mainland site, it is difficult to assess the potential loss. However, it could

Figure 5 – Projected sea level and flood risk in different parts of the port (including the mainland storage patio) under the observed sea level rise scenario. Three sea levels are presented in this figure: 1) mean sea level; 2) mean sea level at the highest spring tide; and 3) mean sea level at the highest spring tide and with a 1 in 300-year high storm surge. The horizontal lines represent the level of the causeway (red line), mainland storage area (blue line) and quay (green line).

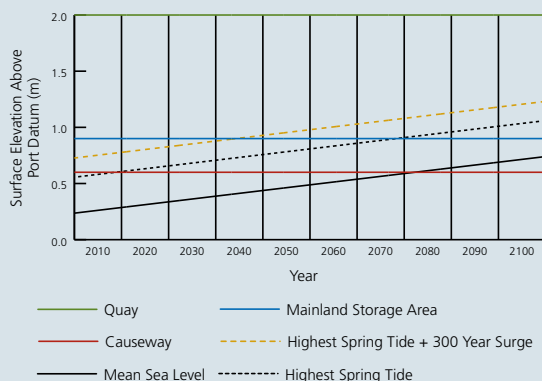


Figure 6 – Projected sea level and flood risk in different parts of the port (including the mainland storage patio) under the accelerated sea level rise scenario. Sea levels and port levels shown on this figure are the same as Figure 5.

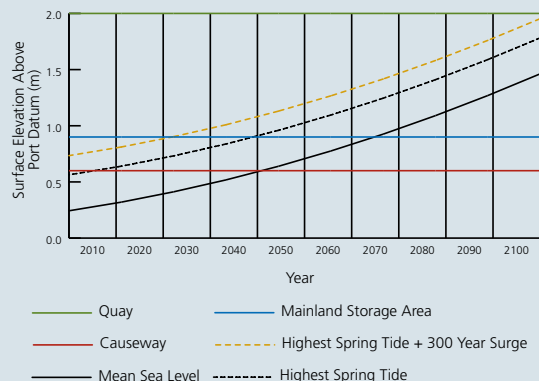
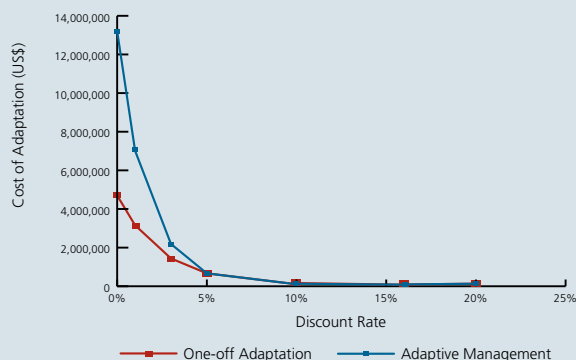


Figure 7 – Costs of raising the height of the mainland storage patio by 1.2 m for a range of discount rates.

Two adaptation scenarios are considered: 1) an *adaptive management* scenario (blue line) whereby the patio is raised by 20 cm six times between 2050 and 2100; and 2) a *one-off* adaptation scenario (red line) whereby it is raised all at once in 2050. (Although difficult to notice in this graph, the cost of adaptive management is lower than the *one-off* option for all discount rates higher than 10%. At DR=16%, it is approximately 60% of the *one-off* option cost.)



represent a significant risk to MEB's reputation as a reliable port. To avoid such impact, MEB could add emergency flood protection or reorganize their storage areas in order to ensure that water-sensitive cargo is stored in less vulnerable areas. Raising the height of the mainland patio to avoid regular flooding is necessary from the 2080s and 2050s onward in the observed and accelerated sea level rise scenarios respectively. The total associated paving and drainage costs (approximately US\$1.1 million and US\$2.2 million in the observed and accelerated sea level rise scenarios respectively) are lower when the patio is raised incrementally by 20 cm (three and six times are necessary over this century in the observed and accelerated scenarios respectively) compared to when the patio is raised only once in the 2030s (for MEB's discount rate of 16%, see Figure 7).

It is possible that water consumption for coke spraying could decrease if the observed trend of increasing rainfall continues in the future. Savings appear to be modest and could amount to US\$14,000 per year. In contrast, higher temperatures will increase electricity consumption of refrigerated reefers; this could correspond to a 30% (or 84 kW) increase in MEB's annual electricity consumption for a 6°C increase in temperature.

The risk of grain dust explosion is expected to be relatively low at MEB at present, provided grain dust and fire risks are adequately managed. Climate change is not expected to lead to any significant change in risk.

