

CLIMATE RISK AND BUSINESS PORTS

Terminal Marítimo Muelles el Bosque
Cartagena, Colombia



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Abbreviations and Acronyms

AAL	Average annual loss
BMI	Business Monitor International
BOD	Biological oxygen demand
CD	Chart datum
COP	Colombian pesos
CIOH	Centro de Investigaciones Oceanográficas e Hidrográficas de la Dirección General Marítima
DEM	Digital Elevation Model
DIMAR	Dirección General Marítima
DHI	Danish Hydraulics Institute
DNP	Department of National Planning of Colombia
EBITDA	Earnings before interest, taxes, depreciation, and amortization
ECLAC	The Economic Commission for Latin America and the Caribbean
ENSO	El Niño Southern Oscillation
EMP	Environmental Management Plan
GCM	Global climate models
GDP	Gross domestic product
GHG	Greenhouse gas
ICA	Instituto Colombiano Agropecuario
IDEAM	Instituto de Hidrología, Meteorología y Estudios Ambientales de Colombia
IPCC	Intergovernmental Panel on Climate Change
MAVDT	Ministerio de Ambiente, Vivienda y Desarrollo Territorial
MEB	Muelles El Bosque
MHC	Mobile harbor cranes
MSL	Mean sea level
MWh	Megawatt hour
NASA	National Aeronautics and Space Administration
NCEP	National Centre for Environmental Prediction
NOAA	National Oceanic and Atmospheric Administration
NPC	Net present cost
NPV	Net present value
PAH	Polycyclic aromatic hydrocarbons
POT	Municipality of Cartagena master planning process
RCM	Regional Climate Model
RTG	Rubber-Tyred Gantry cranes
SPRC	Sociedad Portuaria Regional de Cartagena
SLR	Sea level rise
TE2100	Thames Estuary 2100
UNESCO	United Nations Educational, Scientific and Cultural Organization
USDA FAS	United States Development Agency Foreign Agricultural Service
LiDAR	Light Detection and Ranging
TPA	Tons per annum
VOC	Volatile Organic Compound

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1 Introduction and approach

1.1 Study overview

1.1.1 Context and aims of this report

Even if the world commits to significant greenhouse gas (GHG) emissions reductions, some climatic changes are already underway and further changes are inevitable. Rising sea levels, droughts, floods, heat-waves and storms, with their attendant risks, are becoming more common. Unless appropriate actions are taken to adapt to the risks, the impacts on businesses, the environment and communities may become increasingly severe¹.

Recognizing these issues, the IFC Adaptation Program aims to develop knowledge, tools and methods for analyzing climate-related risks and opportunities to the private sector, and for evaluating adaptation responses. This is being achieved initially by undertaking case studies of some of IFC's investments, to investigate how they could be affected by climate change. Within this context, IFC has commissioned this report for a port, Terminal Marítimo Muelles El Bosque (MEB), in Cartagena, Colombia. The report presents the outcomes of an assessment of the potential risks and opportunities from climate change for MEB, along with analyses of climate-resilient actions that the company can consider.

The report aims to address the following questions:

- *What risks and opportunities does climate change present for MEB?*
- *What are the most significant risks for MEB?*
- *How could MEB manage climate change risks in the most economically optimal way, taking account of environmental and social objectives?*
- *How could climate-related opportunities be developed and exploited?*
- *Where could MEB work in collaboration with other stakeholders to manage climate risks?*
- *What tools and techniques for climate risk assessment and management can be applied to understand these issues?*

1.1.2 Study scope and approach

These analyses have been undertaken through a combination of desk-based studies and modeling, and discussions with MEB, government and Colombian climate change experts, during a two week visit to Colombia in November 2010. Discussions with MEB during the site visit were particularly important in helping to define the key risks associated with climate change. Information and data provided by MEB during and after the site visit form the basis for many of the analyses.

The study has investigated climate risks and opportunities across MEB's activities (Table 1-1). Some of the risks are related to the design and operation of the port (e.g. its vulnerability to sea level rise). In these cases, MEB was often able to provide detailed data about the port, which provided a sound basis for the assessments. Analyses of other risks (e.g. potential impacts of climate change on the global economy and consequences for trade through the port) were more challenging, due to the many interactions between future climate, social and economic factors. In these cases, the study drew upon the climate change literature, aiming to present a synthesis of the latest research, drawing out its relevance to MEB. With the rapid evolution of scientific knowledge about climate change and its impacts, some of the uncertainties that were found in this study should be resolved or better characterized in the near future.

¹ At the same time, it is essential that international action to reduce emissions of greenhouse gases is stepped up, if the world is to avoid the worst effects of climate change in the longer term.

Table 1-1 – Climate change risks to MEB analyzed in this assessment (presented in decreasing order of significance to MEB)

Section no.	Risk issue	Scope and approach
5	Vehicle movements inside the port	Detailed analysis of flood risk to port due to sea level rise, based on oceanographic data and drawings of the port from MEB and cost estimate of disruptions to vehicle movements. Brief discussion on costs of maintaining unpaved areas of the port.
6	Demand, trade levels and patterns	Impacts on total trade through MEB (including grain imports and agricultural exports) assessed by drawing on the climate change literature.
7	Goods storage	Analyses of impacts of heavier rainfall on MEB's drainage system, flood risk to storage areas due to sea level rise, water used for coke wetting, refrigeration costs due to rising temperatures and impacts on grain storage. These analyses draw on engineering and other data provided by MEB, as well as the scientific literature.
8	Environmental performance	Brief assessment of how climate change could affect environmental resources in the bay, drawing on climate change literature, the inter-relationships with MEB and the information provided by MEB during the site visit.
9	Navigation and berthing	Impacts on navigation and berthing associated with sea level rise and storminess, assessed using a 2-D hydrodynamic model of the bay developed for this study, along with details of the port design from MEB.
10	Goods handling	Analysis of impacts of high winds and rainfall on crane operability, using thresholds provided by MEB.
11	Inland transport beyond the port	Assessment of impacts on the local road network due to sea level rise and the road drainage system capacity. Brief review of effects of extreme events on wider transport network in Colombia, using data provided by government.
12	Social performance	Analysis of climate change impacts on MEB's social performance and MEB's workers, based on information provided by MEB and data on social vulnerabilities obtained from government sources and the climate change literature.
13	Insurance	Analysis of the degree to which the climate change risks identified in the study might be mitigated by MEB's insurance and brief review of how climate change could influence future insurance costs and availability.

For the risk assessments, the study used both observed and projected future changes in climate conditions. As discussed in Section 4 and Appendices 2 and 3, analyses of climate change have inherent uncertainties – particularly in relation to precipitation in the case of mountainous countries like Colombia. The most appropriate way to understand these uncertainties is to use a range of climate change scenarios in risk assessments, as have been applied in this study.

1.1.3 Overview of climate change risks and opportunities identified for MEB

Table 1-2 below provides a brief summary of the risks and opportunities identified through the analyses of MEB, as described in later sections of this report. The risks and opportunities are organized into a range of categories (operational, financial, etc.) and risks are rated from 'low' to 'very high'. (For further information, see Section 17.1.)

Table 1-2 – Summary of climate change risk assessment for MEB over the 21st Century, assuming no adaptation

Risk	Risk category	Risk level
Vehicle movements inside the port (Section 5)		
Increased seawater flooding of port areas (observed sea level rise scenario)	Operational	VERY HIGH
Increased seawater flooding of port areas (accelerated sea level rise scenario)	Operational	HIGH
Increased maintenance of port unpaved areas	Operational	Low
Demand, trade levels and patterns (Section 6)		
Reduction in total trade at MEB	Financial	MEDIUM
Reduction in grain imports at MEB	Financial	MEDIUM
Reduction in agricultural exports at MEB	Financial	Low
Better relative performance of MEB compared to other ports	Reputational	OPPORTUNITY
Increase in certain agricultural exports at MEB	Financial	OPPORTUNITY
Goods storage (Section 7)		
Goods damage or loss due to seawater flooding (accelerated sea level rise scenario)	Reputational	VERY HIGH
Goods damage or loss due to seawater flooding (observed sea level rise scenario)	Reputational	VERY HIGH
Goods damage or loss due to surface flooding	Reputational	MEDIUM
Increased customer energy costs for refrigerated containers, affecting customers' views of MEB	Reputational	Low
Grain spoilage in storage facilities	Reputational	MEDIUM
Reduced water use for spraying coke	Financial	OPPORTUNITY
Environmental performance (Section 8)		
Mangrove degradation around the causeway	Environmental	HIGH
Failure to comply with Environmental Management Plan as a result of climate change	Legal	Low
Reduced dredging requirements	Environmental	OPPORTUNITY
Use of mangrove regeneration as an adaptation measure	Environmental /Operational	OPPORTUNITY
Navigation and berthing (Section 9)		
Difficulties with berthing due to increased height of vessels berthed relative to quay and material handling equipment	Operational	MEDIUM
Reduced berth operability because of higher wave height	Operational	Low
Reduced navigability in the Bay of Cartagena	Operational	Low
Opportunity for larger draft vessels to berth at MEB	Operational	OPPORTUNITY
Reduced dredging requirements	Financial	OPPORTUNITY
Goods handling (Section 10)		
Increased crane downtime during periods of high winds	Operational	MEDIUM
Periods of heavy rainfall prevent the loading or unloading of certain goods	Operational	MEDIUM

Risk	Risk category	Risk level
Inland transport beyond the port (Section 11)		
Increased surface flooding of the roads in Cartagena	Reputational	MEDIUM
Increased seawater flooding of the road outside MEB	Reputational	MEDIUM
Increased climate-related hazards on roads across Colombia	Operational	MEDIUM
Increased river flows on Colombia's waterways	Operational	OPPORTUNITY
Social performance (Section 12)		
Increased congestion or mud on the local road network	Local community	Low
Increased discontent because of coke dust and soda ash blowing	Local community	Low
Increased employee absenteeism	Health and safety	Low
Insurance (Section 13)		
Increased insurance premiums or degradation in insurance terms reflecting future climate change risks	External stakeholders	MEDIUM

For MEB, in considering if or how to respond to these risks and opportunities, it will be important that the company considers its risk attitude. If MEB were to choose to adapt to the worst-case scenarios and these did not occur, then the company would have spent money that could have been used productively on other activities. Adapting to the lowest scenarios, or assuming that climate change was not occurring, could mean that MEB is increasingly affected by climate change over the longer-term and its facilities are not economically optimal. Section 2.12 discusses robust approaches to decision-making on climate change adaptation to manage these uncertainties, which can be applied by port operators.

For all the climate change risks identified across MEB's activities, the study identified adaptation measures. Where risks to MEB were found to be significant, an appraisal was undertaken of the costs and benefits of adaptation. The level of detail of these adaptation assessments is function of the level of confidence in climate change projections: where there were reasonably good future projections (for example, for sea level rise), trigger dates for undertaking adaptation were identified and different adaptation scenarios were compared (e.g. incremental adaptation over time against 'one-off' adaptation).

An additional key point that was highlighted by MEB during the site visit is that a customer's choice about which port to use is heavily influenced by the port's reputation for operating reliably. Any factor that can damage the perception of reliability can lead to loss of business. Such climate change-related factors representing a risk to MEB's reputation were considered in this assignment and analyzed in light of the potential impacts on MEB's customers.

Finally, while this report focuses on climate change risks to MEB, it also briefly explores how other ports in Colombia can be affected by climate change. If MEB manages adequately its climate change risks and is seen as more climate-resilient by its clients and stakeholders (including insurers), it could gain a competitive advantage compared to other ports.

1.2 Overview of the main ports in Colombia

Ports in Colombia are grouped in zones by their geographic location. The location of the main ports and the volume of international trade in 2008 by port zone are shown in Figure 1-1 and Table 1-3.

The largest port city in Colombia is Santa Marta, at 32% of international cargo (by tonnage, 2008). This is primarily due to Sociedad Portuaria Drummond Ltda, which exports large volumes of coal. After

Buenaventura, Santa Marta also received the second largest volume of grain from the USA (USDA FAS, 2009). Ports in Santa Marta have no access problems (see Section 9) and can receive Post-Panamax vessels². Some developments are currently planned: for example, the Port Society of Santa Marta is planning to expand its current bulk grain terminal capacity (USDA FAS, 2009).

Buenaventura is the closest port city to Colombia's major cities of Medellin and Cali and is located on the crucial Asian trade routes. The distance between Buenaventura and the capital, Bogota is also approximately half the distance between Cartagena and Bogota. Weather conditions have been highlighted as a major risk for port operations in Buenaventura as they limit hours of operation. Buenaventura is one of the rainiest cities in the world, with annual precipitation between 6,000 and 7,000mm (USDA FAS, 2009). Another risk which Buenaventura faces relates to maintenance dredging of the access channel. It is also notable that the port faces some social issues: it is the biggest employer in the city and strikes have interrupted port operations in the past³. There is significant investment being made in the port of Buenaventura (including by MEB). For example, Terminal de Contenedores de Buenaventura is developing a container terminal located just north of the existing port. Another port is proposed in one of the bays to the north of Buenaventura, which would have a lower dredging requirement⁴.

The port city of Barranquilla is located approximately 22 km upstream from the estuary mouth⁵ of the Rio Magdalena. It handles mostly grain (42% of its total cargo in tonnage 2007), in part due to its location near the hub of the poultry industry. Stainless steel and coal represented 22% and 14% of its total cargo in tonnage in 2007 (USDA FAS, 2009). Access is a major issue, as the natural depth of the channel is significantly below that required for Panamax or Post-Panamax vessels and sedimentation rates are very high (see Section 9). However, a project to deepen the access channel has been running since 2006³. The Rio Magdalena provides another transport option to trucking goods by road from the port.

Figure 1-1 – Major cities and port cities in Colombia



² Post-Panamax vessels are larger than Panamax vessels, which are sized to fit through the Panama Canal. For example, they include super tankers and the largest container ships.

³ See www.ntn24.com/content/huelga-camioneros-colapsa-principal-puerto-colombia (27/09/2010).

⁴ Article in Dredging Today. Accessed from website www.dredgingtoday.com/2010/04/26/colombia-proposal-for-new-port-in-malaga-bay-represents-threat-for-whales/ (17/09/10).

⁵ Sociedad Portuaria Regional de Barranquilla (SPRB). Accessed from website: www.sprb.com.co (18/04/2010).

Table 1-3 – International trade by port zone 2008 (Ministry of Transportation 2009)

Port Zone / City	Total International Trade 2008 (tons)	Percentage of International Trade 2008 (tons)
Barranquilla	6,013,607	5%
Buenaventura	9,252,491	8%
Cartagena	13,803,553	12%
Santa Marta	35,460,013	32%
Golfo Morrosquillo	14,444,240	13%
Guajira	32,402,295	29%
San Andres Islas	57,409	0.1%
Tumaco	884,134	0.8%
Total	112,317,742	

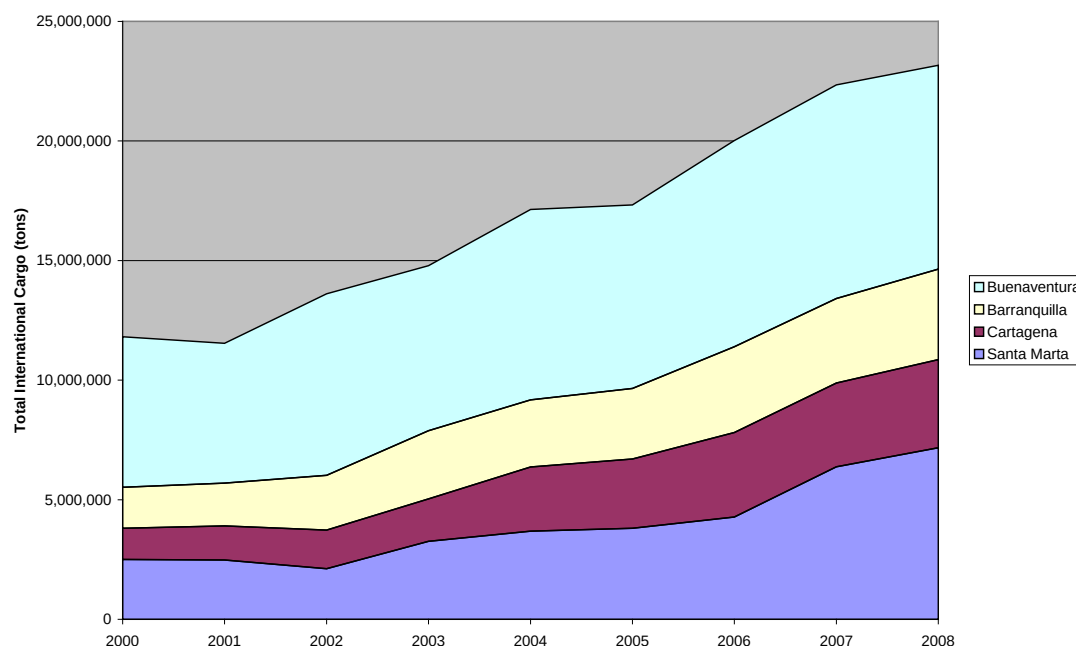
The current Colombian port system includes eight major port zones or cities (as shown in Table 1-3) and 122 port facilities, including five Sociedades Portuarias Regionales (SPRs or regional ports), nine Sociedades Portuarias de Servicio Público (public port societies), seven Sociedades Portuarias Privadas de Servicio Privado (private port societies), 44 Muelles Homologados (approved piers or jetties), ten 'embarcaderos o muelles de cabotaje' (coastal piers or jetties for smaller vessels) and 47 other small facilities. Through these facilities, more than 120 million tons of cargo is moved. 95% of the cargo is moved by the five regional port societies and specialist ports that primarily export oil and coal (Ministry of Transportation 2009).

The Colombian SPRs are the primary competitors of MEB and made up 21% of international trade in 2008 (Ministry of Transportation, 2009). Figure 1-2 shows total cargo throughput in tons for four SPRs from 2000 to 2008. Buenaventura SPR is the largest of these and accounted for 8% by tonnage of international trade in 2008. It is followed by Santa Marta (6%), Cartagena (3%), and Barranquilla (3%) SPRs.

The USA is Colombia's largest trading partner, accounting for 26% of imports and 35% of exports. The regional port societies are not the port authorities but rather a group of private companies that have government concessions to operate the ports.

In the first Business Monitor International (BMI) Colombia Shipping report of 2010, a notable upturn in the maritime sector is forecast. BMI predicts that Colombia's imports and exports will increase by 6% and 3.5% respectively from 2009. Total throughput in Cartagena is projected to increase by 4.8%.

Figure 1-2 – Total cargo movements (tons) for SPRs in Colombia (Ministry of Transportation, 2009b)



Note: These figures do not recognize the importance of the SPRs in the movement of containers or the continuing expansion of port facilities in and around Buenaventura.

1.3 Overview of MEB

MEB was the first privately owned maritime terminal in Colombia. MEB was established in 1992 and the company currently holds a concession from the Government of Colombia to develop and manage the port, which is the second largest in Cartagena, until 2032.

MEB consists of two entities, Terminal Maritimo Muelles El Bosque, which holds the concession and Muelles El Bosque Operadores Portuarios, which provides port operations. For the purposes of this study MEB is treated as a single entity.

The port is located in the Bay of Cartagena which is a natural harbor. It is the largest and most secure harbor on the northern coast of Colombia, being sheltered from all directions. It is about 15km long and up to about 6 km wide, with Cartagena being located at the northern end. Access to the bay is possible through two access channels of depths of 11 to 12 meters. These are Bocagrande (at the northern end of the bay) and Bocachica (at the southern entrance of the bay), as shown in Figure 1-3. Bocachica is the only navigable entrance to the bay for most vessels as it leads to deep water close offshore.

MEB's port terminal is located in El Bosque, a mixed industrial and residential zone of the city of Cartagena. It occupies 10 hectares, including Isla del Diablo and an adjacent mainland area, linked via a causeway road. It is a multi-purpose terminal that handles containerized cargo, general cargo, grains and coke. There are no plans to change from these four product lines. An aerial photograph of the Isla del Diablo showing the handling and storage of the four product lines is provided in Figure 1-4. MEB moved 1% of Colombia's international trade by tonnage in 2008 (Ministry of Transportation 2009a). Seaboard Marine is the shipping company that berths the most at MEB. Figure 1-5 shows the shipping routes used by Seaboard Marine that pass through MEB.

Monthly cargo data for MEB from 2006 to 2009 have been analyzed to assess whether there is any annual variation in throughput at MEB. Seasonality of throughput could be an important factor to consider as climate change will be different across seasons. Taking the mean revenue for each month

across the five year data set there is some evidence of a seasonal variation in total revenue (see Figure 1-6). There is an increase in revenue of only approximately 10% above the mean from August to November, which coincides with the wet season. Similarly revenue is lower around March, where it is approximately 10% below the mean. However, there is not such a clear picture when looking at the throughput of each product line (see Figure 1-7). As the picture is not clear and the annual variation is only $\pm 10\%$ it is assumed in this assignment that there is no seasonal variation in revenue. As the port moves towards full capacity, the absence of seasonality is expected to be confirmed.

Figure 1-3 – Overview of the Bay of Cartagena. The locations of the ports are indicated by yellow stars and yellow name tags. Areas of the city are labeled in yellow (Bocagrande, Castillogrande and Canal del Dique), along with the two access channels to the Bay of Cartagena. The meteorological station is indicated by an orange circle at the north of the city. The tide gauge changed location in 1993; the two locations are shown by the two orange circles on the bay (east of Castillogrande and south of MEB).

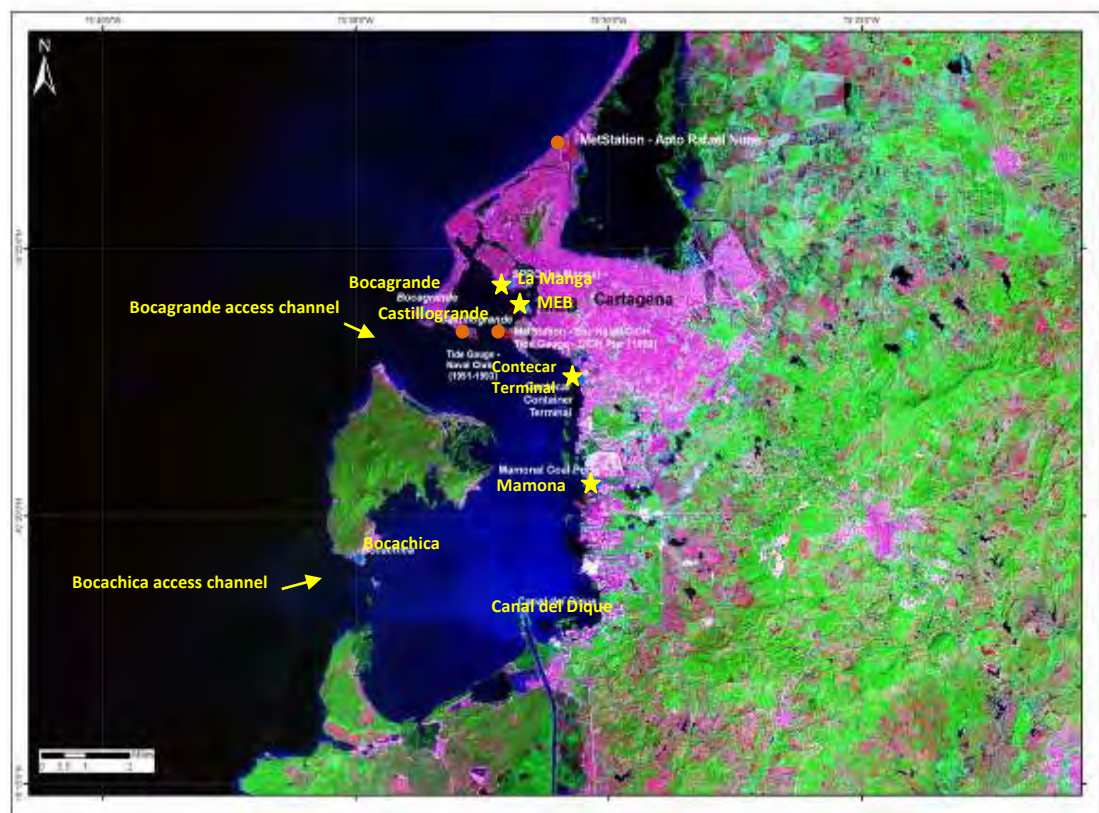
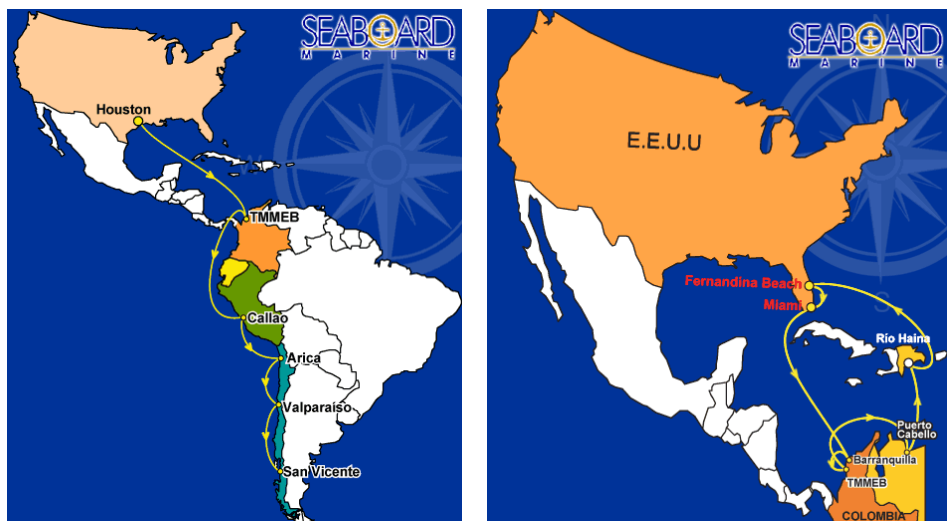


Figure 1-4 – Aerial photograph of Isla del Diablo at MEB. 1) Quays 4, 1 and 2 (from top to bottom); 2) Quay 3; 3) Grain silos; 4) Coke storage area; 5) Patio for containers; 6) Part of the causeway that connects to the mainland site; and 7) the mangrove around the causeway.



Figure 1-5 – Shipping routes used by Seaboard Marine and passing through MEB. Source: MEB.



Note: There is no indication of the value or volume of cargo transported via these routes.

Figure 1-6 – Mean Monthly Revenue by Product Line (2005-2009)

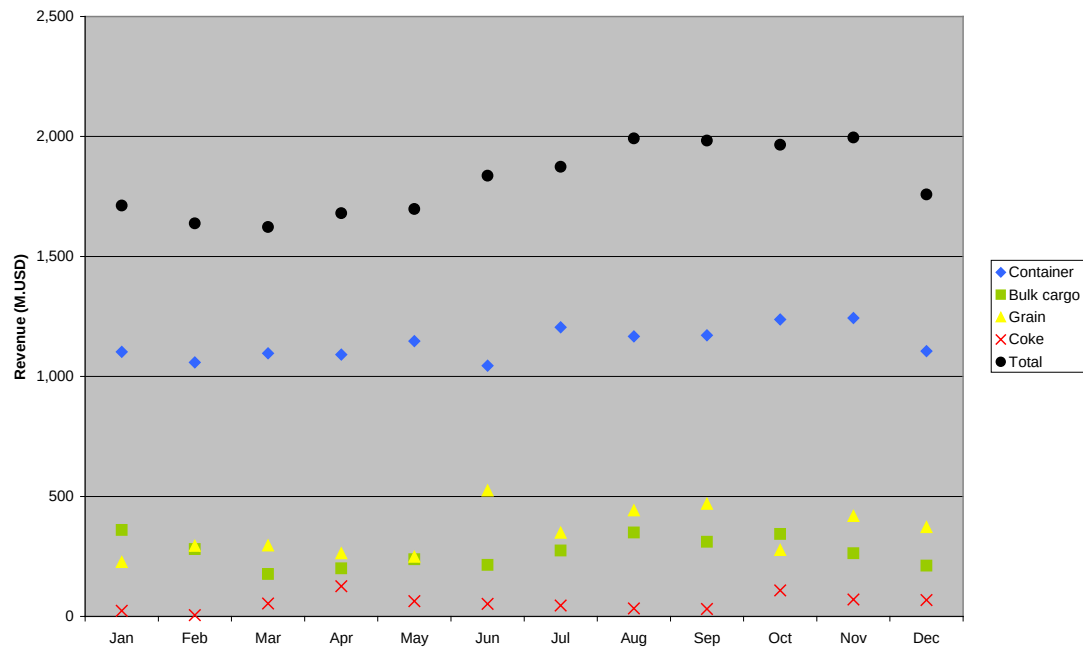
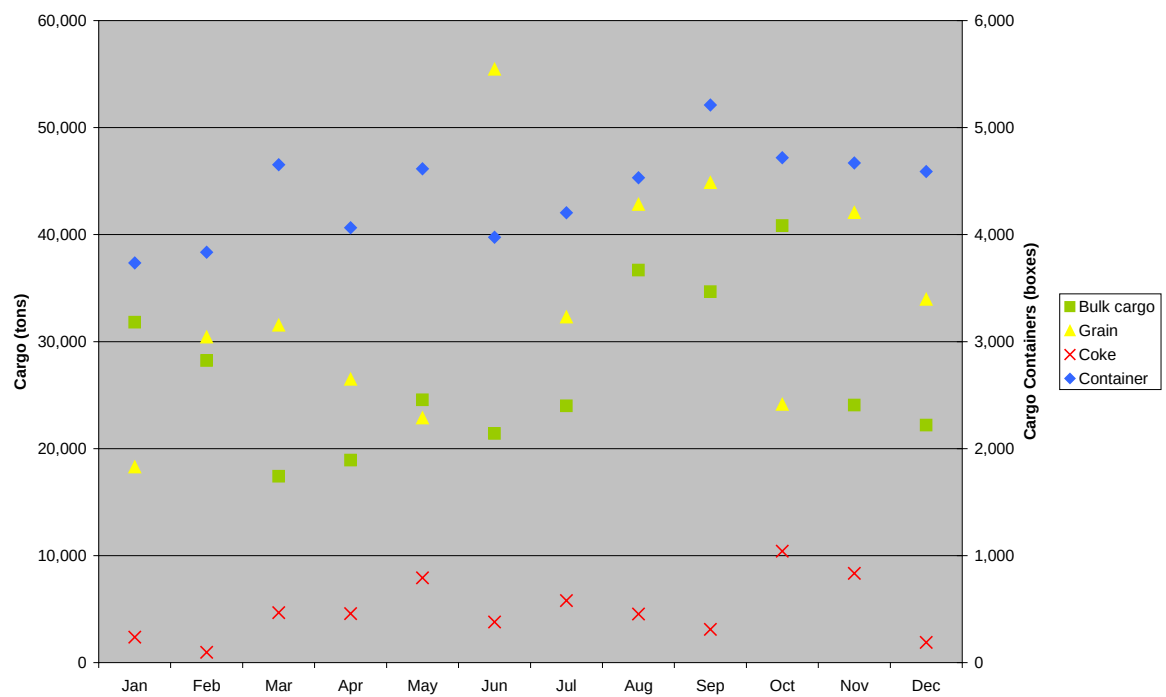


Figure 1-7 – Mean Monthly Cargo Throughput by Product Line (2005-2009)



1.4 Overview of other ports in Cartagena

Sociedad Portuaria Regional de Cartagena (SPRC) operates the ports at La Manga and the new Contecar terminal. These are the largest ports in Cartagena and specialize in the movement of containers. In response to the expansion of the Panama Canal, SPRC is gradually increasing the access channel through Bocachica to a depth of 17 meters to allow the new Contecar terminal to handle Post-Panamax vessels. Figure 1-3 shows the locations of the other ports in the Bay of Cartagena.

Meetings with SPRC and the Mamonal coal port were held during the site visit to understand their views on ports in Cartagena and climate change.

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2 Climate Change Risks to Ports and Adaptation Actions

As highlighted in Section 1.1.1, climate change is underway and will intensify over coming decades. It will increasingly affect long-lived, fixed assets and infrastructure, owned and managed by public and private sector organizations. Ports are likely to be particularly at risk from climate change for a number of reasons:

- Due to their long lifetimes, they will face considerable climate change,
- By virtue of their locations on coasts, rivers or lakes, they are often exposed to a range of climate hazards, including sea level rise, storm surges, extreme wind and waves, and river flooding,
- Shipping movements into and out of ports can be affected by adverse climatic conditions, causing delays to port operations,
- They are vulnerable to the economic impacts of climate change, through impacts on global trade,
- They can transport goods for which demand or supply is climatically-sensitive, such as agricultural products or fuel,
- Inland movement of goods from ports relies on transport infrastructure which is likely to be managed by others, and which is, in turn, vulnerable to climate change,
- Like any other industrial facility, ports are vulnerable to disruptions to utilities, for example water and electricity. Water and electricity supply are both vulnerable to climate change, and decreased reliability of these utilities due to climate change is likely to be a material risk to some ports (Acclimatise, 2009).

Around the world, there are wide variations in the vulnerability of different locations to climatic factors, coupled with which there will be significant regional differences in the extent of climate change. Some ports, for instance, are located on low-lying coasts, in areas where rising sea levels and storm surges will threaten to overwhelm them. Others are situated in areas where permafrost thaw will affect ground stability and rates of erosion. Increases in extreme weather events, such as storms, droughts and heat waves, are generally projected to occur across the globe, though changes in the frequency and intensity of these events will vary from place to place.

Ports vary considerably in the functions they perform, in the type of cargo they handle and in the extent to which they carry out cargo handling themselves. The Port of London Authority (PLA) for example is essentially purely a safety and navigation authority for the tidal River Thames and the Thames Estuary, providing pilotage, navigation and dredging services. The PLA does not do any cargo handling nor does it own land on which cargo handling is carried out by others. At the other end of the spectrum there are ports which provide a wide range of cargo handling and warehousing services themselves. In other cases, such services are provided mainly or in part by businesses who are tenants of the port authority. Given this diversity, the scope and significance of climate change risks will be very different from port to port.

It is clear that, to understand how climate change could affect a given port, the risks need to be assessed based on a solid analysis of the port's particular climatic vulnerabilities. Differences in how severely ports will be affected by climate change will be driven mostly by location, the climatic resilience of their designs and the activities that they undertake. Appraisal of adaptation measures, in terms of costs and benefits, also needs to take account of local conditions, including risks and costs.

This section aims to provide a generic overview of the range of ways that climate change could affect ports and of the adaptation approaches available to ports.

2.1 Port climate-related sensitivities

A conceptual model of a port, showing the main activities which can be affected by climate change, is presented in Figure 2-1.

Figure 2-1 – Conceptual model of a port and the main activities which can be affected by climate change



Estimates of port city exposure to storm surges and extreme wind speeds

A report published by the Organization for Economic Cooperation and Development (OECD) analyzed the exposure of the world's 136 largest port cities to both a 1 in 100 year storm surge (assuming no sea defenses) and to extreme wind speeds during tropical cyclones (Nicholls et al., 2008)⁶. It provides a view of the number of inhabitants and the total asset value (2001 US\$) exposed to these climatic hazards for port cities with large numbers of inhabitants and cities with high asset values respectively. The report does not rank port cities based on the significance of climate change risks.

Figure 2-2 presents the OECD's ranking of those port cities in developing countries, showing those most exposed to storm surges and extreme wind damage, by total asset value, showing that ports in developing countries are projected to see large increases in the total value of assets exposed to climate change risks between 2005 and the 2070s. This is due to a combination of growing levels of industrial development, weak planning regulations and high exposure to climate change (Nicholls et al., 2008).

⁶ Note that the OECD report considered estimates of sea level rise ranging from 0.5 to 1.5m. These are consistent with the sea level rise scenarios used in this study: 0.5 and 1.3m by the end of this century for the observed and accelerated SLR scenarios respectively. The OECD report also built its estimate on the basis of a 10% increase in the wind speeds associated with more intense tropical cyclones. In this study, increased tropical intensity was not considered, as Cartagena is rarely affected by tropical cyclones.

Figure 2-2 – Ranking of port cities in developing countries projected to have the highest total asset value (US\$ billion) exposed to climate change by the 2070s (Note that this ranking neither includes port cities in developed countries, many of which have significant asset value at risk, nor considers the percentage of exposed assets) (Adapted from Nicholls et al., 2008)

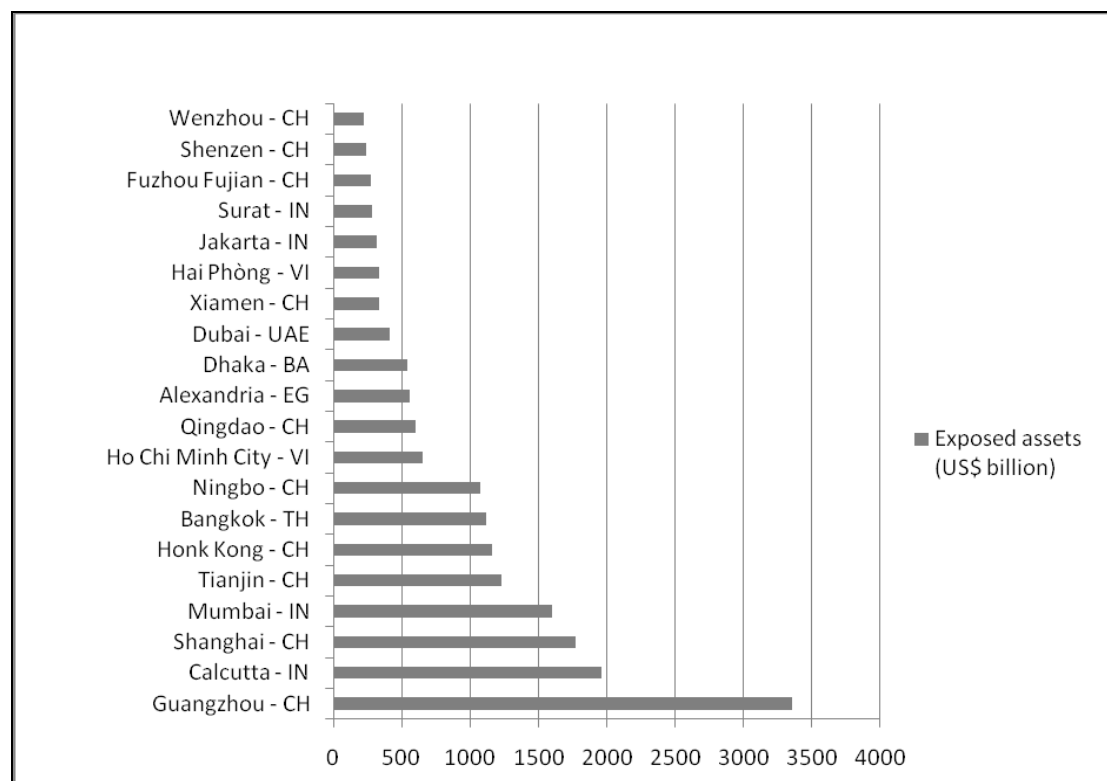
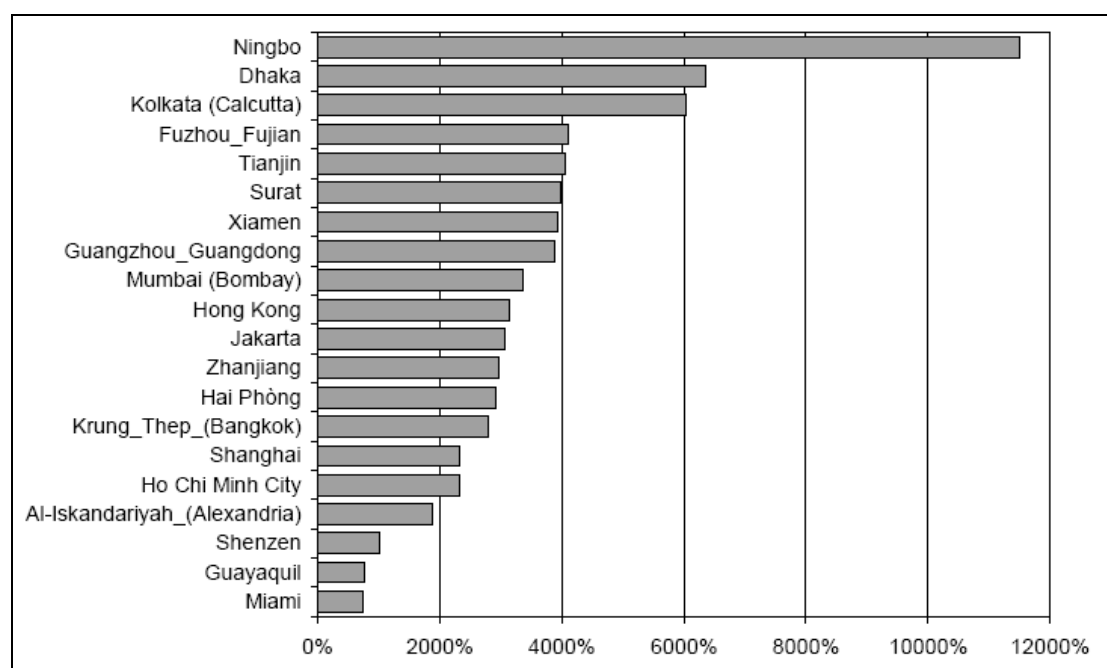
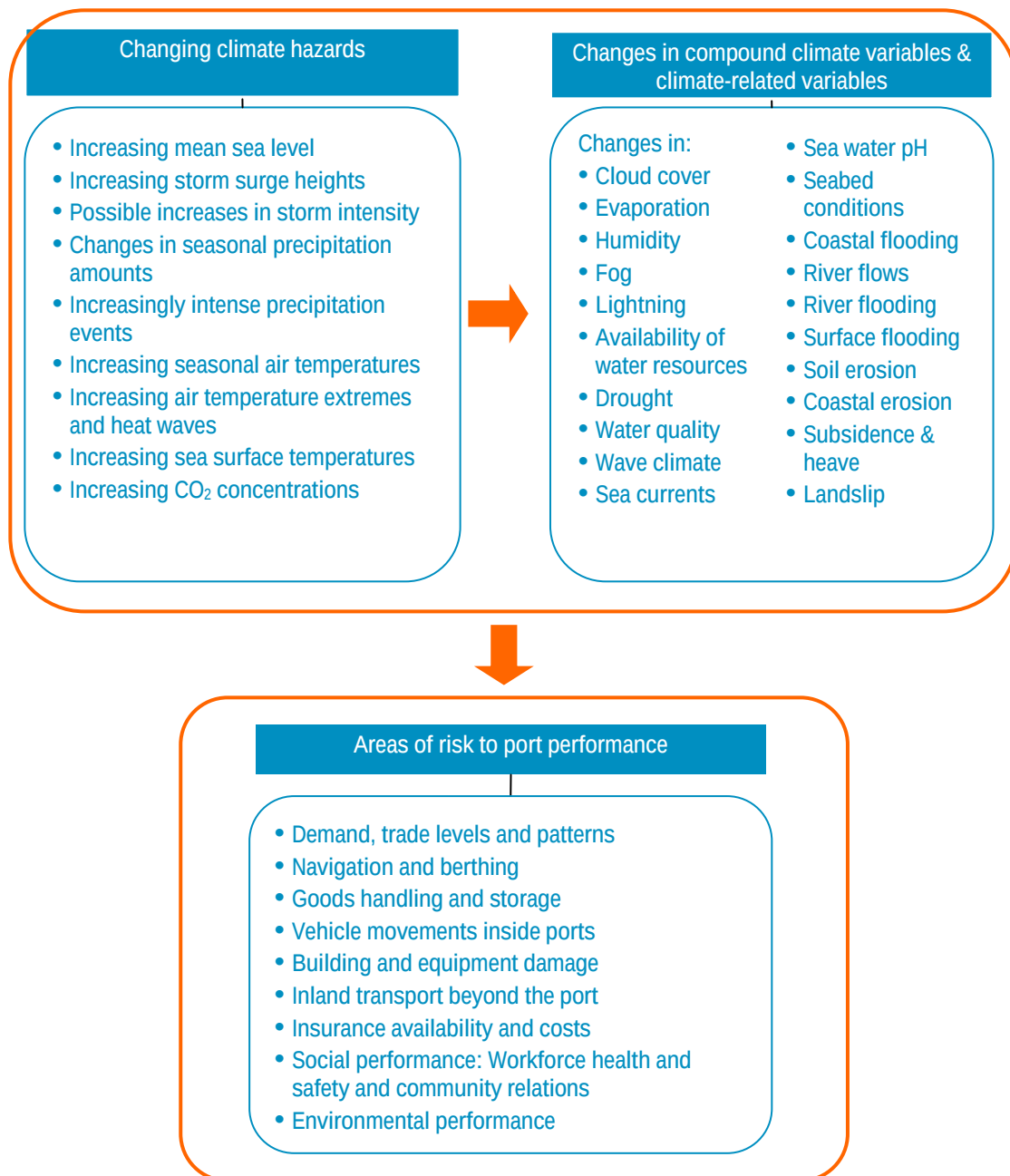


Figure 2-3 – Port cities with the highest proportional increase (%) in asset value exposed to climate change between 2005 and the 2070s (Nicholls et al., 2008)



The key climate change and climate change-related factors which can affect port performance are shown in Figure 2-4. Climate change impacts on each aspect of port performance are discussed briefly in the sections below, along with examples of climate impacts that have been experienced at ports around the world.

Figure 2-4 – Changing climate and climate-related variables, and corresponding risks to port performance

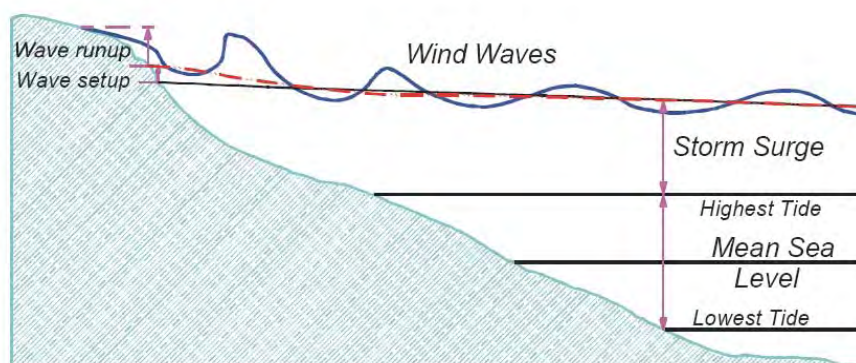


For many coastal ports it is likely that the compound effects of mean sea level rise, high tides and increased storm surges will be the most significant risks of climate change (Wright, 2007). At a given location, sea levels are affected by a number of long-term and short-term processes which are sensitive to climatic factors.

Long-term sea level rise is driven by the combined effect of climate change, local land movements and groundwater depletion (Wada et al., 2010). Areas experiencing land uplift relative to sea level will generally be less vulnerable to flooding than areas affected by subsidence.

Short-term sea levels are influenced by tidal ranges, sea surges during storm events and waves. Short-term contributions to sea level at any time are presented in Figure 2-5.

Figure 2-5 – The factors contributing to sea level (Hennessy et al., 2004)



2.2 Demand, trade levels and patterns

Shipping is an international service industry, and all ports operate in the global economy and are subject to economic cycles (Wright, 2007). As such, port revenues rely on trade levels and patterns which depend on international and national supply and demand. Climate change will have impacts on market conditions for many products which are traded through ports (USCCSP, 2008). In the long-term, changing market conditions will bring new business opportunities for some ports.

The supply of many products is sensitive to climatic conditions, especially agricultural and forest products, so that ports relying on imports or exports from locations exposed to climate change may face changes in their revenue. Demand for certain products is strongly correlated to climatic conditions and will be affected by climate change. For instance, natural gas imports would be reduced in warmer winters when less heating is required.

The demand for a port can also be affected by its vulnerability to disruption from extreme weather events, and customers' perceptions of a port's reliability. For example, following Hurricane Katrina's impacts on ports in the Gulf of Mexico, some customers shifted to alternative ports (Grenzeback et al., 2007 and Emigh, 2005).

Over the long-term, climate change will also lead to population movements, and this could have consequences for port competitiveness, in terms of distance and ease of transport to and from population centers (USEPA, 2008).

Congestion and delays at Australian ports due to storms

It was estimated that storms in Australia cost coal mining companies more than US\$950 million in 2007, by causing congestion at the country's largest coal terminals and shipping delays (Port World, 2007). In June 2007, storms hit the Australian Port of Newcastle, the world's largest coal-export port, and disrupted ship loading for two weeks. Because of inadequate rail and terminal capacity, this created severe bottlenecks which tied up many large vessels in Australian ports and anchored a large bulk shipping fleet off Brazil, China and Australia. At its worst, congestion at Australian ports saw queues of more than 50 vessels. Vessels had to wait on average more than 32 days to load coal, compared with 18 hours for general cargo (Port World, 2007).

Problems of congestion are ongoing for coal terminals in Western Australia, partly due to the lack of capacity of rail and terminal systems to cope with the increasing demand from China for coal. Severe rainfall and flooding regularly aggravate export capacity constraints (Ship Chartering, 2009). The operator of the two coal terminals of the Port of Newcastle has made a large capital investment to increase export capacity.

Xstrata, the world's biggest thermal coal exporter, estimated that coal producers in New South Wales paid about US\$1 million a day in demurrage charges (penalties) for idling ships. Rio Tinto said that its first semester 2007 profits from its Australia coal business had fallen by US\$95m because of shipping delays (Financial Times, 2007).

Delays in Australia have forced Asian coal buyers to seek alternative supplies from Indonesia and South Africa. Delays also drove shipping rates up by 40% for dry bulk (such as coal and iron ore) shipping.

Evidence suggests that storminess is likely to increase in some locations due to climate change, which could add further delays to ports already experiencing capacity problems. Increased frequency of bottlenecks could prompt businesses to switch to other port facilities or could influence foreign buyers to purchase from more resilient areas in the world.

2.3 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. This could bring benefits in terms of decreased dredging requirements. However, additional costs will be required to adapt port terminals if sea levels rise above the operability range of quays, piers or material handling equipment (USCCSP, 2008). Rising sea levels will also decrease clearance under some bridges, reducing the number of low water level windows available for large vessels (USCCSP, 2009).

In the case of ports on rivers and lakes, the impacts of climate change on river flows and lake levels, coupled with increased water demand (also driven by climate change) may lead to reduced water levels (Cochran, 2009). This will restrict ship navigability or cargo carrying capacity, increase dredging costs and/or restrict berthing. For ports in locations where water levels will increase there could be opportunities to accommodate larger vessels. Changes in silt and debris build up resulting from extreme precipitation events can restrict dock or harbor navigability and increase shipping costs (USTRB, 2008). These impacts can also affect coastal ports located in enclosed bays with significant river influx.

Changes in the navigability and protection of access or inland channels (for example by lock or dam structures) are expected due to climate change. Some will become more accessible (and extend farther inland) because of deeper waters, while others will be restricted because of changes in sedimentation rates, potential bank failure and sandbar locations (USGCRP, 2009).

In the medium- to long-term, higher temperatures will bring opportunities for ports located in cold regions where navigation is currently restricted by ice: the length of the shipping season will increase as sea and waterways become ice-free for a longer period of the year (USTRB, 2008; USEPA, 2008). Shipping volumes and costs are likely to change, as new transportation routes open up. For instance, the North-West Passage connecting the Atlantic and Pacific oceans along the northern coast of Alaska and Canada was used by commercial ships for the first time in 2008 (Wright, 2007). However, the opening up of new polar shipping routes could also potentially be detrimental to ports in mid- to low-latitudes regions. For example, the North-West Passage could provide a commercial alternative to the use of the Panama Canal thus potentially decreasing shipping movements around Central America. Its use by ships too large to go through the Panama Canal could also decrease port traffic in other parts of the world, such as South Africa (P&S, 2007).