Hourly average wind speeds of between 13.9 and 17.1 m/s, that prevent cranes from being moved, only occur about 2% of the time in Cartagena at present. Hourly wind speeds above cranes' operational mode threshold (20 m/s) are rare. Gusts can also affect port operations, but no data is available for Cartagena.

No significant risk to MEB's material handling and storage activities due to climate change is expected:

- Climate models project modest wind speed increases in Cartagena, at most 0.5 m/s in July–August by the 2080s.
- There is uncertainty about future increases in the intensity of tropical cyclones in the Caribbean; however, Cartagena will most likely not be affected due to its proximity to the Equator.
- Interruptions to loading or unloading of ships due to heavy rainfall seldom occur at MEB. Future precipitation increases are anticipated, but in the case of MEB it is not expected that the frequency of disruptions to materials handling will increase significantly, based on assuming the observed 0.6% yearly increase in average rainfall continues in the future.

Vehicle movements inside ports

Increases in mean sea levels, storm surge heights and changes in wave regimes will increase flood risk for many coastal ports.

Ports on rivers and lakes could also face increased flood risk in areas where river flows or lake levels will change.

Ports' drainage systems can be overwhelmed by intense precipitation, leading to surface flooding.

The levels of operation interruptions, road closures and delays caused by flooding will depend on flood duration and depth.

MEB's lowest area is the causeway road linking its mainland and island sites, which lies at 0.6 m above the port plan datum. With a continued sea level rise of 5.6 mm per year, the highest spring tide is likely to exceed the height of the causeway by 2018. Under the accelerated sea level rise scenario, this is likely to occur as soon as 2015. Beyond this time, the causeway and surrounding areas will be subject to shallow flooding on a weekly basis during the high tide period (September to December).

The analysis considered that when flooding is above 30 cm in depth, vehicles with high clearances (such as trucks) cannot move across it, which leads to business interruption costs. Frequent flooding of the causeway of more than 30 cm in depth is likely to occur from 2050 and 2080 onward under the accelerated and observed sea level rise scenarios respectively, although this does not include the effects of possible storm surges. Storm surges represent a far more unpredictable source of flooding which will act, in combination with tidal flooding, to overtop the causeway. Storm surge heights observed in Cartagena are low (171 mm for a 1 in 300 year event). The flood analysis carried out in this study is illustrated in Figure 8 and Figure 9.

The financial analysis of seawater flooding to MEB demonstrates that this threatens MEB's business continuity over the longer term, if no action is taken. By 2032 the cost of flooding of the causeway is estimated to be between 3% and 7% of MEB's annual projected earnings in the observed and accelerated sea level rise scenarios respectively. In the accelerated sea level rise scenario, all earnings

Figure 8 – 3D model of MEB showing projected seawater flooding during the highest spring tides (and the highest water level on the bay attributed to wind set up and rainfall) in 2050: under the observed sea level rise scenario (left) and the accelerated sea level rise scenario (right). Blue areas are underwater. In both cases, the causeway road is projected to be flooded. The inset map shows the mainland storage area in the foreground and the island in the background.

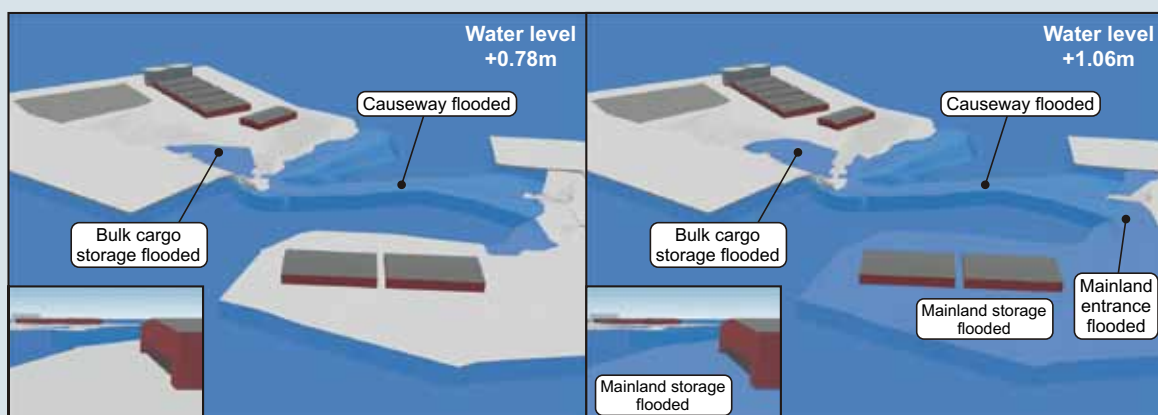
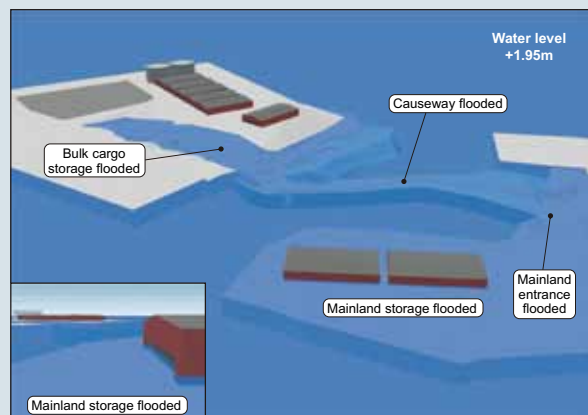


Figure 9 – 3D model of MEB showing projected seawater flooding by 2100 during the highest spring tides (and the highest water level in the bay due to wind set up and rainfall) under the accelerated sea level rise scenario and with the additional effect of a 1 in 300-year storm surge.



are wiped out by about 2065 and in the observed sea level rise scenario significant losses are incurred from 2060 onwards (representing more than 10% of MEB's annual projected earnings).

To ensure that the causeway road is not flooded this century, raising its height by 60 cm and 1.2 m is necessary in the observed and accelerated sea level rise scenarios respectively. It is expected that the cost is relatively small. MEB has two options: either raise the causeway by the required amount at once or raise it incrementally this century as required. Overall, it appears cheaper for MEB to raise the causeway in increments under both sea level rise scenarios for discount rates above 0.2%. This *adaptive management* approach also has the advantage of allowing MEB to monitor the rate of rising sea levels and adjusting adaptation decisions accordingly.

Infrastructure, building and equipment damage

Increased flood risk will have implications for port infrastructure, building or equipment damage. For instance, increased seawater flooding could lead to higher rates of metal corrosion on ports, especially as temperatures rise globally and salinity increases in some locations.¹⁵

While damage by shallow and temporary flooding is likely to be limited in most ports due to the construction materials used in ports, electrical equipment is very vulnerable with risks of arcing and short-circuits.

Fast-moving water associated with storm surge flooding can dislodge containers and other cargo, knock down buildings, and damage equipment and port infrastructure such as piers, pavements and foundations. High winds can have similar impacts.

Increased sea levels, changes in wave activity and river flows can aggravate coastal and soil erosion.

With rising sea levels, the standards of protection of natural and man-made sea defenses will be reduced.

Temperature-sensitive port structures (such as cranes) will be increasingly stressed by higher peak temperatures.

It is not expected that climate change (including seawater flooding) will cause significant damage to MEB's infrastructure, buildings and equipment, or threaten MEB's employees. This is due to both the types of assets and construction materials present on the port and the relatively low storm surge heights.

For instance, the electricity sub-station on MEB's island site is at the same level as the quays and is not projected to be flooded by 2100 (even by a 1 in 300-year storm surge).

However, towards the end of the century, increased frequency of flooding could cause higher corrosion rates.

¹⁵ Increases in salinity have been observed in tropical surface waters. See IPCC WGI (Intergovernmental Panel on Climate Change Working Group 1). 2007. *Climate Change 2007: The Physical Science Basis; Contributions of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Avery, M. Tignor, and H. L. Miller. Cambridge: Cambridge University Press, pp. 996.

Inland transport beyond the port

Ports rely on the efficiency and resilience of inland transportation networks and assets to move import and export goods and connect to major economic centers.

Road, rail and waterway transportation systems can be affected by climate change in a number of ways.

Higher temperatures and longer periods of extreme heat can:

- Affect road surfaces,
- Cause rail tracks to buckle and damage overhead cables, and
- Increase fire risk.

In areas with frozen ground, rising temperatures will increase land instability. Where winters will be less snowy as well as warmer, transport system winter maintenance requirements could decrease.

Changes in rainfall regimes and extreme rainfall, and the associated effects on soil moisture, will increase flood risk and impact on ground stability. This will have consequences for the structural integrity of assets such as roads, bridges and railways. Damage will increase in areas of increased hurricane intensity.

In some areas, cargo transported on waterways will be affected by reduced flows in rivers or water levels in lakes due to the compound effect of higher rates of evaporation and plant transpiration, decreased surface water runoff and increased droughts or dry spells associated with changes in land use.