However, for the next several decades, warmer temperatures and associated sea ice melting are expected to result in increased variability in year-to-year shipping conditions and higher costs, due to requirements for stronger ships and support systems (for example, ice breaker escorts, or search and rescue support) (USTRB, 2008).

Impacts of lake levels on dredging requirements and cargo loads

In recent years, Lake Superior on the US-Canadian border has registered record low water levels. The US National Oceanic and Atmospheric Administration (NOAA) estimates that since 1978 the lake level has been decreasing at an annual rate of 10mm and that water levels have dropped by about 60cm during the last decade (Science Daily, 2007). Climate change can partly explain the decreased lake levels, since warmer temperatures and less ice cover lead to increased evaporation rates, and decreased snow mass means reduced spring runoff to replenish the lake. For instance, research has found that in the Great Lakes area a 1°C increase in mean annual temperature has been correlated to a 7 to 8% increase in evaporation rates (Lemmen et al., 2008). Water levels in the Great Lakes are projected to continue to drop this century (Lemmen et al., 2008).

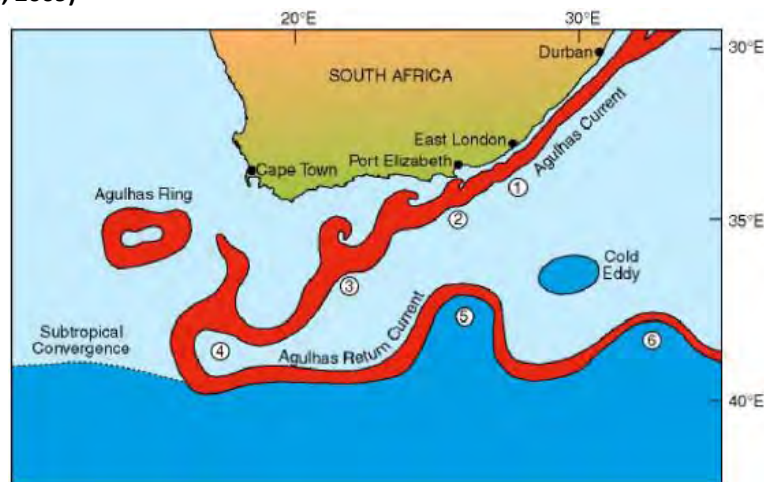
Decreasing water levels in the lakes have had severe impacts for the shipping industry. For example, dredging requirements have increased, while ships have had to reduce their cargo. On average, for every 2.5cm of decreased water levels, cargo ships must reduce their load by 50 to 270 tons (Science Daily, 2007).

Wave impacts on ships in South Africa

Although large vessels are generally well-equipped to cope with wave impacts, areas where gigantic waves occur can lead to damage. For example, regular ship damage occurs on the Southeast coast of South Africa where Southwesterly waves interact with the strong opposing Southwest Agulhas ocean current, resulting in wave amplification and the creation of 'freak' waves (Figure 2-6). 'Freak' waves are waves of a height known to severely damage vessels.

Scientists are uncertain whether climate change will affect the Agulhas current and storminess off South Africa's Southeast coast and, thus, the risk of 'freak waves' impacting on ships. However, observations and climate models suggest that increased storm intensity is likely in the future, which could reduce navigability off the Southeast coast, even if ocean current circulation is unchanged.

Figure 2-6 – Large scale circulation of the Agulhas current off the Southeast coast of South Africa (Rossouw et al., 2009)



Bridge clearance

Bridge clearance has become an operational issue for major ports because the largest vessels need to synchronize their passage with tides, water levels due to weather events and river flows (USCCSP, 2009).

As a response, the US National Oceanic and Atmospheric Administration (NOAA) has installed real-time reporting air gap sensors to ensure safety of bridge clearance in its Physical Oceanographic Real-Time System (PORTS) which provide real-time data to port operators. Air gap sensors have been installed on the Verrazano Narrows Bridge at the entrance of New York Harbour (NOAA, 2005).

Rising sea levels will decrease clearance under bridges by reducing the number of low water level windows available for large vessels (USCCSP, 2009). The importance of real-time monitoring of weather and ocean conditions to navigation efficiency and safety is likely to increase due to climate change, especially as the size of vessels increases.

2.4 Goods handling and storage

High winds can restrict port operations and many port operations have critical thresholds relative to wind speeds (see Figure 2-7). For example, cranes cannot be moved when wind speeds are over a certain threshold, and in extreme wind speeds they have to be taken out of operation all together to avoid damage.

Figure 2-7. Wind speed thresholds related to port operations (Gaythwaite, 2004).

Beaufort Scale/ seaman's descriptions		Wind speed		Effect on operations**	
		(knots)	(m/s)*	Vessel	Facilities
0	Calm	0-1	0-0.5		
1	Light air	1-3	0.5-1.5		
2	Light breeze	4-6	2.0-3.0		
3	Gentle breeze	7-10	3.5-5.0		
4	Moderate breeze	11-16	5.5-8.0		
5	Fresh breeze	17-21	8.5-11.0		
6	Strong breeze	22-27	11.5-14.0	Berthing limit	Crane operations cease
7	Near gale	28-33	14.5-17.0	Tugboat limit	
8	Fresh gale	34-40	17.5-20.5		Loading arms disconnected
				Ferry operations cease	
9	Strong gale	41-47	21.0-24.0	Emergency mooring lines	
10	Whole gale	48-55	24.5-28.5	Larger vessels put to sea	Facilities secured, cranes lashed, etc.
11	Storm	56-63	29.0-32.5		
12	Hurricane	64-71	33.0-36.5		

*Wind speeds in knots have been converted to m/s and rounded to the nearest 0.5m/s.

**Because of wind alone, wave action at exposed locations may result in greater limitations.

Lightning can also force crane operations to be suspended. Heavy rain can also affect a crane's electrical systems and the costs associated with these impacts can be as crippling and costly as the physical collapse of cranes (Strategic Risk, 2007). Port operability is also reduced during heavy downpours because of the risk of goods spoilage, for goods that are perishable or non water resistant.

Low-lying storage areas which are not adequately protected by seawater defenses will be vulnerable to coastal or fluvial flooding, while areas with inadequate drainage can be flooded by heavy rainfall. Increased occurrences of goods spoilage because of flooding can also damage a port's reputation.

Due to higher temperatures, many freight ports will face higher energy costs, as more air conditioning is used in office buildings and refrigerated containers (USCCSP, 2008). Those ports charging their customers a flat rate for energy costs could see their own revenue fall as a result.

Port operations, such as cleaning of ships, quays and piers, and spraying of unpaved areas or dry bulk cargo to avoid dust generation, generally require the use of significant amounts of water. Changing

climatic conditions could affect a port's water requirements, and also water availability, with implications for operating costs.

For ports located in cold regions, higher temperatures are expected to improve operating conditions as ice accumulation on docks and port infrastructure, and the likelihood of ice jams in ports, decreases (USTRB, 2008; USEPA, 2008).

Grain handling and storage activities are potentially also at risk of dust explosion. However, in ports where grain dust and fire risks are adequately managed, climate change is not expected to lead to any significant change in grain dust explosion risk. For further information on grain dust explosions, see Section 7.6.

2.5 Vehicle movements inside ports

Increases in mean sea levels and storm surge heights, together with changes in wave regimes, will lead to increased probability of flooding for many coastal ports. The areas of ports vulnerable to sea level rise will vary from one port to another, though typically the highest area of a port terminal is the quay. Warehouses and open storage areas are often either at the same level or lower (USCCSP, 2008).

For ports on rivers and lakes, changes in precipitation and increased rates of evaporation (due to higher temperatures), combined with changing land use, water extraction and vegetation growth, will lead to variations in river flows and lake levels and potential increases in flood risk.

The capacity of port drainage systems can be overwhelmed by extreme precipitation, leading to surface flooding. For those ports with drainage outlets discharging to a water body, increased water levels can further reduce drainage capacity: if water levels on docks and harbors rise above the level of drainage outlets, drainage pipes can be surcharged (especially if the gradient between the level where water enters the pipe and the level of the outlet is low) and the flow through them can be reduced. Higher average temperatures can also increase growth rates of invasive aquatic vegetation, leading to the clogging of drains and consequent need for increased maintenance (Cochran, 2009).

Shallow flooding can cause significant business interruption to ports if it restricts movements of vehicles, goods and people. Flooding of significant depth can bring operational interruptions which can last hours, days or weeks. Chronic or permanent flooding can render parts of ports inoperable.

Vulnerability of African coastal ports to extreme sea levels

Namibia's main port, located in Walvis Bay, is a key asset for the national economy and an important regional freight access point for landlocked countries such as Botswana. It is protected by a natural peninsular sand bar, which is washed over by waves during seasonal storms. Because it is very low-lying the sand bar is very vulnerable to sea level rise and storm surges (Rossouw et al., 2009).

Some man-made sea-defenses can also be vulnerable to small increases in sea level. For example, the annual maximum seawater levels recorded at Mozambique's main ports, Maputo and Beira, reach the crest of many of the country's protective seawalls and revetments. Many of these ageing structures are poorly maintained, which increases the risks of their being breached under high storm surges (Rossouw et al., 2009).

Vulnerability of US and European ports to sea level rise and storm surge

A relative sea level rise of 61cm has the potential to affect 64% of all US port facilities on the Gulf of Mexico. Around 98% of these ports would be affected by a storm surge height of 5.5m (USCCSP, 2008).

Hurricane Katrina's 7m high storm surge virtually flattened Gulfport's infrastructure, knocking down container cranes and blowing apart storage sheds. The storm surge pushed barges hundreds of feet inland and scattered large containers throughout downtown Gulfport. The port completely lost electrical power, water and sewer services. More than US\$250 million have been allocated to repair Gulfport, the third busiest container port on the Gulf of Mexico (USCCSP, 2008).

Fear of extreme flooding pushed Rotterdam, Europe's biggest port, to close its sea defense barrier for the first time in November 2007, as wind-driven storm swells coincided with high tides. As a result, many ships were delayed (Reuters, 2007).

2.6 Infrastructure, building and equipment damage

Increased flood risk is one of the key impacts of climate change on infrastructure, buildings and equipment. In general, the implications of flooding are similar, regardless of the source of flooding (coastal, river, lake, groundwater or surface), except that seawater is more corrosive than fresh water and fast-moving floodwaters can damage or wash away structures.

Damage to port buildings and equipment as a result of shallow and temporary seawater flooding is likely to be minimal unless it becomes frequent or increases in depth and exacerbates wear and tear. Electrical equipment, however, is more vulnerable to flooding, which can lead to arcing and short-circuits. Furthermore, some ports have electricity sub-stations on-site that can stop functioning if flooded.

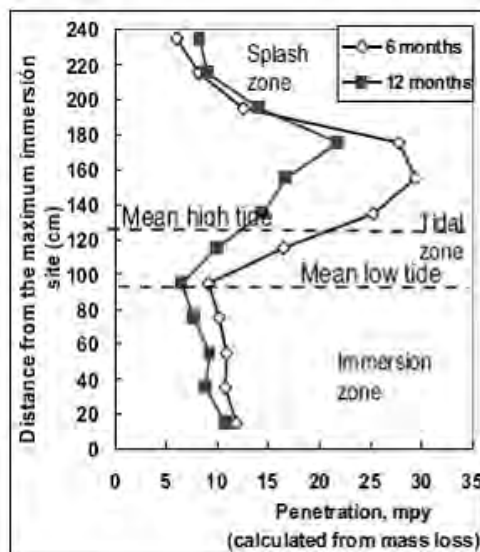
Extreme flooding due to storm surges can cause very severe damage to ports. For instance, fast-moving waters can physically dislodge containers and other cargo from open storage areas, knock down buildings, damage or destroy equipment, damage quay and pier structures and undermine or damage pavements and foundations (USCCSP, 2008). Damage to monitoring equipment which ensures ports security against theft (such as video cameras, fencing and radar equipment) can leave the port exposed to additional losses.

As sea levels increase (and river and lake levels change), the standards of protection of flood defenses (such as walls, rock armors, gabions, offshore breakwaters or flood barriers) will be reduced if no additional investment is made. Increased rates of coastal erosion on beaches or sand bars can also leave ports more vulnerable to flooding. Sea level rise and increased wave activity, or increased river flows, are also likely to aggravate under-scouring: in the case of quay and pier foundations, breakwater, revetments and sea walls, this will likely lead to higher maintenance costs and reduced useful life.

Extreme winds associated with storms or tropical cyclones can damage unreinforced terminal structures, such as metal warehouses which are lightweight and have large surface areas, and port equipment.

Rates of metal corrosion by seawater are an important factor for ports, affecting the structural integrity and strength of metal components (OCIMF, 1997). Corrosion rates depend on a range of factors, including the metal material, cycles of wetting and drying and the water's hydrochemical parameters. As a result, there is no simple correlation between exposure to seawater and corrosion (see Figure 2-8).

Figure 2-8. Profiles of mild steel corrosion rates for 6 and 12 months exposure to seawater at the Peruvian port of Salaverry (Farro et al, 2009)



It is expected that climate change will affect metal corrosion rates through changes in variables which are known to have a corrosive action. The compound effect of changes in flooding, sea spray, humidity, air temperature, seawater acidity and salinity could significantly accelerate rates of corrosion at some ports. As sea levels rise and storminess increases, new areas of ports may become exposed to sea spray (PIANC, 2008), and may require coating or other forms of protection.

High levels of humidity and high temperatures can lead to increased corrosion. Research in controlled laboratory conditions found that metal corrosion rates doubled for every 10°C increase in air temperature, though there is uncertainty on whether this relationship is valid in 'real life' conditions (MacLeod et al., 1987). Higher temperatures can also result in increased numbers of microbial organisms, in turn leading to higher corrosion rates (OCIMF, 1997).

Higher levels of carbon dioxide in the atmosphere are making seawater more acidic (as the oceans absorb some of the carbon dioxide). However, the projected pH decreases (up to -0.5 pH units by 2100) are considered unlikely to be sufficient to lead to a significant increase in corrosion rates (Royal Academy, 2005).

Changes in seawater salinity due to climate change could also affect rates of metal corrosion since salt accelerates corrosion. There is strong evidence that salinity has changed this past half century in near-surface waters (i.e. the upper 500m). Salinity has increased around the Tropics because of greater evaporation, while it has decreased closer to the Poles, due to increased input of freshwater into oceans from higher rainfall, runoff and ice melting (IPCC WG1, 2007). The IPCC does not provide future projections for changes in salinity, but these trends could continue over the twenty-first century.

Most port facilities (including quays and piers) are made principally of concrete and lumber, which are generally insensitive to temperature fluctuations. However, higher temperatures because of climate change are likely to increase stress on temperature-sensitive structures such as cranes, warehouses and other marine terminal assets made of metals (USCCSP, 2008).

Impacts of storms on port buildings and equipment

Much of Hurricane Katrina's damage to the Port of New Orleans (which mostly escaped water damage) was due to wind tearing off warehouse doors and roofs. Although the port reopened just two weeks after the event, six months later it was only operating at 70% of its capacity (USCCSP, 2008).

Typhoon Maemi over the Pacific Ocean produced winds of 135 miles per hour, and toppled eleven gantry cranes in the port city of Busan in Korea (Wright, 2007).

In March 2008, strong winds severely damaged two cranes at the Port of Felixstowe in the UK after a ship broke free from its moorings. Cranes on board the vessel collided with land-based cranes used for handling containers at the port, causing extensive damage (BBC News, 2008).

2.7 Inland transport beyond the port

Ports rely on inland transportation networks to move goods to and from major economic centers. The modes of transport vary and include road, rail and inland waterways. Climate-related impacts on the reliability and cost of transportation to and from a port can affect its attractiveness to users.

Transport systems can be affected by climate change in a number of ways. For instance, longer periods of extreme heat, combined with traffic loading, speed and density can soften asphalt roads, leading to increased wear and tear (Field et al., 2007). As a result, road surfaces are likely to require greater maintenance in higher temperatures (DfT 2004). On the other hand, warmer or less snowy winters are likely to improve road transportation reliability in many places, and decrease the need for winter road maintenance (USGCRP, 2009). However, in high latitudes where roads are built on frozen grounds or ice, melting due to higher temperatures will lead to road deterioration (Larsen et al., 2007; ACIA, 2004).

Changes in precipitation can affect soil moisture levels, which can impact slope stability and result in more landslides affecting roads and railways embankments (Winter et al., 2008). If soil moisture levels become too high or too low, the structural integrity of roads, bridges and tunnels can also be compromised. This can cause closures and require repair or reconstruction (USTRB, 2008). Increases in heavy rainfall and snowfall events is likely to cause increases in weather-related accidents and traffic disruptions. Flooding will also occur more frequently where road drains are unable to cope (USGCRP, 2009).

More frequent inundation and interruptions to travel on coastal and low-lying roadways due to sea level rise and storm surge will occur in some locations. As a result, vehicles would be forced to seek alternate routes during times of inundation, resulting in delays. Underground tunnels and other low-lying infrastructure will also experience more frequent and severe flooding. Higher sea levels and storm surges are likely to erode road bases and undermine bridge supports (USGCRP, 2009).

It is considered likely that climate change will lead to more intense tropical cyclones, with higher peak wind speeds and more intense precipitation. These would deteriorate driving conditions, increase accidents and delays on roads (Potter et al., 2008). For example:

- High sided vehicles become increasingly unstable in gusts of over 45mph (Government of Scotland, 2005),
- There is a greater probability of infrastructure failures such as highway bridge decks being displaced as a result of strong winds (USTRB, 2008),
- Debris can be left on roads following storms.

Extreme heat can cause deformities such as buckling of rail tracks, at minimum resulting in speed restrictions and, at worst, causing derailments (Dobney et al., 2010). Where there is an electric rail network, more extreme temperatures can damage overhead power cables through thermal

expansion (RSSB, 2003, Wilson, 2002). Line-side fires are an additional hazard during prolonged periods of drought, in which case trains may not be able to run (RSSB, 2003, Dobney et al., 2010).

Flooding leads to damaged rail bed support structures and closure of rail stations (USGCRP, 2009; RSSB, 2003). For railways that run close to the coast there could be an increased risk of coastal flooding due to sea level rise. Coastal railways could also face increased corrosion due to salt spray affecting tracks, overhead lines and signals. High winds will increase the risk of trees falling onto tracks and also affect the stability of freight cars (RSSB, 2003).

Climate change impacts on navigation on waterways are covered in Section 9.

Transport through the Panama Canal

The Panama Canal depends on regular and high levels of rainfall for its operation. Potential reduced rainfall due to climate change may limit the draft of ships using the lock system of the Canal. This would have consequences for quantities of cargo which could move through the Canal (Wright, 2007).

2.8 Insurance availability and costs

Ports may face changes in insurance terms and costs as the incidence of severe weather events increases due to climate change (USEPA, 2008). As port loss claims increase in vulnerable locations, insurance underwriters may begin to ask questions of ports about their climate change resilience. Ports that are more vulnerable are likely to see increases in insurance premiums and deductibles, and in extreme cases, insurance may cease to be available. It is possible that port operators with robust climate risk management strategies in place could obtain more favorable insurance conditions than their competitors (USEPA, 2008).

2.9 Social performance

Changing climatic conditions (such as higher temperatures, heavier rainfall and increased wind speeds) can create additional health and safety risks for port workers, especially in relation hazardous activities (e.g. flammable material storage and handling, use of machinery). Shallow flooding, while it may not totally prevent vehicle movements and goods handling, nevertheless increases the risk of occupational hazards, while extreme flooding can lead to deaths and injuries.

Ports' Safety Management Systems, aimed at regulating the safe movement of vessels within harbors and protecting the general public from dangers arising from marine activities at harbors (IFC, 2007), could fail under more extreme climatic conditions. For example, climate change could increase the risk of chemical or oil spills at ports and from ships in harbors, in extreme rainfall, wind and/or wave conditions.

By affecting the generation or dispersion of dust, ozone and volatile organic compounds, climate change can affect port workers' exposure to air pollutants (see Section 2.10 for further detail).

Climate change effects on pollution risk from port activities have the potential to affect the health and livelihoods of surrounding communities. Ports located close to vulnerable coastal communities (such as artisanal fishermen) may be faced with increased tensions in community relations if climate change, in combination with port activities, has significant negative impacts on their livelihoods – for example by reducing the productivity of local fisheries.

Over the longer term, it is anticipated that climate change will result in population migration from areas where there is permanent loss of land to flooding or extreme water resource stress (IOM, 2009; Boyd and Roach, 2006). While most of the burden of dealing with this will fall on governments, it will also create pressure at some passenger ports.

2.10 Environmental performance

Changes in dredging requirements driven by climate change will have implications for port environmental performance. In locations where increased draft due to sea level rise decreases the need for dredging, environmental impacts would be improved. Conversely, disposal sites for dredged material which are not resilient to future changes in climate could lead to off-site pollution, for example, if pits or dikes designed to contain the spread of sediments in open water disposal sites are overtopped or breached due to higher water levels.

Climate change can affect the frequency and intensity of poor air quality episodes during which ports may be required to minimize polluting activities, such as loading or unloading fuel to avoid Volatile Organic Compound (VOC) emissions (Defra, 2007). By affecting air humidity, temperature and wind, climate change can also favor dust creation and dispersion. As a result, additional dust suppression (such as covered storage areas or vacuum collectors) or more constraints on material transport or dust-generating activities could be required. Increased energy use due to increased temperatures and greater need for cooling will also enlarge some ports' carbon footprints.

Water effluents from port activities often contain pollutants. In areas where rainfall intensity is projected to increase, the capacity of drainage systems, filters (such as sediment traps) and oil/water separators may be insufficient and lead to on- or off-site pollution. Similarly, flooding can wash pollutants from contaminated land or storage areas into water bodies.

In relation to nature conservation objectives, some habitats are particularly vulnerable to climate change. For example, changes to water levels, rates of erosion, salinity and sedimentation due to climate change will change some of the major natural controls of coastal wetlands (USCCSP, 2009), potentially putting at risk populations of vulnerable species of fish, migratory birds and aquatic vegetation. Factors which determine if wetlands can adapt include the capacity to raise their levels to match the rate of rising sea levels, rate of erosion of seaward boundaries and space to migrate inland (USCCSP, 2009). Ports located on the landward side of wetlands may be found to prevent wetland migration and thus endanger their conservation. A range of coastal or marine habitats will be increasingly affected by climate change, including mangroves, salt marsh, sea grass and coral reefs (IPCC WG2, 2007).

Finally, greater access to remote and cold regions and increased port activity in these areas due to melting of sea ice, could lead to environmental degradation of fragile ecosystems (USTRB, 2008).

Overall, port environmental impact assessments and environmental management plans which do not consider the implications of a changing climate could underestimate risks of environmental damage or wrongly assume that risks are being adequately controlled.

2.11 Key climate change risks to MEB

The risk areas outlined above were considered for their relevance and importance to MEB. The assessment for MEB revealed that among all the potential impacts that climate change could have on ports in general, only a few issues are of significance to MEB. As summarized in Table 1-2, these include, in order of significance:

- Impacts on vehicle movements inside the port due to sea level rise,
- Demand, trade levels and patterns,
- Goods storage,
- Navigation and berthing,
- Goods handling,
- Inland transport beyond the port,
- Environmental impacts, and
- Social impacts.

Others climate-related issues were found to be less significant for MEB, but may be critically important to other ports. For example:

- Vulnerability to extreme coastal flooding due to mean sea level rise and changes in storm surges can be very critical in some ports, as shown by the costs of Hurricane Katrina for US ports. However, by virtue of its protected location in the Bay of Cartagena, and because Cartagena lies south of tropical cyclone tracks, MEB is unlikely to be affected by potential increases in tropical cyclones.
- High winds can cause damage to port buildings or equipment, as well as costly disruptions. However, Cartagena does not experience strong winds and climate models do not point to large increases in wind speeds in the region.
- It should be noted that, currently, climate models are not good at projecting changes in wind speeds and tropical cyclones. However, ongoing and future climate model improvements will increase confidence in these projections.

2.12 Adaptation approaches for ports

Decisions regarding adaptation are made in the face of uncertainty about future climate change. Under these conditions, there are various types of adaptation action that can be considered (Willows & Connell, 2003). These include:

- ‘No regret’ adaptation measures, which are actions with benefits that outweigh their costs, whatever the extent of future climate change. For instance, if a port is already experiencing weather-related problems, then cost-effective measures to address them should also help to build resilience against future climate change. No regrets measures should be actively pursued by port managers.
- ‘Low regret’ options are low cost measures with potentially large benefits under climate change. They are most often available at the design stage for new assets, when extra capacity to cope with future climate change can be built in more efficiently than through later retrofit.
- ‘One-off’ adaptation involves investing in one up-front adaptation measure which provides resilience against climate change throughout a certain period of time. This may be an appropriate strategy when there is a higher level of confidence in climate change projections and when incremental adaptation over time is more difficult.
- ‘Adaptive management’ is an approach whereby adaptation actions are applied incrementally in response to changing conditions or new knowledge, allowing the most appropriate decisions to be made at each point in time, based on the latest evidence. It is a useful tactic when there is uncertainty about future climate impacts and helps to avoid regretting an unnecessary investment⁷. Adaptive management can make more financial sense than one-off up-front adaptation⁷, provided that actions can be implemented quickly when needed. However, it is worth noting that for greenfield projects, it may be more cost effective to integrate whole-lifetime climate resilience measures early in the asset design process, rather than to have to undertake retrofit later on.
- ‘Win win’ options contribute to climate adaptation while also delivering other benefits. Mangrove protection, for example, can provide coastal protection from hazards such as erosion and flooding due to storm waves and surges, and also promotes biodiversity and protects community livelihoods.
- Finally, it is important to avoid ‘maladaptive’ actions, i.e. those which will make it more difficult to cope with future climate change risks. An example of a maladaptive action for a port would be to build a long-term goods storage facility in a low-lying area of the port, prone to flooding.

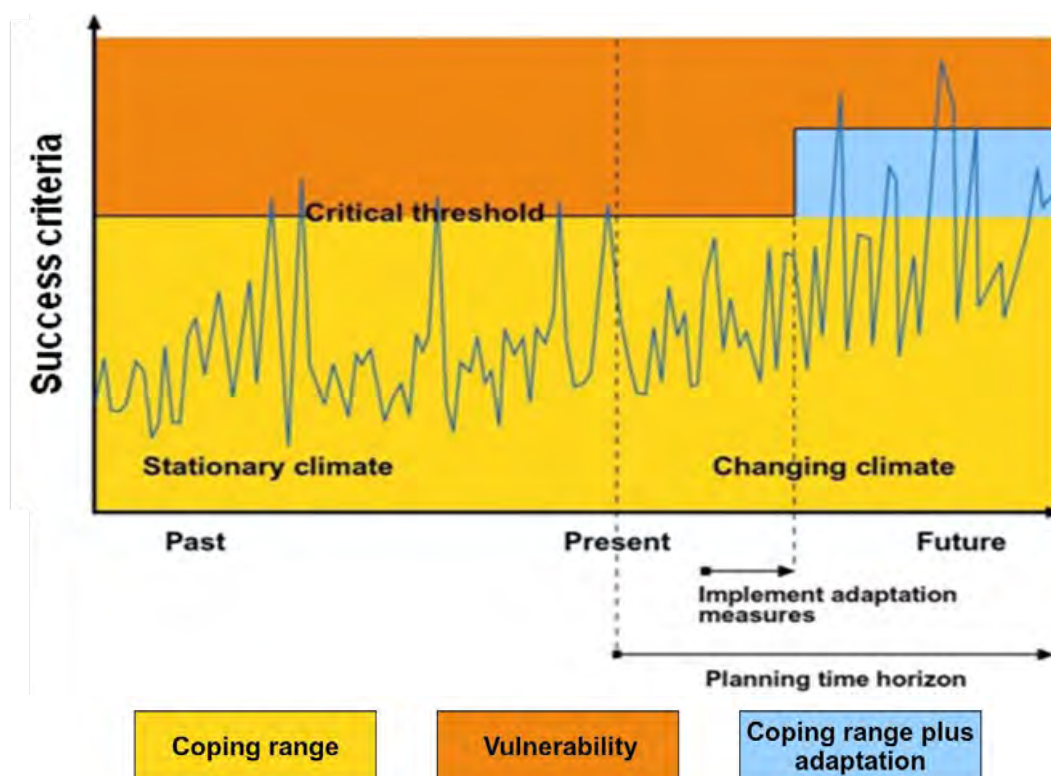
⁷ This study compared the net present value of ‘one-off’ adaptation with the net present value of adaptive management in relation to raising the heights of MEB’s causeway (which links the port’s mainland and island sites) and patio (see Sections 5 and 7 respectively).

The timing of expenditure on adaptation actions is an important consideration in optimizing their net present value, i.e. the difference between the discounted costs of adaptation and the avoided costs of climate change. Trigger dates for adaptation actions can be established by considering observed climate trends and future projections along with climate-related coping ranges and critical thresholds. Nevertheless, determining trigger dates may be difficult when there is high uncertainty about future climate change.

Figure 2-9 shows the relationships between critical thresholds and timescales for adaptation planning and implementation.

The US Climate Change Science Program recommends ports consider the useful lives of their assets and their planning horizons when making decisions on adaptation (see Figure 15-1). For infrastructure, the useful life is generally 50 years, whereas for materials handling equipment it is highly variable. At MEB, some equipment is nearing the end of its life (Scott Wilson, 2007). Replacement of existing equipment with new equipment which is designed to cope with the climatic changes anticipated over its lifetime may prove to be a low regret adaptation measure for MEB.

Figure 2-9 –Relationship between the coping range, critical threshold, vulnerability, and a climate-dependent variable. As shown by the blue area, adaptation aims to reduce vulnerability by increasing climate-related critical thresholds and coping ranges (Willows and Connell, 2003)



It is also worth noting that the US Environment Protection Agency suggested the following adaptation actions for ports to consider (USEPA, 2008):

- Incorporation of climate change predictions in design, dredging, and renewal and maintenance plans,
- Remain informed about climate change,
- Form alliances with public and private organizations to deal with climate change,
- Support research on climate change impacts, as well as national and local adaptation strategies.

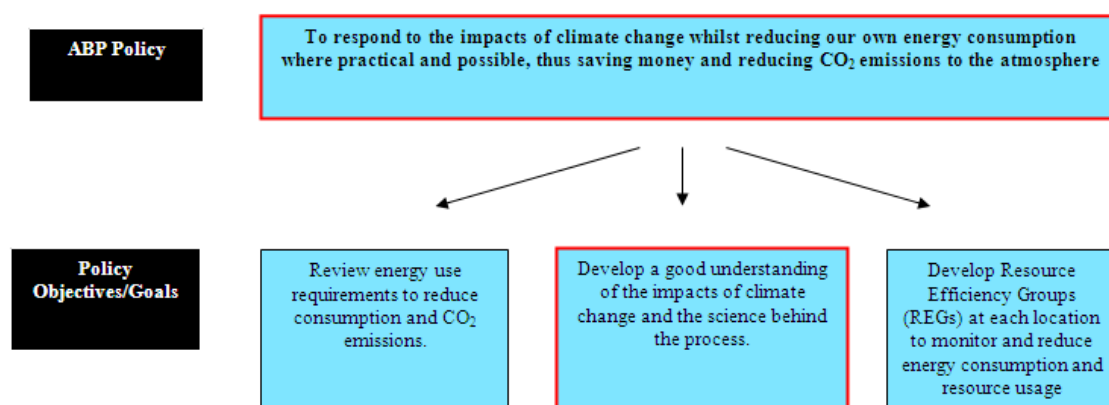
2.13 Progress with adaptation by some US and UK ports

Despite the growing risks outlined above, to date most port owners and operators have addressed climate change in the context of reducing their 'carbon footprint' rather than by building their resilience to future climate change impacts (USEPA, 2008). According to a report published by the US Environmental Protection Agency (USEPA), the main reason for the low level of action on climate change adaptation is a lack of information on the magnitude or likelihood of impacts (USEPA, 2008). A few ports have, however, undertaken initiatives to increase their resilience to climate change. For example:

- The Port of Miami, which is located on an island, participated in a study on the 'Miami-Dade Climate Change Advisory Task Force' which recommended the creation of a detailed elevation map of the county using survey technologies to assess flood risk (USEPA, 2008). The Port of Miami is planning adaptation investments, including raising some of its property during near-term redevelopment works to meet a minimum elevation of 10ft (3m), though the planned elevation is based on old plan datum which does not consider increased sea levels. The plans for a new tunnel which connects the Port to the mainland implemented the 10 feet minimum elevation requirement, designed its storm water system for a 1-in-100 year storm and planned flood gates (USEPA, 2008).
- The Port of Los Angeles has partnered with the RAND Corporation and is currently holding workshops to analyze a range of potential vulnerabilities that the port might face from climate change. The final report generated through these workshops will facilitate the development of a Climate Adaptation Plan (Wunder, 2010).
- The Port Authority of New York and New Jersey, the Ports of Seattle and Corpus Christi and the Georgia Ports Authority have all taken first steps in planning for climate change adaptation, either by commissioning studies on the impacts of climate change or considering sea level rise scenarios in planning for new projects. For instance, the Georgia Port Authority's Environmental Impact Statement considered two sea level rise scenarios to assess the impacts of dredging on wetland habitats (USEPA, 2008).
- Adaptation is part of the climate change policy of Associated British Ports, a British group of 21 ports (Figure 2-10). ABP identified flooding, storm damage and shipping changes as three major climate change risks that it faces and has developed a template so that each of its ports can assess their levels of current and future vulnerability to these risks (McCraig, 2004).

The literature review undertaken for this study did not identify evidence of adaptation actions by ports in developing countries.

Figure 2-10. Climate change policy of Associated British Ports (ABP, 2010). Boxes with red outlines refer to climate change adaptation.



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3 Approach to Financial Analysis

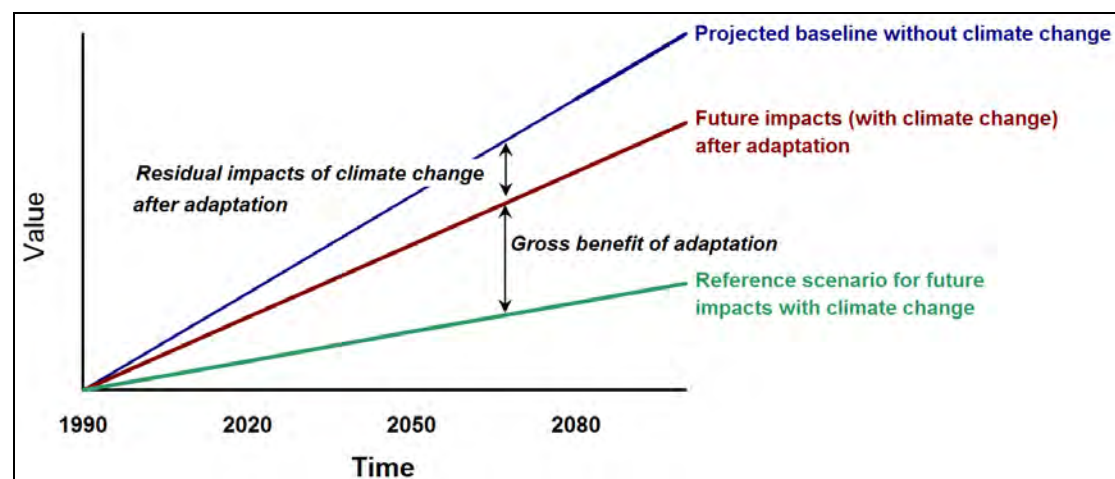
3.1 Overview

For this study, financial analysis is undertaken in three stages as follows:

- 'Baseline case' – establish baseline future projections (ignoring the effects of climate change) within a financial model in consultation with MEB (blue line in Figure 3-1)
- 'Climate change cases' – estimate the financial implications of physical climate change impacts for a range of scenarios within financial model (green line in Figure 3-1).
- 'Climate change with adaptation cases' – assess the financial cost and benefits of adaptation options and identify economically optimal adaptation measures (red line in Figure 3-1).

Adaptation measures have been identified and costed in terms of operating costs and capital expenditure.

Figure 3-1 – Financial Model Schematic. Source: Metroeconomica, 2004



The baseline financial model is the business as usual scenario assuming no climate change. Projections are made into the future based on information provided by MEB. A range of assumptions have been made to simplify the projections and ensure that the costs and benefits of climate change and adaptation measures are clear within the financial analysis. These assumptions are explained in this section of the report.

Information provided by MEB included historical and projected gross cargo movements, revenue, high-level operating costs, financing expenses, taxes, dividends, depreciation and amortization, and ongoing capital expenditure. Several accounting bench marks were provided as well, including earnings before interest, taxes, depreciation, and amortization (EBITDA), EBITDA as a fraction of revenue, and effective income tax rate.

A crucial parameter in adaptation decisions, which is included in this study, is discount rate. The discount rate is a reduction (discount) to expenditure that occurs in the future to account for the investment potential of the capital. The practical implication is that it is generally profitable to push expenditure as far as possible into the future, while having revenue which can produce interests as early as possible. For example, a \$1 investment now at an interest rate of 16% would result in more than \$600,000 in 2100 (this does not take account of inflation).

The optimal adaptation strategy is one that maximizes future revenue streams (EBITDA) with the adaptation costs included.

In this study, the net present cost (NPC) of adaptation is defined as the discounted value of future adaptation investments in present year terms.

For the purposes of this analysis some simplifying assumptions were made. Limiting the complexity of the financial model enables isolation of climate change effects and reduces the need for additional information about MEB finances. Furthermore, the simplicity of the model allows replication for other port facilities because the financial analysis is not tightly tied into the financial accounts of MEB. However, MEB may take the relevant calculations and results and integrate them into the more detailed financial picture of MEB as appropriate.

The key assumptions are summarized as follows:

- Costs and benefits of climate change and adaptation are analyzed in terms of their effect on EBITDA.
- The only revenue source is cargo movements. Like the other simplifying assumptions this isolates the effects of climate change from other financial effects beyond the scope of the study such as foreign exchange and interest rates.
- Business as usual operating expenses are assumed to be fixed as a percentage of revenue. The only changes in this operating expense are when there are changes due to either the effects of climate change or the effects of adaptation to climate change.
- Factors such as inflation, exchange rate, and price escalation have been excluded from the analysis for the reasons mentioned above. The results can later be amended by MEB (or other ports) to include these factors as MEB sees fit.
- The financial model is expressed in US dollars (USD) as some key pieces of information were only provided in USD. Exchange rate is fixed at 1 USD = 2000 Colombian pesos (COP).
- For the purposes of investment evaluation the baseline case discount rate is 16%, as recommended by MEB. The implications for decision making that this discount rate have are explored using sensitivity analysis (in the financial analysis portion of the risk sections).

Using EBITDA rather than cash flow or profits, excludes interest, tax, depreciation, and amortization from considerations. These aspects are highly dependent on a number of factors such as terms agreed with lenders, tax context and internal accounting methods which are beyond the scope of the current study.

The impacts of climate change that were assessed have a time dimension. Impacts and adaptation actions that take place at different points in time have different effects on the bottom line. As such, the timing of adaptation will have a significant effect on the risk of impact and there is a balance to be struck between investment and risk in order to find the optimal timing for adaptation investment. For example, raising the causeway now may avoid future flooding impacts but this action could also be put off into the future, if sea level rise is slower. In economic evaluation costs and benefits that take place at different points in time are differentiated through the use of a discount rate which is applied to the annual cash flows. In private industry the discount rate is usually dependent on the expected return on other investment opportunities or the weighted average cost of capital. MEB have stated that they use a discount rate of 16% for planning purposes. As a comparison, for public projects a lower discount rate (e.g. 3.5%) is often used.

3.2 Baseline Financial Model

MEB have provided actual information about cargo movements for 2008 and 2009, as well as projections to 2018.

These cargo movements were extrapolated into the future based on their growth rates as projected by MEB to 2018. During the site visit, future growth and the maximum capacities that the port could achieve were discussed with MEB. Therefore, and as seen in Figure 3-2, when the annual cargo movements reach the stated maximum capacity they are held constant for the rest of the study period. No detailed analysis was undertaken on the port to verify the maximum capacity, as this was

not an objective of the study. The cargo throughput used for the financial baseline case is summarized in Table 3-1.

Table 3-1 – Summary of cargo volume assumptions for the baseline financial model

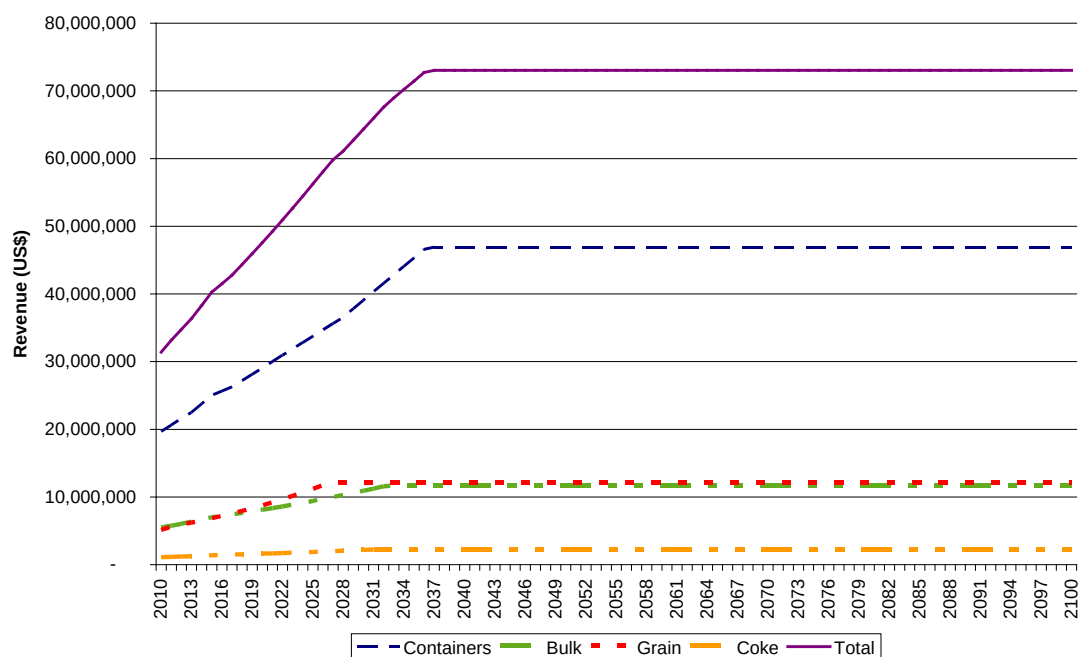
Cargo	2010	Growth 2010 to 2015	Growth 2015 to full capacity
Containers	63,000	5% per year	3% per year to 150,000 in 2037
Bulk Cargo (tons)	469,000	5% per year	3% per year to 1,000,000 tons in 2033
Grain (tons)	490,000	linear to 562,000 tons	5% per year to 1,000,000 tons in 2027
Coke (tons)	98,000	5% per year	3% per year to 200,000 tons in 2031

Revenue per unit cargo is assumed to be constant throughout the study period (Table 3-2). The revenue for containers is USD 310 per container; bulk cargo and grain each receive USD 12 per ton; coke nets USD 11 per ton. The annual revenue in the financial baseline case by product line is shown in Figure 3-3.

Table 3-2 – Unit Price Assumptions

Product	Revenue (USD)
Container	310 per container
Bulk Cargo	12 per ton
Grain	12 per ton
Coke	11 per ton

Figure 3-2 – Annual Revenue in Financial Baseline Case by Product Line



There are a number of factors that affect the operating expenditure at a facility such as MEB. Fixed operating expenditure, such as permanent staff costs is currently approximately 10% of revenue and, according to MEB, is projected to reduce to approximately 8% over the next five years. Variable operating expenditure, which is understood to include costs related to cargo throughput (such as casual labor for port operations and other variable costs), was 56% and 52% in 2008 and 2009 respectively. This expenditure is projected to continue to reduce over the next three years before leveling off at approximately 46%. Therefore, in the financial baseline case, operating expenditure (fixed plus variable) is assumed to be constant at 55% throughout the study timescales.

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4 Observed and Projected Future Climate Conditions

4.1 Introduction

This section provides a brief overview of the climate data which are applied in the risk and adaptation assessments presented in later sections. A detailed description of observed and projected future climatic conditions in Colombia generally, and Cartagena specifically, is provided in Appendices 2 and 3.

Understanding the climate baseline before considering future climatic changes is key to climate change risk assessments. Gridded observed or modeled climate data can be useful, though it is preferable to use them as a complement to quality, long-term records from local meteorological stations.

Climate change risk assessments should draw upon a wide range of sources of information about potential future climatic conditions, because all sources have their strengths and weaknesses. This is particularly the case in mountainous countries like Colombia, where climate models tend to perform poorly. Therefore, the analysis of future climatic conditions over Cartagena has used:

- Projections of future climate from the mean⁸ of 10 global climate models (GCMs) used in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (IPCC AR4, 2007), to capture uncertainties in climate modeling. These have been analyzed for the 2020s, 2050s and 2080s⁹, for 3 GHG emissions scenarios: high (A2), medium (A1B) and low (B2).
- Projections of future climate from empirically downscaled data based on the ensemble mean of 14 GCMs. These are available only for the 2050s for the A2 scenario.
- Projections from a single Regional Climate Model (RCM), PRECIS, available for the 2020s and 2080s for the A2 and B2 scenarios. PRECIS is also being applied by the Colombian government in its national assessments of climate change impacts.
- Extrapolations into the future, based on observed trends in climatic conditions, where climate model projections are not credible.

In using future climate projections, it is important to remember that there is uncertainty about future emissions of GHG, because it is not known how the world will develop socially, demographically, economically or technologically. Scenarios of future GHG emissions are used to capture this uncertainty, and the climate projections used in this study are based on a range of emission scenarios published by the IPCC. It is worth noting that the trend of current global emissions is at the top of the range offered by the IPCC emission scenarios¹⁰.

The results of this analysis are described briefly in the sections below, which summarize the projections applied in the risk assessments for each climate variable.

In some locations, natural climate cycles can drive patterns of interannual climate variability. These variations in climate may need to be considered in risk assessments if their compound effects (superimposed on climate change) are likely to have a significant impact. In the case of Colombia, the El Niño Southern Oscillation (ENSO), which occurs every two to seven years, is the strongest driver of climate variability. ENSO is known to have implications for rainfall in Colombia, though there is high uncertainty in ENSO-related projections, as it has been observed to produce highly variable anomalies in climate. In general, risk assessments based on long-term and quality observed climate records are likely to capture the effects of interannual variability, as is the case in this assignment. For further information on the impact of ENSO on the Colombian climate, refer to Appendix 1.

⁸ Termed the 'ensemble mean'

⁹ These three time periods are often studied in climate change assessments, to provide a view of impacts across the 21st century. The nearer time periods are generally of more interest to business.

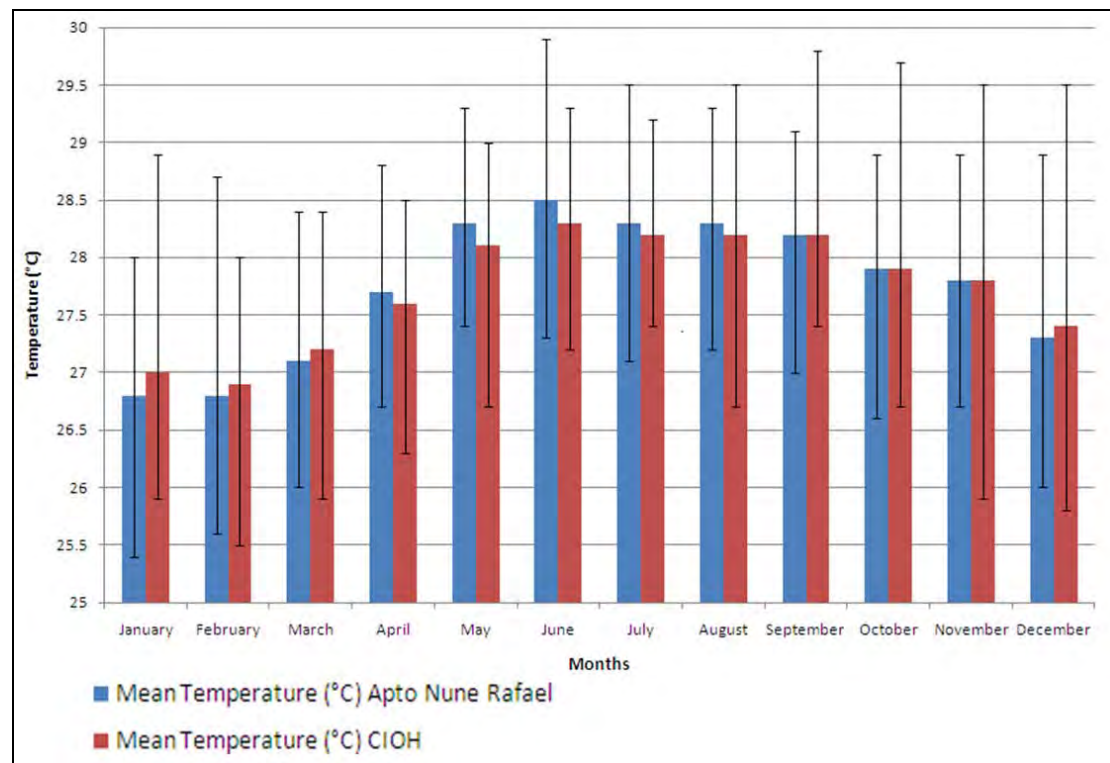
¹⁰ For further information on GHG emissions scenarios, see Appendix 1.

4.2 Temperature

According to the IPCC AR4, global average temperatures increased by $0.74^{\circ}\text{C} \pm 0.18^{\circ}\text{C}$ over the period 1906-2005 (Trenberth and Jones, 2007). The rate of increase over the past fifty years has been almost twice the rate of increase of the previous half century ($0.13^{\circ}\text{C} \pm 0.03^{\circ}\text{C}$ compared with $0.07^{\circ}\text{C} \pm 0.02^{\circ}\text{C}$ per decade).

Data from the National Centre for Environmental Prediction (NCEP) in the USA for 1948-2009 shows an upward trend in average Colombian temperatures, although with considerable interannual variability. However, data from two meteorological stations in Cartagena (Apto Nune Rafael and Esc Naval CIOH) do not show any statistically significant trend in annual average temperature between the 1940s and 2000s. Annual mean temperatures in Cartagena are between $26.5\text{--}28^{\circ}\text{C}$ and temperature varies little from month to month (see Figure 4-1).

Figure 4-1 – Observed average monthly temperatures ($^{\circ}\text{C}$) recorded at Cartagena Apto Nune Rafael (1941-2009) and Esc Naval CIOH (1947 to 2009). The solid blue / red bars show average monthly temperatures over the time period and the error bars show the maximum and minimum monthly temperatures recorded for each month.

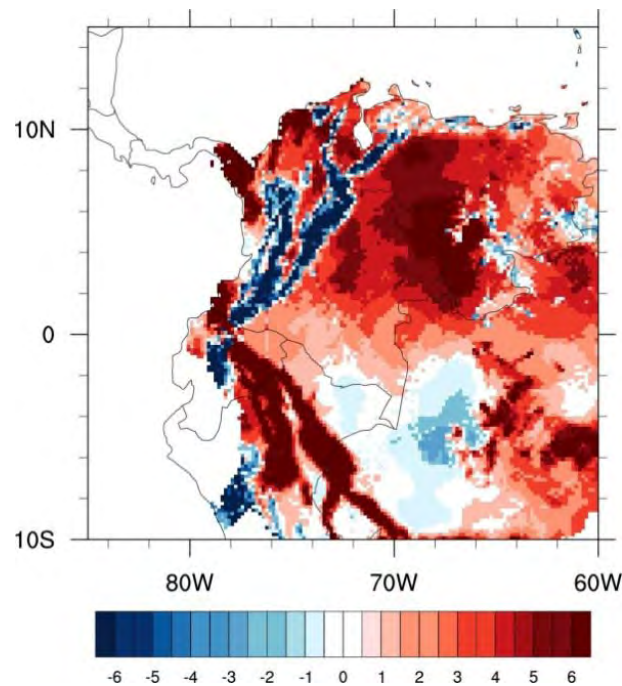


For the future in Cartagena, the projected increases in average seasonal temperatures from the mean of 10 GCMs are:

- 0.7 to 1.2°C by the 2020s,
- 1.2 to 2.2°C by the 2050s,
- 1.7 to 3.7°C by the 2080s.

However, the empirically downscaled data indicate a significantly greater increase in average seasonal temperatures, of about $6^{\circ}\text{C} (\pm 0.5)$ by the 2050s across all seasons (see Figure 4-2). As a worst-case scenario, this increase has been used to analyze the potential impacts of climate change on refrigeration costs at MEB (see Section 14.2).

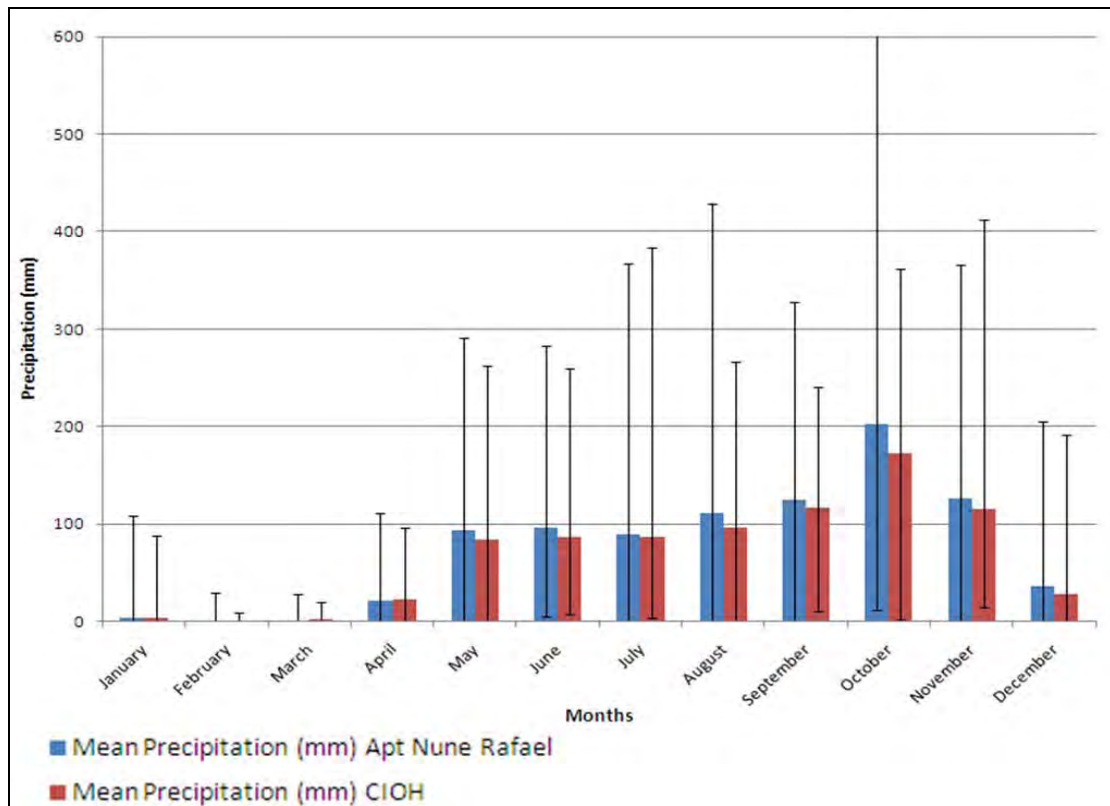
Figure 4-2 – Projections of future changes in average maximum Dec/Jan/Feb temperature (°C) over Colombia from empirical downscaling of 14 GCMs under the A2 emissions scenario for the 2050s (compared with 1961-1990). (Projections for other seasons are similar, as are projections of changes in average minimum and mean temperatures).



4.3 Precipitation

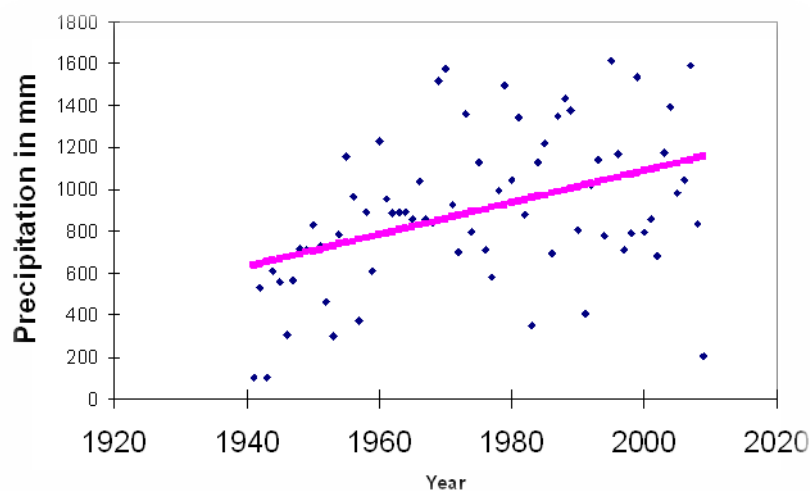
Average annual precipitation in Colombia ranges from less than 50mm on parts of the northern Caribbean coast to greater than 13,000mm on some areas of the Pacific coast, making them some of the wettest places on Earth (Poveda et al., 2005). The north Caribbean coast of Colombia, where Cartagena is located, has a single rainy season from May to November (see Figure 4-3).

Figure 4-3 – Observed average monthly precipitation (mm) recorded at Cartagena Apto Nune Rafael (1941-2009) and Esc Naval CIOH (1947 to 2009). The solid blue / red bars show average monthly rainfall over the time period and the error bars show the maximum and minimum monthly rainfall recorded for each month.



Observed data from the two met stations in Cartagena show a statistically significant upward trend in precipitation at the 5% level. On average between 1941 and 2009, precipitation at Apto Nune Rafael increased by 7.7mm per year (see Figure 4-4), and at Esc Naval CIOH, by 6.0mm per year. Increasing average precipitation was also seen at Buenaventura. The data from Barranquilla, however (where the records were a lot shorter), showed no significant trends.

Figure 4-4 – Annual average precipitation from 1941 to 2009 recorded at Apto Nune Rafael (blue diamonds). The pink line represents the linear trend, which was found to be statistically significantly at the 5% level.



For the future, according to the IPCC AR4:

- The intensity of precipitation events is expected to increase, particularly in tropical areas that experience increases in average precipitation,
- In most tropical areas, precipitation extremes will increase more than average precipitation.

There is statistically significant evidence that precipitation events in some parts of Colombia are already becoming more intense (Aguilar et al, 2005). However, projections of changes in daily rainfall from GCMs are generally regarded as unreliable and extreme rainfall is even less reliable, unless comprehensive work has been done to evaluate whether the models are realistic. Therefore, for the risk assessment on MEB's drainage system, the trends in observed rainfall at Cartagena have been extrapolated into the future. The observed trend shows an increase of 0.6% per year in precipitation amounts on wet days (Table 4-1).

Table 4-1 – Observed change (%) in average precipitation on wet days, used as an approximation for future changes in precipitation intensity

Station	Period	Change in annual average precipitation (mm/year)	Change in average precipitation for wet days only* (mm/year)	% change in average precipitation for wet days only* (%/year)
Apt Nune Rafael	1941-2009	+7.7	(7.7/65) = 0.1	Not available**
Esc Naval CIOH	1947-2009	+6.0	(6.0/65) = 0.1	(0.1/15.4) = 0.6***

* The average number of wet days (defined as days with precipitation amounts ≥ 1 mm) is 65 +/- 20 days per year. This was estimated based on daily precipitation data from the station 'Esc Naval CIOH' for the period 2000-2008. For both data series, increase in average rainfall reached the 5% significance level. Note that in some years, several months of data are missing.

** No daily data was available to calculate the average precipitation on wet days.

*** The average daily precipitation on wet days was 15.4mm based on observations from the station 'Esc Naval CIOH' for the period 2000-2008.

Projections of future changes in seasonal average precipitation over Colombia are very uncertain. The GCMs have systematic errors in their simulations of tropical climate and there are considerable differences between models in reproducing patterns of climate variability (such as the future characteristics of the El-Nino Southern Oscillation). Most of the GCMs are poor at reproducing the country's observed precipitation, because their coarse resolution is incapable of resolving the varied topography of the Andes. Furthermore, in Central and northern South America there is the additional uncertainty of tropical cyclones; changes to the storm tracks could influence summer precipitation in the region but such cyclones are also poorly represented in GCMs (Christensen et al. 2007).

As a result, there is no strong agreement between the GCMs as to whether precipitation may increase or decrease in the future. Overall, though, it seems that in the northern part of Colombia, annual average precipitation is more likely to decrease, whereas over the rest of the country, annual precipitation is projected to show either small decreases or increases. Fortunately, changes in annual or seasonal average precipitation are not very important for the activities at MEB.

4.4 Sea level

According to a detailed analysis of sea level data from tide gauges in the Bay of Cartagena over the period 1951-2000 (Sutherland et al, 2008) sea levels in Cartagena are rising at around 5.6mm (± 0.008 mm) per year. In the future, as the oceans warm and ice melts, sea levels are expected to rise more rapidly. An upper estimate for sea level rise (SLR) is difficult to pinpoint because there is little consensus as to what this should be. Therefore, to assess risks at MEB from sea level rise, two scenarios are explored:

- An 'Observed SLR' scenario, which assumes that the current estimated rate of 5.6mm per year continues into the future,
- An 'Accelerated SLR' scenario – this applies a rate of SLR which increases from the current rate of 5.6 mm per year up to 20 mm per year by 2100.

Storm surges have only a modest impact on sea levels in the bay, with the 1 in 300 year storm surge height estimated at only 171mm (see Section 5.2.1.2). As no change in tropical cyclones is anticipated over Cartagena with climate change (see below), it is assumed that storm surge heights will not change either.

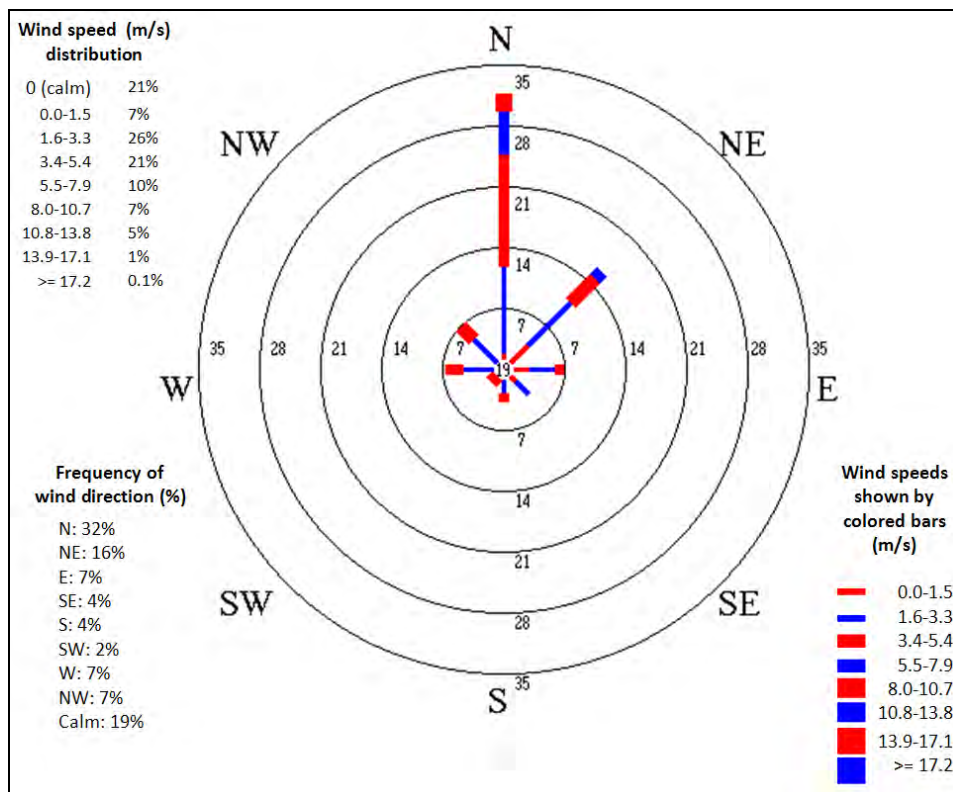
4.5 Winds and tropical cyclones

On rare occasions, high winds can affect activities at MEB by disrupting crane operations (see Section 10.2). The predominant wind directions in Cartagena are from the north and north east (32% and 16% of the time respectively) and wind are generally either calm (i.e. 0 m/s, 21% of the time) or in the range 1.6 – 13.9 m/s (see Figure 4-5).

According to the ensemble mean projections from the 10 GCMs, only modest increases in average wind speeds are projected in the future. For the 2020s, the projected increases are at most 0.2m/s (in June/July/August) and for the 2080s, up to 0.5 m/s. According to the PRECIS model, wind speeds in the range 3 – 10 m/s could become more frequent in future.

Short-term gusts of wind can affect port operations. However, climate change models do not provide projections for gusts. There is also no information on future changes in wind direction.

Figure 4-5 – Wind rose for Cartagena showing wind speed and direction based on 19 years of observed data. Source: IDEAM



Note: Percentage frequencies in each wind speed range have been measured from the wind rose above and are therefore approximate; for instance, the total amounts to 98.1%

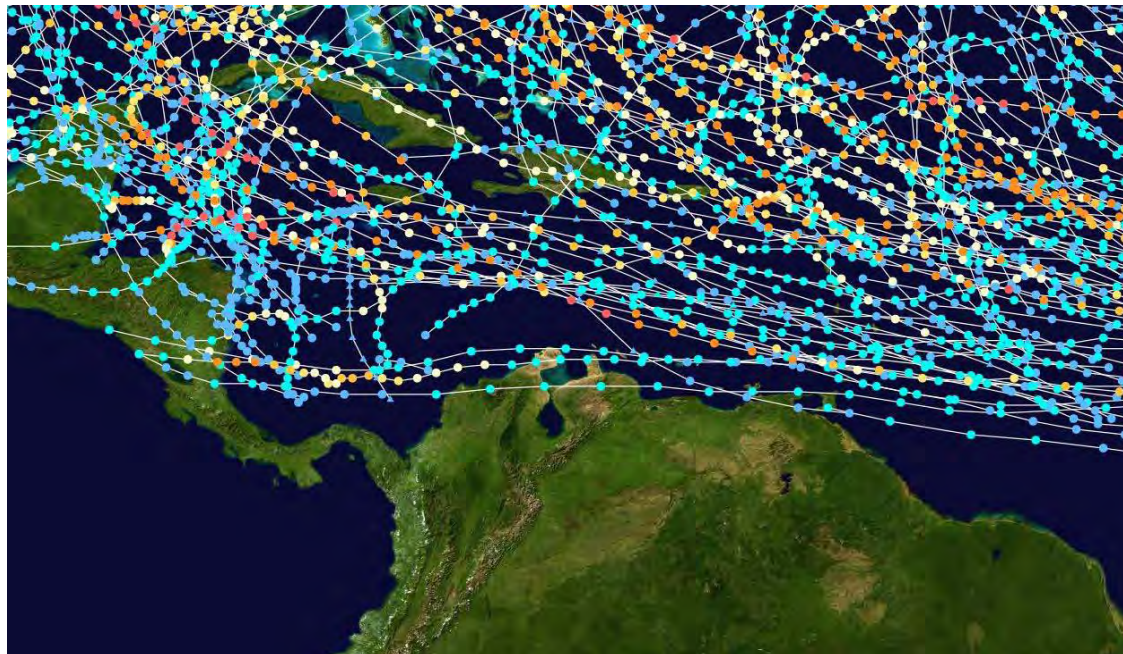
Colombia is located south of the tracks of most tropical cyclones affecting the Caribbean (Figure 4-6) and has seldom been affected by tropical cyclones or downgraded tropical cyclones.

Globally, trends in tropical cyclone point to an increase in tropical cyclone frequency over the twentieth century. However, it is still uncertain if these trends have exceeded the envelope of natural variability (Knutson et al., 2010).

In the future, the latest research indicates that global average tropical cyclone frequency is likely to either decrease or remain unchanged. However, it is considered more likely than not, that tropical cyclones will become more intense, bringing stronger winds and more intense rainfall (Knutson et al., 2010).

There is no evidence to suggest that tropical cyclone tracks will shift, and Cartagena is considered unlikely to experience an upturn in tropical cyclone risk, owing to its position on the landward side of the cyclone tracks and its relatively low latitude.

Figure 4-6 – Observed tracks of tropical cyclones over the Caribbean. Source: NASA, 2009.



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Assessment of Climate Change Risks, Opportunities and Adaptation Measures

5 Vehicle Movements Inside the Port

5.1 Introduction

Vehicles are an essential part of MEB's operations and the continued efficiency of vehicle movements on the port is key to the transport of goods and people.

The following wheeled vehicles are used at MEB:

- Large articulated wagons used to import and export goods to the port,
- Handling vehicles such as reach stackers, and
- Cars for the port's staff and clients.

MEB's capacity for vehicle access is presently being upgraded through an additional bridge linking the causeway to the island site.

The risks of transport disruption due to seawater flooding and degradation of unpaved areas due to rainfall are assessed in the sections below in light of future climate change. Information on potential adaptation measures and costs is also provided.

5.2 Seawater Flooding

5.2.1 Climate-related factor

Sea level at MEB is driven by a combination of four components:

- Astronomical tides,
- Storm surges,
- Annual sea level variations which are driven in the Bay of Cartagena by meteorological factors including trade winds and variations in freshwater input into the bay from the Canal del Dique, and
- Increases due to climate change and local land movements.

Each of these components and their respective contributions to sea level in the Bay of Cartagena are considered below.

The availability of detailed information on each of these sea level components varies: astronomical tides are highly predictable and therefore data are generally readily available from global datasets, while data on storm surge heights is often more difficult to obtain, as storm surges are unpredictable and less frequent events.

To undertake analysis of sea level and associated flood risk it is necessary to define a datum for the assessment. The detail of the datum of each dataset used in this assessment is provided in Appendix 3.

Sea level has been measured in the Bay of Cartagena between 1951 and 2000. There have been a number of investigations of sea level rise for Cartagena which were reviewed for this study. A summary of these is provided in

Table 5-1 – and it can be seen that, for the second half of the 20th century, the annual increase in sea level across all the datasets ranges from 3.6mm to 5.6mm.

Table 5-1 – Summary of the sea level rise estimates for Cartagena based on two tide gauges and four studies

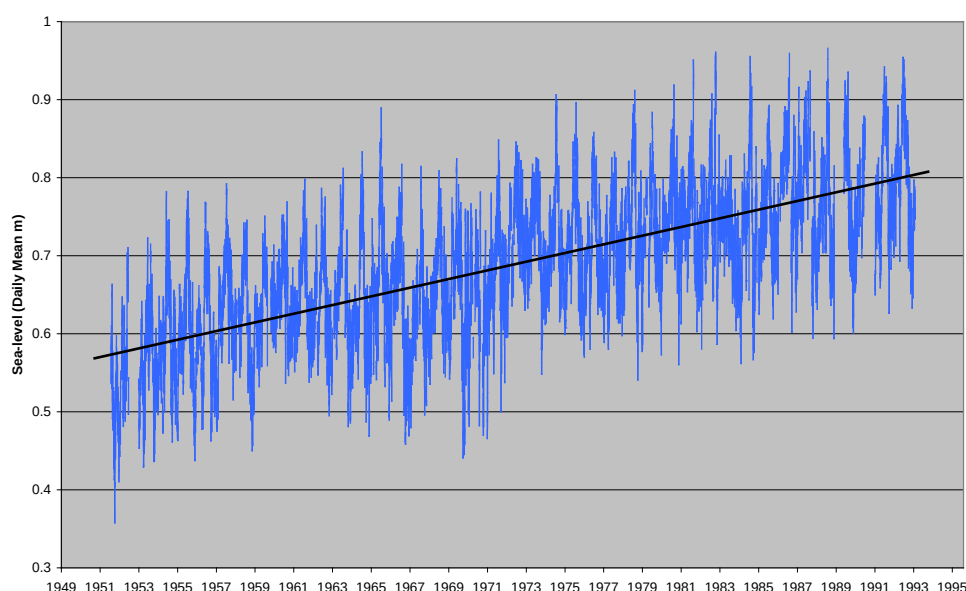
Location of tide gauge	Data period	Observed sea level rise (mm/year)	Reference
Cristobal, Panama	1907 – 1997	2	Torres et al. (2006)
Cristobal, Panama	1952 – 1997	3.6	Torres et al. (2006)
Cartagena	1951 – 2000	4	Alexandre et al. (2008)
Cartagena	1951 – 2000	4.5	Andrade (2008)
Cartagena	1951 – 2000	5.6 ± 0.008	Sutherland et al. (2008)
Cartagena	1951 – 1993	5.6	Torres et al. (2006)

For this study, the observed sea level data from the tide gauge in the Bay of Cartagena were reviewed and analyzed for the period 1952-1993 using linear regression. As shown in Figure 5-1, the dataset exhibits a linear trend, corresponding to an average annual increase of 5.6mm¹¹. This value is in line with previous sea level rise studies for Cartagena (Sutherland et al., 2008 and Torres et al., 2008). This observed rate of increase was selected as the basis for the ‘observed sea level rise’ scenario used in the coastal flood risk assessments undertaken for this study (see Sections 5.2.2 and 7.3).

There is some evidence in the sea level time series for Cartagena (Figure 5-1) of decadal cycles, such as the El Niño Southern Oscillation (ENSO). However, the effect is much less significant than on the Pacific coast of Colombia, where sea levels during El Niño years are raised by 20 to 35cm.

Additional information on sea level rise in Cartagena is provided in Appendix 1.

Figure 5-1 – Observed sea level time series from the tide gauge in the Bay of Cartagena plotted from 1951 to 1993, including linear trend calculated using the least squares method (+5.6mm per annum)



¹¹ Note that, while observed sea level rise in Cartagena has followed a linear trend, globally, the rate of sea level rise appears to be accelerating.

5.2.1.1 Contribution of astronomical tides to sea level

Astronomical tides are highly predictable variations from mean sea level caused primarily by the gravitational pull of the sun and moon.

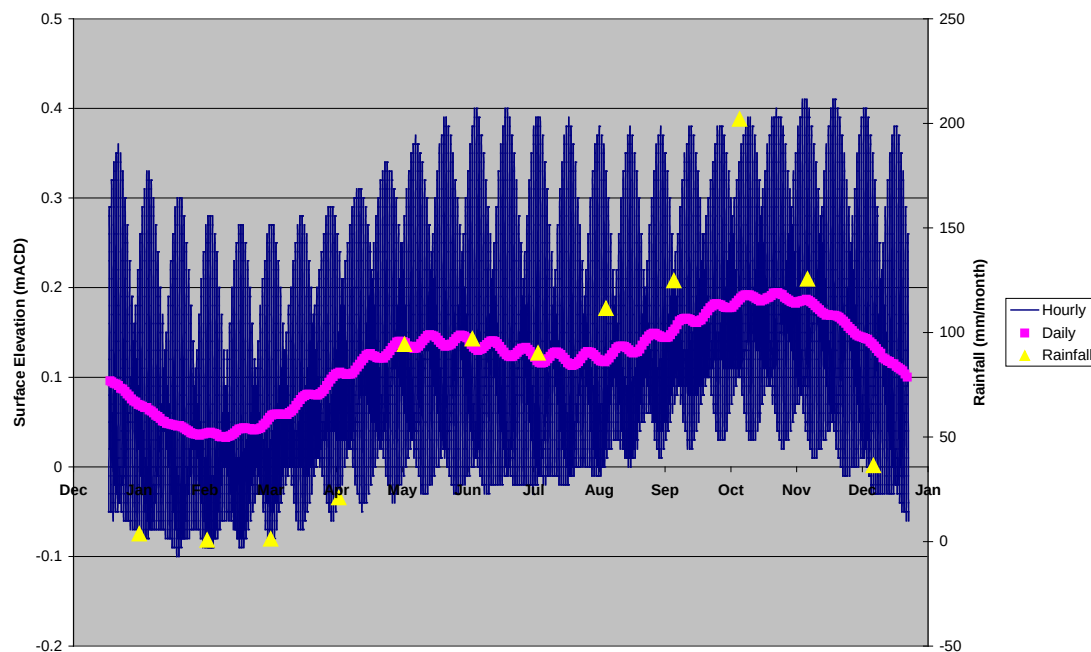
The tidal regime in Cartagena is semi-diurnal. That means that there are two high tides and two low tides every day. It is a micro-tidal environment, with a tidal range of less than 400mm. The tidal range is the difference between low and high water levels. This compares to maximum global tidal ranges of 14m or more in certain areas of the world, for example the Bay of Fundy in Canada or the Severn estuary in the UK.

Modeled sea level in the bay of Cartagena for the year 2000 is shown in Figure 5-2. It is based on a number of harmonic constituents that have been analyzed from measured sea level in Cartagena. The process of this harmonic analysis is described in Appendix 3.

The blue line (hourly sea level) shows semi-diurnal and diurnal tidal components, in addition to longer-term sea level variations. From Figure 5-2, the tidal range appears to be approximately 0.36m.

The pink line (daily sea level) shows the spring/neap cycle which is of approximately 14 days, as well as annual sea level variations. The drivers of these annual variations are further examined in the section below. Monthly average rainfall is also shown on Figure 5-2 by yellow icons, which indicates that there is a potential relationship between rainfall and the annual variations in sea level. Although the El Niño Southern Oscillation (ENSO) is known to have an impact on precipitation in Colombia, there is considerable uncertainty on ENSO-related precipitation anomalies (see Section 4). Therefore, the assessment did not further analyze ENSO implications for precipitation.

Figure 5-2 – Modeled astronomical tides in the Bay of Cartagena plus annual sea level variations (blue line is hourly and pink line is mean daily sea level) plotted against measured average monthly rainfall (yellow icons)



5.2.1.2 Contribution of storm surge and other meteorological factors to sea level

Storm surge is the water surface response to wind-induced surface shear stress and pressure fields caused by storms¹². Water level is increased due to the low pressure at the centre of the storm drawing water upward and the strong winds pushing the sea surface and effectively creating a large wave. This is known as 'wave set up' and is generally the most destructive component of storms (in comparison to wind), as illustrated by the extensive damage caused by Hurricane Katrina's storm surge. For further information on the impact of storm surges on ports, see Section 2.

As explained in the climate review (Section 4), Cartagena is south of the main hurricane tracks as, due to its proximity to the equator, the Coriolis force has insufficient revolutionary energy to maintain a cyclone. Cartagena is also protected by the land mass of South America from cyclones which generally track from the east (see Section 4). This explains why storm surges at MEB have been relatively modest in the past. No significant changes in storminess in Cartagena are projected by climate models (see Section 4).

The extreme value analysis of the measured data undertaken for this study provided storm surge heights for return periods from 1 to 300 years. The analysis was undertaken on the basis of the full sea level dataset for the Bay of Cartagena (for the period 1951-2000). Results are presented in Figure 5-3 and Table 5-2. As shown, storm surge heights in the Bay of Cartagena are very small: even the 1 in 300 year return period is only 171mm. To put these surge heights into context, the storm surge associated with Hurricane Katrina was measured at more than 8m (Knabb et al, 2005).

Storm surges can occur at anytime in the Bay of Cartagena but are most damaging when they occur in conjunction with a high spring tide during the boreal autumn (wet season), as shown by the results of the flood risk assessment presented in Section 5.2.2.

Cartagena also experiences short-term increases in water level due to meteorological factors (wind and rainfall). This annual variability is thought to play a crucial role in the well-known annual floods occurring in the low-lying areas of Cartagena (Invemar, 2005). As shown in Figure 5-3 above, there is an annual signal in sea level in Cartagena, which is generally low at the end of April and reaches its maximum level in October. Based on an analysis of the modeled and measured tidal time series, this annual variation is approximately of 150mm. This is understood to be primarily related to the strength of the northeast trade winds, which affect sea level in the Caribbean (Invemar, 2005). There is also a potential influence from the volume of freshwater input to the bay (Alexandre et al., 2008) from the Canal del Dique. The theory is that the nature of Bay of Cartagena, where the openings to the sea are restricted, causes an accumulation of water in the bay. Whether this is true depends on the total freshwater flow into the bay compared to the flow out of the bay via the Bocachica and Bocagrande channels.

The role of water runoff from the Canal del Dique on sea level in the bay has not been well studied (Andrade, 2009). Although runoff is highly variable in the Magdalena River catchment (located upstream of the canal), data from 1940 provided by IDEAM (recorded at the Calamar gauging station) show little change in mean river flow and a decrease in maximum monthly flows over the same time period. The measured rainfall data do not show a similar decrease (see climate review, Section 4). It is important to note that the Magdalena River has a very large catchment and therefore the link between rainfall and river flow is not straightforward. In addition, it is likely that abstraction for drinking water and irrigation has increased since 1940.

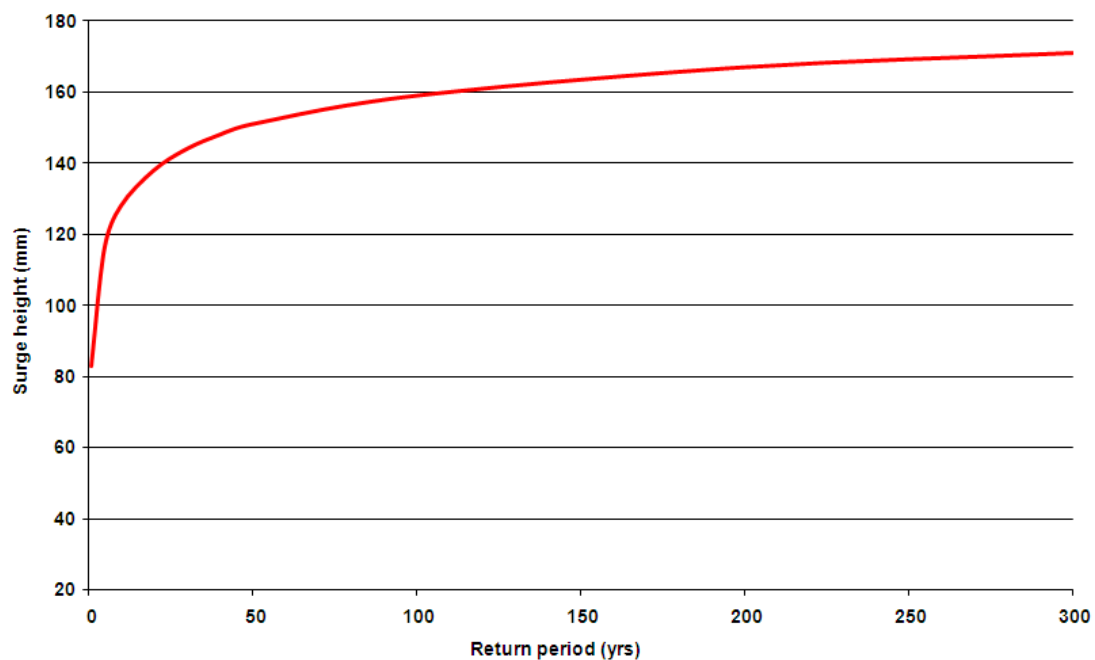
The Canal del Dique is the largest freshwater input into the bay. Therefore, to evaluate the role of rainfall on sea level in the bay (through inflow from the canal) a hydrodynamic model was used. The detail of this analysis is shown in Appendix 3. Other freshwater inputs in the bay include runoff from the city drainage and the adjacent land. The conclusion is that, while there could be a relation

¹² Storms that originate in the tropics are called tropical storms or cyclones and therefore are of interest for this study. Storms that result from the interaction of a warm front and a cold front are called extratropical storms but do not occur in the region of interest.

between rainfall, flow and sea level in the bay, inflow from the Canal del Dique makes only a small contribution to sea level, which indicates that potential future changes in rainfall are unlikely to have a significant impact on flood risk at MEB.

It is worth noting that other studies have been undertaken on the non-tidal components of sea level in the Bay of Cartagena (i.e. storm surges and other non-tidal meteorological and oceanographic movements). For instance, Torres et al. (2008) found slightly higher extreme sea levels, using a shorter dataset and different analytical techniques, of 500-520mm for return periods between 200 and 500 years. This compares to 321mm for the combined effects of the 1-in-300 year storm surge event (171mm) and the annual variation in sea level (150mm) found in this study.

Figure 5-3 – Storm surge heights for return periods up to 300 years based on tide gauge data in Bay of Cartagena



Note: Storm surge height presented here is the incremental height caused by a storm surge which would be in addition to any tidal elevation and any annual variation in sea level.

Table 5-2 – Storm surge heights for return periods up to 300 years based on tide gauge data in Bay of Cartagena (Alexandre et al. 2008)*

Return Period (yrs)	1	5	10	20	30	40	50	100	200	300
Height (mm)	83	116	128	138	144	148	151	159	167	171

5.2.1.3 Summary of contributions to sea level

The various factors contributing to sea level at MEB are summarized in Table 5-3.

Table 5-3 – Maximum contribution to sea level of individual sea level components at MEB

Sea level component	Approx. maximum contribution (m)
Tidal range	0.36
Annual variation*	0.15
Storm surge* (1 in 1 yr)	0.08
Storm surge* (1 in 300 yr)	0.17

*To simplify, all these contributions are termed 'storm surge' in this assessment.

5.2.2 Climate change risk

Flood inundation modeling due to sea level rise can be done with the 2D hydrodynamic model of the bay presented in Section 9.2. However, this was not undertaken for MEB for the following reasons:

- It was not necessary to use a flood inundation model to assess flood risk at MEB as a simple assessment of sea level rise against the elevations of the port plans provided by MEB provided the required information. Flood risk modeling is required when larger areas or inland areas where the propagation of a flood wave is important are concerned.
- A Digital Elevation Model (DEM) of sufficient resolution and accuracy was not available. There is such a DEM of Cartagena using LiDAR (Light Detection and Ranging). The data is held by CIOH, but it was not possible to obtain it for this study.

To assess the risks that sea level rise due to climate change poses to MEB, it is first necessary to establish the rates of mean sea level rise (SLR) that should be considered in the assessment.

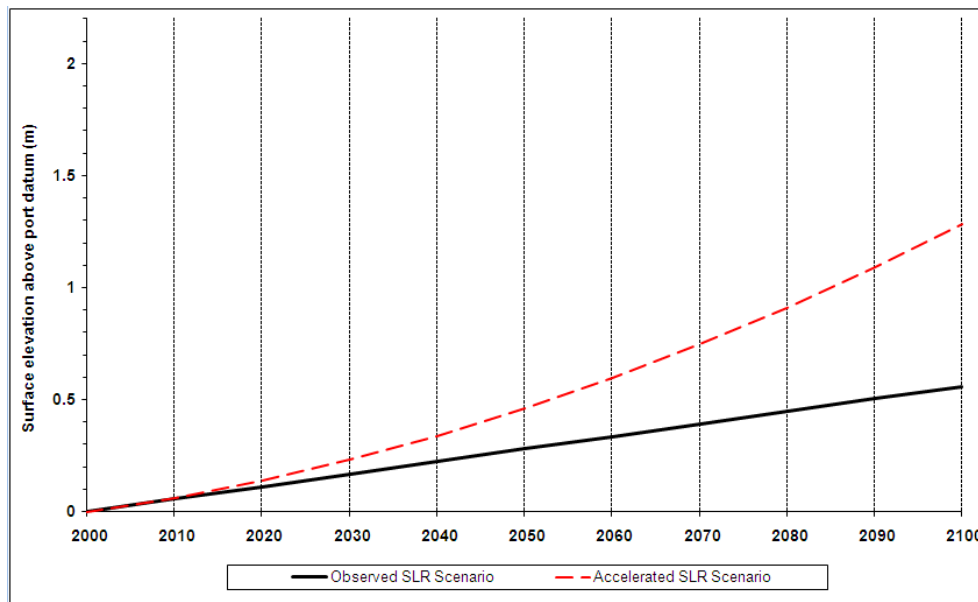
As discussed in the climate review (Section 4), there is uncertainty about future mean SLR. Therefore, it is useful to apply a range of different SLR scenarios to understand the significance of this uncertainty. This assessment considered the following two scenarios (see Figure 5-4):

- An 'observed SLR' scenario, which assumes that the current observed rate of increase continues this century, i.e. 5.6mm per annum (Sutherland et al, 2008), and
- An 'accelerated SLR' scenario, where sea level rises at an increasing rate, starting from the current rate of 5.6mm per annum and reaching 20mm per annum in 2100. This scenario approximates to the exponential SLR that is seen in most of the sea level projections discussed in Section 4.

Land subsidence can accentuate relative sea level rise locally. A robust analysis of the rate of land movement in Cartagena was not found. However, in Panama it can be as much as 2 to 3mm per year. It can be assumed that land movements in Cartagena are captured in the observed sea level time series.

There is no evidence that the other factors affecting sea level in the Bay of Cartagena (i.e. wind set up, rainfall and storms) will be affected by climate change, however this is not the case for other ports where the compound effects of wind, rainfall and storms may constitute a key factor in peak sea levels and where climate change is expected to have an influence on these climatic variables. For example, there is some evidence that the intensity of tropical cyclones in the North Atlantic may increase this century (see Appendix 1).

Figure 5-4 – Rate of sea level rise in both the observed and accelerated sea level rise scenarios used in this assessment. Sea level under the observed scenario increases linearly (at a constant rate), while sea level rise under the accelerated scenario increases following the equation: $y = (7e^{-5})x^2 + 0.0055x$ (where x is years from baseline year of 2000 and y is rate of sea level rise).



As a result of SLR, if no adaptation is undertaken over time, MEB will be flooded in a number of areas. As discussed above, there is some uncertainty regarding datums and 2008 is used as a calibration parameter (see Appendix 3). It is assumed that mean sea level at high spring tide (during the wet season) superimposed by a 83mm-high storm surge is at the level of the causeway, which results in CD 0.06m above the datum used in the port plans.

Projected sea levels under the observed and accelerated SLR scenarios together with the height of the causeway, mainland storage area and quay, are shown in Figure 5-5 and Figure 5-6 respectively. Note that the mean sea level at the highest spring tide (which appears in the figure) refers to the maximum projected annual tidal height. Any annual variation in sea level due to meteorological factors is included in the mean sea level values.

Figure 5-5 – Projected sea level and flood risk in different parts of the port under the observed SLR 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.

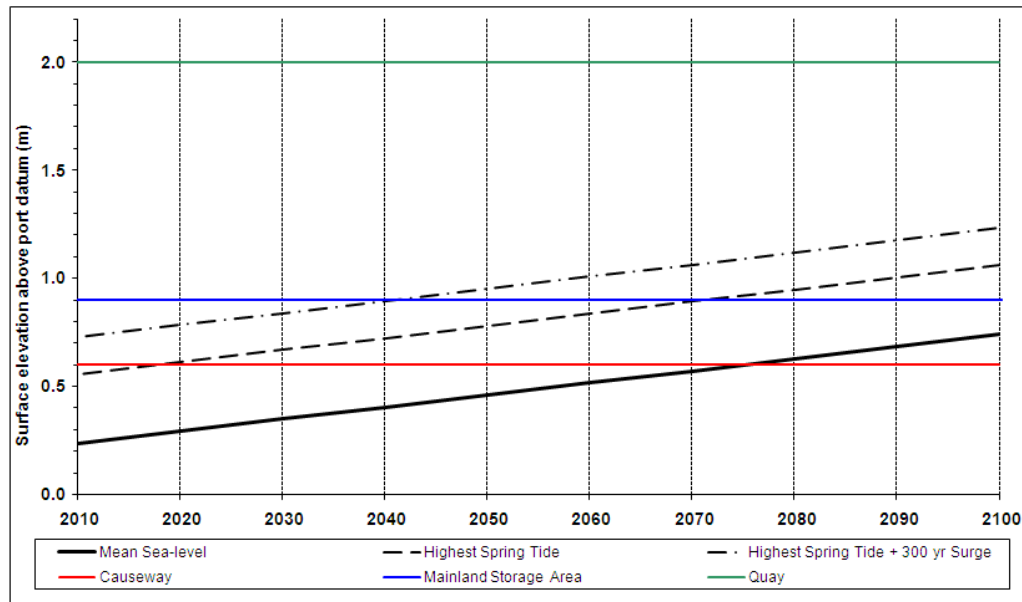
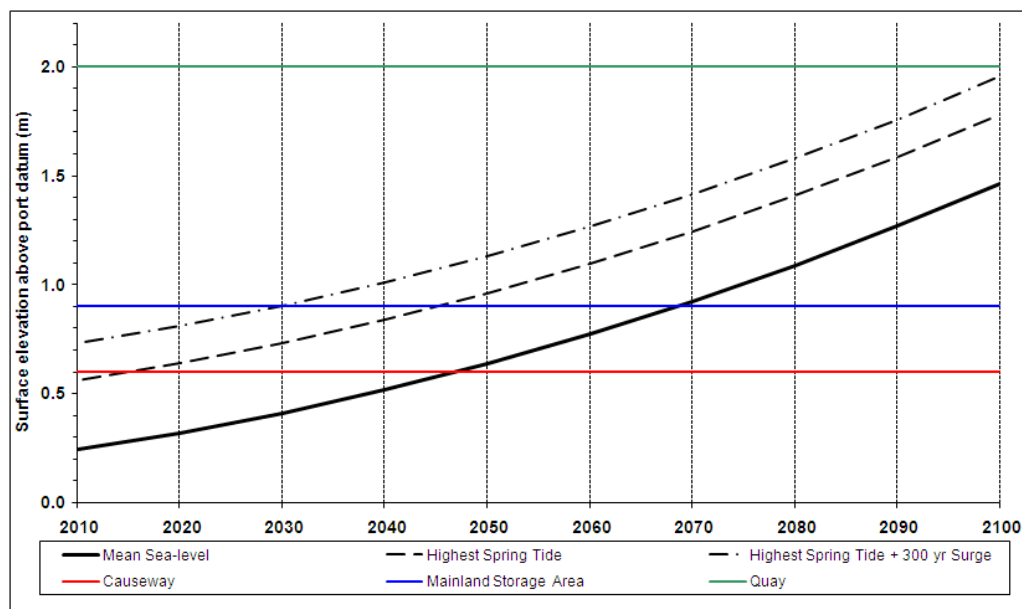


Figure 5-6 – Projected sea level and flood risk in different parts of the port under the accelerated SLR scenario. Three sea levels are presented in this figure: 1) mean sea level; 2) mean sea level at the highest spring tide; and 3) mean sea level at the highest spring tide and with a 1 in 300-year high storm surge.



It is clear from Figure 5-5 and Figure 5-6 that MEB's key area of vulnerability with regards to sea level and vehicle movements is the causeway linking the port mainland site to the Isla del Diablo. The location of the causeway in the port can be seen in Figure 5-7. The causeway is only 0.6m above the port plan datum or an estimated 0.4m above mean sea level in 2000. If flooded regularly, it will have a significant operational and financial impact on the port as it is the only means of transferring goods through the port.

According to MEB, during the flooding events of 2008, trucks were still able to use the causeway when flooding was below 30cm in depth at the edge of the road. MEB indicated that it may still be possible for trucks to run with a flooding depth of 80cm. However, as there may be variability in the height of the road across its width and length, it is assumed in this analysis that the road is not usable if the sea level is more than 30cm above the elevation provided in the port plan.

Under the observed SLR scenario, flood levels reaching the causeway due to mean sea level rise alone are not projected to occur on a frequent basis until 2075 (see solid line in Figure 5-5). However, mean sea level is likely to reach the level of the causeway in 2047 in the accelerated SLR scenario (Figure 5-6). Note that while at this point the causeway would be flooded for approximately 50% of the time, flooding would be of little depth (below 0.3m). If no adaptation action is taken by 2100, the causeway will be 0.15m and 0.9m below mean sea level respectively in the observed and accelerated SLR scenario (only in the accelerated SLR scenario would that cause business interruption).

However, the above does not include the compound effect of mean sea level, high spring tides and storm surge. Mean sea level during the highest spring tide is projected to exceed the height of the causeway from 2018 under the observed SLR scenario (Figure 5-5); under the accelerated SLR scenario it is as soon as 2015 (Figure 5-6). Beyond these dates the causeway will be subject to shallow flooding events on a weekly basis during the period of highest tides (September to December). Although these events may be too shallow to prevent larger vehicles using the causeway, according to MEB they may pose a problem to people moving around the port in cars and on foot.

Storm surges represent a far more unpredictable source of flooding. A 1 in 300-year storm surge occurring during the highest spring tide is already likely to flood the causeway. However, storm surges will not lead to flooding deep enough to restrict vehicle access in the short term. Therefore a detailed analysis of storm surge is not undertaken in this section. Instead it is discussed in Section 7.3 for its impacts on the storage of goods, where a single surge could cause extensive damage, regardless of duration or depth.

In order to better visualize the potential impacts of flooding on the port, a 3D model incorporating the Isla del Diablo, causeway and adjacent mainland has been developed (see Figure 5-8). Data taken from the MEB port plans were analyzed within autoCAD and imported into 3D modeling software. Elevation data within the port plans were used to build up a geometric model with elevations applied to continuous faces or known points in the model; interpolation and approximation was required where survey information was missing or unclear. The model was completed with textures, shading and detailing of surface features¹³. Where elevation data were not available, surfaces were extrapolated using the nearest data point and knowledge of the port from the site visit.

¹³ This model is based on photographs taken during the site visit and is a correct representation of the port plans.

Figure 5-7 – Port plans showing elevation of causeway

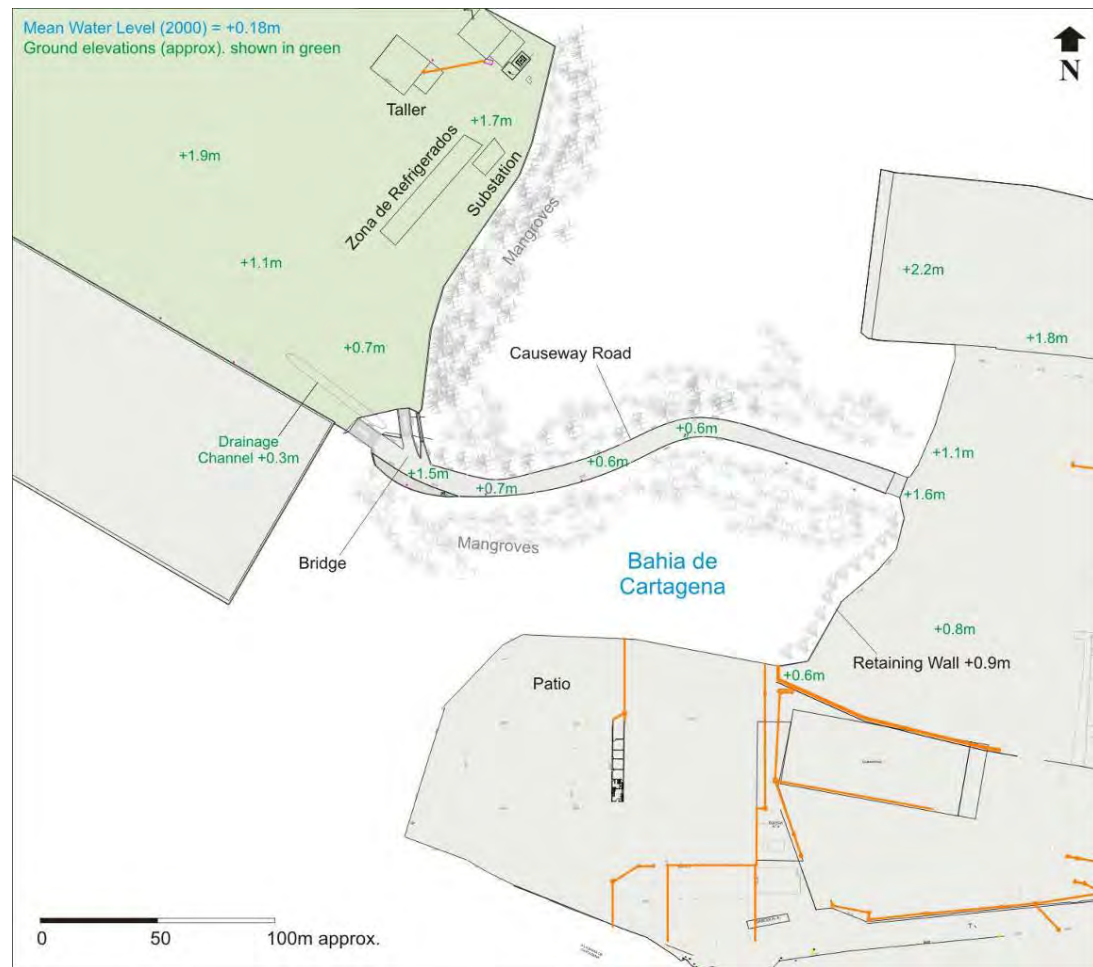


Figure 5-8 – 3D model of MEB port based on port plans (the vertical sections of the quays are represented by the light shading)

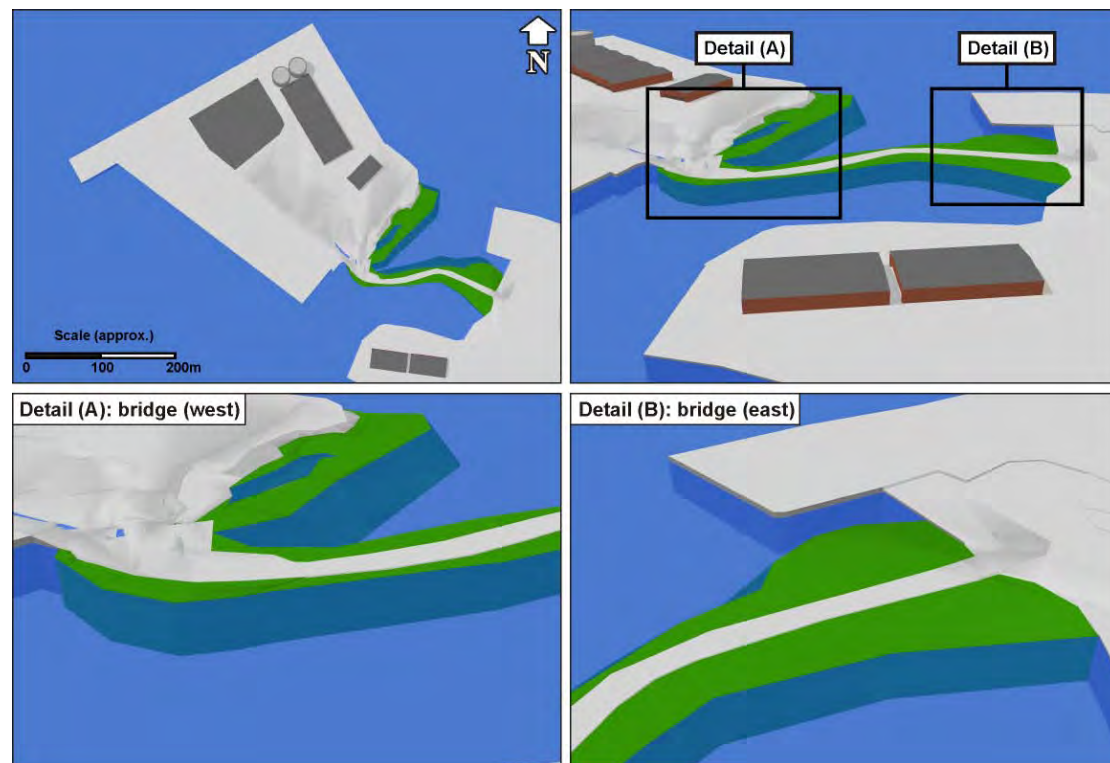


Figure 5-9 visualizes mean sea level at the port in 2000 and also shows the key features and assets at the port. The relative height of mean sea level during the highest spring tide for 2050 and 2100 is visualized in Figure 5-10 and Figure 5-11, for the observed and accelerated SLR scenarios. Figure 5-12 shows the most extreme sea level by 2100 (under the accelerated SLR scenario, and with compound effect of a 1 in 300-year storm surge during the highest spring tide). Areas shown in blue are underwater.