All of these potential impacts on transportation can cause delays, traffic interruptions or transportation restrictions on the transport routes taking goods and materials to ports. They can affect port revenues significantly. For instance, inadequate rail capacity in Australia caused severe bottlenecks for ship loading at major coal-exporting Australian ports.

Most goods to and from MEB are transported by truck, though waterway transport is also available. Transport cost is a decisive factor that influences decisions on which Colombian ports customers use.

Trucks coming in and out of MEB use a limited road network:

- Three two-lane residential streets oriented east-west connecting the port terminal gates and the highways, and
- Two four-lane highways running into El Bosque going south (Avenida Crisando Luque) or north (Avenida Bosque).

Some flooding in Cartagena has been known to be caused by high sea levels. The roads neighboring MEB, assumed to be at 1.6 m above the port plan datum, are projected to be at flood risk in the accelerated sea level rise scenario by 2080 during the highest tides of the year and in the event of a 1 in 300-year storm surge. Flood maps of the city produced using a Light Detection and Ranging (LiDAR) elevation dataset (which was not available for use in this study) indicate that roads outside MEB are at flood risk when sea levels reach 1 m.

Surface flooding is known to frequently affect parts of the city (Castillo-Grande, Bocagrande and the old part of Cartagena). However, it is not known how El Bosque, as well as the roads used by MEB and its customers, are affected. In 2008, the University of Cartagena found that El Bosque had high levels of material damming its drainage channels causing localized siltation and structural flaws. Due to the fact that the municipal drainage system in El Bosque is already experiencing strain and that increased heavy precipitation is expected, it would appear that surface flood risk of the local road network is increasing. It is recommended that MEB monitors progress of the various ongoing studies into the issue and supports better drainage maintenance by the City. It is worth noting that the large drainage channel built to the north of the port by MEB helps to manage surface flood risk.

Outside Cartagena, much of the road network is already in a state of disrepair. Over 50% of it is classified as *bad or very bad*. The analysis of government data on hazards recorded in 2008 identified storms and floods as the major hazards affecting roads around Cartagena. Climate change could increase the rate of flood-related incidents.

Insurance availability and costs

Ports may face changes in insurance terms and costs as the incidence of severe weather events increases and knowledge of climate change impacts in the insurance industry improves.

For those ports that are most vulnerable to future extreme climatic hazards, it is likely that insurance premiums and deductibles will increase at least proportionally to port claim losses.

Insurers commonly agree that port operators with robust climate risk management strategies in place could avoid some of these impacts.

MEB's insurance covers damage related to typical weather-related perils, such as floods, heavy rains, wind storms, tropical cyclones and extreme temperatures.

However, MEB does not have an *ingress/egress* policy, so that the revenue consequences of business interruptions due to increased flooding (e.g., between 3 and 7% of MEB's projected earnings by 2032 because of flooding of the causeway road as outlined earlier) will not be covered, unless it relates to damage or loss of insured assets.

Changes in MEB's insurance conditions because of climate change cannot be excluded since:

- Colombia is already considered by the insurance market as *highly to very highly exposed* to a number of climate-related hazards which are projected to further increase (such as floods), and
- The study found that flood risk will considerably increase at MEB, unless adaptation measures are taken.

In 2010, MEB's annual insurance premium was US\$122,877.

The study showed that raising the height of the causeway is economically beneficial from the 2040s and 2030s onwards for the observed and accelerated sea level rise scenarios respectively. Discussion with insurers conducted for this study indicate that some insurers would consider offering more favorable insurance to customers who have undertaken similar actions that reduce future risk. It is recommended that MEB considers raising the causeway, rather than contracting an *ingress/egress* insurance policy.

Social performance

Changing climatic condition can aggravate or create additional safety risks to port workers related to cargo handling and use of machinery, vehicle movements and flammable materials.

Exposure to pollution may also increase under certain circumstances, for example if changes in sea conditions affect the risk of chemical or oil spills. There could also be new pests and diseases present in ports.

Increased tensions in the relations between ports and surrounding communities is possible if the combined effects of climate change and port activities have negative community impacts.

Overall it is thought that climate change will pose little, if any, health risks to MEB's workforce. There is a small chance that climate change could lead to an increase in eye, skin and cardiovascular complaints among the workforce due to higher exposure to ultraviolet radiation in sunnier conditions and increased peak temperatures in Cartagena. However, present-day costs to MEB for absenteeism due to these conditions are very small.

Despite the limited risk, it would be useful for MEB to raise awareness among staff that certain health and safety conditions can be influenced by climatic changes.