In 2000 all areas of the port are clearly above mean sea level (Figure 5-9). By 2050, the highest annual spring tide under the observed SLR scenario will likely flood the causeway (see Figure 5-10, left). By 2100 the mainland patio and warehouses will likely be under water (the red buildings in the forefront of Figure 5-10).

Under the accelerated SLR scenario, the mainland patio and warehouses are flooded during the highest annual spring tide by 2050 (see Figure 5-11, left). In the extreme scenario of the highest projected annual spring tide superimposed by a 1 in 300 year storm surge, much of the mainland area of the port and the whole of the causeway are below sea level by 2100 (Figure 5-12). The projected sea level is also close to the level of the quays of the island site.

Figure 5-9 - Visualization of MSL in 2000 at MEB (the vertical sections of the quays are represented by the light blue shading which shows the height of sea level).

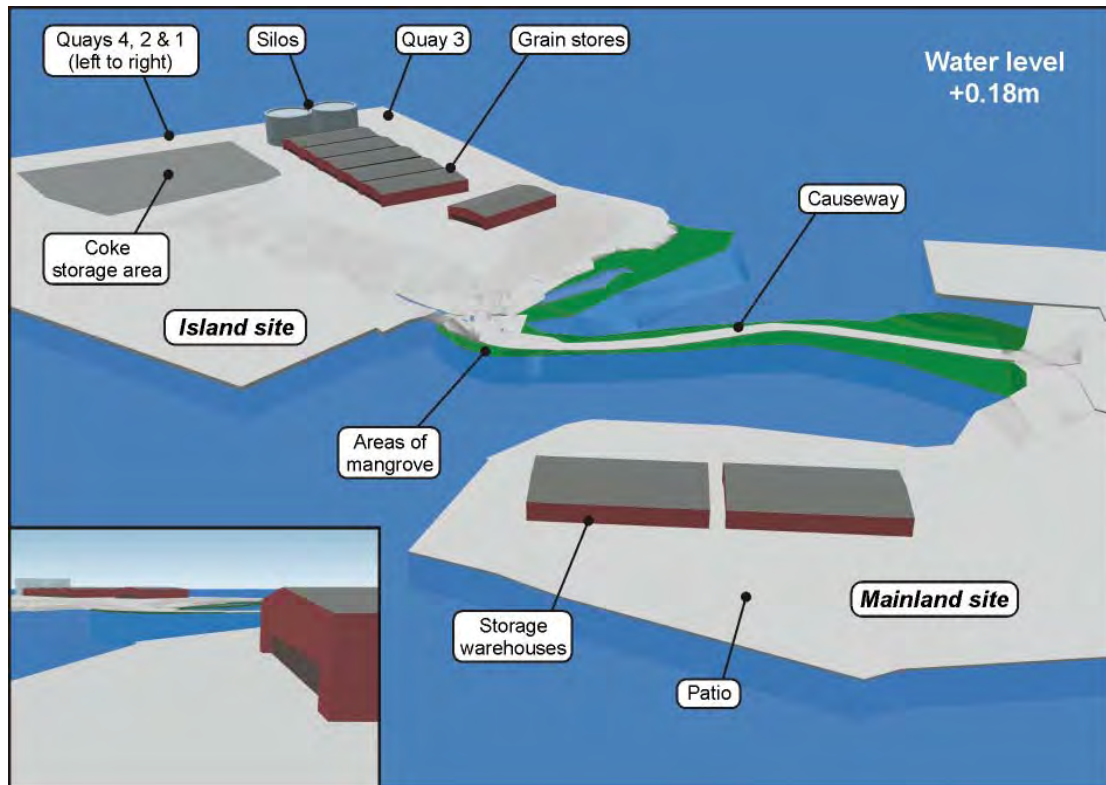


Figure 5-10 – Visualization of projected highest spring tide (tide plus annual variation) in 2050 and 2100 at MEB under the Observed SLR scenario (the vertical sections of the quays are represented by light blue shading)

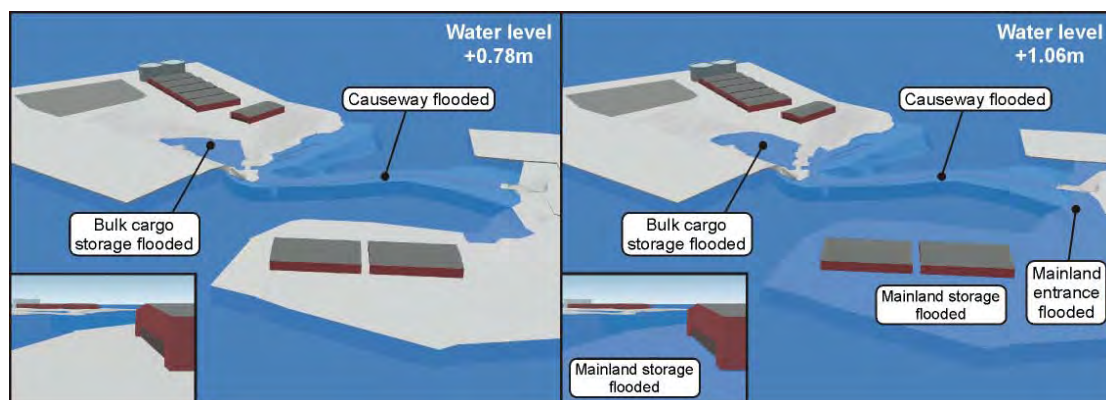


Figure 5-11 – Visualization of projected highest spring tide (tide plus annual variation) in 2050 and 2100 at MEB under the Accelerated SLR scenario (the vertical sections of the quays are represented by light blue shading).

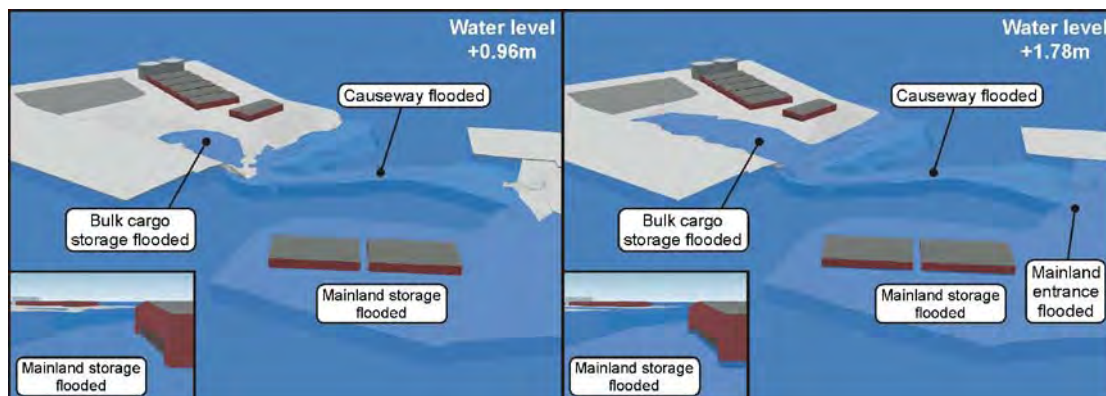
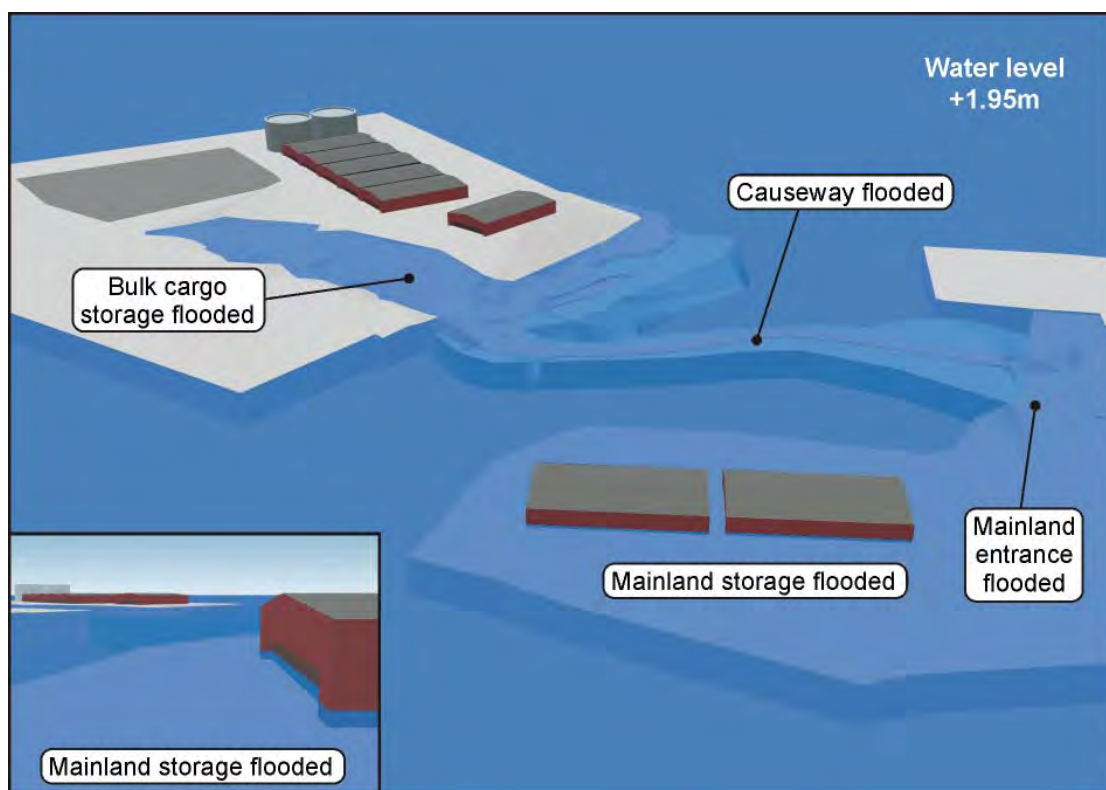


Figure 5-12 – Visualization of projected highest spring tide (tide plus annual variation) plus 1 in 300 yr storm surge in 2100 at MEB under the Accelerated SLR scenario (the vertical sections of the quays are represented by light blue shading)



5.2.3 Adaptation

The key adaptation to flooding of the causeway road is to raise its height. As shown in Figure 5-13, it is a dirt road and therefore is relatively low in cost to raise (as shown in the following section). The retaining walls at the sides of the road would allow the road to be raised through the simple addition of material (such as gravel), assuming the walls are of sufficient strength to support the weight of the additional material. The wall is estimated to be 0.8m high. As the road is raised, it may be necessary to raise the wall and to consider drainage, to ensure that surface flooding is not accentuated during periods of heavy rainfall and that run-off into the surrounding mangroves is managed (see

Section 8.1.1). Above a certain height, further raising the road will present more of a challenge and potentially greater cost, as the stability of the material must be maintained. In addition to the capital cost of raising the road, there are also operational issues, such as the implications for vehicle movements of closing the road to undertake the construction work.

Raising the road may also have an impact on the mangrove surrounding the causeway and the avifauna within it. This may be due to increased run-off of contaminants, dust, light and noise during construction, although the ecosystem must be relatively resistant to these factors, due to the significant number of truck movements (see Section 5).

Figure 5-13 – Road between the mainland and Isla del Diablo



5.2.4 Financial analysis

Flooding of the causeway affects operations at the port because it prohibits the movement of vehicles. When there is a low depth of flooding of the causeway (i.e. below 30cm) foot traffic and vehicles such as cars with low clearances cannot move across it. When flooding is greater than 30cm even vehicles with higher clearances such as trucks may not be able to move across it, leading to a halt on cargo movements until flooding has subsided⁴¹.

Flooding of the causeway in particular has consequences for operations across the port. The causeway is a bottleneck as it is the only route for moving cargo to and from the quays on the Isla del Diablo. Although the port may be able to continue operating if the causeway is only flooded for a few hours, closure for longer periods of time could create backlogs of cargo that need to be moved and further interrupt logistics, if trucks are not in place when and where they are needed. Resolving these problems thus could make any delays last longer than the time that the flooding of the causeway actually lasts. The cost of these delays is incorporated into the financial model described in the following sections.

The observed and projected sea level rise scenarios projections presented in Section 5.2.2 were used as the basis for a financial model of the impacts of sea water flooding on MEB's earnings. It is not expected that seawater flooding would cause significant damage to MEB's buildings and equipment, or threaten MEB's employees. However, towards the end of the century, increased frequency of

flooding could increase damage, such as higher corrosion rates. The cost of such damage was not assessed due to the difficulty of quantifying the issue and lack of data on the value of each of MEB's buildings and items of equipment. Clearly for ports that are vulnerable to flooding by fast-moving water (for example, due to high storm surges), damage to buildings and equipment, and risk to workforce, can be very significant. However, this is not the case of MEB. For further information on the impacts of flooding on building and equipment damage in ports, see Section 2.

The flooding model provided the number of days per year when the causeway would be flooded for various water depths, and the mean duration of the flood events. The operational thresholds considered in this assessment were a flood depth below 30cm causing some traffic disruption, and a flood depth above 30cm in which case it was assumed no vehicle could use the causeway.

For each day in a given year that the causeway is flooded, business interruption costs are subtracted from earnings. The assumptions are set out below (in addition to those presented in Section 3.2):

- MEB does not do anything to prevent flooding.
- The baseline financial case (i.e. ignoring the effects of climate change) is defined in Section 4. All EBITDA estimations are relative to this baseline.
- The average cost of a full day of interruption, when the causeway is flooded by more than 30cm is \$250,000.
- The average cost of a full day of interruption, when the causeway is flooded by less than 30cm is \$50,000¹⁴.
- The cost of a flooding event is calculated at the pro-rata of the cost of a full day of interruption, based on mean flood duration as follows¹⁵:
 - ≤ 2 hours: no cost
 - > 2h but < 6h: 20%
 - > 6h but < 12h: 40%
 - > 12h but < 18h: 60%
 - > 18h: 100%

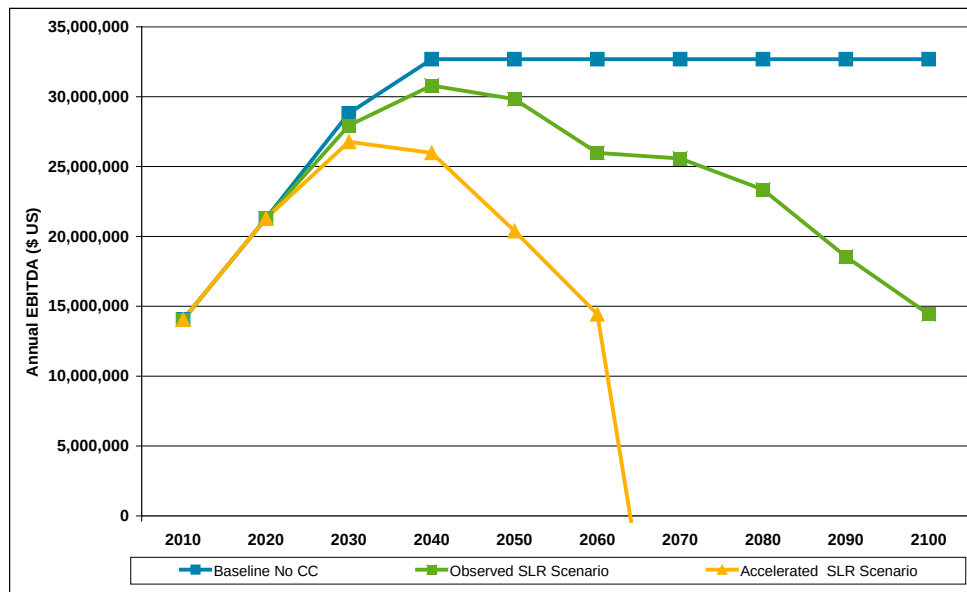
Note that the financial impact of flooding could be higher during the months of August to November when revenue was on average 10% above mean monthly revenue for the period 2005-2009 (see Section 1.3). However considering that MEB is planning to operate at full capacity from around the 2030s onward, only average annual revenues are estimated in this section. Other ports may have more significant seasonal variations in revenue, in which case assessing the financial impacts of flood risk on a seasonal basis may be necessary.

Figure 5-14 shows the impact of flooding of the causeway on MEB's revenue for the two SLR scenarios. In both SLR scenarios, EBITDA begins to decline compared to the baseline (no climate change case) between 2020 and 2030. This demonstrates how close the causeway is to being flooded and is within the period of the current concession. By 2032 the cost of flooding of the causeway is estimated to be between 3% and 7% of MEB's baseline case earnings in the observed and accelerated SLR scenarios respectively. In the accelerated SLR scenario, all earnings are wiped out by about 2065. Therefore flooding poses a long-term business continuity risk to MEB in the accelerated SLR scenario. In the observed SLR case, significant losses are incurred from 2060 onwards, equating to 20.5% of MEB's EBITDA in 2060.

¹⁴ This is based on the assumption that if water is at the same level as the causeway road, people and cars cannot pass but trucks still can. At 30cm depth, trucks can no longer pass and the cost implication is greater.

¹⁵ Note that in reality the hourly cost of flooding may not be linear.

Figure 5-14 – MEB’s EBITDA 1) without climate change (blue line); 2) in the observed SLR scenario (green line); and 3) in the accelerated SLR scenario (yellow line) (the costs associated with the observed and accelerated SLR scenarios assume that MEB does not take action to prevent flooding).



Two adaptation scenarios are considered in this assessment:

- ‘Adaptive management’ (whereby the road is raised several times by 20cm this century), and
- ‘One-off adaptation’ (whereby the road is raised once, by a sufficient amount to cope with SLR out to 2100).

‘Adaptive management’ means that incremental adaptation is put in place as and when required, with increments designed to deal with relatively short timescales, in this case 10 years. For adaptive management to be successful it is crucial that adaptation can be implemented quickly and at low cost. This is a useful approach to managing climate change risk, where detailed information on climate change is not available and capital available for longer-term investment is limited. ‘One-off adaptation’ assumes that adaptation is undertaken once to deal with long-term change, in this case sea level rise to 2100.

The optimal approach to adaptation will be one that maximizes the benefit-cost ratio of adaptation. It will depend on the cost of flooding, the cost of adaptation and, most importantly, the additional cost of repeated adaptation compared to the cost of one-off adaptation expenditure. Repeated adaptation can add costs, compared to a one-off investment, including set up costs, such as design, regulatory approvals or the mobilization of equipment. Other factors such as the design life of the infrastructure or equipment also affect the timing for adaptation. In general, is preferable to plan adaptation so that it coincides with asset replacement timetables.

Overall, the cost of raising MEB’s causeway road is made up of three components:

- A variable cost for construction that relates to the volume of material required,
- A fixed cost for construction, and
- A variable cost for disruption, as the causeway will have to be closed while the work is undertaken. If the port is not at full capacity it may be possible to undertake construction without any disruption and therefore avoid this cost).

These costs are based on the following assumptions provided by MEB:

- The cost of raising the causeway is \$150,000 per 30cm (equivalent to \$100,000 per 20cm increment) plus an additional \$30,000 of set up costs each time adaptation is undertaken¹⁶; and
- Costs due to road closure are assumed to be \$250,000 per day (as in the case of flooding events) and each 20cm increase in the height of the causeway is assumed to take one day.

Overall the cost of 'adaptive management' (i.e. raising the road incrementally throughout this century rather than at once) is likely to be relatively small as it involves the simple addition of material (such as gravel) to the existing causeway, although that may not be the case above a certain height.

In line with the rate MEB uses, a discount rate of 16% is used and a sensitivity analysis around different discount rates is provided below.

MEB's earnings (EBITDA undiscounted) for each decadal time step under the two adaptation scenarios (adaptive management and one-off) are provided in Figure 5-15 and Figure 5-16 for the observed and accelerated SLR scenarios respectively.

To ensure that the causeway is not flooded before 2100, under the observed SLR scenario, the causeway needs to be raised by 60cm. Under the accelerated SLR scenario, it needs to be raised by 1.2m.

The impact of adaptation on EBITDA, compared to the baseline EBITDA without climate change, is shown by the yellow and red markers in Figure 5-15 and Figure 5-16. For example, under the observed SLR scenario (Figure 5-15), to prevent flooding MEB has the option of either raising the causeway by 20cm three times this century (approximately in the 2030s, 2070s and at the end of the century). Alternatively, under the 'one-off' adaptation scenario, it would be raised or raising it once by 60cm in the 2030s. By contrast, in the accelerated SLR scenario (in Figure 5-16), the causeway would either need to be raised by 20cm six times (by the 2030s, 2050s, 2060s, 2080s, 2090s and at the end of the century) or once by 1.2m.

Each year that adaptation is undertaken (in both adaptation scenarios), MEB's EBITDA is below the baseline 'no climate change' case (as shown in the figures below when the yellow and red markers are below the blue line).

¹⁶ The combined cost of raising the height of the causeway, widening and straightening the road is estimated by MEB at US\$2.5 million.

Figure 5-15 – EBITDA (undiscounted) under the observed SLR scenario in two adaptation scenarios: 1) ‘adaptive management’ (whereby the causeway is raised by 20cm three times this century); and 2) ‘one-off adaptation’ (whereby the causeway is raised by 60cm once)

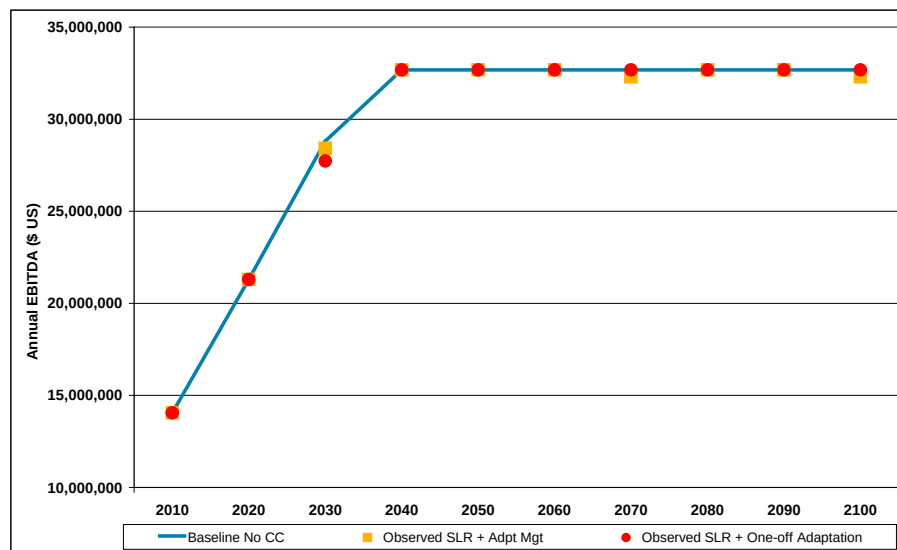
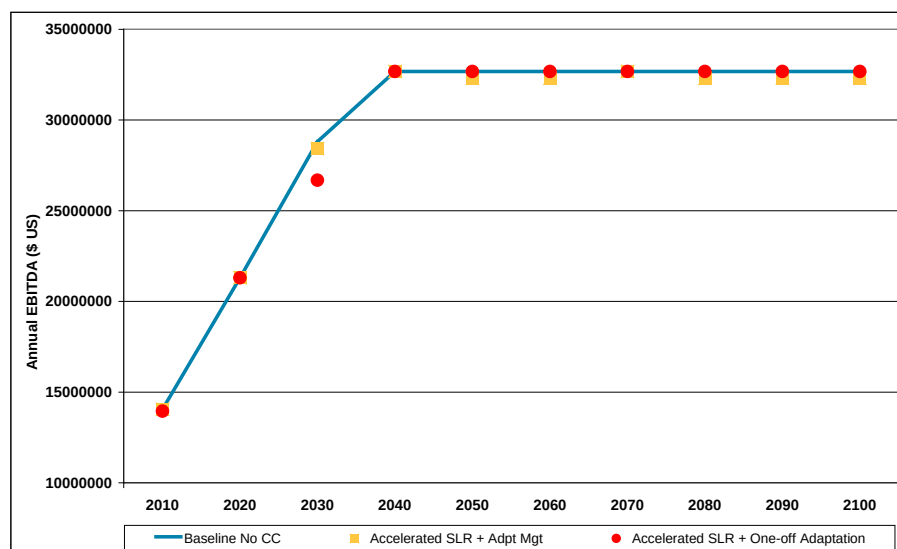


Figure 5-16 – EBITDA (undiscounted) with adaptation under the accelerated SLR scenario in two adaptation scenarios: 1) ‘adaptive management’ (whereby the causeway is raised by 20cm six times this century); and 2) ‘one-off adaptation’ (whereby the causeway is raised by 120cm once)



As noted above, the discount rate is not taken into account in Figure 5-15 and Figure 5-16. Comparison of different investment schedules requires comparing investments on a like-for-like basis. This is done by discounting all the investments in adaptation to a common year, the present year. The sum of all the investments expressed in present year terms is known as the NPC. Note that, in line with common practice, 2010 (the present) was chosen as the base year to discount adaptation costs. However, in recognition of the fact that any adaptation investment decision may not be taken until 2030, when the risk of coastal flooding due to sea level rise becomes significant, it is also worth considering adaptation costs if 2030 were the present. This would not markedly change the results, though the discount rate at which point adaptive management becomes cheaper than one-off adaptation would be slightly higher.

The NPC of raising the causeway to 2100 for a range of discount rates is presented in Figure 5-17 and Figure 5-18 for the observed SLR and accelerated SLR scenarios respectively. The adaptive management and one-off scenarios are compared on each graph. Overall, the NPC of the adaptive management option is lower than the NPC of 'one-off adaptation' for discount rates above 0.2%. At the discount rate that MEB uses (16%) the discounted costs of adaptive management are 22% of those attached to raising the road in one go under both the observed and accelerated SLR scenarios. Even at a discount rate of 3%, which is commonly used by the public sector, the adaptive management option costs are less than 50% of those for the one-off adaptation option under both SLR scenarios.

The other advantage that adaptive management has in this case is that if SLR is not as great as projected, then not all of the investments need to be made, i.e. adaptation decisions can be adjusted over time, based on the rates of SLR experienced.

In this case study, the financial consequences of flooding for MEB are so high compared to the cost of raising the causeway, that the financial case for adaptation is clearly established for all the discount rates considered in Figure 5-17 and Figure 5-18. For other assessments of the costs and benefits of adaptation where the decision is less clear cut, calculating net present values (discounted cash flows of adaptation costs and avoided climate change costs) will be necessary to identify if and when it makes financial sense to undertake adaptation. In these cases, it will be useful to compare the internal rate of return of adaptation investments against the return of alternative investments.

Figure 5-17 – NPC of adaptation investments to 2100 under the observed SLR scenario

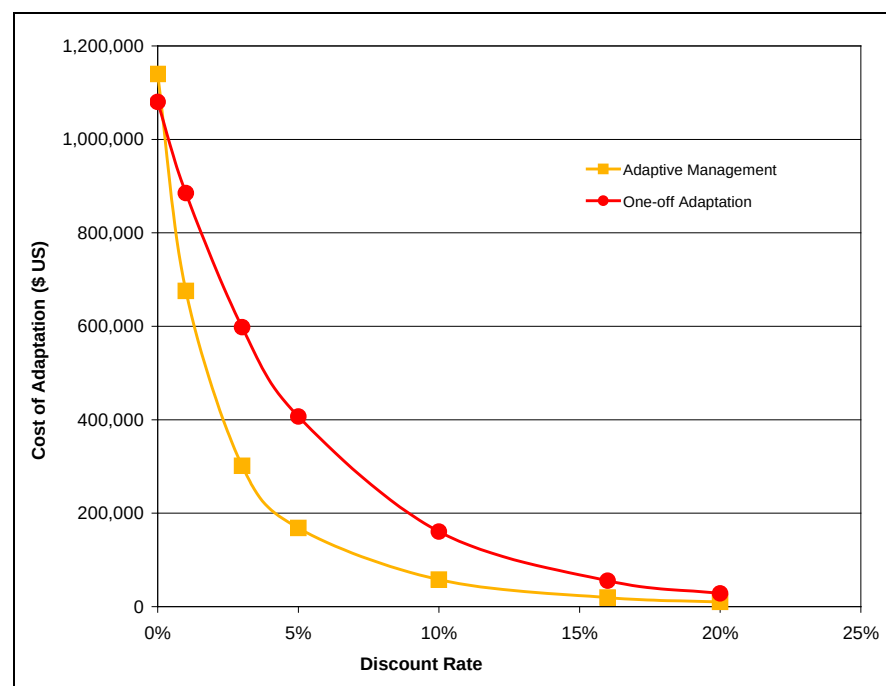
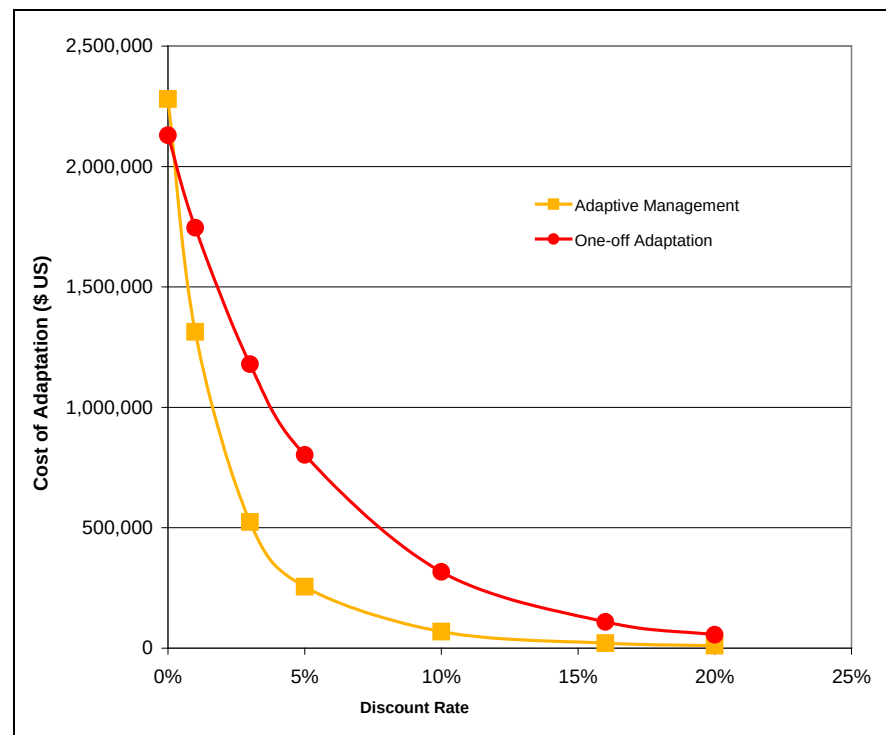


Figure 5-18 – NPC of adaptation investments to 2100 under the accelerated SLR scenario



5.3 Maintenance of Unpaved Areas

5.3.1 Climate-related factors

According to MEB, variations in maintenance costs of the unpaved areas of the port are at least partially dependent upon the weather. Primarily, rainfall can degrade the state of unpaved roads and require higher maintenance.

As discussed in Section 4 rainfall has increased at a rate of 0.6% per year between 1941 and 2009¹⁷. Although ENSO is known to have an impact on precipitation in Colombia, there is considerable uncertainty on ENSO-related precipitation anomalies (see Section 4). Therefore, the assessment did not further analyze ENSO implications on precipitation.

5.3.2 Climate change risk

The unpaved roads at the port require periodic maintenance, as erosion due to vehicle movements and natural processes affect the quality of the road service. It has been highlighted that the unpaved areas have a number of problems, including: uneven surfaces, need for continual re-grading, poor drainage of rainwater, inability to provide surface markings for roads or stacks and wind-blown dust (Scott Wilson, 2007).

According to MEB, variations in maintenance costs can, at least partially, be explained by rainfall. As such, climate change could lead to a change in these costs. However, there is a lack of data available from MEB on maintenance costs. Only 16 months of maintenance data were available, from which it was not possible to deduce a relationship between rainfall and maintenance costs.

¹⁷ Note that climate model output for rainfall over Colombia is unreliable. According to the IPCC, rainfall intensity is projected to intensify in the future as the climate warms, so assuming that existing trends will continue could be an underestimate (IPCC WG1, 2007). For further detail, see Section 4.3.

5.3.3 Adaptation

The obvious adaptation measure would be to pave the remaining unpaved areas of the port. Another option that could be considered consists of limiting the movement of heavy vehicles on unpaved areas.

If MEB paves more of the port then the volume of run-off entering the drainage system may increase, requiring upgrades. Further information on the drainage system is provided in Section 7.2.

5.3.4 Financial analysis

MEB provided costs for road maintenance as shown in Table 5-4. If the effects of climate change lead to an increase in road maintenance, then this will impact on EBITDA. Adaptation could alleviate some of the increased maintenance costs.

In cases like this one, where data are limited or when taking a high-level view of adaptation issues, there are several quick financial tests that can be done. First, one can examine the impact that climate change may have on bottom line (in this case, the impact in terms of increases in road maintenance costs). Secondly, one can look at the overall cost and benefit of adaptation.

As described in the financial baseline (Section 3.2), MEB's current earnings (EBITDA) are in the range of US\$14 million per year and projected to grow to approximately US\$30 million per year in the future as cargo capacity is increased. As shown in Table 5-4, road maintenance costs are in the range of US\$1,000 to US\$35,000 per month. Taking the low estimate of MEB's earnings (US\$14 million) and the annual average of the above costs (US\$154,000 per year), annual road maintenance costs are estimated to be only 1.1% of earnings.

For the purpose of illustration, if road maintenance costs were to double from their very highest over the past year and a half (in a hypothetical extreme climate change scenario), and earnings were not to grow at all, earnings could decrease by 1.1%. This is not necessarily an insignificant amount, but at the same time probably will not drive the success or failure of the business.

Another indicator of the desirability of investment in adaptation is comparing the investment cost with the expected savings (benefits). Based on data received from MEB, the capital investment required for paving the roads is approximately US\$2.5 million. The expected savings are the reductions in road maintenance costs. Assuming that the annual road maintenance costs (US\$154,000) are completely eradicated, then it would take approx 16 years for the investment to pay off. This is a conservative estimate as it is likely that the annual road costs would reduce but not completely disappear. When the discount rate is incorporated, the analysis suggests that MEB would get little return on the investment within the remaining time of the concession (24 years), if only road maintenance costs are considered.

However, there are other reasons why MEB may choose to pave the unpaved roads, such as reducing dust and mud, and therefore any potential impact on the environment and local communities in the vicinity of the port, as well as improving operations. In fact, it is understood that MEB intends to pave these roads, regardless of climate change.

Table 5-4 – Road Maintenance Costs

2008	Month	USD
September	Sep-08	20,000
October	Oct-08	18,000
November	Nov-08	35,000
December	Dec-08	25,000
Average:		24,500
2009		
January	Jan-09	15,000
February	Feb-09	18,000
March	Mar-09	13,000
April	Apr-09	9,000
May	May-09	12,000
June	Jun-09	10,000
July	Jul-09	12,000
August	Aug-09	9,500
September	Sep-09	3,500
October	Oct-09	2,500
November	Nov-09	2,000
December	Dec-09	1,200
Average:		8,975
Annual Total:		107,700

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6 Demand, Trade Levels and Patterns

6.1 Introduction

6.1.1 Approach to the analysis

In this section, climate change impacts that could affect imports and exports at MEB are considered, including:

- (i) Impacts on total trade at MEB (including impacts on maritime transport of goods),
- (ii) Impacts on grain imports, and
- (iii) Impacts on agricultural exports (transported inside containers).

The purpose of this analysis is to provide evidence of the potentially significant impacts on ports of climate-driven changes to trade. These impacts are difficult to quantify with confidence over coming decades. This is 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. Despite high uncertainties, this could be a material risk area for ports and it deserves more research (WTO, 2009).

The study for MEB adopted a practical approach to assessing potential climate change impacts on MEB's imports and exports, drawing on literature reviews and analysis, discussions with staff at MEB and other stakeholders during the site visit. From these sources, high level scenarios were developed that describe potential impacts, and financial analysis was conducted on the basis of these. Considering the uncertainties in future trade projections on long timescales, the study produced high level estimates of potential impacts on MEB's revenues up to the 2050s.

The analyses presented in this section are discussed at various spatial scales:

- Analysis of impacts on total trade is conducted at a global level and for MEB;
- Impacts on maritime transport are analyzed at a regional and local level;
- Impacts on grain imports are analyzed at the global, North American, Colombian and MEB level; and
- Analysis of agricultural exports focus on Colombia and MEB.

While attention is focused on climate-related risks and opportunities, some reference is also made to non-climatic factors which interact with climate change to affect trade at all spatial scales in Appendix 4. Furthermore, it should be noted that this analysis does not investigate the effects of mitigation policy on imports and exports, though these may have an effect on trade at the port.

6.1.2 Recent and projected future trade through the port

Between 2005 and 2010, MEB imported grain, exported coke, and imported and exported containers and bulk cargo (Figure 6-1). Containers, which hold a variety of products, have created the most revenue for MEB to date (Figure 6-2).

Figure 6-1 – Total trade at MEB from 2005-2010, measured in tons (grain, coke, bulk cargo) and number of containers

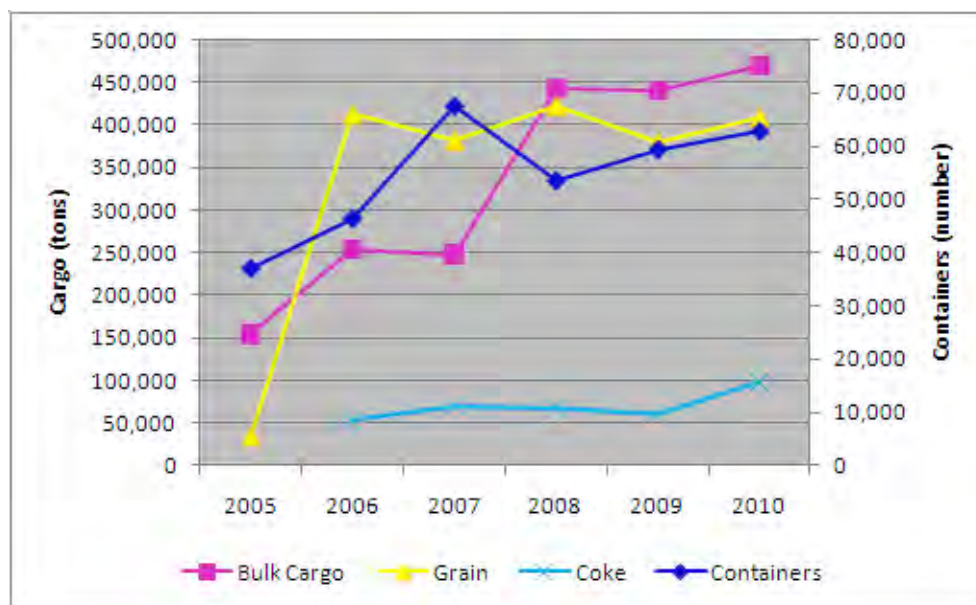
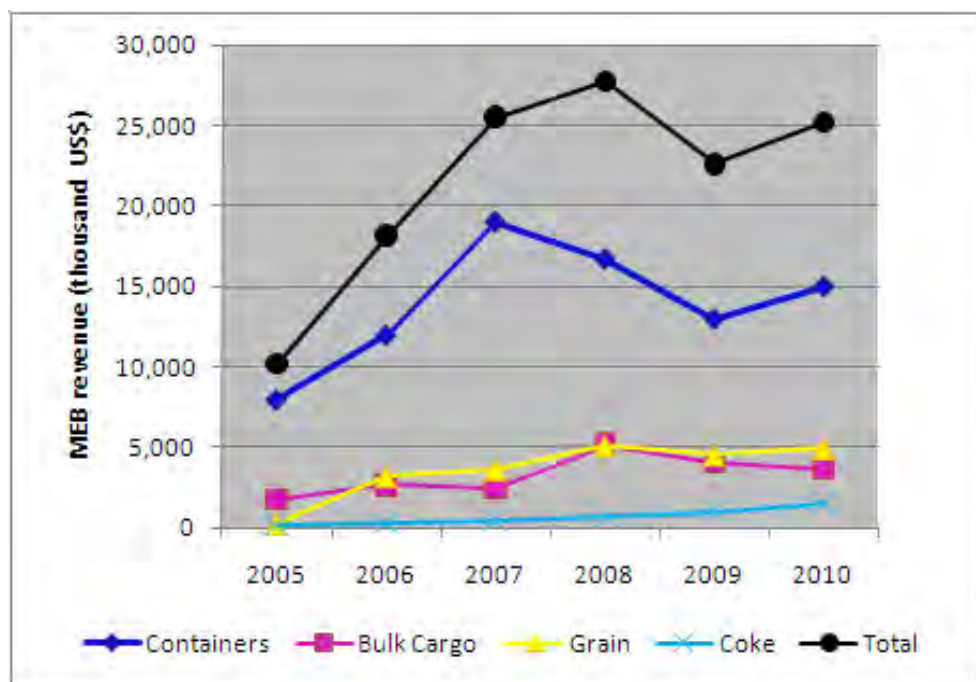
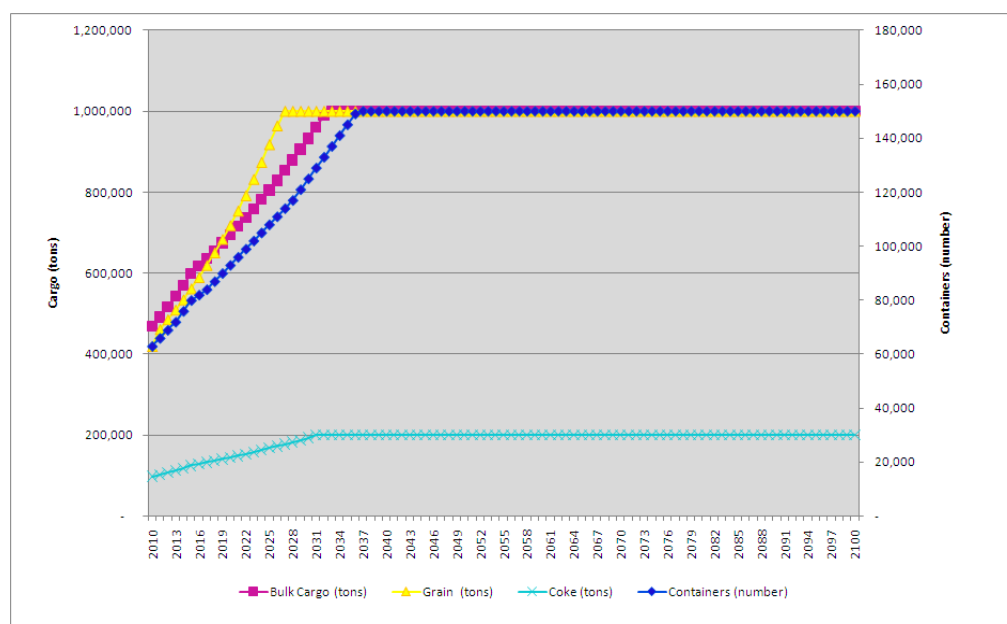


Figure 6-2 – Total trade at MEB from 2005-2010, measured in revenue



MEB's projections for future trade and revenue indicate an increase in grain, bulk cargo and containers until capacity is reached in 2027, 2033, and 2037, respectively. Projections for coke indicate a slower rate of increase until capacity is reached in 2031. See Figure 6-3 for data on projected volumes for the baseline case (i.e. ignoring the effects of climate change). Projected revenues for the baseline case were provided in Figure 3-1.

Figure 6-3 – Total trade at MEB projected for 2010-2100, measured in tons (grain, coke, bulk cargo) and number of containers



MEB derives its revenue from imports and exports by charging a fixed price per unit of goods. As shown in Table 6-1, the price varies each year. As stated in Section 3.2, however, for the purposes of financial analysis, revenue per unit cargo is assumed to be constant in the future (see Table 6-1).

Table 6-1 – MEB's revenue (US\$) per unit of goods imported or exported

Product	2005	2006	2007	2008	2009	2010
Containers (number)	259	282	313	219	217	239
Bulk Cargo (tons)	10	10	12	9	12	8
Grain (tons)	8	10	12	12	7	12
Coke (tons)	6	7	11	17	0	16

6.2 Impact of climate change on total trade at MEB

6.2.1 Context

At a broad level, climate change impacts are likely to affect trade at MEB if they affect the world economy in general, and the economies of the three countries with which MEB does most business, namely the USA, Colombia and Argentina. Evidence suggests that seaborne trade and a country's Gross National Product¹⁸ (GNP) are closely correlated, with wealthier countries having higher levels of imports. In an analysis of 94 countries, Stopford (1997) found that 69% of the variation in seaborne imports was explained by GNP variations.

¹⁸ GDP, which was used in the analysis of impacts on trade at MEB, is related to GNP. GNP is the sum of GDP and total capital gains from overseas investment, minus income earned by foreign nationals domestically.

Other factors that were found to influence trade were:

- The physical size of a country: smaller countries have less physical resources available locally, and therefore need to import more. Stopford found that 22% of the variation in trade was explained by land area.
- A country's natural resources: according to Stopford's analysis, 24% of variation in trade was explained by natural resources (i.e. tonnage of cereals, oil, coal and iron ore produced).

In contrast, trade was found to have a very low correlation with population (4%).

Overall, therefore, economic activity is the dominant factor determining levels of seaborne trade. In order to examine the potential effects of climate-driven changes in economic activity for MEB, first, the possible impacts of climate change on the world economy are discussed, and secondly, the consequences for MEB. Potential consequences for MEB are considered by examining how MEB responded to changes in global gross domestic product (GDP) in the past. This may indicate how business at the port might respond to changes in global GDP, and to changes in the GDP of its three main trading countries, in the future. However, it is important to acknowledge that the relationship between MEB revenues and global GDP could be unstable, so projections of impacts on MEB's future revenues based on future changes in global GDP should be regarded as only 'ball-park' estimates.

6.2.2 Impact of climate change on the world economy: a summary of Stern's key findings

The Stern Review on the Economics of Climate Change ('Stern Review'), published in 2006 for the British government, is the most comprehensive study conducted to date on how climate change may affect the world economy over time. The Review examines the economic impacts of climate change under business as usual conditions (i.e. with no action to address climate change) as well as the costs and benefits of action to mitigate and adapt to climate change.

For purposes of clarity, the Stern Review's various scenarios are referred to as:

- (i) The 'Stern baseline case' – Stern's global economic projections without climate change,
- (ii) The 'Stern with climate change' case – Stern's global economic projections with climate change, and
- (iii) The 'Stern with mitigation and adaptation' case – Stern's global economic projections with mitigation and adaptation action.

Stern's analysis identifies the mean costs of climate change from the 2020s to the 2080s, ranging from 0.2% to 1.88% of global per capita consumption in the 'with climate change' scenario, i.e. where climate change impacts are experienced and no efforts are made to avoid the effects (see Table 6-2). These values decrease to 0.05% to 1.00% of global GDP in the 'with mitigation and adaptation' scenario, as shown in the table. In this scenario, the effects of climate change are counteracted by adaptation and mitigation costs are entirely avoided from 2055 onwards based on the stabilization of carbon emissions at 500-550ppm CO₂e (parts per million carbon dioxide equivalent). A summary of Stern's results is presented in Table 6-2 and further details are presented in Appendix 4.

Table 6-2 – Stern Review (2006) projections of the economic impacts of climate change for 2025, 2055 and 2085. (Results are given as percentage change in global per-capita consumption and are intended to resemble the 2020s, 2050s and 2080s).

Scenario			Losses in per capita GDP per annum (%)		
Climate	Economic	Year	Mean	5 th percentile ¹⁹	95 th percentile
Baseline climate	Market impacts + risk of catastrophe	2025	-0.20	NA ^(a)	NA
		2055	-0.25	NA	NA
		2085	-0.50	-0.01	-1.00
High climate	Market impacts + risk of catastrophe	2025	-0.25	NA	NA
		2055	-0.50	NA	NA
		2085	-0.75	-0.01	-1.75
	Market impacts + risk of catastrophe + non-market impacts	2025	-0.50	NA	NA
		2055	-1.00	-0.25	-1.75
		2085	-1.50	-0.75	-4.00
	Market impacts + risk of catastrophe + non-market impacts + value judgments for regional distribution ^(b)	2025	-0.63	NA	NA
		2055	-1.25	NA	NA
		2085	-1.88	NA	NA
Mixed climate scenarios	Mitigation and adaptation ^(c)	2025	-0.05 to -0.50 ^(d)	NA	NA
		2055	-1.00 ^(e)	NA	NA
		2085	-1.00 ^(f)	NA	NA

Notes

(a) NA = not available.

(b) This analysis has followed Stern's logic by raising the 'High climate + market impacts + risk of catastrophe + non-market impacts' scenario 25% to estimate the for the most extreme climate change scenario, including value judgments for regional distribution.

(c) These scenarios include costs of adaptation and mitigation to 2050, but only mitigation costs from 2050 onward, as all significant impacts are assumed to be avoided by this point. The stabilization target used is 500-550ppm CO₂e. (It should be noted that even with this target, there will be significant climate change impacts in some sectors and regions).

(d) Adaptation costs of making new infrastructure and buildings resilient to climate change in OECD countries.

(e) Range of -5% to +2%, depending on scale of mitigation required, pace of technological innovation and efficiency at which policy is applied globally.

(f) Range extending from -15% to +4%, though with significant uncertainty.

¹⁹ Some 5th and 95th percentile data are 'not available' (NA).

6.2.3 Climate change, the world economy and MEB

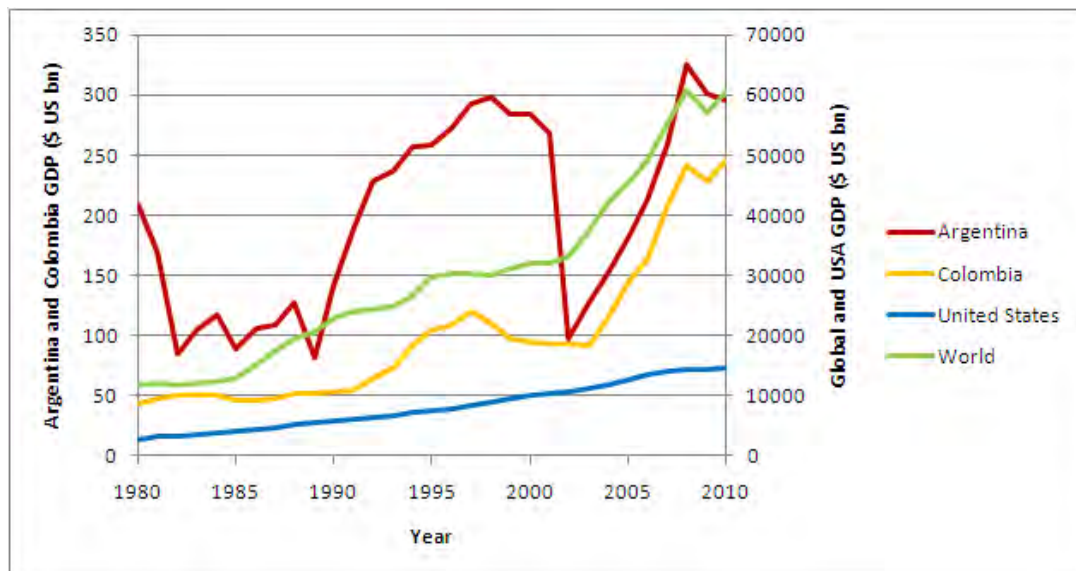
In order to understand how climate change impacts on the global economy and on the economies of its three main trading countries might impact on MEB in the future:

- First, a comparison is made between global GDP over the period 1980 – 2010 and the GDP of the USA (with which MEB does 60% of its business), Colombia and Argentina. This indicates that the GDP of these countries has generally tracked global GDP.
- Secondly, the analogue of how MEB's revenue responded to recent changes in global GDP is examined. The time period for which data are available from MEB (2005-2010), includes the global recession which began in the USA in December 2007 (National Bureau of Economic Research, Dec 2008), spreading quickly to the rest of the world. Based on the observed relationship between MEB's revenue and global GDP, and drawing on the Stern review information presented above, high-level estimates are then made of the possible impacts of climate change on MEB's total trade. (Clearly, this observed relationship could be different in the future). Given that only six years of historic data are available for MEB, this is a very speculative assessment.

6.2.3.1 Comparison between global GDP and the GDPs of MEB three main trading countries

Figure 6-4 demonstrates that the GDPs of the USA, Colombia and Argentina have generally followed a similar pattern to global GDP since 1980. Some differences can be seen, including the economic crises which affected Argentina during the 1980s and in 1999-2002, and the fact that the GDP of the USA has generally been smoother than global GDP. While not implying a causal relationship, this suggests that trade at MEB will likely be responsive to changes in global GDP.

Figure 6-4 – Global GDP plotted against the GDP of the USA, Argentina and Colombia. Source: IMF, 2009

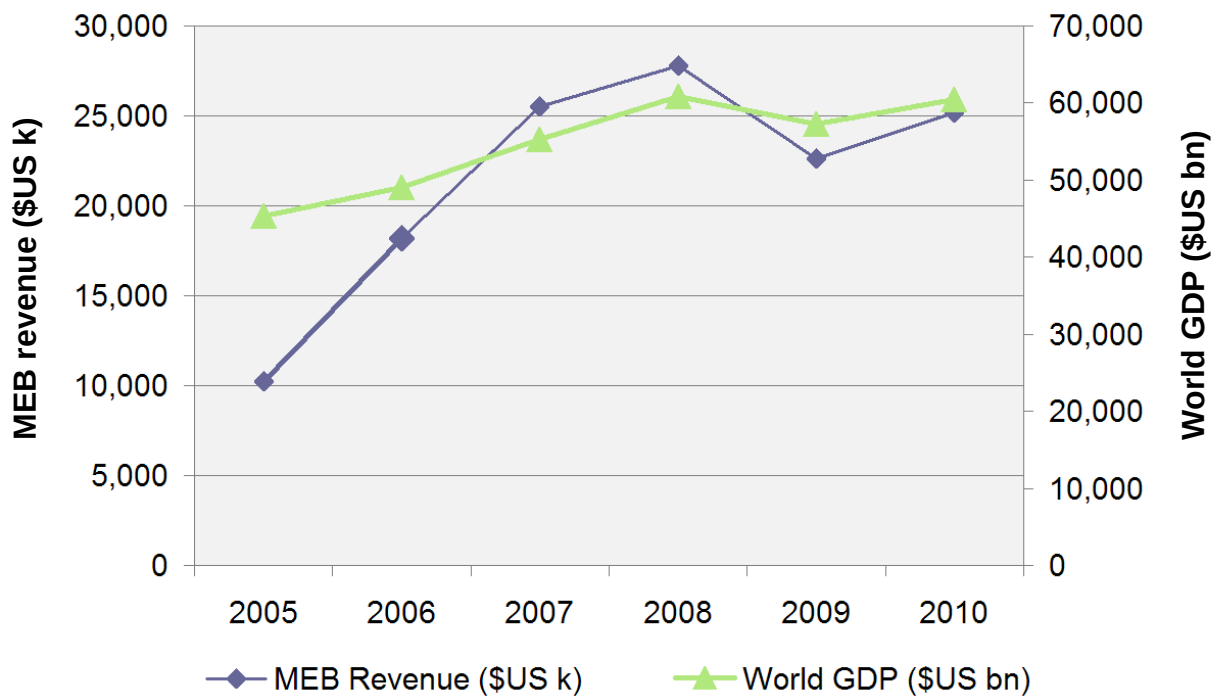


6.2.3.2 Comparison of MEB's revenue and global GDP over the period 2005 - 2010

Figure 6-5 shows global GDP and MEB's revenue for the period 2005-2010. They follow a similar pattern, as shown in the correlation presented in Figure 6-6. As a very rough first approximation, these data indicate that a 1% change in global GDP could lead to a 0.7% change in MEB's revenue.

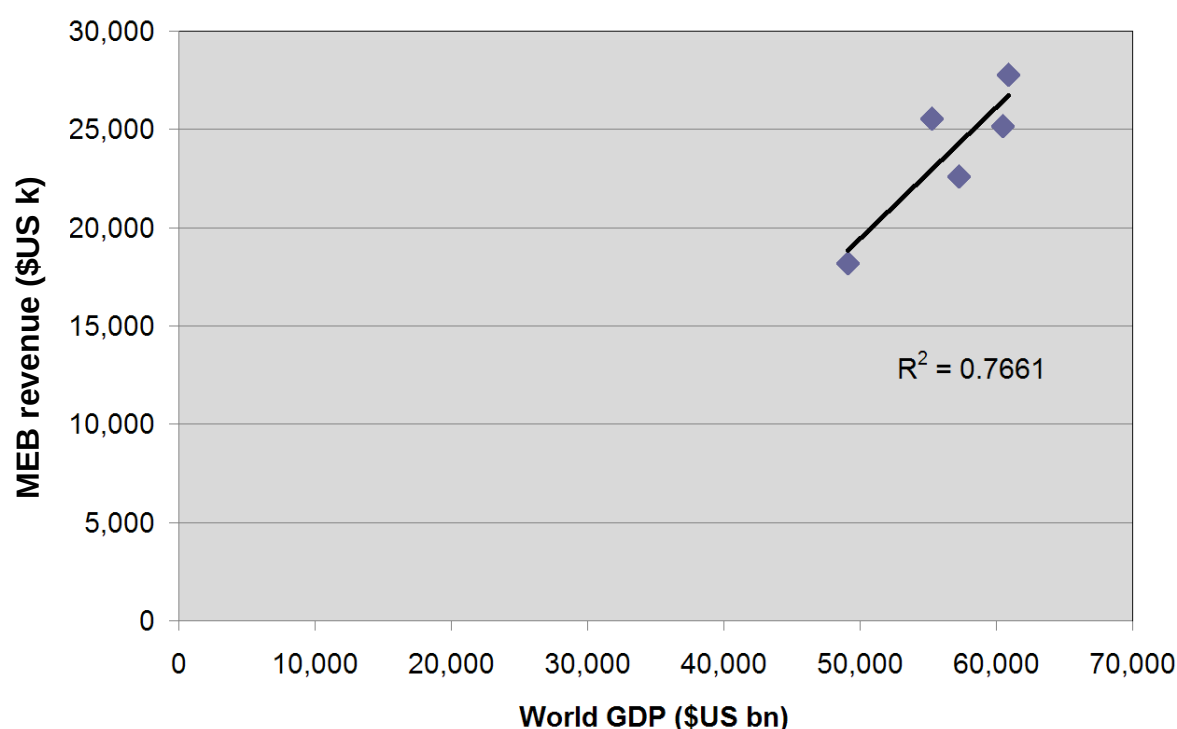
Clearly, however, while MEB's total revenue may be affected by the impacts of climate change on global GDP, MEB's revenue patterns are affected by other factors, principally the company's ability to win business in a competitive market. As can be seen from Figure 6-1, individual product lines at MEB vary from year to year, depending on MEB's relationships with clients, and on the company's sales success²⁰.

Figure 6-5 – MEB revenue, global GDP and Colombian GDP from 2005-2010. Source: MEB and IMF, 2009



²⁰ It is noted that this may also be affected by global GDP.

Figure 6-6 – MEB revenue plotted against global GDP, 2006-2010 data. Source: MEB; IMF, 2009; EIU, 2008 & 2009²¹



As already noted, drawing conclusions about the future impacts of climate change on trade at MEB, based on only a few years of historic data is highly speculative. It is even more difficult to make robust trade projections over several decades, due to the number of factors which can affect trade and the instability of economic systems.

With this in mind, Stern's projections, together with the observed relationship between global GDP and MEB's revenue, are used to provide high-level estimates for how climate change might impact MEB's revenues in the 2020s and 2050s (see Table 6-3). Note that losses are benchmarked against projected GDP growth in Stern's 'baseline case' without climate change.

For the 2020s, mean projected revenue losses range from -0.14% to -0.44%, and for the 2050s they range from -0.18% to -0.88%²². The impacts on MEB's revenue under the different Stern scenarios are shown in Figure 6-7 and Figure 6-8.

²¹ Note that data from 2006 to 2010 is used to calculate this relationship rather than from 2005. This is because MEB's management changed in 2006, substantially changing the nature and success of the business.

²² Note that because of the high uncertainty of trade projections at the end of the century, this study does not present potential global economic impact of climate change on MEB revenues for the 2080s.

Table 6-3 – Potential global economic impacts of climate change on MEB’s revenue in the 2020s and 2050s (% change).

Scenario			MEB revenue reduction (%)		
Climate	Economic	Year	Mean	5 th percentile	95 th percentile
Baseline climate	Market impacts + risk of catastrophe	2025	-0.14	NA ^(a)	NA
		2055	-0.18	NA	NA
High climate	Market impacts + risk of catastrophe	2025	-0.18	NA	NA
		2055	-0.35	NA	NA
	Market impacts + risk of catastrophe + non-market impacts	2025	-0.35	NA	NA
		2055	-0.70	-0.18	-1.2
	Market impacts + risk of catastrophe + non-market impacts + value judgements for regional distribution	2025	-0.44	NA	NA
		2055	-0.88	NA	NA
Mixed climate scenarios	Mitigation and adaptation	2025 ^(b)	-0.04 to -0.35	NA	NA
		2055	-0.70	NA	NA

Notes:
 (a) NA = not available
 (b) Losses in GDP for 2025 only incorporate adaptation costs, as there is no figure available for mitigation costs.

Figure 6-7 – Potential global economic impacts of climate change on MEB’s revenue (US\$), 2010-2055

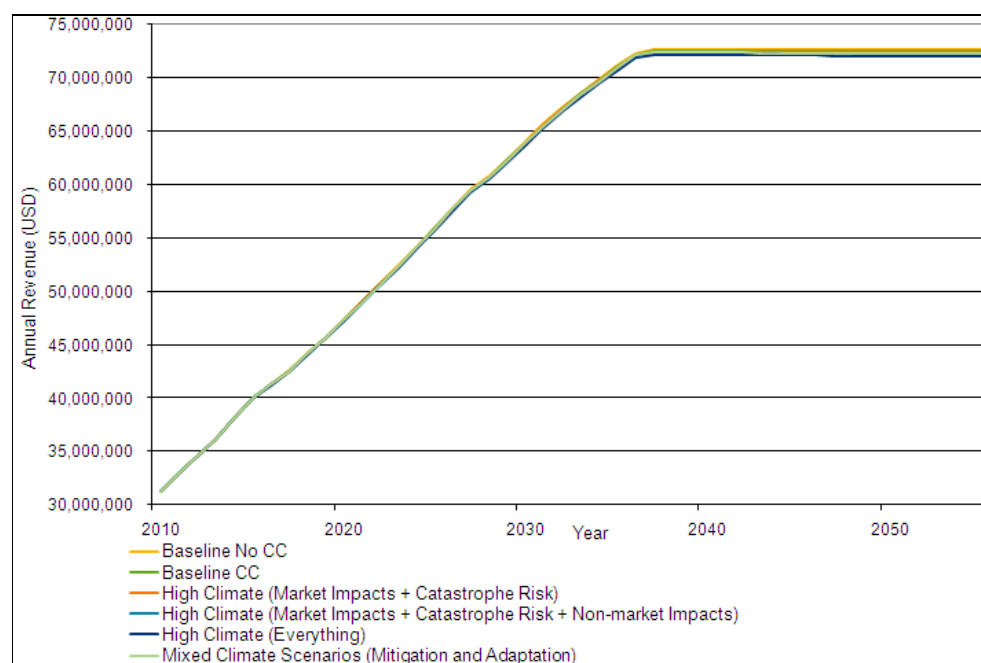
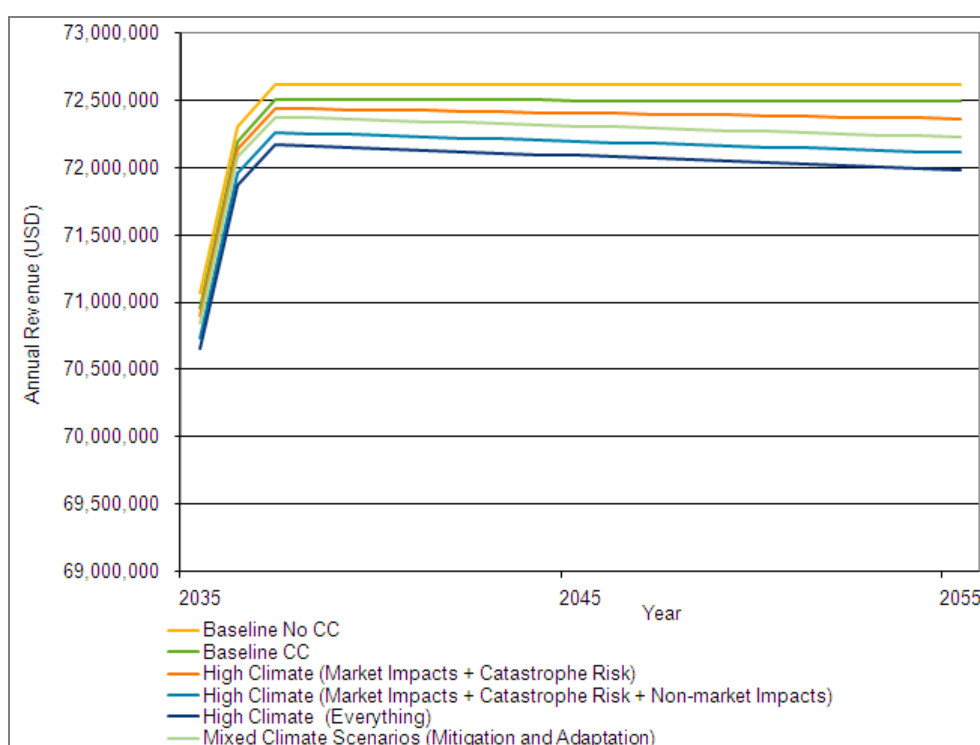


Figure 6-8 – Potential global economic impacts of climate change on MEB’s revenue (US\$), 2035-2055



As shown in Figure 6-7, the projected impact of climate change on MEB’s revenue becomes notably apparent in the 2030s. Figure 6-8 which provides a closer view, shows the variation between different revenue projections associated with Stern’s scenarios. Under the worst-case scenario (the dark blue line in both figures), the annual reduction in revenue is approximately US\$640k (compared to projections without climate change) by 2055. Given a projected revenue of about US\$72.6m by this time (without climate change), these losses do not carry great significance.

6.2.4 Adaptation

In terms of finding an adaptation strategy for climate-driven changes in the global economy and in the economy of MEB’s main trading countries, there is no clear solution for MEB. Either mitigation and adaptation will be conducted on a global scale, reducing the negative impacts of climate change on global GDP overall, or MEB will have to conduct their business in a slower economic environment.

While the Stern Review (2006) is the authority on the economic impacts of climate change on the world economy, a range of reports have been published that address the economic impact of climate change on specific geographic regions. The Economic Commission for Latin America and the Caribbean (ECLAC) published a summary report on their initial analysis of the ‘Economics of Climate Change in Latin America and the Caribbean’ in 2009 and the Department of National Planning (DNP) in Colombia are currently preparing a similar report focused specifically on Colombia. The data in ECLAC’s (2009) report are not adequate for this current analysis, however, MEB would benefit from an understanding of DNP’s results when they are published, as they may help them to understand the relationship between climate change, Colombia’s GDP and potential implications for MEB’s revenue.

Demand for Cartagena versus other ports in Colombia

Tropical cyclones

If climate change were to significantly affect shipping routes then it could affect the amount of business that MEB and other ports in Colombia receive. For instance, if tropical cyclones were to become much more problematic (as is possible given projections of more intense cyclones in the future) then ships could be delayed in arriving at ports and this could create some scheduling difficulties, causing a loss of efficiency in port operations. During the site visit, MEB noted that ships are already delayed due to hurricanes on occasion, causing minor scheduling changes. While this has not led to losses of revenue to date (as the construction of Quay 4 and the recession have led to increased berth capacity and reduced utilization), according to MEB, this situation could lead to revenue losses in the future if ships arrive late and berths are full. Losses could however be avoided if materials handling is reprogrammed.

Considering the relative exposure of the various ports in the Caribbean to tropical cyclones, MEB noted a difference between ports on Caribbean islands, such as Santo Domingo (Dominican Republic) and Cartagena. Cartagena is considered a safer hub during hurricanes and MEB has reported anecdotally that it gains about 2% of total income, when hurricanes disrupt ports in other parts of the Caribbean. As the latest research considers that it is more likely than not that tropical cyclones would become more intense in the future (Knutson et al., 2010), Cartagena may see further increased trade relative to island ports during hurricanes. Additionally, it is interesting to note that MEB reported that when a hurricane has affected the Caribbean islands, MEB tends to see a slight increase in trade, due to demand for bulk materials for reconstructing damaged buildings. Under conditions of more intense cyclones, it is likely that MEB will continue to see this trend, which may be amplified by the need for more extensive reconstruction. Hence overall, intensification of hurricane activity in the Caribbean north of Cartagena could provide opportunities for increased revenue for MEB (noting that, as outlined in Section 4.5, scientific knowledge about future changes in hurricanes is still evolving.)

On a Colombian scale, there are some small differences in the Caribbean ports' levels of exposure to hurricanes. In general, the historic numbers of hurricanes affecting the three Colombian Caribbean ports are low. Both Santa Marta and Cartagena are on north-west facing coasts and they are therefore somewhat protected from hurricanes by the South American land mass. Barranquilla is 12.4 miles upstream of the Rio Magdalena estuary mouth and is also protected. However, over the period 1985-2005, three tropical cyclones have tracked through or within 250km of Santa Marta. While the mountains behind Santa Marta will stop hurricanes from propagating east to west, low-level winds will still be very high with the hurricane system off-shore. With hurricanes expected to intensify in the future, Cartagena may gain some business from Santa Marta during hurricane periods.

Rainfall and river flows

Buenaventura, on the west coast, is much wetter than the Caribbean ports. This produces many delays unloading ships. Historically this has led to penalties being paid to charters, of up to US\$3 million, and impacts on the port's reputation. As a result, according to MEB, some shipping companies have delivered goods to Cartagena instead. As highlighted in the climate review (Section 4), there is considerable uncertainty over future changes in seasonal precipitation for the whole of Colombia, so it is not possible to determine with confidence whether these issues will become more or less problematic for Buenaventura in the future.

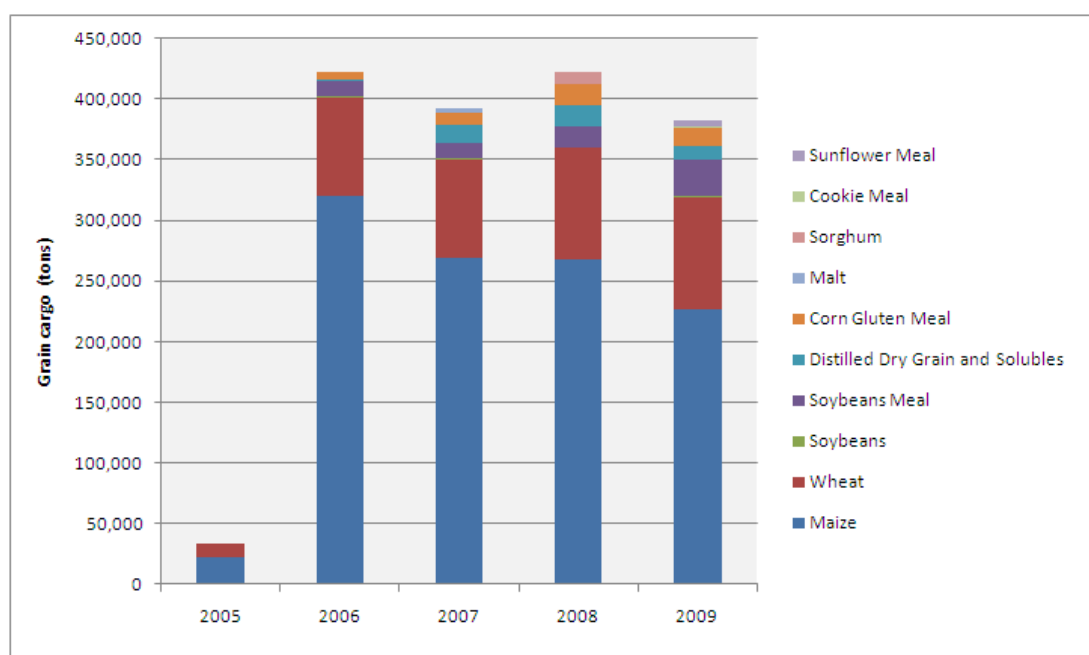
According to discussions with MEB during the site visit, when the Magdalena River is very low (approx. 15-20 days/year), Barranquilla is unable to take cargo and therefore the port closes. As a result MEB gains about 200,000 TPA of cargo (50% grain, 50% bulk cargo). The climate change scenarios do not indicate clearly whether seasonal precipitation will increase or decrease in the future across the Andes (where the rainfall that feeds the Magdalena River originates). It is therefore not possible to state with any confidence whether Barranquilla will become more or less reliable in the future. However, if river flows were to drop, Barranquilla's reputation could deteriorate, and MEB's operations in Cartagena could stand to benefit.

6.2.5 Impact of climate change on grain imports at MEB

6.2.5.1 Context

Grain imports are MEB's most climate sensitive product line. Since 2006, grain has constituted a significant portion of MEB's total cargo, ranging from 14% to 20% of total trade (see Figure 6-1), and has been the second largest source of revenue after containers (see Figure 6-2). MEB's grain imports are also significant for Colombia as a whole, making up about 12% of the country's imported grain. Some 60% of total grain imported through MEB is sourced from the USA and 40% from other countries, largely Argentina (MEB, Pers. Comm., 2010). It is handled by ADM and Cargill for the most part, is almost all for consumption by livestock and is largely made up of maize (Scott Wilson, 2007). Figure 6-9 illustrates the break-down of grain types imported from 2005 to 2009.

Figure 6-9 – Types of grain imported at MEB, 2005-2009. Source: MEB.



6.2.5.2 Climate change factors affecting global grain imports

In addition to potential climate change impacts on total global trade discussed above, climate change may affect grain production specifically (due to its climate sensitive nature), and in turn grain price. Price may then affect grain import patterns. Additionally, climate change may affect the demand for grain (e.g. by negatively affecting the livestock industry which requires grain for feed), which again may affect grain import patterns.

In terms of production, on a global level, grain yields increased on average by 2% per annum from 1970 to 1990, but halved to a 1% growth rate from 1990 to the present (Fischer, 2009). While baseline scenarios (without climate change) project increasing grain yields over the next century, the impacts of climate change are projected to both positively and negatively affect them in different regions of the world. For an in-depth analysis of how climate change may affect agricultural yields across the world, and the concomitant effects that climate change may have on food prices and grain imports, see Appendix 4. Additionally, see Appendix 4 for information on climate change impacts on demand for grain.

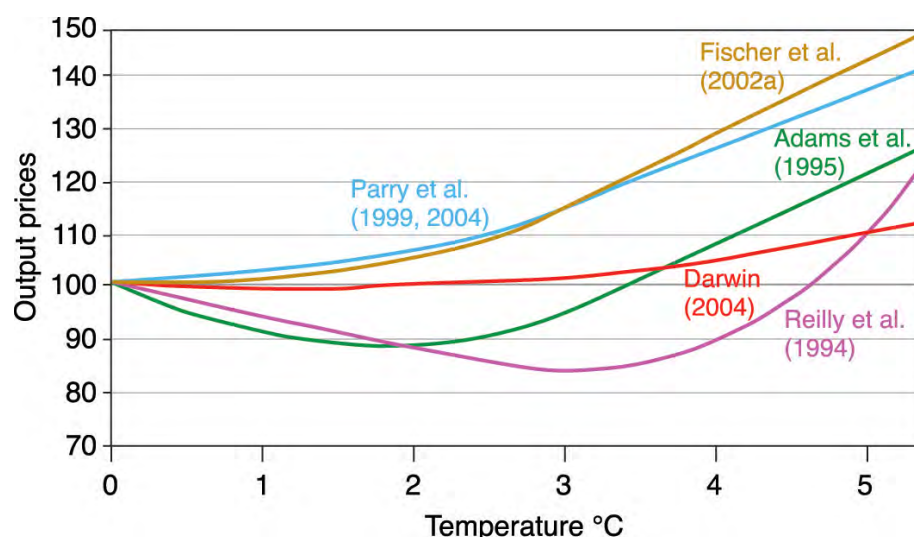
In terms of future projections for the impacts of climate change, Table 6-4 shows Fischer's (2009) changes in cereal price index (relative to a baseline, no climate change scenario) as a result of direct climate change impacts. One climate change scenario (Hadley A2) projects decreases in price for 2020 and 2050 (related to projections of increasing productivity specifically in mid to high-latitudes in the medium-term), while all other scenarios project price increases. IPCC (2007) projections similarly show a range of price estimates. As shown in Figure 6-10, most recent modeling studies project increases in global cereal prices with an increase in global

mean temperature, while the older studies project decreases in price until global temperature changes of 3.5°C or more occur. A modeling study by Darwin (2004) also projects a more subtle change of very slight price decreases until temperature changes of 1.6°C or more occur²³. As trade is sensitive to price, climate change impacts on both grain production and in turn on price may indeed affect imports. While low prices are unlikely to restrict imports, high prices may do.

Table 6-4 – Impact of climate change on cereal prices. (Source: IIASA world food system simulations, May 2009, In: Fischer, 2009).

Scenario	CO ₂ fertilization	Change of Price Index relative to Reference Climate (percent)			
		2020	2030	2050	2080
Cereals					
Hadley A2	with	-4	-1	-1	23
Hadley A2	without	1	6	10	44
CSIRO A2	with	1	3	2	21

Figure 6-10 – Cereal prices (% of baseline) versus global mean temperature change for major modeling studies. (Source: IPCC, 2007).



6.2.5.3 Climate change factors affecting Colombian and MEB grain imports

A changing climate is projected to alter global grain prices. However, it is unclear how trade in grain will respond to this, and thus how sensitive Colombian grain imports are to price. In order to establish potential effects of climate change on Colombian grain imports in the future, an analogue of how Colombia responded to past changes in price is examined²⁴. This analysis is shown in Appendix 4.

To turn to the potential *future* impacts of climate change on Colombian grain imports, it is necessary to consider projected future price increases resulting from climate change in light of the sensitivity of imports to price. In the most extreme case (high climate scenario, 2080), cereal price is projected to increase by 44% relative to a baseline scenario of no climate change, as shown in Table 6-4 (Fischer, 2009). Colombian grain imports did not decrease in the past even when prices increased by more than a factor of 2 (from 2005-2008,

²³ It is worth noting that there are other studies of climate change impacts on agricultural commodity price, such as in IFPRI's (2009) paper on 'Climate Change Impact on Agriculture and Costs of Adaptation'. However, many of these studies incorporate demand for biofuel (a climate change *mitigation* issue) into their price projections. This leads to significantly higher prices than under direct climate change impacts alone, meaning they are incomparable.

²⁴ Note that global price is considered here as, despite current duty on US agriculture exports from the US to Colombia of up to 35% (Washington Council on International Trade, 2010), imports are nevertheless sensitive to global price.

maize prices increased by 129%). This suggests that imports are not likely to be reduced as a result of climate change driven change of up to 44%.

Even if an extreme climate event (resulting from natural variability) coincided with the average climate change signal, reducing grain supply and increasing price even further, it seems that price increases (relating to climate alone) would be very unlikely to occur to the degree they have in recent years. The reasoning behind this is that during the 2007-2008 food crisis (when maize prices increased by 35%), the Australian drought climatic driver was considered to have made only a 'slight' contribution, alongside approximately seven other factors (Gregory & Ingram, 2008). Thus, in the absence of any information about the relative contributions of the various factors, it is assumed that climate variability might have contributed approximately an eighth – or 4% – of the price increase. This increase is significantly less than the price increases Colombian imports have tolerated in recent years.

In conclusion, on the basis of evidence that Colombian grain imports have been price inelastic since 1990 and that climate change is expected to increase price up to 2080 by significantly less than it has risen during this period, climate change impacts alone are not expected to lead to declines in grain imports in Colombia before 2080. Following from this, it is assumed that climate change will not lead to a reduction in grain imports at MEB, other than any reduction accounted for by climate impacts on total trade. It is worth noting, however, that this analysis assumes that Colombia will experience persistent growth and that Colombians will continue to buy grain at a higher price during potentially longer time periods than they did during the shorter 'shock' of the food crisis.

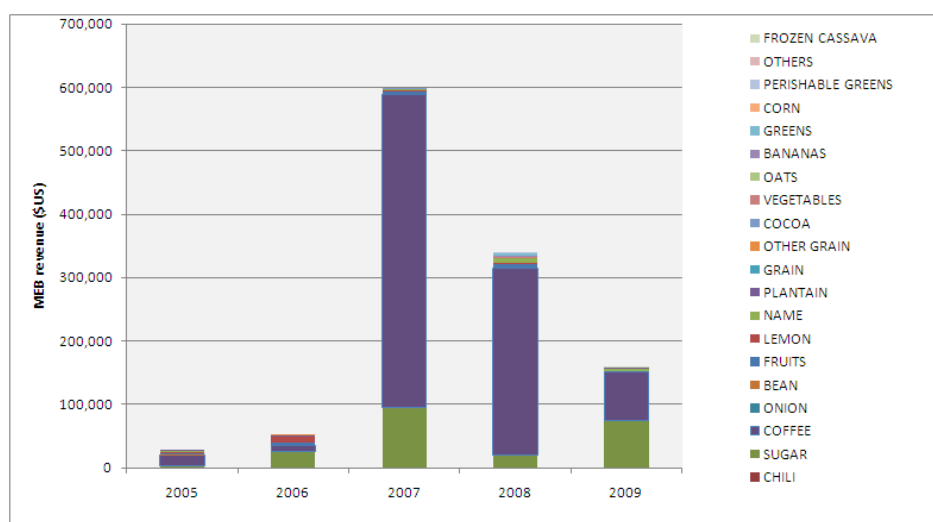
Finally, it is important to note that non-climatic factors could lead to significant changes (as discussed in Appendix 4). To further understand this, a broader analysis is required. Of course it should be stressed once again at this point that only direct climate change impacts on grain production and price are being considered here. Clearly, climate change mitigation policy will also be a key influence on these factors.

6.2.6 Impact of climate change on agricultural exports at MEB

6.2.6.1 Context

As shown in the Introduction, exports from MEB include containers, coke and bulk cargo. Agricultural exports (the most climate sensitive exports) are transported in containers. From 2005 to 2009, containers earned 57-78% of MEB's revenue; however agricultural exports were only a small portion of this. Between 2005 and 2009, agricultural exports accounted for 0.3-3.2% of container revenue, and for 0.3-2.3% of total trade. Figure 6-11 shows the breakdown of agricultural products exported during this period in terms of revenue.

Figure 6-11 – Types of agricultural product exported from MEB, by revenue, 2005-2009. Source: MEB



While it is clear that coffee and sugar have been the most significant agricultural exports for MEB in terms of revenue, it is worth noting that MEB is not committed to these products specifically. According to Carlos Munoz, MEB's decision about what products to export is driven by negotiations with shipping lines and by the paths these lines travel. For example, MEB handled a large quantity of coffee in 2007 and 2008 because Mediterranean Shipping was a client and intended to export coffee. According to MEB, when Mediterranean Shipping moved to another port, MEB's coffee exports declined.

6.2.6.2 Impact of climate change on Colombian agricultural exports

The volume of agricultural products exported by an entity is influenced by a range of factors. These include drivers of supply (land productivity, production efficiency, government support, costs of production), drivers of demand (the state of global and national economies, wealth, and population growth), competition from other producers/exporters and trade agreements. Climate change may also affect agricultural exports, first by affecting the global economy and trade patterns as a whole (as discussed in section 6.2), and also by directly influencing supply.

Impact of climate change on Colombian crop suitability

In the case of Colombia, Ramirez and Jarvis (2009) have modeled how climate change (under the A2 climate scenario) may affect various crops' suitability in 2050. In order to generate their outputs, Ramirez and Jarvis used information about crop temperature and precipitation sensitivities. Table 6-5 shows the results of their analysis, indicating whether the area of land suitable for each crop is projected to increase or decrease by 2050, and by how much. As shown, six crops are expected to gain suitable land while 13 crops are expected to lose it. Overall, 346,857km² of suitable crop land is projected to be lost, equating to a 6.8% loss.

Table 6-5 – Changes in crop suitability in Colombia between 2009 and 2050 (under the A2 climate scenario). Increases are marked in green while decreases are marked in orange. Source: Ramirez & Jarvis, 2009 – outputs from EcoCrop model.

Crop	Change in crop suitable area (km ²)
Sesame	1,720
Cotton*	-4,301
Rice	-23,227
Bananas*	27,270
Coffee*	-221,516
Cane sugar*	-45,680
Barley	-27,872
Coconut	10,839
Beans	-8,689
Maize	4,989
Potatoes*	-7,398
Plantain*	22,195
Sorghum	602
Tobacco*	-7,054
Wheat	-4,043
Cassava	-23,142
Cocoa*	-13,850
Yam	-13,850
Oil Palm*	-13,850
TOTAL	-346,857

* Indicates support from the Colombian government 'Apuesta Exportadora' strategy (export support strategy), for 2006-2020 (Colombian Ministry of Agriculture, 2010).

When interpreting these data to consider climate change impacts on Colombian agricultural production and exports, it is important to understand that each crop modeled will still have suitable land to grow on in 2050, though this amount may increase or decrease. Also, crop suitability is not directly comparable with production. This is because there may be obstacles to suitable land being farmed, such as inadequate commodity prices and lack of government support. Alternatively, farmers may find ways to adapt unsuitable land for growth. Crop yields may not fulfill expected targets and the split between future domestic use and export is not known. Also, Ramirez and Jarvis's model only addresses some of Colombia's many export crops (listed on the Ministry of Agriculture website).

Despite these limitations, it is still useful crudely to interpret changes in crop suitability to equate to changes in trade in 2050. Crops gaining suitable land, notably bananas and plantain which are projected to gain the most and are to be supported by the Colombian government's export strategy, are likely in turn to be exported more. Conversely, crops losing land are likely to be exported less (unless they were previously for domestic consumption). On a crude level, as 6.8% of suitable crop land is projected to be lost overall by 2050, it is estimated that Colombia's exports will be reduced by approximately 6.8%. Interestingly, however, as exports decline, agricultural imports may increase to fill the production gap.

Case studies: climate change and Colombian export crops

To gain a deeper understanding of how climate change may impact on Colombian crop success in the future, it is useful to examine several crops in detail. Appendix 5 provides information on coffee, bananas, sugar cane and plantain, all export crops in Colombia and at MEB, detailing how growth as well as relevant pests and diseases are sensitive to climate and climate change. Some initial suggestions on how farmers can adapt to climate change are also included.

Climate change and phytosanitation

Climate change is projected to lead to changes in pest and disease occurrence, which may in turn add to climate-driven changes in crop yield. For example, the coffee berry borer and coffee rust are more prolific at higher temperatures, and thus are likely to become a greater problem under a changing climate. The Instituto Colombiano Agropecuario (ICA), the Colombian institute responsible for monitoring and controlling pest and disease outbreaks (in the field and at country borders) is concerned about the potential negative impacts of climate change and are currently analyzing the impacts of climate change on a range of pests and diseases in Colombia. Pests and diseases relevant to coffee, sugar cane, fruits, potatoes, flowers, cotton, rice and oil palm are the current focus of their study. This is due to their being socially and economically important crops as well as having potentially climate sensitive pests and/or diseases.

Any negative climate change impact found on these crops may in turn lead to reduced exports either because the crop fails/is low yielding or because exports are quarantined and likely destroyed at the border. If pests or diseases are found in agricultural products at a border (e.g. a port), the correct course of action is to quarantine the suspected goods, diagnose the problem and then destroy, re-embark or fumigate the merchandise (Soto, 2009). In addition to affecting exports, these interruptions are likely to lead to added costs associated with export. To date, ICA has not closed down a port.

6.2.6.3 Impact of climate change on MEB's agricultural exports

If climate change affects Colombia's exports, it may in turn affect MEB's exports of agricultural goods. However, due to the nature of the impact of climate change on crop suitability, and its impact on production and in turn on trade, it is not possible to quantify accurately how MEB's exports will be affected in financial terms. Using the same crude estimation for Colombia's exports however (derived from Ramirez & Jarvis's crop suitability projections), MEB's agricultural exports could decline by 6.8% in 2050. Using MEB's average agricultural export from 2005 to 2009, a 6.8% loss equates to a decline of approximately \$50,000. Compared to an EBITDA of \$30 million, this is a small impact, though this figure should be used with caution. Once climate impacts on agricultural pests and diseases are further quantified, this projected change in exports may be further refined.

Another factor to consider here is how reductions in export crop availability might affect the wider port industry around Colombia, and how this may indirectly impact on MEB. Reduced availability of certain crops could lead to a 'price war' between ports as they compete to export. While noting this, it is important to keep in mind the relative insignificance of MEB's agricultural exports to overall revenue. Also, sourcing an alternative crop for export could avoid a 'price war'.

6.2.6.4 Adaptation Options

In terms of adaptation to these potential changes in agricultural export product availability, it could be of interest to MEB to monitor output and trade developments for those crops which will grow more favorably under a climatically changed future. Opportunities to export new product lines could develop (e.g. those crops colored in green in Table 6-5). It is useful for MEB to note the Colombian export products being supported by the government's 'Apuesta Exportadora' scheme. As investment is being targeted at these crops, it is more likely that they will be protected from/adapted to the worst impacts of climate change.

Though ICA interventions at the port have no significant impact on MEB's operations, it could also be of interest to MEB to maintain contact with ICA, and see the outcomes of their research on climate change implications for crop pests and diseases.

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7 Goods Storage

7.1 Introduction

Goods storage capacity has been highlighted by MEB staff as one of the key limiting factors in MEB's growth. As a result, any climate impacts which compromise the existing capacity may have important consequences.

The storage facilities at MEB consist of several components: there are five horizontal silos of approximately 0.7ha in the area behind Quay 3, a 12ha unpaved area for storing coke behind Quay 1, and 6ha of paved and unpaved container yards, divided between the Isla del Diablo and the mainland. The coke storage area is uncovered but includes a system for wetting the coke to reduce dust.

Overall it has been recognized that whilst the layout of the storage facilities is not optimal, owing to the staggered development of the port, significant re-organization is impractical and future expansion of storage facilities will be necessary if the port is to increase its capacity (Scott Wilson, 2007). To this end, MEB have acquired additional storage capacity in Mamonal, which will be utilized to improve operations at the port facility.

This study identified four risk areas for MEB's storage activities which can be affected by changing climate conditions:

- Surface flooding due to precipitation and sea level rise,
- Reduced energy efficiency of refrigerated containers due to higher temperatures,
- Variation in rainfall affecting the volume of water required for coke wetting, and
- Changes in grain storage conditions due to higher temperature and air moisture.

Of these climate change risks, the one with the largest potential impact is surface flooding: the cost associated with goods damage (which is borne by the owners of the goods, not by MEB), could be significant and could affect MEB's reputation.

This section provides an appraisal of these risks and potential management responses, as well as a financial assessment of climate change impact and adaptation costs.

7.2 Surface Flooding

7.2.1 Climate change risk

Flooding due to precipitation can occur if the drainage system is overwhelmed. Therefore the capacity of the drains in light of potential precipitation changes needs to be assessed to fully consider the risk of flooding of the quay and therefore damage to goods.

There are three ways in which the efficiency of the drains could be insufficient and lead to surface flooding:

- If the volume of rainfall on the quay is beyond the capacity of the drainage pipes,
- If the pipes become surcharged due to sea level being above the drainage pipe outlet, or
- If heavy rainfall and seawater surcharge of the pipes are combined.

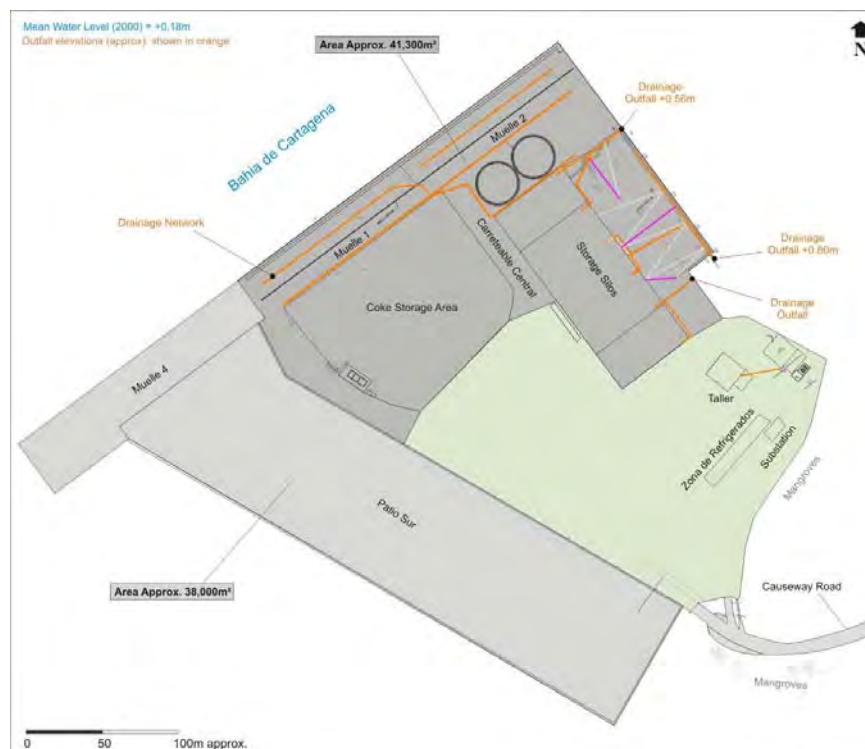
A high-level assessment of the capacity of MEB's drainage system to cope with increased rainfall and sea level rise is provided here²⁵. All three scenarios presented above were assessed in this study.

²⁵ Note that a more detailed hydraulic analysis of MEB's drainage system would be required to confirm drainage capacity.

The analysis focused on the capacity of MEB's drainage system on the Isla del Diablo (or the island site). MEB's mainland site has a different drainage system. Given the limited information available, the relatively small increase in rainfall projected because of climate change and the relatively low adaptation cost of increasing the pipe diameter, the risk of surface flooding on the mainland site was not assessed further. For more information, see Appendix 6.

The drainage plan provided for the island site covers all paved areas other than the expansion of 2008. Therefore the assessment of drainage capacity includes Quays 1, 2 and 3 and the grain and coke storage areas. The plan was used to calculate surface areas of the port island site to estimate the volume of water runoff.

Figure 7-1 – Drainage plan for areas of the Isla del Diablo (island site) (used to calculate the volume of water runoff)



7.2.1.1 Surface flooding risk due to increased rainfall

The rainfall required to overwhelm MEB's drainage pipes is 27mm per hour (equivalent to 639mm per day). The maximum daily observed rainfall recorded near MEB between 2000 and 2009 was 158mm per day. If precipitation is considered in isolation to other factors (such as maintenance and sea level), the drainage on the island site appears to have the capacity to deal with the present measured maximum daily rainfall.

Note that it is possible that observed maximum daily rainfall over a time period longer than the 2000-2009 record could be higher than 158mm/day. This is because interannual precipitation variability is known to be influenced by ENSO, which occurs every two to seven years. Significant ENSO-related precipitation anomalies have been observed over Colombia, which means that the El Niño and Niña events that the 2000-2009 record captured, may not be representative of the effect of ENSO on precipitation in Cartagena. For further information on ENSO and its impact on the Colombian climate, see Appendix 1.

Ideally, drainage analysis should be undertaken using high resolution data (hourly or less) to assess peak rainfall during storm events. High resolution (hourly) rainfall data can be difficult or costly to obtain in certain locations; in these cases, daily data can be used as an indication of how critical

drainage capacity is. In cases where drainage capacity is limited, sensitivity analysis can be used to test a wide range of extreme precipitation values.

In the case of MEB, if precipitation is considered in isolation, the drainage system of the island site appears to have the capacity to deal with the observed maximum daily rainfall, given its large capacity. However, the risk of short duration flooding (of less than 24 hours) cannot be excluded. This risk was not assessed as no hourly data were available. To exceed the hourly rainfall necessary to overwhelm the drainage pipes (estimated at 27mm per day), all of the rain on the day of maximum rainfall would need to fall within less than 6 hours.

As described in the climate review (see Section 4), rainfall intensity is expected to increase in the future under climate change. To avoid flooding, the drainage channels must be able to deal with the total volume of rainfall as it increases. Because of climate model uncertainty in precipitation projections over Cartagena, the study uses the observed trend extrapolated into the future (see Section 4 for further details).

Considering a future increase in extreme precipitation of 0.6% per annum (equal to 55% to 2100)²⁶, the minimum required flow through the drainage system serving the paved area of the island site considered in the analysis is calculated and presented in Table 7-1. The increase in rainfall because of climate change has little effect on the required capacity of the drainage pipes (up to 0.12m³/s at the end of this century) in comparison to the estimated total drainage capacity of 0.48m³/s. However, the risk of short duration flooding due to heavy rainfall cannot be excluded. If the projected maximum daily rainfall in 2100 of 245mm per day falls within less than 9 hours, MEB's drainage capacity will be overwhelmed.

There is anecdotal evidence from MEB of short term flooding events on the island site quay already. However, these did not have any impact on MEB.

Table 7-1 – Minimum required flow in drainage pipes on Isla del Diablo to avoid flooding

	Unit	2000-2008*	2050**	2080**	2100**
Maximum daily rainfall	mm/d	158	198	226	245
Corresponding water volume	m ³ /d	6,525	8,168	9,342	10,124
Min flow requirement	m ³ /s	0.076	0.095	0.108	0.117

* Values for 2000-2008 are observed (based on daily precipitation data from CIOH meteorological station)

** These are projected maximum daily rainfall (assuming that extreme rainfall increases linearly this century by 0.6% a year).

7.2.1.2 Surface flooding risk due to seawater ingress (including in combination with increased rainfall)

Sea level rise could also accentuate flooding due to precipitation. If the sea level is higher than the outlet of the drainage pipe, it will become surcharged and the flow through it will be reduced. Although this will not prevent the drainage system from working, the reduced gradient between the water entering the drains at the surface and sea level will lead to reductions in flow rate through the drains.

The proximity of the drainage channels to sea level on quays 1 and 2 is evident in Figure 7-2. The lowest drainage channels are already projected to be reached by peak spring high water. Mean sea

²⁶ These figures are based on the assumption that observed historic trends in rainfall will continue into the future, because the climate model output for rainfall over Colombia is unreliable. According to the IPCC, rainfall intensity is projected to intensify in the future as the climate warms, so assuming that existing trends will continue could be an underestimate (IPCC WG1, 2007). For further detail, see Section 4.3.

level is at the level of the drainage channel by 2060 and 2040 in the observed and accelerated scenarios respectively. By 2060 under the accelerated scenario the bottom of the drainage outlets will be below the lowest astronomical tide so the outlet will spend most of its time under water. This does not occur until 2100 in the observed scenario.

Utilizing the minimum flow requirements presented in Table 7-1 and using the same assumptions as the ones used for assessing the drainage capacity to cope with increased rainfall alone (3 outlets and 100m-long pipes), the year in which the drainage system will not be able to deal with the daily rainfall run-off due to increased rainfall and seawater ingress is estimated. This occurs when sea level is between 0.2 and 0.3m below the height of the quay, which is more than 1.7m above the port plan datum. The future mean sea level during the highest spring tide (and excluding storm surge) is not expected to exceed 1.7m by 2100, except towards the end of the century in the accelerated SLR scenario. Further, if a storm surge occurs at the same time as the highest spring tide in the accelerated sea level rise scenario, sea level is projected to largely exceed 1.7m towards the end of the century (as shown in Figure 5-12 for a 1 in 300 year storm surge), though the probability of such occurrence is difficult to assess.

There are other issues associated with seawater ingress of the drainage pipe. Seawater ingress can lead to the flooding of sediment traps and oil water separators, which is a cause of pollution of the marine environment. Seawater ingress can also lead to marine growth and reduce the life of the drainage pipes. It is estimated that marine growth would double with a 10°C increase in water temperature (BSI, 2000)²⁷. As marine growth has not been found to be a risk to MEB it is not investigated further.

As the frequency of ingress increases it may be necessary to fit valves to the outlets. If valves are fitted, the flow through the pipes will be further reduced and potentially stopped all together, depending on the type of valve used. A detailed analysis would be required to ensure that the system can deal with the volume of rain as this would significantly increase the risk of flooding from precipitation. At this point raising the drainage channels should be considered.

Drainage is also crucial to the operation of the underground conveyors on Quay 3. These are drained using pumps to discharge at 1.5 m above mean sea level. These conveyors do flood from time to time due to pump failure caused by something solid entering the pump and preventing the impellor from turning. Increased precipitation could lead to a need to increase the size of the pumps, especially as, in the longer term, there is a risk that sea level could exceed the height of the drainage outlet. If this were the case, drainage outlets would have to be raised. This is not projected to occur during this century under the observed sea level rise scenario and not until around 2090 in the accelerated sea level rise scenario.

²⁷ This estimate is provided as a guide to the difference in marine growth between tropical and temperate waters.

Figure 7-2 – View of MEB, including a drainage outlet into the sea



7.2.2 Adaptation

As there is uncertainty surrounding rainfall projections under climate change and the projected increase is relatively small compared to the capacity of MEB's drainage system, it is expected that it will not be necessary to undertake any adaptation to reduce flooding associated with precipitation in the short- to medium-term. For further analysis of the drainage system capacity, refer to Appendix 6.

If there is a need to increase the capacity of the system the first step in relation to Quays 1, 2 and 3 is to undertake repairs to pavements and grates to ensure that the maximum capacity of the existing system is achieved. Similarly, to prevent flooding of the underground conveyors, monitoring and maintenance of the pumps should continue. On the mainland, increasing the size of the small drainage pipes on the outside wall is a relatively low cost step.