There are very few people living in the vicinity of the port and MEB itself has limited impacts on these surrounding communities. MEB's leadership is committed to good social management and maintains good relations with the surrounding communities. It has been found that climate change is unlikely to create new problems for these communities or aggravate existing ones. For instance:

- Whatever precipitation changes occur in the future, MEB plans to pave the unpaved areas of the port, which will reduce the likelihood of mud spray on local roads.
- The unfounded community perception that MEB handles coal which produces dust detrimental to human health (it handles coke) will not be affected by climate change. In fact, if the observed trend of increasing rainfall continues, coke dust generation could be reduced.

Environmental performance

By influencing port dredging requirements, climate change can disturb sea beds and areas important to marine life. Increased temperatures, sea levels and storminess, as well as modified salinity, sea currents and water runoff, will have implications for seabed conditions and sedimentation.

Some of the major sources of port air pollution, as well as the ways port air pollution is dispersed into the atmosphere, will be affected by changes in factors such as wind, humidity and temperature. Higher frequency and intensity of poor air quality episodes, which can lead to restrictions to port operations, could increase as a result.

Future increases in precipitation intensity will increase the risk of on-site or off-site pollution due to pollutant runoff, in particular for ports with limited drainage capacity or with low levels of maintenance of sediment traps and oil/water separators.

Waste reception and management facilities at ports could have limited capacity to cope with future climatic changes.

Ports located near protected habitats or species could see their reputation challenged if changes in climate negatively impact these natural assets.

Overall, port environmental impact assessment and environmental management plans which do not consider future changes in climate could be inadequate.

MEB is certified according to ISO14001, which demonstrates a commitment to environmental protection.

The environmental impact of MEB's operation is not expected to be significantly affected by climate change, except for:

- A 30% increase in energy use for refrigeration and associated greenhouse gas emissions,
- A possible increase of the risk of overflow of sediment traps and oil/water traps due to seawater flooding at the port, and
- A limited, but not impossible, increased risk of pollutant runoff during episodes of surface flooding.

In and around Cartagena, sea level rise and rising temperatures are expected to further degrade corals, mangroves and seagrass.

Works to raise the height of the causeway are likely to damage the surrounding mangrove. MEB could be required by the environmental agency of Cartagena (CARDIQUE) to pay for mangrove (re)generation elsewhere.

Sea level rise is also expected to have an impact on the mangrove. Due to its location on the narrow tidal fringe against the port, it is not possible for the mangrove to retreat as sea level rises. Therefore it must move upward out of the water. To do this, the sediment substrate must increase in height and it may be possible for MEB to assist this process, for example through the use of dredge material.

Climate risk and adaptation checklist

The analyses undertaken for MEB in this study have shown that climate change can have material business implications for ports. Though some of the risks analyzed in this study are likely to be specific to MEB and may not apply to other ports, a number of them will be of broad relevance to the industry around the world.

The existing climate change research base often addresses port cities, rather than operational ports themselves. To help port operators and their stakeholders to identify climate-related risks and possible adaptation options, a checklist is provided below. It is based on the findings of the study on MEB and a comprehensive literature review. While it is focused on cargo ports, many of the issues it raises will be relevant to other types of port facilities.

This checklist:

- Categorizes climate impacts (risks and opportunities) according to the key operations undertaken at cargo ports (navigation, berthing, goods handling, etc.), along with other factors related to port performance, such as demand, insurance availability and environmental and social performance.

- Gives an overview of the climate-related sensitivities and thresholds of cargo ports in general, and also outlines some impacts which are specific to ports in particular environments (e.g., tropical and polar regions).
- Provides a list of adaptation measures which can be considered by port operators in response to climate change risks and opportunities. These include actions which help to build adaptive capacity (such as improved monitoring of climate impacts) as well as the implementation of physical adaptation measures (such as modifications to port infrastructure).

Notes on the checklist:

1. The climate-related sensitivities and critical thresholds for which the MEB study undertook risk assessments are highlighted in blue. For more information refer to the full study report.
2. There is not a one-to-one mapping between columns 2 and 3. For instance, for some climate-related risks, the checklist provides more than one adaptation option.