There is no evidence that upgrades to increase the capacity of the drainage system are required, in the short-term, so no further analysis of adaptation is provided.

For the drainage system, SLR is again highlighted as the significant climate change factor. To reduce seawater ingress, valves should be fitted to drainage outlets, if they are not already.

Towards the end of the century, and in the case the accelerated SLR scenario is realized, there is some probability that raising the drainage outlets will be necessary. This is because sea level is projected to exceed the threshold at which drainage cannot cope with the combined effect of increased rainfall and seawater surcharge (namely 1.7m above the port plan datum) at the highest spring tide by the end of the century (there is also the additional probability of a storm surge occurring).

7.2.3 Financial analysis

As outlined above, climate change is not expected to increase significantly the risk of surface flooding due to the combined effects of higher rainfall and seawater ingress before the end of the century. Therefore, this study did not undertake a detailed financial analysis of these effects. However, in general terms the adaptation measures recommended in Section 7.2.2 would entail the following operating and capital costs:

- Increased maintenance and repair,
- Fitting one-way valves to drainage outlets to sea (expected to be a low cost investment) and the associated maintenance requirements to ensure the valves operate correctly²⁸,
- Raising the height of the drainage outlets. Note that this cost was not estimated but is expected to be significant as, according to MEB, it would require changes to the quay walls. As a result, it would be sensible to undertake these changes at the same time as the quays are being renewed at the end of their life (around the year 2050). Under the observed SLR scenario, the drainage outlets would still be 0.1m above mean sea level at this time, but they would be 0.2m below sea level under the accelerated SLR scenario.

7.3 Seawater Flooding

7.3.1 Climate change risk

Containers are to a certain extent waterproof as they are designed to cope with long periods at sea on the open decks of container ships. It is only when they are in standing water of a depth reaching the bottom of the doors, that there is a risk of water seeping in. Therefore the risk of damage to goods within containers from flooding is relatively small. On the contrary, goods that are stored in warehouses, such as grains and other agricultural products, are at greater risk from seawater flooding, as are some bulk cargos such as trucks and cars.

There are a number of storage areas that will be flooded under the sea level rise scenarios of this study. The storage area and warehouses on the mainland site of the port are at the lowest elevation; the warehouses within this area are used to store agricultural goods. Elevation data are not included in the port plan for this area but it is estimated to be at approximately 0.6m based on the heights of the drainage outlet and of the neighboring area of the port. This flood risk assessment also takes into account the small wall that surrounds the port. This wall is estimated to be 0.3m high. Although the wall is not watertight, it is assumed that flooding occurs when sea level exceeds 0.9m.

Storm surge flooding, even of a short duration, can damage goods and therefore is incorporated into this assessment. This is because goods damage does not depend on flooding duration as it does in the case of business interruption (which is assessed in Section 5). The years in which sea level will exceed the estimated level of the wall surrounding the port during a range of storm surge heights is provided in Table 7-2.

The estimated frequency of flooding of the storage area (number of days per year in which flooding is likely to occur) and the average duration per flooding event is provided in Table 7-3. In this analysis of frequency and duration, storm surge was not incorporated as it is difficult to predict when a storm surge of a high return period (e.g. 1 in 300-year) could occur and to calculate the joint probability of a combined storm surge and tide of specific heights.

Without knowing the value of the goods stored it is impossible to estimate the potential cost of damage. In principle, any damage to goods will affect the goods owner. However, the question of

²⁸ The required maintenance of the valves will depend on the type of valve fitted. For example, if flap valves are fitted marine growth can inhibit their operation and efficiency and therefore the maintenance requirements needed would be relatively frequent.

liability and insurance can determine the actual cost to MEB and this is discussed further in Section 13. There is also reputational risk to MEB associated with goods being spoiled while stored at MEB (which can translate into loss of revenue).

Flooding of the port could also impact electricity supply. It is understood that there is an electricity sub-station on the Isla del Diablo. From the port plans it can be deduced that the sub-station is at the same level as the quays, which are not projected to be flooded by 2100 even in the accelerated sea level rise scenario. Therefore, no further analysis was undertaken.

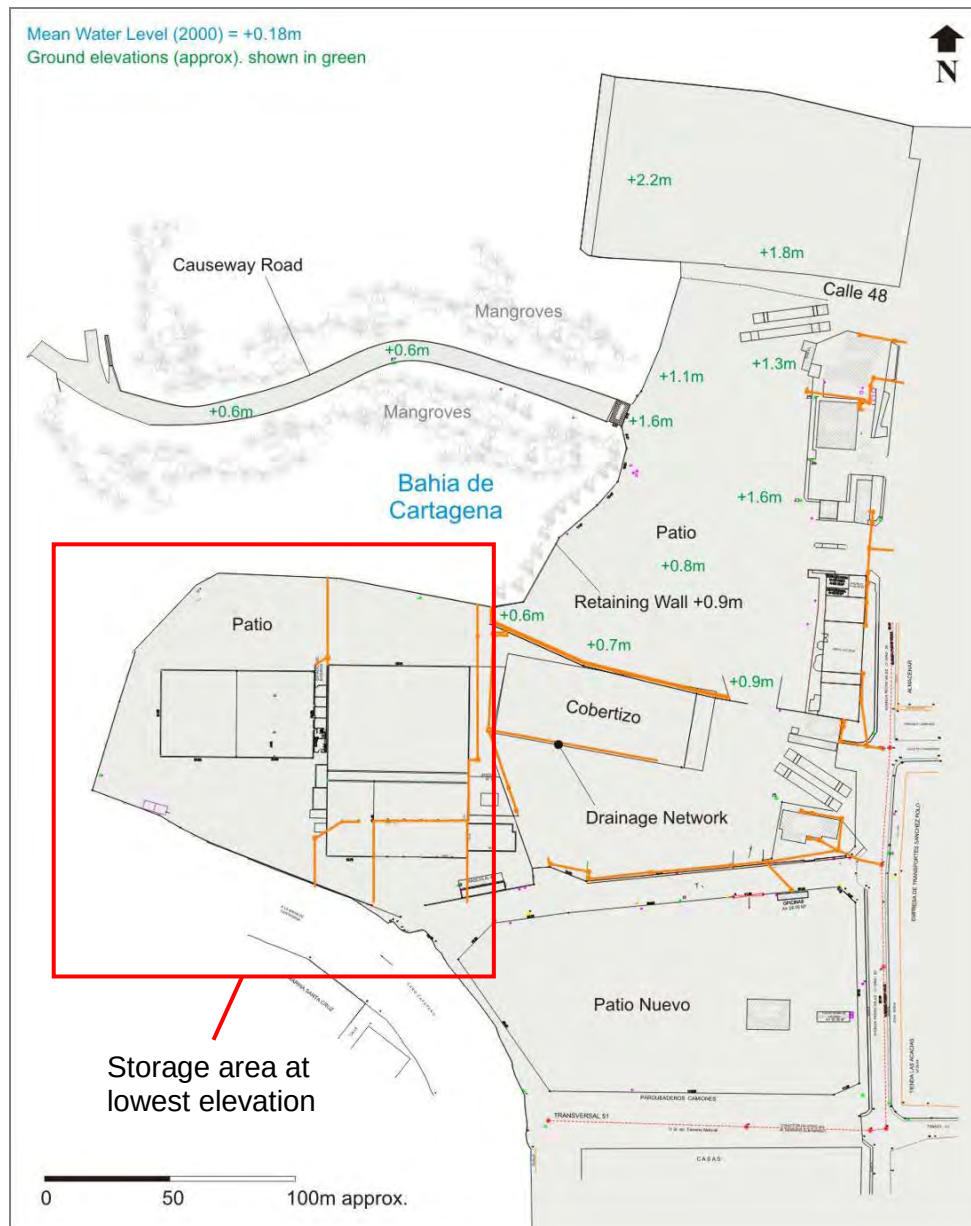
Table 7-2 – Estimated timing of seawater flooding of the mainland storage area under a range of storm surge return periods

Storm surge return period (1 in year)	Decade in which sea level is projected to flood the mainland storage area under two SLR scenarios	
	Observed SLR	Accelerated SLR
1	2050 – 2060	2030 – 2040
10	2040 – 2050	2030 – 2040
100	2040 – 2050	2030 – 2040
300	2040 – 2050	2020 – 2030

Table 7-3 – Estimated frequency and duration of flooding of the mainland storage area

	Number of occurrences per year				Mean duration of flooding event (hours)			
	2020	2050	2080	2100	2020	2050	2080	2100
Observed SLR scenario	0	0	53	259	0	0	1.9	4.3
Accelerated SLR scenario	0	67	365	365	0	2.2	23.6	24.0

Figure 7-3 – Port plan of the mainland storage area and warehouses



7.3.2 Adaptation

There are five adaptation options to protect against seawater flooding of the storage areas, dependent on the sea level rise that occurs in Bay of Cartagena. They are presented in order of increasing capital cost:

- Reorganize storage to ensure that perishable cargo is stored in less vulnerable areas, for example use of the additional storage space that MEB has at Mamonal;
- Ensure liability is not MEB's and that appropriate insurance is in place (while this may ensure that the direct financial risk is mitigated, there are other secondary risks such as reputation that must be considered);
- Provide emergency flood protection to warehouses and storage areas;
- Increase height of wall around patio; or
- Increase height of patio and warehouses.

These adaptation measures fit within all three of the categories of adaptation that have been distinguished by the IPCC for coastal zones. These are 'protect', 'retreat' and 'accommodate'. The three options requiring the largest capital investment are typical engineering solutions to coastal protection, although the focusing of attention on key assets is becoming more common due to the increased flood risk on the coastal zone. Protecting only the warehouses involves a certain amount of 'accommodation' of risk. Moving goods to higher ground near Mamonal is an example of 'retreat', and insurance and avoiding liability are methods of 'accommodation' of risk.

At present, the opportunity to reorganize storage is limited as the port is close to capacity. However, it would be an option as the additional storage area purchased by MEB comes on line. The timing of potential flooding events is predictable, which makes planning easier.

While flooding events are infrequent, one option is to accept flooding of the patio as long as the warehouses are protected. There are a number of flood protection options for commercial buildings. Generally, these involve the raising of flood protection barriers. However, the cost of such a system would be fairly prohibitive and it could be more cost effective to raise the height of the warehouses.

If SLR increases to such an extent that flooding of the patio becomes frequent, it will be necessary to increase crest height (wall or patio) to hold back seawater levels. To accommodate SLR, it will often be necessary to re-engineer the whole structure due to the changes in forces acting on it. Therefore the cost of increasing the height of the patio or the wall protecting it, is not directly proportional to the SLR (Burgess, 2007). For example it may be necessary to increase the depth of foundations or increase the armor. This situation is accentuated where waves are acting upon the structure, which is not the case at MEB.

If the wall is raised it will be necessary to upgrade the drainage system to ensure that seawater cannot penetrate the wall. This would probably involve the use of valves or a pumped system similar to that used in the underground conveyors.

7.3.3 Financial analysis

Without knowing the value (volume and price) of the goods stored at the port, it is difficult to estimate the potential cost of flood damage. However, a scenario where the warehouses within the mainland storage area are flooded whilst 50% full of grain was evaluated as an example.

Based on port plans, the floor area of the warehouses in the mainland storage area is approximately 6,500 square meters. Assuming that grain is stored to a height of 5m and that the warehouses were 50% full at the time of the flooding event, the total volume of grain stored is approximately 16,000 m³ or approximately 12,000 tons²⁹. The value of goods lost to flooding would then be \$1.6m at an estimated corn price of \$100 per m³ and assuming that all grain is lost³⁰. The estimated cost equates to approximately 2.5% of MEB's estimated future revenue.

If that cost were to fall on MEB it would be significant. However any damage to or loss of stored goods caused by *force majeure* is not covered by MEB but by the owner of the goods. Even if MEB, were held liable it would be covered by insurance. Insurance is discussed further in Section 13. However, there is also the reputational risk associated with goods being spoiled while stored at MEB, which can translate into revenue loss if flooding influences customers to switch to another port. This potential cost is not assessed here but could be significant.

Under the observed SLR scenario the goods storage area is not projected to be flooded in 2050, except during a 1 in 10 year storm surge but by 2080, 53 flood events, excluding storm surge, are expected per year. The mean duration of flooding is only 2 hours but such frequency could make the

²⁹ Density of dry bulk corn is estimated to be 0.72 metric tons/m³
(http://www.powderandbulk.com/resources/bulk_density/material_bulk_density_chart_c.htm).
Accessed on 4 June 2010.

³⁰ Corn price of \$3.5 per bushel or ~ \$160 per metric ton. 1 bushel ~ 0.035 m³.

area unusable even if the risk of cost of flood damage to goods is not on MEB. Under the accelerated SLR scenario a similar frequency and duration of events occurs by 2050 and by 2080 the patio area is under water approximately 98% of the time.

Estimating capital costs for raising the height of the patio or the protecting wall is difficult with the information available. A budget all-in cost for paving the terminal area, including raising the height of the water drainage system, would be in the order of \$100 per square meter³¹. Assuming that only the patio in the area within the red box in Figure 7-4, is raised the area is approximately 22,000m² and therefore the adaptation cost would be \$2.2m. This does not account for the costs of raising the warehouses or any structural engineering required to support the additional paving, which could make the costs substantially higher. In addition to the capital cost there would also be the operational costs associated with the disruption to the port while the works took place. As the port moves toward full capacity, the disruption will become more significant but as MEB is expanding its storage space through the use of land outside the port, this may be less of an issue in the future. Even so the value of goods damaged by flooding could be greater than the cost of adaptation with relatively few significant flood events.

To compare the cost of raising the patio (\$2.2m) in different adaptation scenarios, two forms of adaptation are tested: 'adaptive management' (whereby the patio is raised by 20cm every 10 years between 2050 and 2100) and 'one-off' adaptation (whereby the patio is raised once by 1.2m in 2050). Costs include repaving the patio and the associated costs of business interruption. A hypothetical scenario has been evaluated based on the following assumptions:

- The total cost of raising the patio is estimated at \$2.2m, including \$1.7m in fixed costs and \$500,000 per 20cm of increase in height in variable costs.
- It is necessary to raise the patio by 1.2m by 2100.

Whilst flooding is infrequent and only associated with storm surges (which is projected to be the case in the 2050s and 2030s for a 1 in 10 year storm surge in the observed and accelerated SLR scenarios respectively, as shown in Table 7-2), the cost of raising the patio is expected to be greater than the cost of projected flooding, particularly as the cost would fall on customers and be likely to be covered by insurance in the short-term. However, as flooding becomes more frequent (i.e. when flooding occurs during the highest spring tides) adaptation becomes beneficial; this is projected to occur by the 2070s and 2050s onward in the observed and accelerated SLR scenarios respectively (see Table 5-3). Other lower cost interim adaptation measures could be considered, such as flood barriers. However, as storm surge height is relatively modest at MEB, the benefit of such temporary adaptation measures would be short-lived before frequent flooding occurs. At other ports where the threat of frequent tidal flooding is low but storm surge is high, flood barriers can be a preferable adaptation option.

The NPC of total adaptation expenditure to 2100 for a range of discount rates in both adaptation scenarios is shown in Figure 7-4 and Figure 7-5 (note that Figure 7-4 presents the same information as Figure 7-5 except that the y-axis in Figure 7-4 is expanded to better show the NPC of adaptation under high discount rates). Raising the patio once by 1.2m has a higher cost than raising it incrementally for discount rates above 10%. When discount rates are not incorporated into the financial analysis, adaptive management is nearly three times the cost of the prescriptive adaptation scenario (and for a 3% discount rate it is approximately 1.5 times). At MEB's discount rate of 16%, the net present cost of adaptive management is much lower than that of 'one-off' adaptation (approximately 60% of it).

³¹ Estimated costs are based on 'ball park' figures for paving provided by MEB and WorleyParsons marine engineering group. This is a largely hypothetical illustration that would need to be revisited with accurate costs before being used in decision-making.

Figure 7-4 – Potential adaptation costs for raising the patio by 1.2m for a range of discount rates.

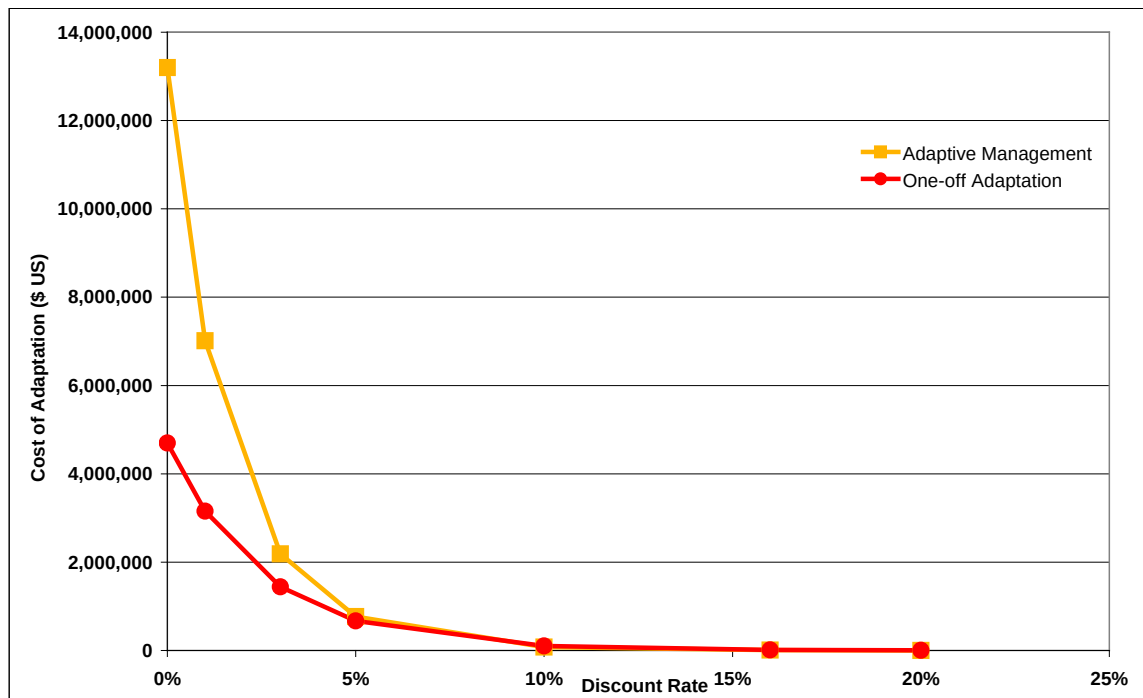
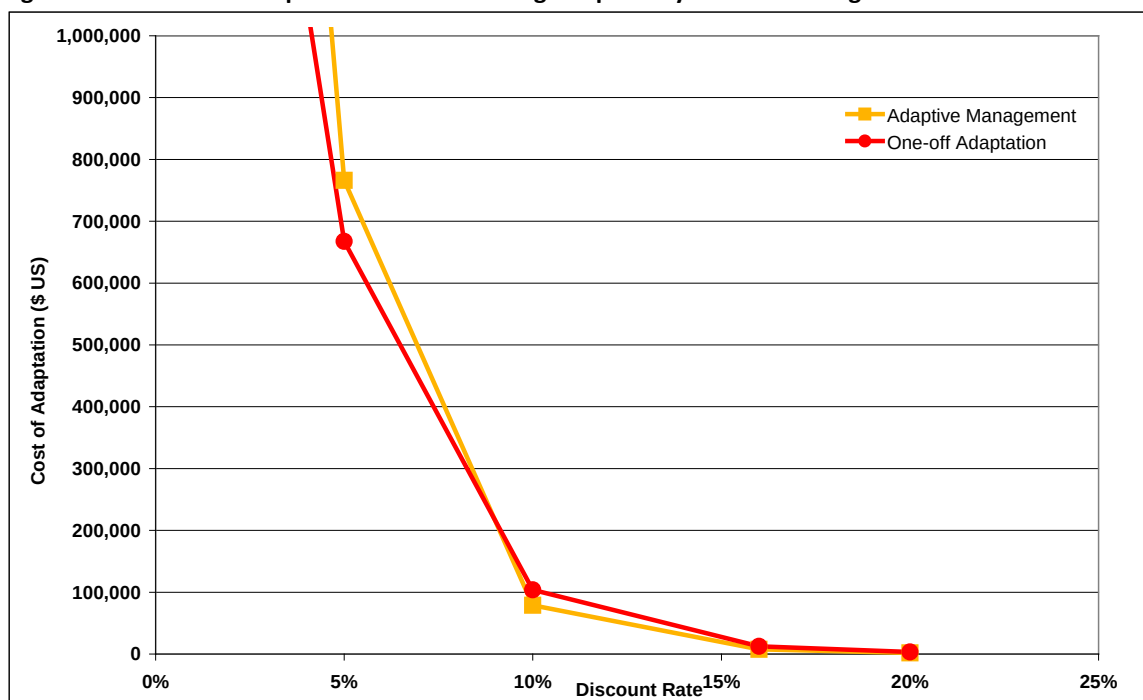


Figure 7-5 – Potential adaptation costs for raising the patio by 1.2m for a range of discount rates.



7.4 Coke Spraying

7.4.1 Climate change risk

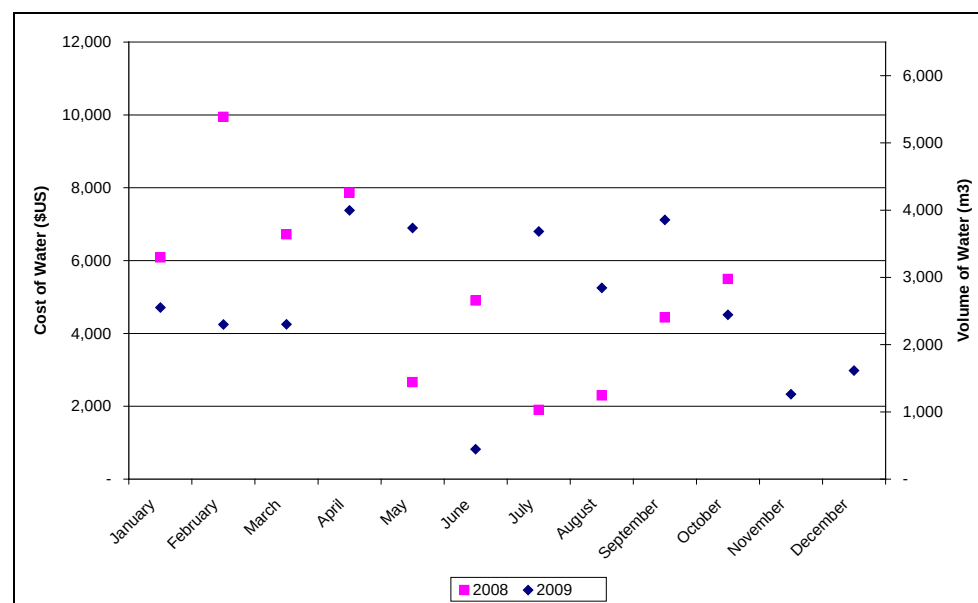
Coke is sprayed to minimize dust as part of MEB's Environmental Management Plan. Spraying is required when the coke is below a certain humidity level, to ensure that it cannot be suspended by the wind. Therefore in times of greater rainfall the volume of water required is lower. According to MEB, the run-off from the coke stockpile is collected through a drainage channel leading to a

settlement basin where particulate matter settles out, and which serves to recycle water for re-use. This helps to reduce MEB's water consumption.

The volume of water used on the island site and the associated cost is recorded by MEB. It is believed by MEB that the annual trend in water use is the inverse of the annual trend in rainfall, meaning that the highest water use occurs in the dry season. The cost and volume of water use during 2008 and 2009 for the Isla del Diablo, where the coke is stored, is provided in Figure 7-6. The majority of the water used is for spraying the coke.

The volume of water used for spraying coke is necessarily related to the amount of coke stored. Therefore attempts were made to calculate the volume of water used per unit volume of coke stored. However, data on the amounts of coke stored on the port were not available³².

Figure 7-6 – Cost of water used on the Isla del Diablo



It is difficult to directly use rainfall projections to estimate future changes in water use for coke spraying, since, as outlined above, water use will primarily depend on the amount of coke stored. Further, and as discussed in Section 4, there is a wide range of precipitation projections across climate models for Cartagena. For example, the downscaled projections for the 2050s show a contrast between seasons, with both potential increases and decreases in rainfall. Annual rainfall is also highly variable, as evidenced by the fact that the maximum annual rainfall over 69 years measured near MEB (at the Apto Nune Rafael meteorological station) is approximately 90% greater than the mean of that same period. In addition to rainfall variations due to climate change, patterns of decadal variability can constitute a significant factor to take into account in risk assessments where rainfall is a significant factor. For example, the El Niño Southern Oscillation (ENSO) has been found to have a significant effect on rainfall in Colombia: on average, precipitation is 48% higher in La Niña years compared to El Niño years (Poveda and Mesa, 1997).

Despite the absence of data on amounts of coke stored on the port and the wide range of rainfall projections, a hypothetical assessment using observed daily precipitation data for Cartagena was carried out to illustrate potential impacts on water costs for MEB. The implications of rainfall decadal variability were not considered to simplify the assumptions.

³² Data on the volume of coke exported was provided by MEB, but it did not account for the volume and timing of coke deliveries to the port. The short period of the dataset also makes it very difficult to ascertain the correlation between rainfall and water use.

There has been a trend of 0.6% increase per annum in total rainfall from 1947 to 2009. If the observed trend were to continue until 2050 the total increase in rainfall would be 25% from 2008³³. If it is assumed that an increase in rainfall is directly proportional to a reduction in water use on the Isla del Diablo, the reduction in water use by 2050, would be 25%.

7.4.2 Adaptation

The cost of spraying the coke is relatively small and is not projected to change significantly in the future (due to uncertainties over changes in precipitation). Therefore no specific adaptation is proposed.

As water use becomes more of an issue, either due to cost or scarcity, adaptation options that should be considered include:

- Maximizing recycling of water,
- Construction of a covered storage area for the coke.

7.4.3 Financial analysis

The total expenditure on water for the Isla del Diablo in 2008 was approximately \$57,000. Therefore the saving, based on a 25% reduction in water consumption for spraying coke, would be approximately \$14,000 per year, assuming the cost of water remains constant. This is only a small percentage of current operational costs.

As already discussed, the climate change projections show a wide range of rainfall projections across climate models for Cartagena. Nevertheless, it is clear that the cost of water is relatively small and therefore not a significant issue for MEB.

There is the potential for the cost of water to increase under climate change, if water were to become increasingly scarce. Cartagena's water supply is primarily sourced from abstraction from the Canal del Dique. As discussed in Section 5.2.1.2, the flow in the Rio Magdalena that feeds the canal is highly variable, but the decreasing trend in maximum monthly flows is relatively constant over the last 50 years, and the projected potential changes in rainfall under climate change are small compared to natural variability. As the canal is a man-made channel, there is the opportunity to manage its flow, and the provision of drinking water is a crucial factor in the proposed improvements to the canal (Giraldo et al, 2009).

7.5 Refrigeration

7.5.1 Climate change risk

Within MEB's container storage area, refrigerated containers or reefers can be found. There are 72 plug points available for reefers at MEB but the number at any one time is variable. If the number of reefers at MEB increases, additional plug points will be required (Scott Wilson, 2007). However, according to MEB, the number of reefers is not expected to rise significantly. The reefers run from MEB's electricity supply and the cost of electricity is included in the storage costs of the reefers that MEB charges to its customers.

³³ This is based on the assumption that observed historic trends in rainfall will continue into the future, because the climate model output for rainfall over Colombia is unreliable. According to the IPCC, rainfall intensity is projected to intensify in the future as the climate warms, so assuming that existing trends will continue could be an underestimate (IPCC WG1, 2007). For further detail, see Section 4.3.

Figure 7-7 – MEB reefer stack



Reefer power consumption is highly variable, with suppliers competing to minimize energy consumption to reduce costs and GHG emissions. The energy consumption of reefers has been shown to be dependent on a number of factors including the quality of the unit, size, turnover of goods, temperature of incoming goods, product target temperature and external temperatures. There has been little research into the potential costs associated with the impact of climate change on large scale cold-stores.

Analysis carried out on domestic refrigerators suggests that between 60-70% of the thermal energy that a refrigerator has to remove comes from leakage through the insulating walls. The rate at which this energy is conducted is dependent on the temperature gradient across the wall. Therefore, higher ambient temperatures lead to faster heat conduction into the cold-store and greater energy consumption to dissipate the heat. This factor is compounded by the fact that the efficiency of the compressor (the most energy consuming component in the refrigerator) also drops away at higher ambient temperatures (James & James, 2010).

Using the relationship between temperature and energy consumption observed for domestic fridges (Saidur et al., 2000), and considering a 6°C increase in average temperature as an upper-bound estimate (as projected by an ensemble of 14 downscaled GCMs for the 2050s, see Section 4), an increase in energy consumption of 30% is found, which corresponds to an increase of 84kW in MEB's annual electricity consumption. For more information, see Appendix 6.

There is no evidence that temperature changes in Cartagena will be greater than at competing ports, so the relative energy consumption of reefer storage in different ports is not projected to be affected by climate change.

7.5.2 Adaptation

The electricity use associated with reefer storage is relatively small, which ensures that even if the conservative estimate of 30% increase in energy consumption is realized, the risk to MEB is low.

There are two adaptation options for ensuring that costs are managed if temperatures are increased. These are to reduce energy consumption and/or to ensure that the cost is passed on to the customer.

There is a general move to more energy efficient reefers, which the industry is a major objective of the industry and it is clear from the manufacturers website's that extensive research and development going on. The drive for energy efficiency and efficient cooling is primarily driven by the

time at sea when the reefers are tightly packed into a small space and temperatures can reach more than 40°C. However, the choice of reefer does not sit with MEB, though MEB can encourage energy efficiency.

It may be in MEB's interest to reflect future energy cost increases in its charge-out rate for storing refrigerated containers.

7.5.3 Financial analysis

The average industrial electricity tariff in Colombia in 2005 was approximately \$98 per MWh (World Bank, 2009). For a 84kW annual increase in MEB's electricity consumption, the annual energy cost increase is estimated to be approximately \$65,000.

7.6 Grain Storage

7.6.1 Climate change risk

Large increases in temperature have a direct impact on the quality of stored grain, with grain quickly spoiling as temperatures in the storage facility rise (Burgos, 2004). At temperatures found in grain stores, the biological activity of insects, mites, fungi and grain itself doubles for each 10°C rise in temperature. Furthermore, temperatures between 24°C and 33°C provide optimal breeding conditions for most insects, mites and fungi (HGCA, 2003).

Storage environments high in moisture content also lead to an increased risk of quality reduction and eventually crop loss. Grain that is too moist during storage experiences mould growth and mycotoxin production, mite infestation and sprouting. On the other hand, grain that is too dry can split or crack (HGCA, 2008).

According to MEB, the principal cause of quality problems with grain storage at MEB is the temperature of the grain. This is felt particularly keenly in the boreal summer, when grain from the US has been known to arrive at temperatures greater than 26°C. At these temperatures, the grain is at an elevated risk of quality loss.

As detailed in the climate review (Section 4 and Appendix 1), temperatures across Colombia are very likely to increase in all seasons from now until the end of century. This in turn is likely to lead to increased biological activity in the stored grain and potentially to reductions in quality of grain stored over time.

While high humidity has not been identified by MEB as a current problem for grain storage, it is noted that current humidity levels are high. As shown in Appendix 1, relative humidity in Cartagena ranges between 78% and 83% throughout the year. Although seasonal precipitation projections for the future are uncertain, the projected increases in temperature suggest that absolute humidity will increase. In this case, the risk of problems associated with high moisture content such as mould growth, mycotoxin production, and mite infestation and sprouting would be expected to increase.

Grain handling and storage activities are potentially also at risk of dust explosion. Although grain dust falls within the category of the least explosive kinds of dust, research has shown that grain dust explosions can occur when a combined set of factors are met (Namib, 2004), namely:

- a high concentration of dust, in the form of a high density dust cloud with a minimum dust concentration of 50g per m³,
- presence of oxygen, and
- a source of ignition (for example, mechanical friction, electrical equipment, fire, spontaneous combustion).

Temperature increase alone due to climate change (of up to 6°C by the 2050s) is unlikely to increase significantly the risk of grain dust explosion. Tests have found that the minimum temperature at which a grain dust cloud could explode is 430°C (Namib, 2004). A layer of grain dust more than 5mm thick can ignite when it is in contact with a hot surface above 450°C (Namib, 2004). It is also worth noting that dry air favors ignition, whereas humidity levels in Cartagena are high throughout the year, as highlighted above. MEB have not indicated that the port has suffered grain dust explosions in the past and, given that climate change does not appear significantly to increase the relevant risk factors, this issue was not assessed further.

With regard to flood risk for the grain stores from sea level rise, it is worth noting that even under the worst case scenario for the end of this century, grain storage silos at MEB are not expected to flood (see Section 7.3).

7.6.2 Adaptation

MEB is in an interesting position with respect to the quality of grain stored. Once the grain moved by MEB goes into storage at the port, it ceases to be MEB's responsibility. Any problems related to quality losses while in storage are the responsibility of the customer, who is obliged to collect the grain as soon as possible in order to avoid quality loss.

However, it is reasonable to assume that even if MEB are not legally responsible for any quality loss in their storage facilities, having appropriate storage practices in place to avoid product loss would make MEB an attractive port to use, and would be a selling point for the business if it makes MEB's storage facilities more secure than its storage offered by its competitors.

While grain quality may be expected to decrease at faster rates as temperatures rise, it is clear that MEB already has excellent grain surveillance practices in place to detect problems as fast as possible. It is not considered that more frequent monitoring would add to this process.

Additionally, it is noted that long-term grain stores are cooled in some cases. It is assumed that as grain is only stored temporarily at MEB, this is the reason that no cooling system has been put in place. Cooling requires a large investment, and in MEB's circumstances (i.e. having no direct responsibility for stored grain), this is unlikely to be an attractive adaptation measure.

So long as there is proper management of the grain handling and storage areas, the risk of grain dust explosion is expected to be relatively low. Prevention measures that can be considered include:

- controlling dust concentrations,
- eliminating ignition sources,
- ensuring proper ventilation of grain storage areas.

7.6.3 Financial analysis

The cost of losses in product quality while stored at MEB falls on customers and not on MEB, though the risk of decreased reputation or of litigation against MEB to recover some of these costs in case of negligence cannot be overlooked (see Section 13).

If grain quality decreases at a faster rate in the future, increased monitoring would increase MEB's operational costs moderately. In light of the low risk to MEB, no further cost assessment was done.

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8 Environmental Performance

8.1 Baseline Environment

The Caribbean coastal zone, including the Cartagena region, contains many complex ecosystems. Marine habitats include coral reefs, sea grass beds, mangroves, coastal lagoons and sandy beaches.

The following protected areas are in the Cartagena region:

- World Heritage Site – Port, Fortresses and Group of Monuments, and
- Parque Nacional Natural Corales del Rosario y de San Bernardo.

The World Heritage Site covers the fortifications of Cartagena, which are the most extensive in South America and the old city, including San Pedro, San Diego and Gethsemani (Figure 8-1).

Figure 8-1 – Cathedral de San Pedro Claver, part of the World Heritage Site (UNESCO World Heritage Centre)



The Parque Nacional Natural Corales del Rosario (Coral of Rosario National Natural Park) is one of the 54 protected areas of Colombia, created in order to protect one of the most important marine environments of the Colombian Caribbean coast. The park extends over an archipelago which covers 120,000 ha, including coral reefs, mangrove forest, coastal lagoon and seagrass beds.

CARDIQUE (Corporación Autónoma Regional del Canal del Dique), the environmental regulator for the region of Cartagena, identified the following key environmental issues (CARDIQUE, 2009):

- Pollution and siltation of water bodies,
- Poor management and disposal of solid waste, and
- Poor environmental awareness and inadequate management of natural resources, including deforestation.

8.1.1 Mangrove

In 2005, there were around 350,000 ha of mangrove forest in Colombia, which is approximately 18% of the total area of mangrove in South America. Of this 20 to 30% is found along the Caribbean coast, where the relatively low rainfall and small tidal fluctuation restricts the mangroves to a relatively narrow coastal fringe.

Globally, between 1980 and 2005 about 3.6 million hectares were cleared, corresponding to 20% of the global mangrove coverage, although the rate of decline has decreased (FAO, 2007). The area of mangrove in the bay of Cartagena declined by 90% over between the 1980s and the late 1990s (CIOH, 1998).

8.1.2 Corals and sea grass

The impacts of heavy sediment loads and freshwater discharges from the Canal del Dique to Bay of Cartagena have contributed greatly to the partial disappearance of coral formations and also to a considerable reduction in the abundance of seagrass beds in the bay and neighboring areas (Restrepo, et al. 2005). Seagrass provides nursery and feeding grounds for fisheries and other marine fauna and are highly susceptible to changes in the surrounding environment. Sedimentation in Bay of Cartagena has led to a loss of over 92% of seagrass (Diaz et al, 2003). Sediment plumes from the Canal del Dique discharging into Bay of Cartagena and toward the Islas del Rosario can be seen in Figure 8-2.

8.1.3 Beaches

The biggest hazard to the preservation of this ecosystem comes from human interference, where numerous groins and other rock structures have been built in an attempt to increase the size of the beach bordering the city (Invemar, 2005), as seen in Figure 8-3.

There is much evidence of pollution of beaches by anthropogenic sources in the bay of Cartagena. The issues of sewage discharges are well known by the people and authorities in Cartagena and then municipality is evaluating options to deal with Cartagena's sewage³⁴. The bay of Cartagena was also found to be highly polluted in terms of polycyclic aromatic hydrocarbons (PAHs) from samples of sediments and fish. PAHs are formed during the incomplete burning of coal, oil and wood. They are of concern due to being irritants and are believed to be carcinogenic; they are also toxic to aquatic life (National Pollution Inventory of Australia, 2010).

³⁴ Discussions with the municipality and the University of Cartagena during the site visit.

Figure 8-2 – Sediment plumes (shown by arrows) from the Canal del Dique (Repestro, 2005). Pavitos (Pa), Barú (Ba), Grande (Ig), Rosario (Ro), and Tesoro (Te) are locations of reef studies around the Rosario Islands.

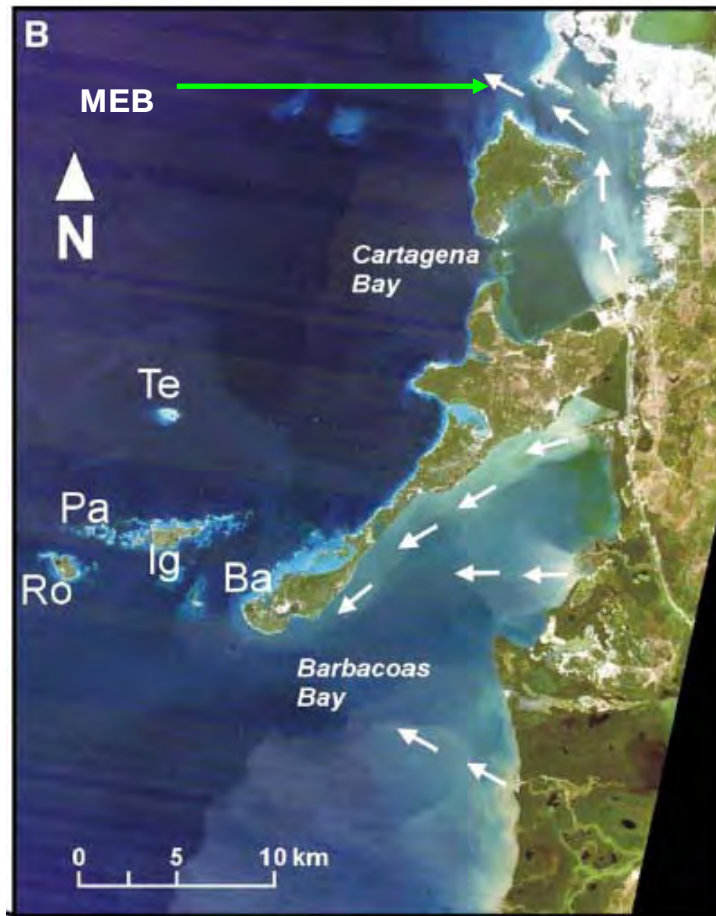


Figure 8-3 – Overview of the hard structures constructed along the Bocagrande sector between 1999 and 2004 (Invemar, 2005)



8.2 MEB and the environment

MEB is certified to ISO 14001, which demonstrates the company's commitment to environmental protection. ISO 14001 was first published in 1996 and specifies the requirements for a robust environmental management system. It applies to those environmental aspects which the organization has control over and can be expected to have an influence on.

The operations at MEB have a range of environmental impacts as described in their Environmental Management Plan (Castillo, 1998). The following potential environmental impacts were identified by MEB:

- Impacts of dredging,
- Risk of spills, dust and run-off associated with coke, and
- Dust from unpaved areas.

In terms of the key habitats described in Section 8.1, the impact of MEB's operations on those habitats is believed to be limited.

MEB only dredges in the inner harbor, where turbidity is already relatively high and sub-tidal habitats, such as seagrass, which may have once existed, have already been significantly degraded by human activity.

Dust is more of a social issue than an environmental one at MEB. Although contaminants may be carried in air-borne dust, the primary risk of coke dust is managed through coke spraying.

According to MEB, the drainage channels of the port areas where containers and equipment are washed and where coke is stored have oil/water separators and sediment traps. These are used to reduce contaminants entering the Bay of Cartagena. Other parts of the port where drainage channels are only meant to collect rain water have no sediment traps or oil/water separators.

There is an area of mangrove around the road linking the mainland and the island. The mangrove system is highlighted as the main habitat of interest in MEB's Environmental Management Plan (EMP). This consists of an area of red mangrove (*Rhizophora mangle*) and black mangrove (*Avicennia germinans*) covering 0.26 ha and 0.012 ha respectively. There has not been a detailed survey of the mangroves to evaluate its biodiversity but it is believed to provide habitat to many birds³⁵.

The environmental authority granted MEB with an authorization to partially clear some areas of mangrove around the causeway to undertake works to enlarge and straighten the causeway road, which would improve vehicle movements on the port by enabling two-way circulation. However, according to MEB, if the company decides to make use of this authorization it will need to reforest an area ten times the size of the mangrove area cleared in a location designated and protected by the environmental authority. MEB sees the mangrove as an important part of their environmental responsibility and has no intention to reduce the area. There is a 'Programa de Reforestacion Paisajistica' (Program of Mangrove Reforestation) within the EMP and it is assumed that this has been implemented.

³⁵ Observation by WorleyParsons Environmental Impact Assessment specialist during MEB site visit.

8.3 Climate change risks to the environment and to MEB's environmental performance

8.3.1 Climate change impacts on the environment around MEB

The four primary habitats in and around Bay of Cartagena that are vulnerable to climate change have been identified as (Invemar, 2005):

- Mangrove,
- Seagrass,
- Coral, and
- Beach.

8.3.1.1 Mangrove

Although changes in temperature and precipitation can affect mangrove growth, sea level rise is projected to be the greatest climate change threat to mangroves (McLeod and Salm, 2006). SLR could have an impact on the mangroves around MEB. They are restricted to a narrow fringe within the intertidal area and as sea level increases the region where suitable conditions exist for mangrove may move or disappear.

8.3.1.2 Seagrass

Seagrass is known to survive in a relatively narrow band of thermal tolerance. Therefore increases in water temperature are expected to cause significant seagrass mortality in areas where water temperature is already at the upper end of its band of thermal tolerance. Seagrass requires regular sunlight for photosynthesis. Increasing water depth will reduce light penetration and therefore shift the areas of potential seagrass habitat. Changes in currents, salinity and carbon-dioxide concentrations will also have an effect, either directly or through increased competition with algae. Storms can uproot and cause smothering of beds: in areas less sheltered than Bay of Cartagena and where storm intensity is projected to increase, seagrass will be impacted (Short et al., 1999).

8.3.1.3 Coral

Since the early 1980s, episodes of coral reef bleaching and mortality have occurred almost annually in one or more of the world's tropical or subtropical seas and this is believed to be a result of climate change (UNEP, 2010). Ocean acidification and warming will compromise carbonate accretion resulting in less diverse reef communities and carbonate reef structures that fail to be maintained. Corals will become increasingly rare on reef systems. Climate change also exacerbates local stresses (for example declining water quality or overexploitation of key species), thus driving reefs increasingly toward the tipping point for functional collapse (Hoegh-Guldberg, 2007). The role of coral reefs as a nursery habitat is crucial and therefore loss of reef has implications for the wider marine ecosystem.

8.3.1.4 Beach

Beaches experience a constant loss and gain of area due to climatic processes that affect currents and waves and result in erosion and accretion in different areas. In the dry season the beaches of Cartagena are eroded due to the strong winds coming from the north and associated waves. During the rainy season, sediment deposition reconstructs these areas (Invemar, 2005). Sea level rise will change the dynamics of coastal zones and in particular intertidal areas and surf zones. Deeper water will allow waves to travel further up the beach, as wave height is related to water depth, thus increasing coastal erosion rates. No significant changes in wind characteristics in the Cartagena region are projected, which indicates that large scale sea currents are not likely to change. The volume of sediment entering the coastal zone can also affect beaches, but no future change due to climate change are projected in Cartagena.

There is also a significant risk to the World Heritage site in Cartagena from climate change. The old city of Cartagena is low lying and frequently experiences flooding from both precipitation and the sea. The University of Cartagena is undertaking a number of studies looking at adaptation options for the city and although these are currently focused on Bocagrande and Castilligrande, these include adaptation measures to reduce the risk to the old city. This is discussed further in Section 11 . A number of the coastal forts, including those that were built to protect the entrance to the bay at Bocachica, are already under water.

8.3.2 Climate impacts on MEB's environmental performance

The environmental impact of MEB's operation is not expected to be significantly affected by climate change. Under pressure from climate change, the following potential environmental impacts need to be considered:

- Increased energy use and associated GHG emissions due to the effect of increased temperatures on refrigeration,
- Increased run-off due to precipitation,
- Increased run-off and overflow due to seawater flooding, for example of sediment traps and oil/water separators, and
- Changes in dredging requirements.

Increased energy use for refrigerated containers due to higher temperatures will increase MEB's GHG emissions to the atmosphere. Although the majority of Colombia's electricity is sourced from hydropower plants, Cartagena has a natural gas power station which most likely feeds MEB (USDOE, 2003). Therefore, a 30% increase in energy use (estimated for a 6°C increase in average temperatures) would deteriorate MEB's carbon performance, unless energy efficiency measures are put in place (the financial impact to MEB has been estimated to be relatively small, approximately US\$65,000 per year). For more information see Section 7.5.

In theory, changes in rainfall could increase the risk of negative impacts on water quality, through increased run-off, overwhelming of the drainage system and exceeding the capacity of oil/water separators or sediment traps. Similarly, seawater flooding could lead to contaminants from the paved and unpaved areas and equipment being washed into the bay. However, increased precipitation and potential seawater ingress are unlikely to overwhelm the port's drainage system and lead to surface flooding (see Section 7.2.1.1). Seawater flooding of the causeway, projected to frequently occur from 2015 to 2018 at the highest spring tide under the observed and accelerated sea level scenarios respectively (see Section 5.2), is unlikely to lead to significant water pollution, unless the causeway and the surrounding areas have been contaminated.

SLR is likely to reduce the dredging requirements on the two short access channels for which MEB have responsibility, by increasing their depths. This will have a very small positive impact on MEB's environmental performance, due to their length and because dredging is only required once every five years on average (see Section 9.3.2). However, increased dredging requirements on Bocachica channel to allow access to the bay of Cartagena for Post-Panamax vessels are expected to have a much larger impact on marine ecosystems. This is because Bocachica channel is closer to sensitive ecosystems (such as Islas del Rosarios) and the volume of dredged material is much higher than on the channels managed by MEB. The management of dredged material is covered by the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter – London Convention and Protocol (IMO, 1972 and 1996) although Colombia is not a contracting party. The disposal of dredged material is crucial and dredging disposal sites must be selected carefully to minimize the impact on the benthos and minimize the risk of sedimentation affecting sensitive marine habitats, especially as climate change impacts on sensitive ecosystems may lead to increased scrutiny on nearby dredging activities.

8.4 Adaptation and the environment

CARDIQUE has identified the following key steps to deal with environmental issues on the Bay of Cartagena (CARDIQUE, 2009):

- Mangrove and wetland recovery,
- The establishment of an Environmental Management Plan (EMP), and
- The establishment of a monitoring system.

MEB have had an EMP in place since 1998. It is understood that there is not a regular environmental monitoring campaign but this could be considered in the future. Supporting efforts to improve the quality of data on water and air quality could be an interesting area of private-public partnership for MEB as it could help to improve MEB's understanding of the environmental issues affecting the Bay.

8.4.1 How preservation of ecosystems can build climate resilience

Mangrove can act as a climate change adaptation measure. It is proven to act as coastal protection from hazards such as erosion and flooding due to storm waves, surges and tsunamis. This was observed during the 2004 Indian Ocean tsunami (Gilman, 2008 and Danielsen et al, 2005). A comparison of two villages in Sri Lanka hit by the tsunami showed the importance of mangroves in protecting infrastructure and saving lives. In Kapuhenwala, surrounded by 200 hectares of dense mangroves and scrub forest, the tsunami killed only two people but in Wanduruppa, which is surrounded by degraded mangroves, the impact was much greater and 5,000 to 6,000 people died in the district (IUCN, 2005).

Mangrove regeneration has been used as an adaptation measure for coastal protection for a number of years (IFRC, 2002). Mangrove primarily protects against short term events by absorbing a wave's energy and acting to reduce its height. However, in the case of MEB it is not waves or short term surges that threaten operations in the port, but rather sea level rise. Mangrove can protect against SLR by stabilizing morphological features such as sand bars that may act as flood protection barriers, but this does not apply to MEB. MEB have undertaken mangrove protection and reforestation, driven by their environmental objectives, rather than as a coastal protection measure (Castillo, 1998). Nevertheless, mangroves can be an important instrument in improving coastal protection in the wider Cartagena region.

8.4.2 How adaptation actions by MEB can benefit the environment

MEB may wish to consider adaptation measures which could help the mangrove to adapt to SLR. 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 in place. 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 (Gilman, 2008). Reducing other negative stressors can also assist the mangroves in adapting to climate change. Further investigation would be required to determine the right approach to support mangrove adaptation.

Adaptation associated with improving the energy efficiency of their refrigeration containers will have a positive impact on the environment through reduced GHG emissions associated with the consumption of thermal electricity (assuming that MEB's electricity comes from Cartagena's combined cycle gas turbine power plant).

8.4.3 How adaptation actions undertaken by MEB could impact the environment

If MEB undertakes to raise significantly the height of the causeway, it may have an impact on the bordering mangroves. Although unlikely, MEB could be required to pay for compensation measures which would involve (re)generation of mangrove forest elsewhere. CARDIQUE stated that their policy requires the creation of ten times the area cleared. This would mean that 2.72 hectare of mangrove would have to be regenerated. The cost of reforestation in the region was estimated by CARDIQUE to be \$35,000 per hectare. The financial cost to MEB would therefore be approximately \$95,000.

If the seawalls, quays or patios need raising there will be a range of impacts on the environment, as is the case for most engineering solutions. These include potential impacts to water quality during construction and the indirect effects of using materials such as concrete.

Flooding events may require new containment methods to prevent leaching of contaminants (USEPA, 2008). As a keystone measure, MEB could ensure that sediment traps and oil water separators have sufficient capacity to deal with increased rainfall intensity (see Section 4). Further, in the face of increased flooding events, there may be a need to raise the size and location of sediment traps and oil/water separators.