Risk areas for ports	Port sensitivities and potential climate change impacts	Adaptation options and opportunities for ports
Demand, trade levels and patterns	Supply and demand for products traded through ports is sensitive to climate change impacts on the global economy, production, commodity prices and buyers (e.g., increased temperatures may reduce crop yields, affect price and contribute to trade fluctuations)	Monitor impacts of climate change on supply and demand for traded products (e.g., on production and price of existing or potential products)
	Port import and export markets are likely to shift in response to climate-driven population movements. (Climatic changes such as increased flood and drought incidence may lead to substantial population movement over the longer term)	Consider updating assumptions used in business forecasting and strategy planning
	Customers' perceptions of port service reliability may change in response to increased climatic disruptions	Over the longer term, identify opportunities for creating new or expanded port facilities in response to population movements
Navigation, shipping and berthing	Navigation depths in coastal ports and shipping channels are sensitive to changes in sea level	Explore diversification of product lines in response to positive or negative climate change impacts on supply/demand
		Monitor customer expectations of reliability and concerns about disruptions, and inform them of plans to address these issues
		Monitor changes in sea level and review dredging plans and schedules
		Engage with those responsible for dredging to ensure changing risks are being managed appropriately
		Identify opportunities to accommodate larger ships due to sea level rise

Risk areas for ports	Port sensitivities and potential climate change impacts	Adaptation options and opportunities for ports
Navigation, shipping and berthing (continued)	Vertical operability range of quays, piers and material handling equipment may be affected by changes in relative sea level	<p>Conduct berth operability assessments in light of projected changes to sea level and, potentially, storminess. Review suitability of berthing equipment or operations based on research outputs</p> <p>Consider sea level rise in refurbishment or replacement programs for infrastructure with a long design life (e.g., quays, docks, bridges)</p>
	Clearance of vessels under bridges may be more difficult due to sea level rise	Monitor frequency of bridge openings. Where bridges are operated by others, engage with them on their plans for addressing climate change impacts
	Maximum cargo limits, ship navigability and berthing restrictions at ports on rivers and lakes are sensitive to changes in water level	Monitor customer responses to reduced cargo loads, navigability and increased berthing restrictions, and inform them of plans to address these issues
	Sedimentation in enclosed bays, rivers and lakes is sensitive to climate impacts on runoff and soil conditions. Dredging requirements may be affected	Monitor levels of sedimentation and review dredging plans and schedules
	Ports on rivers, lakes and enclosed bays with large river influx may be increasingly affected by debris build-up following extreme rainfall	<p>Engage with those responsible for managing changes in sedimentation</p> <p>Engage with waterborne transit and navigation authorities to ensure changing risks are being managed appropriately</p> <p>Review contingency plans for delays and loss of traffic caused by reduced navigability</p>
	Levels of protection for port access channels may be affected due to climate impacts on man-made or natural defenses	<p>Review levels of protection for port access channels in light of climate change</p> <p>Engage with relevant authorities on design and construction of climate change-resilient protection schemes</p>
	Choice of port (and thus port competition) is sensitive to the impacts of climate change on shipping costs. For instance, as Arctic ice is melting to record levels, ships are beginning to use the Northern Sea Route from Europe to Asia. It offers significantly lower fuel costs than the southern route via the Indian Ocean	<p>Monitor research on climate change impacts and shipping routes</p> <p>Monitor changes in regional and international shipping conditions and costs</p>
Goods handling and storage	<p>Northern latitudes are seeing some of the most rapid changes in climate. Increasing seasonal and year-to-year variability in ice conditions will bring both risks and opportunities for shipping, access to ports and berthing operations</p>	Identify shipping routes and ports that are projected to see the most significant changes, and take advantage of opportunities for new trade or longer access periods
	<p>Crane operability will be affected if wind speed thresholds are exceeded more frequently and/or if lightning incidence increases</p> <p>More frequent and intense heavy downpours may lead to greater disruption to operations involving weather-sensitive cargo</p>	<p>Review climate resilience of material handling systems in the light of climate change (e.g., use of closed areas for cargo handling)</p> <p>Review choice of material handling equipment on renewal or purchase, taking account of climate change projections</p>
	Goods may be spoiled if flooding increases due to sea level rise and/or increased storminess	Consider reorganizing storage to ensure perishables are in less vulnerable areas
	Increases in peak rainfall intensity may exceed drainage design standards, causing surface flooding and goods spoilage	Measures to manage flood risk are described under <i>Vehicle movements inside ports</i> below
	Security of supply of water and electricity utilities may decrease (e.g., due to climate change impacts on water resources affecting water supplies and power production, and increased energy demand for cooling)	Engage with utilities providers to understand their level of preparedness for climate variability and change, and the conditions under which they would cut off supplies to the port