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9 Navigation and Berthing

9.1 Introduction

As is the case at many other ports around the world, pilotage in the Bay of Cartagena is compulsory. The pilot must board the vessel at the Bocachica and support the master to safely navigate to port. The use of tugs for berthing in the inner harbor is also compulsory. Pilotage in the Bay of Cartagena is compulsory, as is the use of tugs for berthing in the inner harbor. As of 2007, there were some 600 vessel movements per month (300 in and out of the Bay of Cartagena). Since 1,432 vessel calls were reported in 1997, it appears that traffic has increased by 150% over 10 years. Despite the increase in traffic, the wide dispersion of terminals around the Bay and the well devised channel layout means that congestion in the short- to medium-term is unlikely (Scott Wilson, 2007).

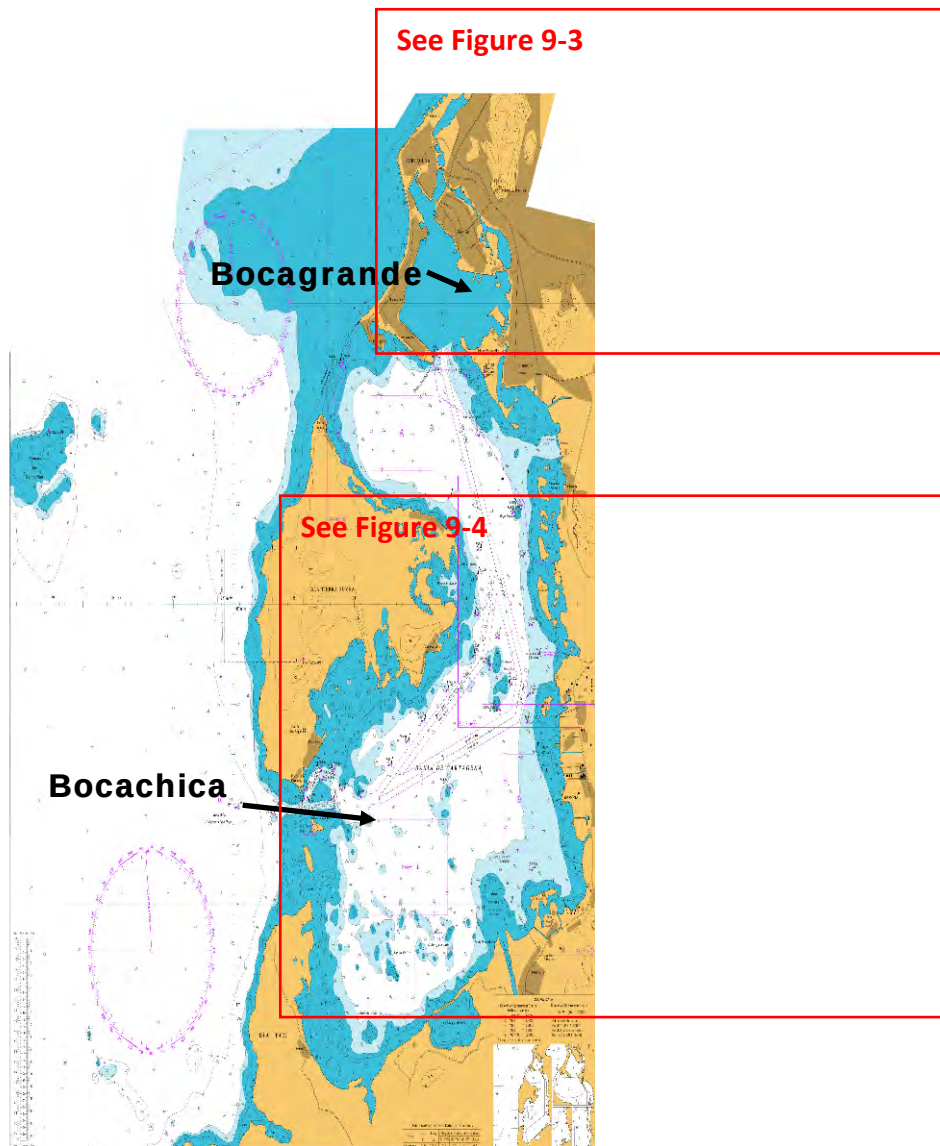
Even at the southern entrance to the bay, named 'Bocachica', which is the only entrance to the bay for commercial shipping, there are no congestion problems (see Figure 9-1 and Figure 9-2). Bocachica is dredged to a depth of 14.7m to chart datum (CD) and has a minimum reported width of only 84m. It is restricted to one-way traffic. All access channels in the bay including Bocachica, are well marked by illuminated buoys and shore lights sufficient for 24-hour marine operations and there is a large, deep anchorage in the bay. Marine operations come under the jurisdiction of the Port Captain, who is appointed by the Dirección General Marítima (DIMAR).

The tidal streams in both directions along the Bocachica channel (of approximately 0.5 knots) are not sufficient to present a serious risk to navigation; similar tidal velocities occur outside the bay near the entrance to the channel. The tidal range in the bay is small (approximately 0.36m, as estimated in Section 5).

Inside the Bay, there are two channels that are sufficiently wide (~300m) for two way navigation, thus avoiding the risk of potential delays for vessel transits. However, both routes contain three bends, where it is assumed that only one-way operations are permitted. The total distance from deep water to the inner harbor, where MEB is located, is 12 to 14km depending on the route taken. According to the Port Captain, accidents in the Bay are very rare (Scott Wilson, 2007).

MEB is only responsible for the two short dredged channels leading to their terminal and their berth pockets. According to MEB, maintenance dredging is infrequent and occurs approximately every 5 years.

Figure 9-1 – Admiralty Chart of Bahia de Cartagena



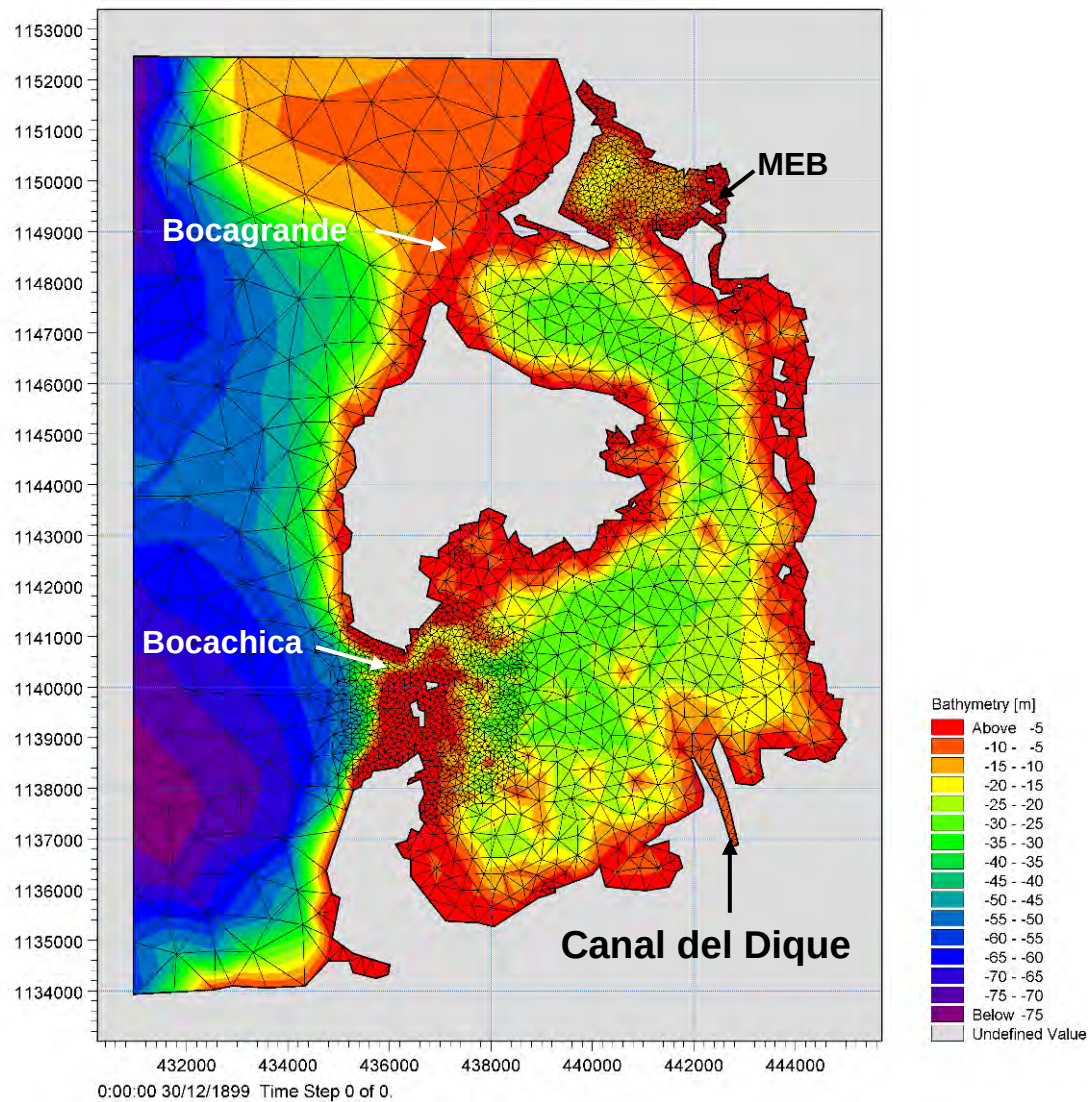
9.2 Assessment Tools

A 2D hydrodynamic model of the bay has been created to assess elevation in the bay and the critical factors influencing sea level at MEB (see Section 5)³⁶. The model takes into account the effects of tides, the impact of precipitation via the Canal del Dique and wind set-up in the bay. The model has not been calibrated and validated but provides a conceptual model against which the role of various critical parameters that drive sea level in the wider bay and at MEB can be tested. The model grid and bathymetry is shown in Figure 9-2 below.

The model is built with the industry leading MIKE 21 software from the Danish Hydraulics Institute (DHI). The model boundary is driven by the projected tides modeled from the UK Hydrographic Office and the water flow from the Canal del Dique is included as a constant source into the model grid.

³⁶ The model can also be used to assess the propagation and impact of waves and tropical cyclones (via storm surge).

Figure 9-2 – Model Grid of the Bay of Cartagena



9.3 Climate-related Factors and Climate Change risks

The Bay of Cartagena provides protection against waves. In addition, Cartagena's position within the Caribbean Sea on a north-west facing coast provides protection from swell waves and storm surges coming from the Atlantic (see Sections 4.5 and 0). Therefore, the impacts of waves and storm surges on navigation and berthing at MEB do not require further investigation.

SLR will increase water depth throughout navigation channels and at berthing quays, which in general terms has the following potential impacts:

- Changes in the relative height of vessels berthed compared to quays and materials handling equipment, and
- Opportunity for larger draft vessels or reduced maintenance dredging.

Sea level rise can also increase wave height due to increased water depth, which has the potential to affect berth operability; however, this is not a risk for MEB as explained above.

9.3.1 Changes to the relative height of vessels berthed compared to quays and equipment

The top of the quay is currently approximately 2m above mean sea level. According to MEB, the operating range of MEB's fenders and cranes can accommodate a rise in sea level of at least 1.5m. As described in Section 4.4, the maximum projected rise in sea level used in this study is 1.3m by 2100, which is within the operating range of MEB's equipment³⁷.

9.3.2 Increased draft and decreased dredging maintenance

An increase in sea level of 1.3m is expected to increase the draft available in the Bay of Cartagena, for example by 10% in a 13m deep sea channel.

The approach channels which MEB have to dredge every five years are not marked on the Admiralty chart below but their approximate location is shown (see Figure 9.3).

For new port developments or for operators looking to accommodate larger vessels an additional 1.3m in water depth could represent a significant opportunity. For example, the volume of dredging material for a 1km long by 100m wide sea channel would be reduced by 130,000m³ (assuming that the reduction in the depth of dredging required is equal to the projected sea level rise). For a dredging cost of \$10 to \$12 per cubic meter³⁸, the saving would be between \$1.3m and \$1.6m.

For MEB this benefit is limited because:

- MEB only dredges two relatively short channels, and
- MEB does not have aspirations to accommodate larger vessels requiring additional dredging maintenance.

However, in the long-term MEB's dredging maintenance costs could still be reduced as sea level rise increases draft and reduces the amount of sediment that needs to be removed from navigation channels. Assuming that the reduction in the required volume of dredging material is equal to the amount of sea level rise, the total saving by 2100 for MEB would be between \$325,000 and \$400,000 under the accelerated SLR scenario (if no discount rate is used). This assumes that MEB has responsibility over two 50m wide channels with a total combined length of 500m and that dredging costs are between \$10 and \$12 per cubic meter³⁹.

The accumulation of sediments in the sea bed, reducing water depth, is not generally considered a problem for the channels within the Bay of Cartagena, except close to Canal del Dique (see Figure 8-2). Canal del Dique carries large volumes of sediment into the bay and much of this is deposited close to the mouth of the canal where the current slows down.

The closest navigation channel to the mouth of the canal is shown in Figure 9-4. The frequency of maintenance dredging in this channel is not known but is not believed to be frequent due to the natural water depth. SPRC undertakes the dredging of the major access channels in the bay and MEB has no responsibility for maintenance dredging in this area. Clearly, if due to climate change, the flows

³⁷ This is because in the case of MEB (1) storm surges are very modest (storm surge height for a 1-in-300 year event is approximately 0.17m); (2) no significant increase is projected by climate models over Cartagena; and (3) annual sea level variations due to wind set up and rainfall are also limited (approximately 0.15m) and there is no evidence that they could change in the future. Equipment in other ports exposed to significant storm surges will have to accommodate a larger range of sea levels. For further details, see Section 5.

³⁸ Figure provided by WorleyParsons port engineering department, Vancouver, who have extensive experience of port development in South America.

³⁹ This is calculated as follows: 50 x 500 x 1.3 x 10 = \$325,000.

in the canal were to increase, this could mean that SPRC would need to dredge more frequently. This issue has not been assessed further.

The maximum size of vessels that can dock at MEB have a draft of less than 12m. The SPRC and Contecar terminals are planning to accommodate Post-Panamax vessels (i.e. ships that are larger than the size of the Panama Canal) of approximately 18m draft. This means that the access channels to the bay will be maintained at a depth that is significantly greater than that required by MEB.

In the climate analysis carried out in this assessment (presented in Section 4) nothing suggests that sedimentation around MEB will increase and therefore MEB's maintenance dredging requirements should remain very low.

Though climate change should not affect navigation and berthing at MEB due to the port's sheltered position and the relatively favorable weather conditions in Cartagena, it will have significant implications for other maritime ports, as shown in Section 2.

Figure 9-3 – Approximate location of MEB approach channels

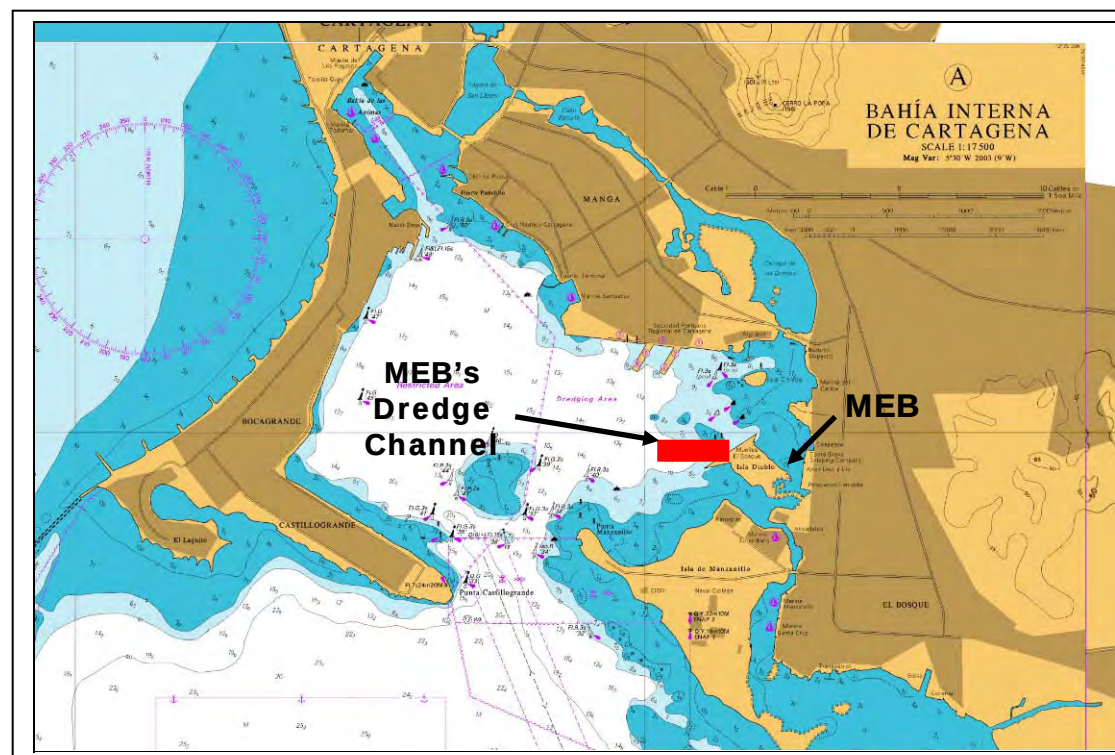
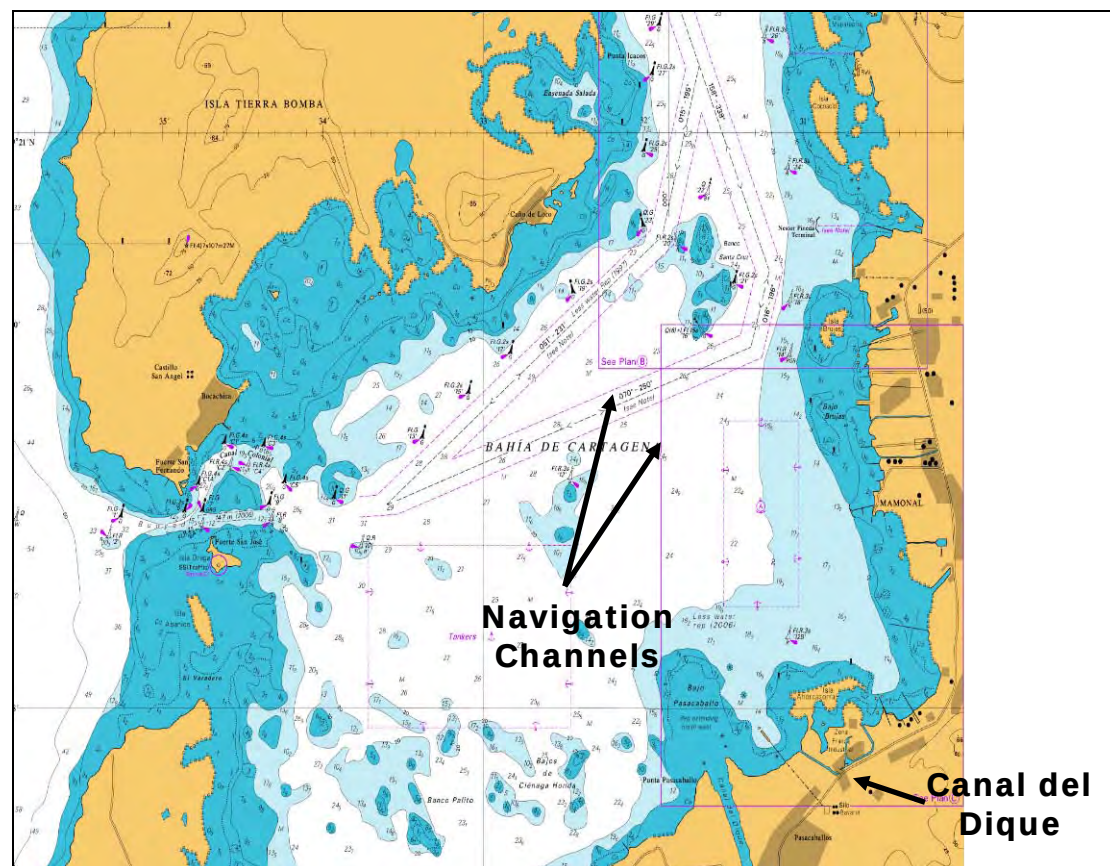


Figure 9-4 – Navigation Channels in Bay of Cartagena



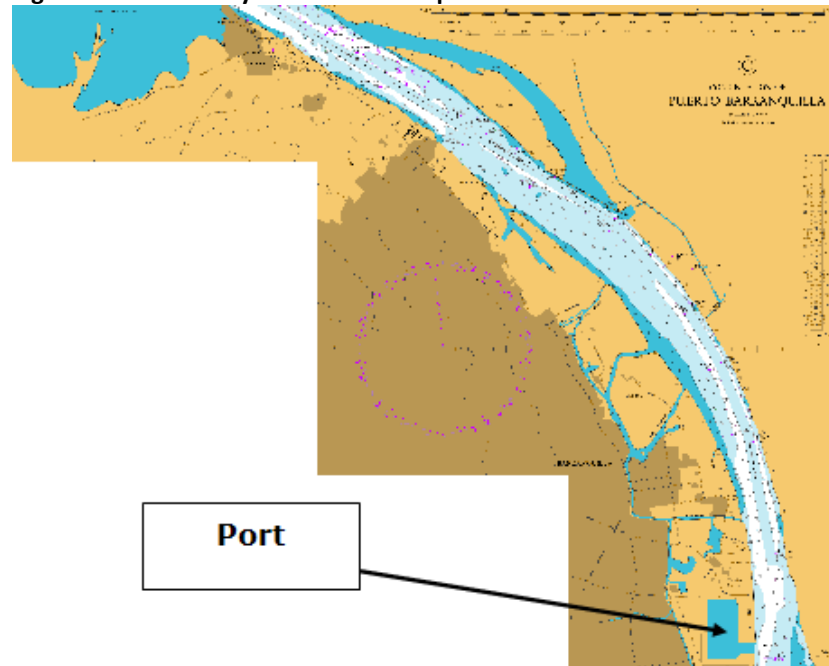
Navigation and Berthing at Other Ports in Colombia

Barranquilla is approximately 22km upstream of the Rio Magdalena estuary mouth and therefore, like Cartagena, is protected from wind and swell waves. Santa Marta's port is on an open stretch of coastline and therefore it is more exposed. However, it is on a north-west facing coast, which affords much protection from swell waves coming from the Atlantic and locally generated wind waves, which would tend to be from the north and north east as this is the direction of the prevailing winds.

Although Santa Marta and Barranquilla are farther north than Cartagena and closer to the tropical cyclone tracks, the cities are still south of the region of primary cyclone activity and are protected by the South American land mass from cyclones that typically track from the west

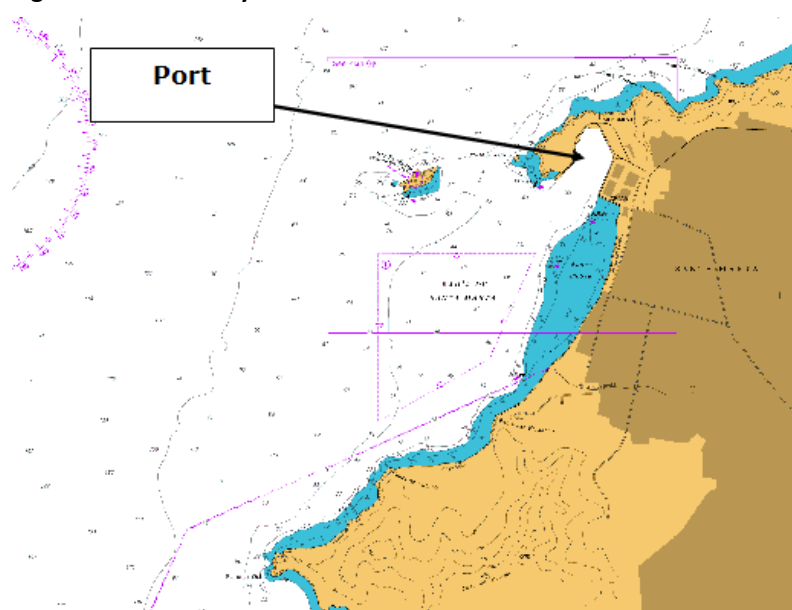
Limited depth causes navigation limitations in the port of Barranquilla. Dredging and construction works are ongoing to improve access to the port by larger vessels (SPRB, 2010). It is understood that the works already undertaken ensure a depth of 12m throughout the year (Ministry of Transportation 2009). Increases in sea level may reduce the problem. However, access is controlled not only by sea level but also by water flow in the Magdalena River and therefore if there were a reduction in rainfall across the catchment and/or increased water abstraction for irrigation because of climate change, water depth in the river channel will reduce and sediment load from the Magdalena River could increase and reduce water depth, thus requiring more dredging. The Magdalena catchment is very large and rainfall projections across the catchment are uncertain (with both increases and decreases projected across models). More intense and frequent storms would increase sediment load, though this is not projected for north-east Colombia (other ports within estuarine environments could face such a risk). There are no channel depth issues at Santa Marta, which is a natural harbor and can already handle Post-Panamax vessels.

Figure 9-5 - Admiralty Chart of Barranquilla



Similarly, Buenaventura on the Pacific coast has no underkeel clearance issues.

Figure 9-6— Admiralty Chart of Buenaventura



Buenaventura is within an estuary. Navigation to and from the port of Buenaventura is limited in depth to between 10.5m and 12.5m (Ministry of Transportation 2009) and maintenance dredging is required to ensure access. Due to the intense rainfall regime of the region, sedimentation rates from rivers into the coastal zone are very high. A new port has been proposed in Malaga Bay, which is to the north of Buenaventura and does not have any rivers feeding into it. Some believe that Buenaventura cannot be a successful hub port due to its high maintenance dredging requirement. Average rainfall projections for Buenaventura indicate potential future increases (up to 0.6mm per day across season according to downscaling projections presented in Appendix 1), and given the trend of increasing extreme rainfall characteristic of South America (Aguilar et al. 2005), it is possible that maintenance dredging requirements at Buenaventura will be exacerbated by climate change because of increased sediment load from rivers.

As no significant climate change risks to MEB related to navigation and berthing have been identified, no adaptation measure has been assessed in detail. However, given that the study timescale of 2100 is beyond the design life of the quays (which is 50 years), it is suggested that sea level rise should be considered before undertaking any replacement program.

- Berth operability assessments, where there is a potential for increased storm intensity which may lead to changes in berthing equipment or operations.
- Increased maintenance dredging in cases where sedimentation is projected to increase.

References

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10 Goods Handling

10.1 Introduction

One of the key factors which determine the number of ships that can dock at MEB and the rate at which cargo can be transferred through the port is the efficiency of the materials handling equipment.

A full description of MEB's materials handling equipment was provided by IFC (Scott Wilson, 2007). Mobile harbor cranes (Liebherr LHM 400 104 t) are used for unloading and loading containers and bulk cargoes such as grain and coke. The port also has a single 'Ship to Shore' crane (Paceco 237 – 27t) and a number of Rubber-Tyred Gantry (RTG) cranes (Mi-Jack 750 D 45t).

Other equipment is used for moving and storing cargo around the port, including four mobile reach container stackers (2 × Kalmar DRS4531-S5 and 2 × SISU Valmet), various container empty stackers and tractors (Sisu Magnum).

10.2 Climate-related factors

A number of climatic factors can affect the rate at which material can be unloaded, including wind, rain and lightning. Materials handling operations are reported to be seldom affected by high winds, rainfall or other adverse weather conditions (Scott Wilson, 2007). However, according to MEB, there are limitations placed on the operations of mobile harbor cranes (MHC) at MEB.

10.2.1 High winds

During periods of high winds these cranes are unsafe to operate (see Table 10-1). Other materials handling equipment are not believed to be affected, although high winds should be considered when evaluating maximum stack height for containers. At MEB it is understood that stack height is driven by the capability of the materials handling equipment, which limits the maximum stack height to four or five full containers and to six in the case of empty containers. There are empty handlers available that will stack up to eleven containers, but due to the risk that high winds may overthrow them this number is generally limited to six or seven. In locations where wind speeds may significantly increase under climate change, for example due to increased storm intensity, ports should consider the possible need to reduce stack height. This is not the case at MEB.

The financial impact to MEB of high winds affecting cranes can be of two types:

- Interruption in operations if the crane cannot be used and
- Damage to the crane if winds are of sufficient strength.

There are two key wind speed thresholds for cranes, which relate to two different modes of crane activity, as shown in Table 10-1: *Transportation mode* which refers to the movement of the crane and *operation mode* is corresponds to the loading and unloading of ships. *Boom of crane on ground* relates to the tying down of the boom to prevent damage.

If the transportation mode wind speed is exceeded, the interruption to operations will be limited. However, if the operation mode wind speed is exceeded, ship (un)loading would cease and a delay would occur. It is assumed that due to the systems that are in place to measure wind speed and take appropriate action, damage will only occur if wind speeds exceed the 'boom of crane on ground' threshold. Note that other meteorological factors can affect crane operations, namely:

- Thunderstorms cause operation interruptions and require the boom to be lowered at a height lower than the height of surrounding lightning rods on the port.
- Heavy rainfall can also cause operation interruptions.

Table 10-1 – Operating criteria for MEB’s cranes (Liebherr MHC type). Source: MEB, 2009)

Mode	Maximum wind speed	
	m/s	knots
Transportation mode	14	27.2
Operation mode	20	38.9
Boom of crane on ground	42	81.6

An anemometer measures wind speed on the crane boom and the operator is notified if the safe operating wind speeds are exceeded. There have been times when the cranes have not been able to operate due to high wind speeds, although these are understood to be rare at MEB. It has not been possible to get information on the dates and duration of these stoppages from MEB.

Measured daily wind speeds and directions at Cartagena airport meteorological station (Apto Nune Rafael) are discussed in Section 4.5, where a wind rose is provided. Frequencies for the higher daily wind speeds of interest to crane operations are provided in Table 10-2. Given the low frequency of daily winds greater than 13.9 m/s and the fact that daily wind speeds above the ‘operation mode’ threshold (20 m/s) are quasi-inexistent, frequent interruptions to cranes are not expected. This is consistent with the experience of MEB reported during the site visit, although no specific data on interruptions were available. However, in the absence of data on observed and future short-term wind gusts (as opposed to mean wind speeds), it is difficult to evaluate accurately crane operation interruptions.

Table 10-2 – Wind speed frequency based on wind rose using 19 years of measured hourly data during the period 1961-1990 from Cartagena airport, sourced from IDEAM

Wind Speed		Frequency	Beaufort Scale Description
m/s	knots		
13.9 – 17.1	27 – 33.3	1%	Near gale
>= 17.2	>= 33.4	0.1 %	Gale

10.2.2 Rainfall

Rainfall can affect materials handling operations in two ways:

- The movement of containers will be impacted if rain is sufficient to limit visibility or to flood the port (the latter is addressed in Section 7.2).
- Dry bulk cargoes can be loaded or unloaded in light rain, but in periods of heavy rain it is customary to suspend operations⁴⁰. This is particularly true for materials such as grain, where an increase in moisture content can spoil the product.

General thresholds for suspension of operations due to rainfall are not available as it is dependent on both the cargo and the port. Thresholds are set within the operational procedures of each port. Such thresholds have not been set by MEB, due to the moderate rainfall regime in Cartagena, but are likely to exist in other ports such as Buenaventura where rainfall is greater.

In ports where there is a clear seasonality in the movement of goods which can be spoiled by rain (such as grain), taking into account seasonal rainfall projections can be useful to correctly assess risk of spoilage to such goods. However, MEB’s throughput between 2005 and 2009 (including grain) does not show a clear seasonal pattern (see Section 1.3) and there is no indication from MEB that rainfall has caused any loading or unloading issues at MEB in the past. It is however reported to be an issue in the port of Buenaventura, where precipitation is much higher (USDA FAS, 2009a).

⁴⁰ Information provided by WorleyParsons materials handling specialists in Vancouver.

10.2.3 Lightning

It is understood from MEB that lightning can also prevent cranes from operating. However no information was available for MEB and due to the rarity of lightning storms and the short term nature of such events, it has not been pursued further.

10.3 Climate Change Risks

10.3.1 High winds

According to the analysis of future average wind speeds under climate change (Section 4.5 and Appendix 1):

- Modest increases in average wind speed are projected of at most 0.5 m/s (in June/July/August by the 2080s). Confidence in this projection is low.
- Cartagena is unlikely to experience an increase in tropical cyclone frequency because of its relatively low latitude and its position on the landward side of the east-west cyclone track.

While it is noted that short-term gusts of wind can affect crane operations, the climate change models do not provide projections for gusts, so it is not possible to evaluate whether future changes in gustiness could affect materials handling equipment at MEB.

10.3.2 Rainfall

The estimated increase in precipitation is 0.6% per annum (see Section 4.3)⁴¹. This is a total increase of approximately 54% by 2100. The maximum daily rainfall measured in 2008 was 158mm/d, which leads to a maximum daily rainfall in 2100 of approximately 245mm/d if the observed trend continues. Hourly rainfall data would be preferable to assess peak rainfall intensity, however daily data is a good guide to analysis in the absence of higher resolution data. Because of climate change, the intensity of precipitation events is expected to increase, particularly in tropical areas that experience increases in average precipitation (IPCC WG I, 2007). However, projections of extreme rainfall are generally considered unreliable, unless comprehensive work has been done to evaluate whether climate model projections are realistic. Such work does not appear to have been undertaken for the Caribbean coast of Colombia.

Rainfall thresholds for suspending operations at MEB are not available and therefore a more detailed analysis of this climate change risk is not possible. However, in general, rainfall intensity in Cartagena is low, exceeding 50mm/day less than 1% of the time. While this looks likely to increase in the future due to climate change, it is not expected to lead to a significant increase in the frequency of disruptions to materials handling.

10.3.3 Lightning

Increased global mean surface temperatures and higher atmospheric water vapor are generally expected to increase rather than decrease lightning incidence. However, climate model projections are not currently available. Further information on climate change implications for lightning is given in Appendix 1.

⁴¹ This figure is based on the assumption that observed historic trends in rainfall will continue into the future, because the climate model output for rainfall over Colombia is unreliable. According to the IPCC, rainfall intensity is projected to intensify in the future as the climate warms, so assuming that existing trends will continue could be an underestimate (IPCC WG1, 2007). For further detail, see Section 4.3.

10.4 Adaptation

As no risk of increased materials handling equipment disruptions is projected under climate change, adaptation options are not evaluated. However, if risks are identified in other ports, adaptation strategies will generally relate to the choice of materials handling equipment on renewal or purchase and the development of materials handling systems that can cope with future climatic conditions, for example the use of closed systems in areas with high precipitation.

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11 Inland Transport Beyond the Port

11.1 Introduction

Trucks coming into and going out of MEB use a limited road network. Without continued access to these roads the port would be unable to operate efficiently. Therefore, despite the fact that the roads fall outside MEB boundaries, they are integral to its function and must be factored into an assessment of climate change risks.

All goods that are imported or exported are transported within Colombia. Containers and bulk cargo are likely to come from and go to Colombia's main population centers: Bogota, Medellin, Barranquilla and Cali (World Bank, 2010). Imported grain is likely to be transported to major poultry-producing regions, and coke will depart from key coke production centers. Most goods are transported to and from MEB by truck on Colombia's road network, though waterway transport is also available. Rail transport is also used in Colombia, notably by Santa Marta for coal transport (USDA FAS 2009b). It is the owners of the cargo that finance and coordinate this transport. MEB is not directly involved.

However, according to MEB, the cost and accessibility for the inland transport of goods to and from the ports in Colombia is a major factor in the decision by customers about which port to use. It is estimated that land transportation accounts for around one third of total transportation costs (USDA FAS, 2009b). Geographical location therefore plays a key role in a customer's choice of port; the nearer the port is to population centers, the lower the land transportation costs. If roads to a port are adversely affected by climatic factors, other forms of transport may become increasingly cost effective. Adapting to the land transport realities will therefore be increasingly important.

It is important to note that much of the road network in Colombia is already in a state of disrepair, with over 50% of the road network being classed as 'bad or very bad' (USDA FAS, 2009b). Any delays in the movement and access of goods to and from the port can have a direct impact on the day-to-day work at the port, increasing load times and affecting departures from the port to international markets. Blockages may also occur on roads around the port, as goods truck attempt to leave the port perimeter.

In this section, climate change impacts on the road network directly outside MEB in Cartagena are considered including impacts of sea level rise as well as changing precipitation patterns. Climate change impacts on the wider transport network from Cartagena to the major population and industry centers are examined. For comparison, climate impacts on transport routes for the competitor ports of Buenaventura, Barranquilla and Santa Marta are briefly discussed.

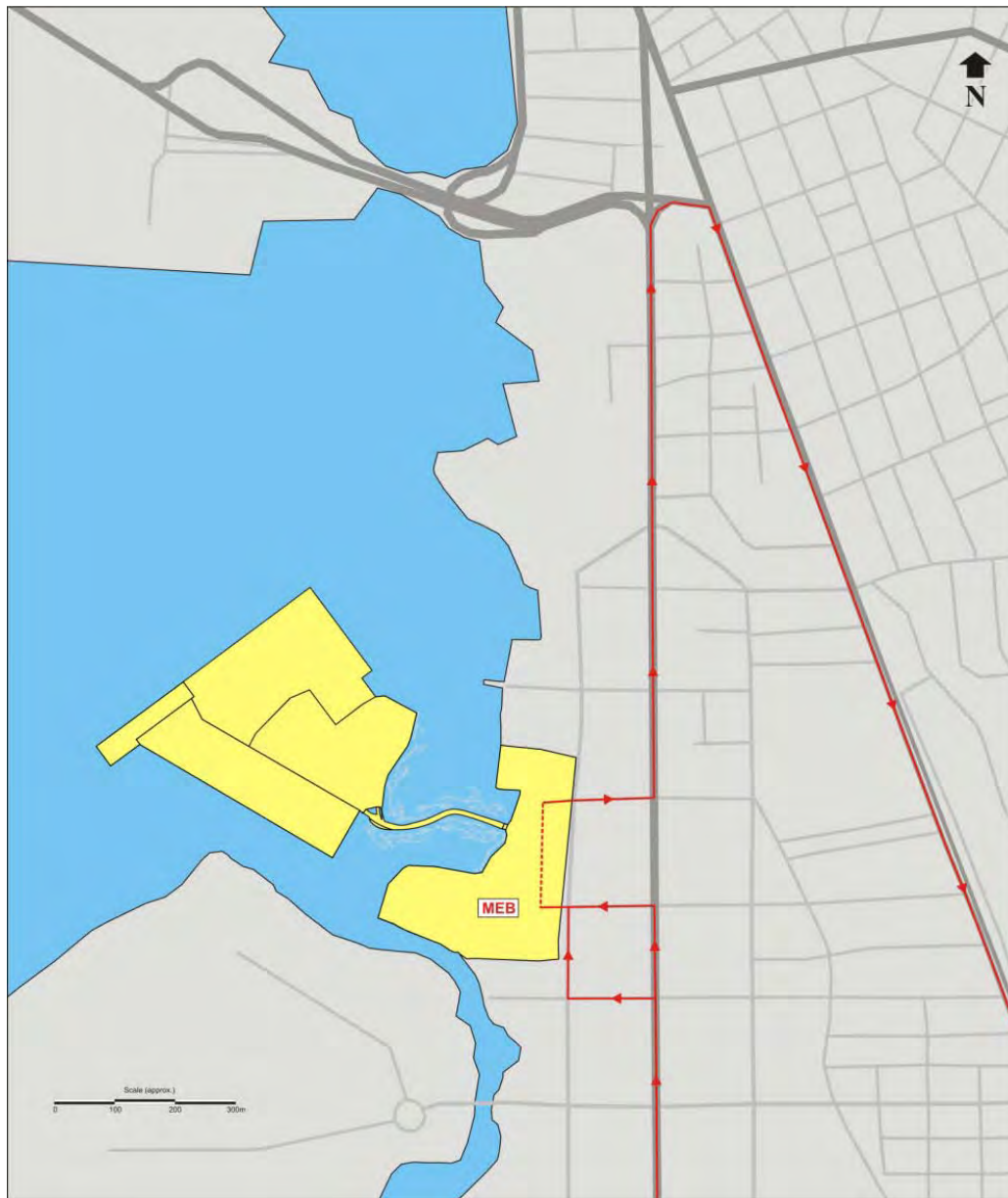
11.2 Climate-related Factors and Climate Change Risks to Roads Directly Outside MEB

There are two four-lane main roads running into El Bosque that are used by trucks to and from MEB, a few blocks behind the port. They are both oriented north-south, with Avenida Crisanto Luque (the closest to the shore) flowing southwards out of the city and towards the Mamonal industrial zone, and Avenida Bosque along which traffic flows northwards (see Figure 11-1).

Trucks arriving at the terminal generally use Avenida Bosque and then turn back on themselves where the road meets Avenida Luque, a few blocks north of the terminal. Exiting trucks generally go southwards along Avenida Luque (Scott Wilson, 2007).

Connection between the terminal gates and these highways is via one of three two-lane residential streets oriented east-west. MEB has recently set-up a one way system for users of the port, so that trucks arrive at the port from the south and enter through the central gate. Trucks leaving the port use the northern gate and head north before turning right and heading east towards the major routes. A plan of the road access is provided in Figure 11-1.

Figure 11-1 – Road Access for Trucks using MEB (traffic direction is indicated by arrows)



Climate change risks to the local road access to MEB include:

- Flooding due to intense rainfall,
- Flooding due to sea level rise, and
- Increase damage to the road surface due to changes in temperature and rainfall.

Figure 11-2 – Street outside MEB port. Source: Scott Wilson, 2007.



11.2.1 Impact of sea level rise on road transport in Cartagena

This section analyses the risk of seawater flooding of the local road network used by vehicles going to and from the port, as it can affect MEB's staff and transportation of goods. The risk of SLR on roads inside the port fenceline is discussed in Section 5.

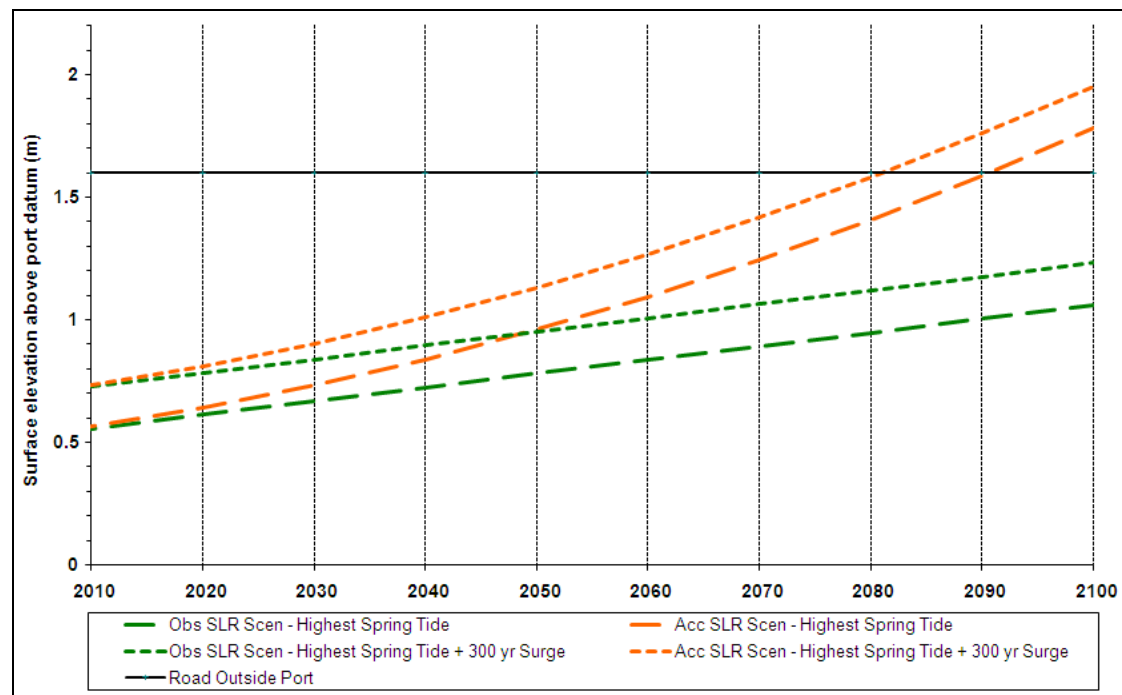
To carry out a robust assessment of Cartagena's flood risk, it is important to use a Digital Elevation Model (DEM) of the city (similar to the one built during this assignment for the bay of Cartagena). This would be of value to the city as a whole as well as for MEB's purposes. Because a DEM of Cartagena could not be obtained, this assessment reviewed existing inundation assessments for Cartagena (Invemar, 2005 and Alexandre et al, 2008), and due to the lack of elevation data for the road network directly outside the port, this assessment assumes that it is at the same level as the roads of the port mainland area (1.6m above the port plan datum)⁴². The road running east-west from the port climbs so significantly that the major roads entering El Bosque are considered at no risk from SLR.

Under the Observed SLR scenario, sea level out to 2100 is not projected to be above the level of the road outside MEB, as the maximum projected sea level (including astronomical tide, annual variations and a 1 in 300 year storm surge) is approximately 1.2 m (see Figure 11-3). Under the Accelerated SLR scenario, there is a risk of flooding: a 1 in 300 storm surge aligned with a high spring tide would flood the road after 2080 and the highest spring tide of the year alone (i.e. without a storm surge) is projected to flood the road after 2090 (Figure 11-3).

As discussed in Section 5, trucks can still run if the flood water depth is relatively shallow (below about 30 cm). Only in the Accelerated SLR scenario with the highest spring tide and 1 in 300 year storm surge is the 30cm flooding depth exceeded by 2100.

⁴² Based on review of aerial photography and the site visit.

Figure 11-3 – SLR scenarios relative to the estimated elevation of the road outside the port



It is important to recognize that if the road outside MEB is flooded by seawater, it means that much of the port itself is also under water. Only the quays and neighboring storage patios would not be flooded. Without adaptation such flooding would challenge business continuity at MEB and could be catastrophic for Cartagena. In such cases, the role of the public sector and regional-scale adaptation are crucial to protecting the local road network connecting the port to the city.

CIOH has undertaken flood mapping of Cartagena using the LiDAR dataset. SLR is projected directly onto the Digital Elevation Model (DEM) of the city. The dataset has a high resolution and a quoted accuracy of approximately 300 mm, although it is likely to be better than quoted. Although flood mapping was not the primary driver for obtaining the data (Sanabria, 2007), it is highly valuable in the assessment of flooding by CIOH and climate change in Cartagena. The output from these assessments has been presented and should be made widely available. The projected flooding for SLR up to 100cm is presented in Figure 11-4⁴³. It is not clear what existing water level is used. Based on the extent of flooding at MEB it is believed to be high tide water levels. Figure 11-4 shows extensive flooding of the mainland port area when SLR is 100 cm, which appears to extend to the neighboring roads around the port, although it is difficult to see.

⁴³ Images extracted from presentation provided by CIOH. The original images showed a large area of Cartagena and have been cropped and expanded to focus on MEB.

Figure 11-4 – Projected extent of flooding due to SLR according to Alexandre et al. (2009)



11.2.2 Impact of changing precipitation on road transport in Cartagena

Flooding in Cartagena is common (Lacambra et al., 2007), most frequently affecting the Castillo-Grande, Bocagrande and old quarter part of the city centre (Centro) areas (University of Cartagena, 2008). Flood events affecting roads in these areas are shown in Figure 11-5 and Figure 11-6. While flooding can be caused by high sea levels, precipitation-derived flooding is also common in Cartagena, due to rainwater run-off from hard surfaces. There may also be an element of groundwater and riverine intrusion into the drainage system from the surrounding catchment (University of Cartagena, 2008). While it is clear that flooding is a problem for roads in the city, it is unclear how frequently and to what extent flooding occurs in the El Bosque region of Cartagena, and on the roads used by MEB and its customers.

Figure 11-5 – Flooding of Roads in Barrio Castillo-Grande (University of Cartagena, 2008)



Figure 11-6 – Flooding of roads in Barrio Centro (University of Cartagena, 2008)



In order to consider the risks of precipitation to MEB's road network in Cartagena under a changing climate, it is necessary to have an understanding of the drainage system as well as of rainfall projections. In terms of the drainage system, the University of Cartagena is currently conducting a study of rainfall drainage as part of the master planning process for the city (see section 6). In 2008 this study reported on the conditions of drainage channels across Cartagena. As shown in Table 11-1, El Bosque, where MEB is located, had high levels of rubbish, debris, sediment and damming in its channels, with high localized cases of siltation and structural flaws. Additionally, in some drainage channels, insufficient hydraulic capacity was noted.

Table 11-1 – Status of drainage structures in El Bosque region (marked as A37 to A41). Source: University of Cartagena, 2008, p67.

VERTIENTE BAHIA DE CARTAGENA												
Cuenca		A37	A38	A39	A40	A41	A42	Santa Clara	Bellavista	Mamonal	Albornoz	Total
Numero de estructuras		No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	%
Problemas Presentes	Basuras	28	5	58	24	61	14	186	63	45	31	515 90
	Escombros	17	1	17	14	34	12	109	43	36	18	301 53
	Sedimentos	29	5	62	27	70	14	191	65	46	36	545 95
	Aguas Residuales	8	1	1	4	19	0	40	30	19	24	146 26
	Invasion de Zonas de Retiro	2	0	1	1	2	1	21	1	6	1	36 6
	Represamiento	10	1	8	6	25	3	62	35	27	24	201 35
	Incap. Hidrául.	2	0	1	2	4	1	17	5	1	1	34 6
	Socavación	0	0	1	0	1	2	4	3	1	1	13 2
	Colmatación	4	1	20	6	9	3	16	6	3	2	70 12
	Falla Estructural	6	1	20	7	17	2	32	10	0	5	100 17
	Inestabilidad Geol.	0	0	0	0	0	0	3	0	0	0	3 1

Table 11-1 -Translation of key terms of the table above

Cuenca	Catchment area
Numero de estructuras	Number of structures (drainage channels)
Basuras	Rubbish
Escombros	Debris e.g. concrete, blocks, rocks
Sedimentos	Sediments
Aguas residuales	Wastewater
Anvacion de zonas de retiro	Inundation of buffer zone
Represamiento	Damming
Incap. Hidraul	Insufficient hydraulic capacity e.g. surcharging
Socavacion	Scouring
Colmatacion	Siltation in specific areas of channel
Falla estructural	Structural flaw
Inestabilidad geol.	Geologic instability

To consider whether intense precipitation events may lead to flooding (either due to insufficient capacity or blocked drains), it is important to have hourly rainfall data and projections. This would allow an analysis of whether a high-intensity storm event may overwhelm the drainage system. While hourly data are not available, there has been an observed trend of increasing precipitation on wet days of 0.6% per year in Cartagena. As accurate information on trends in the most extreme rainfall events in Cartagena is not available, this 0.6% per annum increase provides a broad-brush estimate of future trends⁴⁴.

Although the El Niño Southern Oscillation (ENSO) is known to have an impact on precipitation in Colombia, there is considerable uncertainty about ENSO-related precipitation anomalies (see Section 4). Therefore, the assessment did not analyze further the effects of ENSO on precipitation.

While the relationship between precipitation, the drainage channels in El Bosque and flooding is unknown, the evidence that it is “very likely...that heavy precipitation events will continue to become more frequent” (IPCC, 2007, p15) in the future, combined with the knowledge that precipitation intensity has been increasing to date and that the drainage system is already experiencing strain, suggests that the risk of flooding is increasing.

⁴⁴ Note that according to the IPCC, rainfall intensity is projected to intensify in the future as the climate warms, so assuming that existing trends will continue could be an underestimate (IPCC WG1, 2007). For further detail, see Section 4.3.