Risk areas for ports	Port sensitivities and potential climate change impacts	Adaptation options and opportunities for ports
Goods handling and storage <i>(continued)</i>	Energy costs for refrigeration are likely to increase in response to higher temperatures	Investigate opportunities for reducing energy consumption (e.g., more energy efficient reefers) Consider passing on increased energy costs to customers
	If conditions are becoming drier, needs for dust suppression may increase, and at the same time, water availability may be reduced	Review dust mitigation measures in light of changing conditions Maximize opportunities for water recycling and harvesting
	Perishable goods may spoil more quickly in response to temperature increases and rainfall changes (e.g., due to increased mold, mycotoxin, mites, sprouting)	Review frequency of quality checks/controls for stored perishable goods Consider putting refrigeration, cooling, insulation and ventilation systems in place. (Note that this could conflict with greenhouse gas emission reduction targets, so where possible systems should be energy efficient or powered by renewable energy)
	Risk of dust explosions may increase in areas where climate change is expected to lead to lower humidity	Review dust mitigation measures in light of changing conditions Review plans for managing explosion risks
	Handling operations may be affected by changes in ice conditions at the port	Review measures for managing operations during icy periods
Vehicle movements inside ports	Standard of coastal flood protection provided by man-made or natural defenses may be reduced due to mean sea level rise and increased storminess. Low-lying port areas are more vulnerable to these impacts	Review standards of protection from flood risk on site in light of knowledge about climate change impacts and upgrade where necessary Review evacuation and business continuity plans for coastal flooding Avoid new development in low-lying areas Retrofit infrastructure or assets vulnerable to flooding if cost-effective to do so (e.g., use water-resistant materials, insulate electrical equipment or move it out of flood risk areas, raise height of low-lying areas) Engage with public authorities responsible for flood protection to ensure that climate change resilience is being built into their investment planning Review insurance coverage for coastal flood risk In extreme cases where flood risks cannot be managed, consider relocating
	Increases in peak rainfall intensity may exceed drainage design standards, causing flash flooding and restricting vehicle movements Sea water ingress through drainage outlets due to sea level rise may occur, leading to surface flooding	Review on-site drainage system capacity and elevation of outlet pipes above sea level, in light of increases in precipitation intensity and sea level rise Consider need to increase drainage system capacity and/or to fit one-way valves on drainage outlets to sea Review evacuation and business continuity plans for flash flooding Increase frequency of maintenance for drainage systems Review insurance coverage for surface flood risk
	On-site road conditions may be sensitive to rainfall changes and higher temperature extremes	Monitor changes to on-site road conditions and associated maintenance costs Consider upgrading road surfaces to make them more climate-resilient

Risk areas for ports	Port sensitivities and potential climate change impacts	Adaptation options and opportunities for ports
Infrastructure, building and equipment damage	Coastal erosion and under-scouring of quays, pier foundations, breakwaters, revetments and sea walls may be exacerbated by climate change	<p>Increase monitoring of infrastructure condition</p> <p>Review and upgrade maintenance programs</p> <p>If necessary, strengthen infrastructure foundations, stabilize slopes / embankments, taking account of climate change projections</p> <p>Restrict new development in low-lying areas</p> <p>In extreme cases, where risks cannot be managed, consider relocating</p>
	<p>Risk of water damage to electrical equipment may be sensitive to changing rainfall conditions</p> <p>Containers, cargo and equipment may be dislodged or damaged by fast moving sea water or tidal river water</p> <p>Quay and pier structures, pavements and buildings may be damaged by fast moving sea water or tidal river water</p>	<p>Measures to manage flood risk are described under <i>Vehicle movements inside ports</i> above</p> <p>Consider use of water-resistant materials and equipment</p> <p>Review and upgrade maintenance programs</p>
	Unreinforced terminal structures and equipment may be vulnerable to damage in high winds	<p>Monitor exceedance of wind-related thresholds for light structures and sensitive assets</p> <p>Review design standards for wind-sensitive equipment</p> <p>Review emergency and business continuity plans</p>
	Temperature-sensitive structures and equipment may be at risk from higher temperature extremes due to climate change	<p>Monitor performance of temperature-sensitive structures and equipment in extreme temperatures</p> <p>Review design standards for temperature-sensitive structures and equipment</p> <p>If necessary, upgrade equipment to be able to cope with higher temperatures</p>
	Corrosion rates are sensitive to flooding and water spray and temperature (which affects microbial activity)	<p>Monitor corrosion rates</p> <p>Consider use of corrosion-resistant materials</p>
Inland transport beyond port	<p>Reliability of inland transportation to and from ports may be affected by higher temperatures (e.g., buckling of rails, melting of road surfaces), changing rainfall (e.g., surface flooding, erosion of embankments) and sea level rise (coastal flooding and erosion). Inland transportation costs may change as a result</p>	<p>Monitor levels of disruption to inland transport due to climatic conditions</p> <p>Monitor research on climate change impacts on transport systems in regions of interest</p> <p>Engage with public authorities or transport infrastructure companies on actions they are taking to build climate change resilience</p> <p>If possible, identify alternative transport routes which can be used if needed for business continuity</p>
Insurance availability and costs	<p>Insurance terms and costs for weather-related losses are sensitive to changes in climate</p>	Implement cost-effective measures to prevent weather-related losses, as outlined above
	<p>Insurance underwriters may direct more climate change-related questions at ports</p> <p>Insurance cover may become prohibitively expensive or unavailable in high risk areas. This can have consequences when seeking finance</p>	<p>Prepare for questions from underwriters by undertaking risk assessments and updating management and business continuity plans</p> <p>Engage with insurance providers on actions being taken to build resilience to weather-related events</p>

Risk areas for ports	Port sensitivities and potential climate change impacts	Adaptation options and opportunities for ports
Social performance	<p>Occupational hazards related to extreme weather conditions may increase (e.g., heat stress, high winds, heavy rainfall, lightning, flooding)</p> <p>Potential for increased risks of fire and spontaneous ignition due to higher temperatures and solar radiation</p> <p>Climate change impacts may increase worker exposure to pollution (water, land and air)</p> <p>Changing disease patterns due to climate change may expose workers to new diseases</p>	<p>Review health and safety policies and standards, and emergency evacuation plans</p> <p>Review storage and handling protocols for flammable and explosive materials</p> <p>Provide training to workers on changes in weather-related risks</p> <p>Monitor correlations between occupational health and safety incidents and weather conditions</p> <p>Measures to manage changes in environmental risks are described below under <i>Environmental performance</i></p>
	<p>Potential for increased conflicts with surrounding vulnerable communities whose livelihoods are adversely affected by climate change (e.g., artisanal fishing)</p>	<p>Understand vulnerability of surrounding communities to climate change</p> <p>Maintain good relations with surrounding communities and engage with them on climate change issues</p> <p>Identify and implement actions which can have co-benefits for the port and surrounding communities (e.g., malaria control programs). These can be integrated into corporate social responsibility programs</p>
	<p>Climate change may lead to changes in country socio-economic conditions (e.g., through loss of land and water stress leading to increased poverty and unrest) with consequences for business at the port</p> <p>In extreme cases, if climate change leads to <i>environmental refugees</i>, there could be mass migrations through ports (especially non-cargo ports)</p>	<p>Engage with national government to understand impacts of climate change on country socio-economic conditions, and actions being taken to manage these</p>
	<p>Risks of water, land and air pollution may increase due to changes in temperature, rainfall and storms</p> <p>Energy use and greenhouse gas (GHG) emissions may increase due to temperature increases</p>	<p>Review and revise environmental management and monitoring plans and GHG emission reduction plans in light of climate change risks</p>
Environmental performance	<p>Dredging requirements may change due to changes in sedimentation rates and flows</p>	<p>Review and revise dredging and environmental management plans</p>
	<p>Sensitive or protected habitats and species in the vicinity of a port may become stressed due to changing conditions, e.g.:</p>	<p>Monitor research on climate change impacts on sensitive habitats and species found in the vicinity of the port</p>
	<p>Coastal habitats can be squeezed between rising sea levels and man-made coastal defenses</p> <p>Coral reefs are under threat from increasing ocean acidity (as higher levels of carbon dioxide in the atmosphere drive the oceans to absorb more carbon dioxide) and rising ocean temperatures</p> <p>In response to climate change, protected species may migrate away from a port's zone of influence (e.g., cold-loving fish species are already migrating polewards), and the port may be wrongly viewed as responsible for local species losses</p>	<p>Monitor the condition of surrounding habitats and species</p> <p>Engage with environmental regulator on climate change impacts</p> <p>Examine benefits provided to ports by surrounding ecosystems and consider <i>ecosystem-based adaptation</i> (e.g., mangroves for coastal protection)</p> <p>Identify opportunities to improve the adaptive capacity of vulnerable species and habitats (e.g., facilitating their migration)</p>
	<p>Adaptation actions being considered by a port may have adverse environmental implications (e.g., creating <i>habitat squeeze</i> as outlined above)</p>	<p>Consider environmental implications when appraising potential adaptation actions</p> <p>Seek adaptation actions that have environmental co-benefits</p>



International Finance Corporation
2121 Pennsylvania Ave. NW
Washington, DC 20433
Tel. 1-202-473-1000
www.ifc.org/climatechange

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