11.2.3 Adaptation of Cartagena's road system

Responsibility for adaptation of the road system would fall under the Secretaria de Infraestructura of the Municipality of Cartagena. Therefore if MEB implement adaptation measures to increase the height of the port or provide flood protection for it, there could become a point where the road is the most vulnerable part of the system upon which the port relies.

MEB would benefit from monitoring the progress of Cartagena's rainwater drainage study, CIOH's SLR flood studies and also from supporting better drainage maintenance by the City. This is because, while MEB is not directly responsible for transport, delayed movement of goods could damage MEB's reputation. If transport is frequently delayed, port clients may switch their business to less flood-prone areas.

It is noted that MEB has already built a large drainage channel to the north of the port to assist drainage of the area. Continued cooperation on drainage with the City (for example, to maintain high standards of maintenance) will help manage the risk of flooding.

11.3 Impact of climate change on the transport network across Colombia

A further potential impact of climate change on MEB could be impacts on MEB's reputation, if transport delays within Colombia due to climate change are felt strongly by its clients. If climate change were to detrimentally affect the reliability of road transport to and from MEB more than its competitors, the port's reputation could suffer.

The Ministerio de Ambiente, Vivienda y Desarrollo Territorial (MAVDT) provided a dataset of hazards recorded in Colombia in 2008. These data were analyzed to identify the climatic events that are currently occurring throughout Colombia and the possible effects of these events on transport to and from Cartagena. The climatic events affecting transport to and from competing ports were also examined, to try to determine where MEB stands in relation to its competitors.

The pattern of climate hazards experienced across Colombia in 2008 is presented in Figure 11-7 and Figure 11-8. It should be noted that only one year's worth of data was available, and the frequency and locations of extreme vents in other years could be quite different.

As shown in Figure 11-7 and Figure 11-8, climatic hazards were largely concentrated around the coastal areas of Barranquilla and Cartagena, in the area between Medellin and Cali, and around Bogotá.

Around Cartagena, the main climate risks observed are storms⁴⁵ and flooding (Lacambra et al., 2007), although landslides have also been a problem. There was one landslide in Cartagena in 2008. Landslides affecting roads to and from the port could lead to delays, and in the worst case scenario temporary road closure.

⁴⁵ It is not known whether this refers to rain storms, wind storms or both.

Figure 11-7 – GIS map showing climatic hazards reported in 2008 in the northern region of Colombia by the Colombian Ministry of Environment, Housing and Territorial Development (MAVDT). Hazards were reported at the municipality scale.

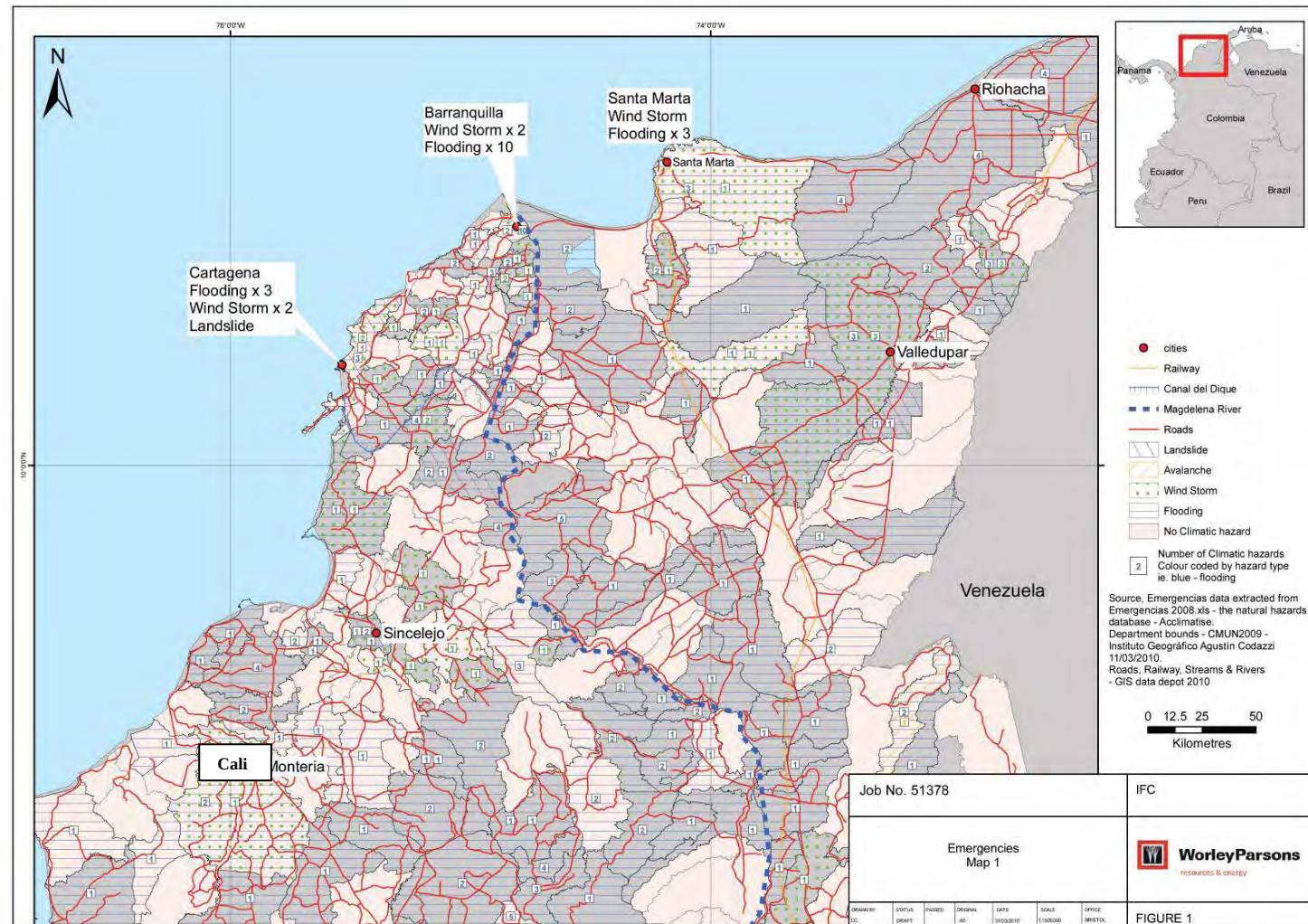
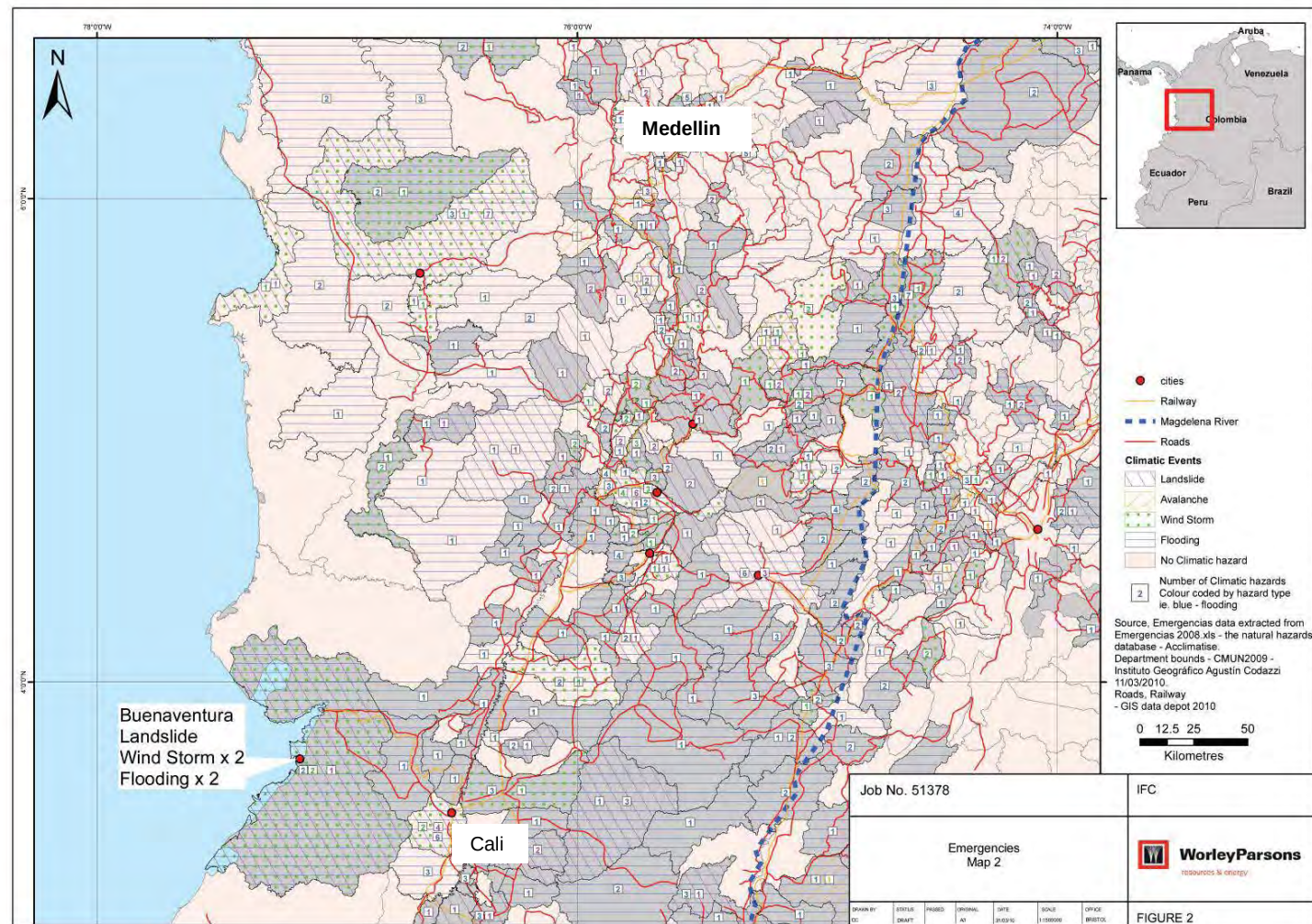


Figure 11-8 – GIS map showing climatic hazards reported in 2008 in the western region of Colombia by the Colombian Ministry of Environment, Housing and Territorial Development (MAVDT). Hazards were reported at the municipality scale.



Three floods were reported in the MAVDT dataset in 2008 in Cartagena, and a number of floods occurred along transport routes to Bogotá, Sincelejo, Medellín and Cali. Two storms were reported.

Though transport via waterways is not currently important for MEB, the effect that both flooding and storms may have had on waterway transport is nonetheless worth noting, with flooding in 2008 having affected almost the entire course of the Canal Del Dique to the Magdalena River. Extreme precipitation events can also cause silt to build up in waterways, restricting the ability of cargo to be transported downstream.

Transport to and from the other three major ports in Colombia may also have been affected by extreme events in 2008. Santa Marta appears to have been the least affected, with only one reported storm and three floods in 2008. Buenaventura, sometimes known as the 'wettest city in the world' saw only two flood events in 2008, along with two storms and one landslide. This may be atypical; it is understood from MEB that the roads to and from Buenaventura are often closed during wet periods due to landslides from the Andes. On the other hand, Buenaventura's proximity to Cali and Bogotá result in lower transport costs overall, a strong advantage compared to the other three main ports, according to MEB. There has and continues to be significant investment in Buenaventura, for example the upgrading to the road system to double lane highways within the next 6 to 7 years.

The port of Barranquilla experienced two storms and ten flood events in 2008, with further flooding all along the course of the Magdalena River, one of the main arteries for the flow of goods to and from the port to southern Colombia, and Bogotá in particular (USDA FAS, 2009b).

On the basis of the 2008 MAVDT data, it would appear that Barranquilla was worst affected by extreme climate events, with little to choose between the number of events hitting the other three port cities. Clearly, however, one year's worth of data is insufficient to assess properly the relative exposure of the cities.

In 2008, transport links connecting Cartagena to major population hubs were affected primarily by flooding (Cartagena to Bogotá) and storms (Cartagena to Sincelejo and Cali). This may, on occasion, have slowed the transport of goods to and from the port to the surrounding areas. From the 2008 data, flooding along the main road transport links was the principal climate hazard to and from all of the ports. There do not appear to be significant differences in the number of incidents seen along the various road transport routes; the routes from all four ports passes through areas with high frequency of flooding in 2008. However, it appears that the route southwards from Santa Marta was generally less affected by floods.

As outlined in the climate review (Section 4) it is expected that climate change will aggravate the kinds of climate risks experienced in 2008. Due to increases in rainfall intensity, more floods and landslides may be expected.

Clearly, MEB is not responsible for the roads and waterways outside the port and beyond, and so the risk posed to MEB due to climate change in this respect is primarily reputational.

MEB and its competitor ports can do little directly to reduce the vulnerability of Colombia's transport network to climatic events, and, any upgrades will be the responsibility of local and national transport departments and agencies. However, if MEB has evidence from its customers that they have experienced disruptions, it could use this information to engage with government on the importance to the economy of having a climate-resilient transport system.

The effects of precipitation on transport on Colombia's waterways

Colombia's inland waterway system carried less than 3% of Colombian general cargo in 2005 and received less than 2% of the Colombian transportation budget (USDA FAS, 2009b). However, there may be opportunities in the future to increase its use.

There are four main inland waterways. The Magdalena, which is connected to the Bay of Cartagena by Canal del Dique, accounted for 45% of the 2007 inland waterway cargo movement (Ministry of Transportation 2009). Major products shipped along the Magdalena include petrochemicals, machinery, cattle, cement, fertilizers, and wood but it does not provide a link with any of the major cities and does not operate at full capacity. One of the primary issues is the maintenance of access. Barranquilla does have 24 hour navigable access but only to a depth of a couple of metres. The Canal del Dique has more serious access problems and is not navigable at night (USDA FAS, 2009b).

The trend in observed flow in the Magdalena has been relatively constant over the past 50 years. Its flow is affected by rainfall and by abstractions for drinking water and irrigation schemes. The future projections of total rainfall over the Andes, which provide much of the rainfall within the Magdalena catchment, are variable, with both increases and decreases projected depending on the season and model (see Section 4).

Sedimentation is a key issue in the Magdalena and Canal del Dique and the majority of sediment is transported in the Magdalena during extreme rainfall events (Restrepo et al, 2005). Therefore increased rainfall intensity could increase sedimentation and reduce the navigability of the Magdalena.

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12 Social Performance

MEB's social performance can be affected by climate change if:

- Its relationship with its local communities is degraded because communities are negatively affected either directly by changes in climate or by impacts from the port aggravated under the influence of changing climatic conditions, or
- The health and safety of its employees is affected by changes in climate.

12.1 Analysis of climate change risks to local communities

This section reviews climate-related impacts on local communities living in the area immediately surrounding MEB, outlining the key climatic vulnerabilities and identifying potential risks to MEB. For the most part, these issues are discussed qualitatively, though the analysis draws on quantitative information where available.

A more detailed discussion of the local context and the state of human development in Colombia and around Cartagena is presented in Appendix 7.

12.1.1 Climate-related risks to MEB because of impacts on communities around the port

The MEB leadership is committed to good environmental and social management and maintains good relations with stakeholders. MEB supports local communities through a variety of philanthropic and awareness activities. MEB is the only terminal in Colombia to have received ISO certifications (including ISO9001, ISO14001 and ISO18000).

Nevertheless, as reported during the site visit, MEB does from time to time receive complaints from the community regarding specific activities at the port as follows:

- **Truck movements on local roads**

The route taken by trucks between the highway and the port passes through some residential areas. These, combined with traffic from other local industry can lead to congestion. MEB estimates that 1,584 trucks move through the area each day, of which MEB is responsible for approximately 18%.

Complaints have been received by MEB from local residents relating to blocked roads, and the deposition of mud along roads, picked up by trucks from the unpaved sections of roads at the port, during wet weather.

While future climate projections are unclear as to whether average seasonal precipitation will increase or decrease, it seems likely that the intensity of precipitation will increase, which may lead to greater likelihood of mud being picked up by trucks. However, as outlined in Section 5.3, it is understood that MEB plans to pave these areas which will reduce the likelihood of mud being deposited on local roads.

- **Dust from coke handling**

In general, dust generated by cargo handling does not disperse out of the site and has therefore not caused concerns among the community.

However, there is a perception among the local community that the port is handling coal rather than coke and that the dust they see from time to time is coal dust. Colombia is one of the largest coal exporters in South America. Many of the coal mines in Colombia have been linked to health problems relating to coal dust inhaled by miners and local residents, and coal dust has become a polemic issue in Colombia. Coal dust can cause respiratory and lung diseases, including pneumoconiosis, pulmonary tuberculosis, emphysema and chronic bronchitis. The port of Santa Marta is one of the busiest coal exporting hubs and has seen its tourism industry decline as a result of the black dust left from coal exports (International Labor Rights, 2006).

Local residents have complained to MEB that their children are becoming sick through exposure to coal dust. In all cases, MEB followed up the complaints with a medical inspection to reassure residents that they are in fact handling coke and this is not the cause of illness.

MEB manages dust from coke by spraying it with water every few days to prevent it from drying out (see Section 8.2). Future increases in temperatures could result in the coke drying out more quickly and requiring more frequent spraying. However, the cost of water for such activities is passed onto the client.

Sodium carbonate or soda ash is also handled at the port. Direct contact or inhalation can cause irritation to the skin, eyes and respiratory system. MEB has received complaints of eye irritation at times of high winds, and has since revised its handling procedures for soda ash.

In summary, given that the immediate population around MEB is not thought to be particularly vulnerable or exposed to climate change, it is not expected that they will present additional risks to MEB.

12.1.2 Climate-related risks to MEB due to impacts on the wider Colombian community

The study has reviewed the possibility of climate change leading to a greater incidence of unrest or violence in certain parts of the country, which could impact either supply routes or the production of certain crops being exported through the port. According to the World Bank, the civil conflict in Colombia has had a significant economic impact: if the country had been at peace for the last 20 years, the per capita income of the average Colombian would be 50% higher today, and it is estimated that 2.5 million children would live above the poverty line (World Bank 2008).

A range of studies have explored the linkages between climate change and conflict, generally concluding that rising temperatures and unpredictable weather events can give rise to increased scarcity of natural resources, including land and water, which in turn can trigger conflict (Raleigh, 2006). Some experts have suggested that climate change was a factor in the war in Darfur (University of Peace, 2006). However, scarcity of resources is generally one element in a complex patchwork of social, political and economic factors that drives conflict.

Poverty in Colombia is higher in rural areas, where there is also a greater presence of armed conflict. In rural areas the rate of extreme poverty is around 30%, double the rate of urban areas (World Bank, 2007). This means that people in rural areas are both more vulnerable to climate change and more likely to come into contact with violence. However, very little research has been carried out on the links between global environmental change and crime or violence in Colombia, and no data exists on it. (See Appendix 7 for a series of maps that illustrate the level of human development, and unmet basic needs across Colombia.) Cartagena's level of unmet basic needs is in the range of 5% to 30%.

Discussions with experts in climate change and social development, and analysis of the local context have led to us ruling this out as a potential risk to MEB for the following reasons:

- The areas of conflict are located away from Cartagena, primarily in the rural parts of the country.
- Many other factors affect both MEB's supply and distribution network across the county and the dynamics of the ongoing conflict, making it difficult to isolate the impacts resulting solely from climate change.

12.1.3 Conclusion

Findings from the site visit, research and analysis of information collected suggest that the population around MEB is not particularly vulnerable to climate change, and unlikely to represent a major risk to MEB, as:

- Only marginal parts of Cartagena are poor (most of the population is comparatively more well-off than the Colombian average), and those communities located close to the port are not classified as low in socio-economic development,
- Fishing communities are not active in the bay of Cartagena,
- MEB is located within a mostly industrial zone of Cartagena,

- MEB has plans in place to reduce its impacts on surrounding communities due to mud from truck movements and coke handling, and
- MEB has good relations with its neighbors and addresses proactively any complaints it receives regarding its activities.

This study has ruled out the possibility of any risk to MEB from wider climate related socio-economic impacts, including climate change contributing to increased drug-related violence in the rural areas.

12.2 Analysis of direct climate risks related to MEB's workforce

12.2.1 Overview

MEB employs approximately 250 people. These employees represent a second stakeholder group, in addition to the local community, which could potentially be impacted by climate change, with potential implications for MEB's performance and reputation.

Here, climate-related risks to the workforce which could affect MEB are reviewed. The existing health complaints of MEB staff, climatic vulnerabilities and impacts on the health and productivity of the workforce are outlined, and potential risks and costs to MEB are identified.

12.2.2 Climatic vulnerabilities of MEB staff

This section examines the climatic sensitivities of the causes of absenteeism and illness among MEB workforce to establish whether or not the number of employees absent or ill could be affected by climate change.

Although vector-borne diseases, such as malaria, have been highlighted at a national level as a likely health risk impacted by climate change, these diseases do not affect Cartagena.

The most common causes of absenteeism recorded by MEB over the past five years are attributable to orthopedic problems including fractures, sprains, strains, and other injuries to fingers, hands, knees, ankles, toes and to back pain, as well as maternity leave. These are unlikely to be affected by changes in climate. The top ten causes for staff to be absent are shown in Table 12-1.

Table 12-1 – Top causes for MEB staff to be absent (days absent) (Source: MEB). Red text indicates conditions potentially affected by climatic conditions.

Year	2004	2005	2006	2007	2008	2009	Total days
Total days lost	86	119	374	521	975	923	
Most common recorded reasons							
Knee injury	3		32	30	101	127	293
Maternity leave				84	63	124	271
Backache		20	16		58	106	200
Back or leg pain after surgery					123		123
Finger injury	36		20			53	109
Pterygium				55	37		92
Arm injury						89	89
Muscle contracture	4			45		30	79
Chicken pox			21	20	38		79
Dislocation, sprain of lower limbs			24	21	30		75
Eye infection, e.g. conjunctivitis			17		37	13	67
Toe fracture				15	43		58
Cutaneous/ skin abscess	2		31		3	20	56
Dysfunction of cranial nerve					42		42
Sprained hand	11			29			40
Convalescence after surgery				20		20	40
Spinal condition						40	40
Common cold	1		10		8	18	37
Intestinal infection	3					31	34
Ingrown nail	8	3	19				30
Shoulder injury		30					30
Clavicle fracture				30			30
Fracture (unspecified)					30		30
Gallbladder			27				27
Hernia				24			24
Trauma (unspecified)	5	15					20
Appendicitis			20				20
Detached retina		19					19
Pregnancy related illness						18	18
Joint pain		16					16
Tennis elbow		16					16
Hypertension					5	6	11
Sprained wrist	5						5
Viral congenital disease	4						4
Chest contusion	4						4
Heat stroke					2		2

At MEB the company pays full salary to any employee during the first three days of sick leave. Following this the government pays, through reimbursement to the company, for up to 70% of their salary for the remaining period of absence. Because of the limited period during which the company must pay, the costs to MEB arising from sick leave are small. Table 12-2 shows the costs of absenteeism for illnesses that may be related to climatic factors.

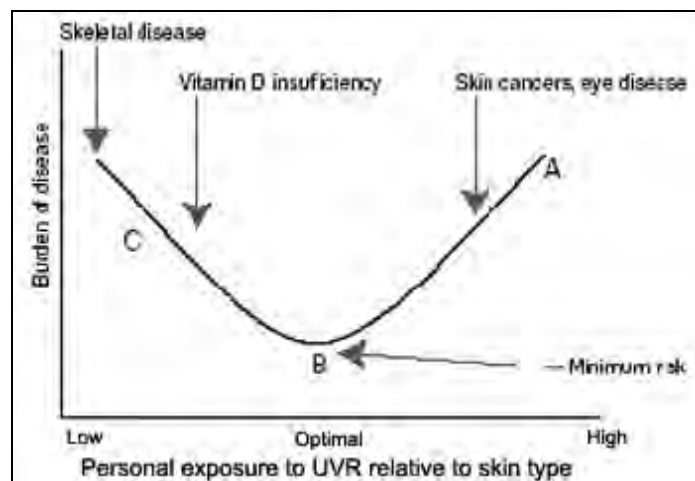
Table 12-2 – Cost of absenteeism relating to climatically linked illnesses from 2004 to 2009, US\$

	Cost to MEB (U\$S)					
Illness	2004	2005	2006	2007	2008	2009
Pterygium	0	0	0	507	393	0
Cutaneous/ skin abscess	86	0	553	0	129	768
Hypertension	0	0	0	0	84	126
Heat stroke	0	0	0	0	84	0

Note: These figures have been calculated based on the following: an average monthly salary of US\$ 1,300 per employee; MEB paying for the first three days of sick leave only; each monthly recorded illness corresponds to one single case. The following are unknown and have not been included in calculations: administrative costs of processing government reimbursement claims; and costs of replacement workers.

Considering the illnesses in Table 12-1 that may be linked to climatic conditions, skin and eye complaints are a relatively common cause of absenteeism recorded by MEB. Exposure to solar ultra violet radiation is important for human health: too little can cause deficiencies in vitamin D and lead to bone diseases such as rickets. However, excessive prolonged exposure can also be harmful and lead to a range of skin and eye problems including sunburn, skin cancer, cataracts and others, as Figure 12-1 illustrates.

Figure 12-1 – Schematic diagram of the relation between ultraviolet radiation (UVR) exposure and the burden of disease (Lucas et al., 2006)



Points A and C represent inappropriate UVR exposure. Fair-skinned populations in Australia with high outdoor UVR exposure typify point A. Point C represents people with insufficient UVR exposure, whose dietary vitamin D intake will also be important in determining their vitamin D status. Point B represents optimal UVR exposure: a person with careful titration of correct UVR dose for skin type.

The European Environment and Health Commission predicts that exposure to higher levels of UVR will 'result in increased levels of skin and eye damage over the coming decades. In particular, Caucasian populations of Europe and North America may experience a 5–10% increase in skin cancer cases during the middle decades of the 21st century' (EEHC, 2007).

Although there is 'currently little research and no systemized tracking of how climate change may be affecting dermatologic conditions' (International Society of Dermatology, 2009), some research does point to a link

between certain eye conditions and exposure to ultraviolet radiation. In a paper on the health impacts of climate change on people in the Maldives, Moosa (2008) states that, 'in addition to infectious diseases, the Maldives is witnessing an increase in the negative conditions of the skin, subcutaneous tissue and of the eyes. This increase is linked closely to climate change that is resulting in increased exposure to ultraviolet radiation (UVR). Medical records in the Maldives indicate a rapid increase in radiation-related disorders of the skin and subcutaneous tissue, as well as in cases of herpes viral vesicular dermatitis (cold sores). They also show an increasing trend of pterygium, a condition of the eye related to exposure to UVR'. Although benign, if untreated, it can lead to visual impairment.

With regards to pterygium at MEB, four periods of leave attributed to this condition were recorded in 2007 in the months of May, July, September and November, amounting to a total of 55 days absent and corresponding to 7.6% of total days absent in that year; and in 2008 periods of leave were recorded in February, March and June, amounting to a total of 37 days absent and corresponding to 3.8% of total days absent in that year.

To investigate whether a relationship between incidence of absenteeism for pterygium and climatic conditions at MEB can be identified, the number of days lost was correlated against monthly rainfall (an inverse proxy for UV radiation). Figure 12-2 and Figure 12-3 below illustrate the lack of correlation between cases of pterygium and rainfall. While this may be for a number of reasons (e.g. insufficient number of cases for meaningful statistical analysis, the need for sub-monthly rainfall data etc), given the low cost to MEB of absenteeism (Table 12-2), the financial risks to MEB are not important.

Figure 12-2 – Days lost due to pterygium and average precipitation per month for the period 2004 to 2009

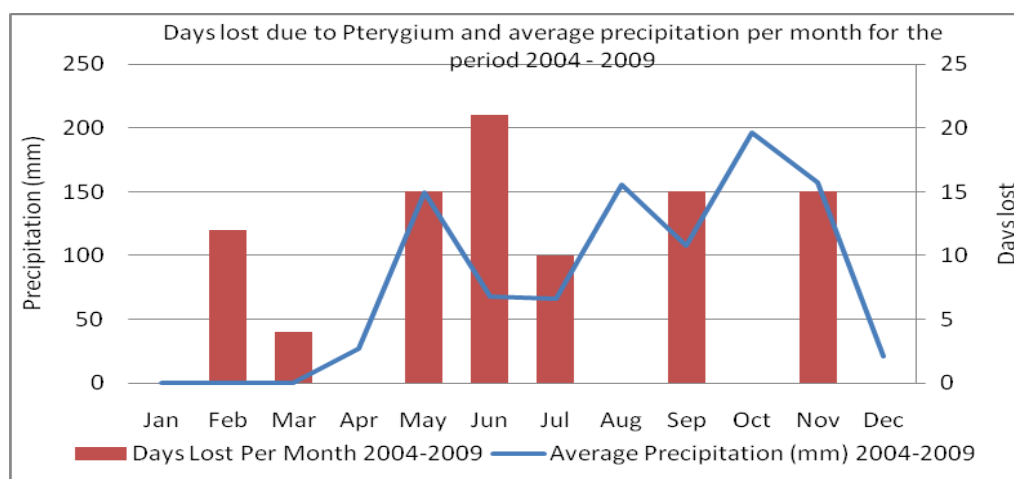
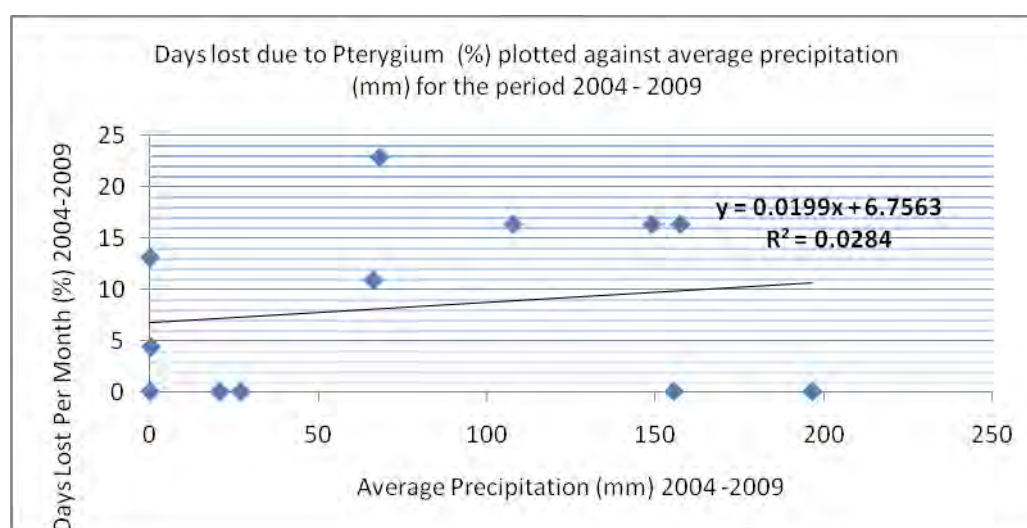


Figure 12-3 – Days lost due to pterygium plotted against average precipitation for the period 2004 to 2009



Skin complaints have also been recorded by MEB as a cause for employees to be absent. However the cases do not indicated a seasonal sensitivity, as they were presented at various different times of the year. Extended exposure to sunlight is known to lead in some cases to skin cancers, however MEB does not record skin cancer as a cause of staff absenteeism.

In conclusion, neither the cases of pterygium nor of skin complaints show any pattern correlating with rainfall or temperature patterns. Furthermore, the costs of absenteeism do not represent a material risk to MEB.

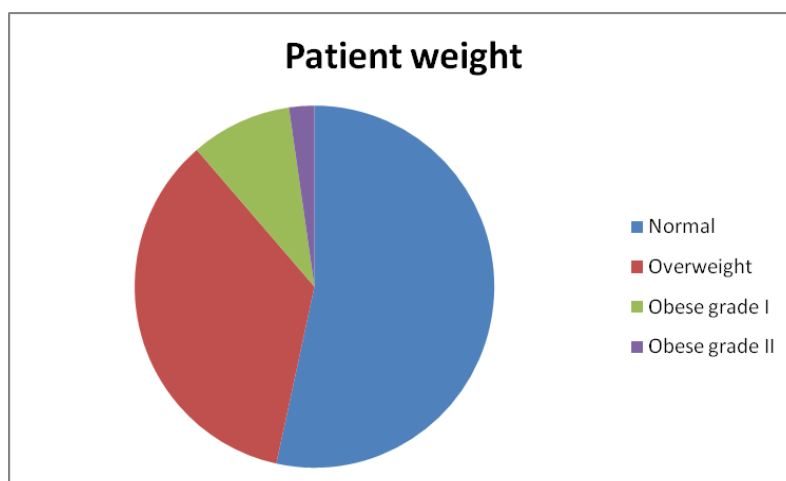
A second measure of health within the workforce is the consultation rate at the company infirmary, representing the number of cases presented rather than the number of days leave taken. The highest number of consultations at the company infirmary between July and September 2009 (the period for which data were available) was for blood pressure monitoring. It is not known whether this monitoring was undertaken as a routine precaution or whether it was triggered by cases of high blood pressure among staff. Hypertension, linked to obesity and cardiovascular illnesses, is a health issue for workers at MEB, which could potentially be affected by climate change.

Table 12-3 – Top recorded visits to the MEB infirmary, 2009 (MEB)

Medical condition	Number of consultations		
	July	Aug	Sept
Blood pressure monitoring	14	12	22
General illness	14	8	
Cures (Curaciones)	15		
Headaches	18	6	5
Muscular pain		6	
Injuries			8

Of the patients weighed during a visit to the infirmary (not all weights were recorded) over 45% were either overweight or obese (Figure 12-4).

Figure 12-4 – Weight of patients recorded during visits to the MEB infirmary, 2009 (MEB)



Increased average and peak temperatures, particularly episodes of heat waves, are known to increase the risk of death and serious illness, especially for those with cardiovascular or respiratory problems. For example, cardiovascular conditions are closely linked to heat stress. Studies show that exposure to extreme (high or low) temperatures is associated with an increased risk of (mainly cardio-pulmonary) mortality (Campbell-Lendrum et al; WHO, 2003). The IPCC also highlights the links between thermal stress and mortality and notes that *“much of this excess mortality from heat waves is related to cardiovascular, cerebro-vascular, and respiratory disease (IPCC 2001).”* MEB is already working to reduce stress levels among its workforce.

At MEB a very small number of recorded days absent were attributed to heatstroke (2 days in 2008 only). Those particularly vulnerable to heat stress or heatstroke are the elderly (above 50 years), the very young and those already suffering from illness (Kovats, 2007). Nevertheless, given that the incidence of heat waves is likely to increase with climate change, it may be useful for MEB to raise awareness among staff that heatstroke risk is increasing as temperatures rise due to climate change.

Influenza was also described in interviews at MEB as a common illness in the rainy months of the year. However, neither the absenteeism data nor the infirmary registration data supports this suggestion. A total of 13 consultations for influenza were recorded by the infirmary between July and September 2009, however no cases of absenteeism relating to the illness are recorded at all. Although influenza epidemics are associated with winter and thus lower temperatures in colder regions of the world, the World Health Organization highlights non-climatic factors such as virus type, vaccination programs and human behavior as being more closely related to the spread of epidemics (WHO). General immunization coverage in Colombia is relatively high and the MEB workforce is not a group considered to be vulnerable to infectious diseases such as influenza. The average temperature in Colombia may also be too high to be a major contributing factor to influenza.

12.2.3 Conclusion

Overall it is thought that health impacts of climate change on the workforce will pose very limited financial risk, if any, to MEB. The majority of causes of absenteeism is related to occupational health and includes strains, fractures and injuries to limbs.

MEB is obliged to pay the first three days of sick leave, after which the government covers the cost of the absentee's salary. Extended periods of sick leave would only present a financial cost to MEB if a replacement worker was hired. Higher numbers of individual cases taking short term sick leave would also present a possible financial risk to MEB.

There is a small chance that climate change could lead to an increase in eye, skin and cardiovascular complaints among the workforce, and therefore higher visits to MEB infirmary, health care costs and absenteeism. However, present-day costs to MEB for absenteeism due to these diseases are very small indeed.

MEB is already taking steps to manage stress and cardiovascular disease by running an anti-stress campaign among its workforce.

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13 Insurance

13.1 Introduction

The objectives of this section are to consider the extent to which MEB is covered for weather-related losses which could change in the future because of climate change, so as to quantify the residual financial impacts of climate change, and to discuss potential future changes to MEB's insurance terms.

13.2 Terms of MEB's insurance

MEB has contracted a comprehensive insurance package with MAPFRE, Colombia, which protects it against several climate-related hazards. There are two policies on asset damage and business interruption, and liability (including for acts of terrorism).

MEB's insurance on damage and business interruption includes the following assets or elements of the business:

- Quays,
- Buildings,
- Equipment,
- Machinery (including cases of breakdown due to mechanical failure, wear and tear or electric malfunction), and
- Furniture and belongings.

In MEB's insurance policy documents, there is no reference to either roads or the causeway. MEB's roads are almost certainly not insured. Only rarely do certain businesses insure roads (such as toll road operators), as roads are not prone to many of the perils that other assets are exposed to and require specialized insurance. It is also unlikely that MEB's causeway is insured.

Further, MEB's insurance does not include either Contingent Business Interruption or an Ingress/Egress cover, which would cover MEB against business interruption from respectively:

- Climate-related hazards affecting MEB's customers, and
- Flooding, strong winds or heavy rainfall affecting the access to and from the port or vehicle movement at the port (though the IFC Loan Agreement requires insurance against, if necessary and available in the market, trade disruption or port blockage).

In general, only a physical loss or damage to an insured asset can trigger a business interruption loss. A Contingent Business Interruption or an Ingress/Egress policy would cover MEB's loss of revenue, regardless of the existence of a loss or damage to an insured asset (International Risk Management Institute).

Its liability policy covers MEB against any legal action taken by clients or third parties who suffer damage to goods stored on the port.

MEB has been paying an insurance premium of 1.95% of the value of insured assets. In 2010, this amounted to US\$122,877 (or COP 245,753,818). MEB's insurance covers typical perils, including weather-related events of a sudden onset nature which cause damage such as: flood, heavy rains, wind storms, tropical cyclones and extreme temperatures.

However, the summary documents which were examined⁴⁶ explicitly indicate that the insurance does not extend to the following climate-related impacts:

- Subsidence, displacement, cracking and sinking of walls, floors, roofs, pavements or concrete which would occur because of the bad state of the soil or construction errors.

⁴⁶ 'Poliza todo riesgo daños materiales y lucro cesante' Nos 1301206000326 and 13012080001119; and 'Poliza integral de puertos' No 1301208000115

- Robbery following natural disasters.
- Suspension or reduction of utility services (including electricity, gas or water) because of losses or damage due to towers, posts, transmission and distribution lines.
- Business interruption because of a reduction of the water depth of the access canal (either from sedimentation or low water levels).

Table 13-1 – Value of insured elements at MEB (US dollars)⁴⁷

Elements covered ⁴⁸	Total value insured (US\$)	Deductibles per event*
Buildings	39,809,692	For Earthquake, Tsunami, Volcanic Eruption and other natural perils: 2% of the insured value with a minimum of 1,000
Furniture and equipment	66,325	10% of the loss with a minimum of 2,000 for damage 15% of the loss with a minimum of 2,000 for all portable and mobile equipment
Machinery & Equipment	2,807,215	For Machinery Breakdown: 10% of the loss with a minimum of 3,000
Electronic & other equipment	2,475,797	10% of the loss with a minimum of 2,000 for damage 15% of the loss with a minimum of 2,000 for all portable and mobile equipment
Quays	Not specified	Impact damage: 10% of the loss with a minimum of 10,000
Business interruption	16,500,000	First 7 days and for an indemnity period of 6 months

* Note: Insurance deductibles are a function of the perils and not of the business elements covered by insurance.

When comparing MEB's insurance cover with other large port operators, it appears from conversations with IFC's Principal Insurance Officer that it may be less extensive, especially in terms of access to and from the port. For example, larger port operators may have insurance policies covering interruption from reduced ingress and egress or from port blockage causing trade disruption.

⁴⁷ Exchange rate is fixed at 1 USD = 2000 Colombian pesos (COP).

⁴⁸ Depreciation rates will apply to equipment and have not been taken into account in this table.

13.3 Extent to which MEB is covered by insurance for climate risks

Section 14 summarizes the financial risks of climate change for MEB. In relation to the risks identified which might be insurable, only business interruption due to flooding and damage to goods stored have been estimated (see Section 7) because:

- The amount of goods stored at the port at any time, as well as the value of these goods, are unknown. (If goods were damaged while stored at the port, MEB's liability policy could be called upon).
- Impacts on buildings, equipment, furniture and belongings at MEB, due to climate change would most likely involve increased maintenance costs or reduced useful life rather than significant damage costs that would be covered by insurance. (Climate-related impacts on MEB's buildings were not assessed because they were not considered significant).

For some of the risks described in this report, the impacts of climate change could not be quantified or were considered to be insignificant. However, damage or business interruption cannot be completely excluded up to the 2080s; therefore Table 13-2 summarizes the extent to which MEB is covered for potential costs related to these risks.

Because MEB does not have an ingress/egress clause in its business interruption cover, the revenue consequences of business interruption caused by seawater flooding will not be covered by its insurance, unless it involves damage to or loss of insured assets. Damage to MEB's roads or the causeway due to a climatic event will not trigger MEB's business interruption cover, since these assets are not insured.

Table 13-2 – Extent of MEB’s insurance cover for the risk areas identified in this study, per type of loss

Risk areas	Description	Business interruption		Equipment and machine damage or failure (including electronics)		Liability*	
		Potential costs	MEB’s insurance cover (USD)	Potential costs	MEB’s insurance cover (USD)	Potential costs	MEB’s insurance cover (USD)
Vehicle movements inside the port (flooding from sea level rise) (Section 5)	Flood of areas of the port due to sea level or surcharge of the port’s drainage system	Interruption to vehicle movement between the island and the mainland.	100% of revenue losses during a maximum of six months, minus the first 7 days, provided insured assets were damaged or lost. In absence of damage or loss of insured assets, there is no cover.	Frequent submergence in salt water may increase maintenance costs and decrease useful life. Equipment breakage or failure is also possible. Exposure to water may create equipment or machine failures.	100% of insured value minus 2% of the sum insured with a minimum deductible of 1,000.	Goods stored at the port may be lost or damaged.	Up to 7m in total and for each event.
Goods storage (Section 7)	Coke is stored in silos and grains in warehouses on the port and are vulnerable to flooding and high temperatures (which can cause spoilage)	None	n/a	None	n/a	Damage to stored goods and to third parties	Up to 7m for stored goods and for damage because of agents in total and for each event Up to 1m for damage under civil professional liability or liability in front of authorities in total and for each event.

Navigation and berthing (Section 9)	Because of MEB's sheltered position, its low dredging needs and the height of its quays, no significant risks were identified.	Inadequate dredging may delay ships or prevent them accessing the port.	n/a <i>Revenue loss due to blockage of access to the port is excluded, including reduced water depth on the access channel because of increased sedimentation or low water flows.</i>	None	n/a	Inadequate dredging may affect ship movements and cause delays, losses or damage.	Up to 1m in total in civil professional liability. Note that it was not possible to determine from MEB's insurance policy documents if the company would be covered for such an event.
Bulk handling at the port (Section 10)	In periods of high winds or lightning, cranes cannot operate. Heavy rainfall can prevent grain unloading.	Cranes may be stopped	100% of revenue losses during a maximum of six months, minus the first 7 days, provided cranes are damaged. In the absence of crane damage, there is no cover.	Equipment and machines (e.g. cranes) could be damaged in extreme conditions.	100% of insured value minus 2% of the sum insured with a minimum of 1,000.	None	Up to 1m for damage under civil professional liability or liability to authorities in total and for each event.

* MEB's liability policy only applies to situations in which MEB is legally liable for a damage or loss.

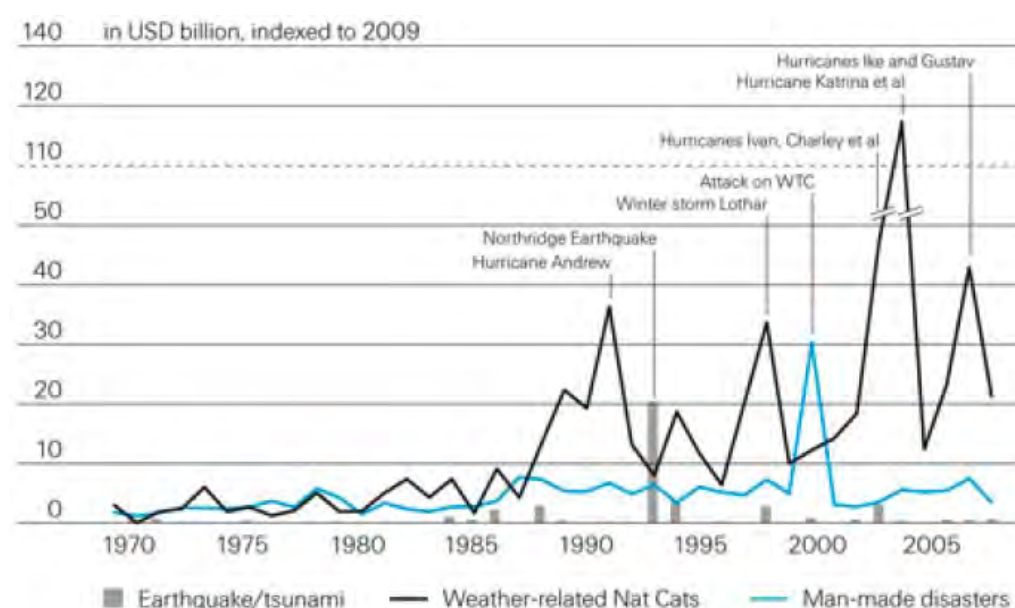
Note: n/a (not available) refers to losses or damages not covered by MEB's policies.

13.4 Impacts of climate change on MEB's potential future insurance terms

Insurers admit that as knowledge of climate change impacts increases, return periods of climate-related hazards increase, and adaptation methodologies and actions develop, the terms and conditions of insurance contracts are likely to change (Haines, pers. com.).

Globally, the insurance industry is aware of increasing insured losses due to weather-related catastrophes. This increase has been observed in the past 40 years. While there are several factors explaining this upward trend (such as increased property values and insurance cover), climatic factors are considered to be partly responsible (Figure 13-1).

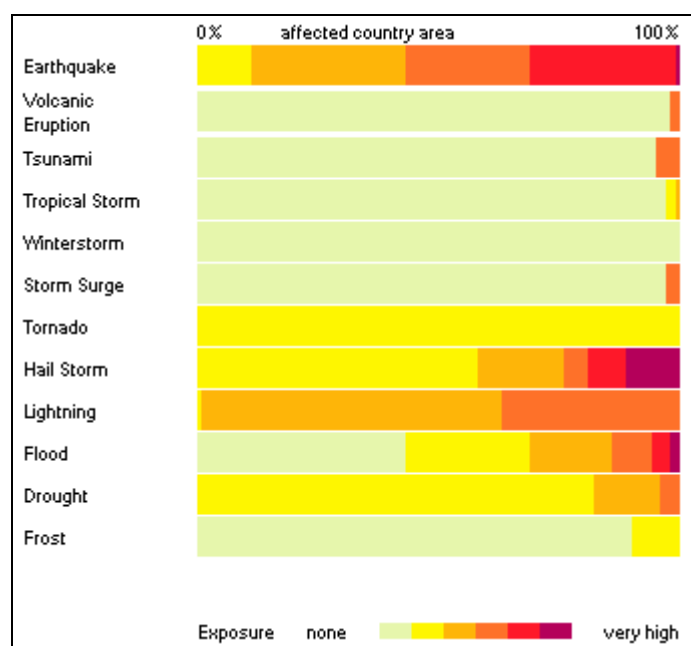
Figure 13-1 – Insured losses between 1970 and 2009. Source: Swiss Re.



Over the long-term, and partly as a result of climate change, average annual loss (i.e. the aggregated losses that can be expected to occur each year over many years) is expected to continue rising. The Association of British Insurers (2009), using a typical insurance pricing formula, demonstrated the relationship between average annual loss (AAL) and premiums (P): $\Delta P = 1.1 \cdot \Delta AAL / 0.25$, where 1.1 represents fixed expenses and 0.25 variable expenses and profit load.

Colombia is considered by the insurance market as being highly to very highly exposed to the following climate-related hazards, for a significant part of its territory: hails storms, lightning, flood and drought (Figure 13-2). The Caribbean coast in particular is especially exposed to flood and drought risk. MEB reported to not be significantly affected by lightning and did not mention hail storms during the site visit. Cartagena is too close to the Equator to be at significant risk from tropical cyclones, (see Section 4).

Figure 13-2 – Colombia’s exposure to natural catastrophes by degree of exposure (from none to very high) and affected country area (in %). Source: Munich Re.



Unless adaptation actions are undertaken, increased flood risk because of sea level rise could push insurance claims up for flood-related loss or damage and thus increase insurance premiums in the region. If MEB’s costs for the flood component of insurance claims increase, then (and in the absence of adaptation) it is likely that MEB’s insurance terms would also change.

It is likely that the maturity of the Colombian insurance market with regards to integrating climate change projections in insurance pricing mechanisms will increase in parallel with the global market. At present, insurers are not doing this, despite many years of expressing their concerns over climate change. They are instead following traditional actuarial practices, repricing premiums each year based on losses in preceding years.

If insurers do change their practices in the future, changes in insurance premiums and exclusion clauses could be more significant, to reflect future risks. Insurers may also start questioning their clients about their climate change risk management practices.

13.5 Adaptation

As shown in Section 5, raising the causeway from the island to the mainland is economically beneficial from the 2030s onwards for the accelerated SLR scenario and 2040s onwards for the observed SLR scenario. Discussions with insurers conducted for this study also indicate that some insurers would consider reducing insurance premiums, or offering more favorable insurance terms, to customers who have undertaken actions like this, which reduce risk (Johnson and Haines, Pers. Comm.)

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14 Financial Summary

14.1 Costs of climate change impacts

In the previous sections of this report, the possible financial implications of climate change risks and adaptation actions, taking into account MEB's insurance cover, have been examined separately for each risk area.

Overall, the assessment demonstrated that the primary climate change risk to MEB in financial terms is flooding of the causeway, and the associated disruption to vehicle movements, due to sea level rise (see Section 5). The second most significant potential financial risk to MEB due to climate change relates to changes in demand, trade levels and patterns (see Section 6).

The key findings on the costs of climate change impacts for MEB are summarized in Figure 14-1 to Figure 14-3 for the years 2030, 2050 and 2100. For flood risk, the costs under both the observed and accelerated sea level scenarios are given. For climate change impacts on world trade, two climate change scenarios (a low or 'baseline' and a 'high') are given; these correspond to the scenarios used in the Stern Review, as explained in Section 6 (Stern, 2006). The findings indicate that seawater flooding of the causeway could have a great enough impact to pose a business continuity risk to MEB over the longer-term, if no action is taken. The potential impacts of climate change on trade could moderately reduce MEB's revenues. With respect to other risks, the estimated financial impacts are relatively small, or cannot be quantified, and are therefore not shown in the figures. Additionally, there are costs which are likely not to fall on MEB but which could have significant implications for the port's reputation. This is the case for flooding of the port's storage areas, which could have significant impacts in terms of value of the goods lost. However, as explained in Section 7 the losses will likely be borne by MEB's customers or by MEB's insurers.

Figure 14-1 – Climate change impact costs in 2030 (undiscounted). The figures in the yellow boxes represent these costs as a percentage of MEB's projected EBITDA without climate change in 2030 (\$28,809,000). For further details see Section 5 and Section 6.

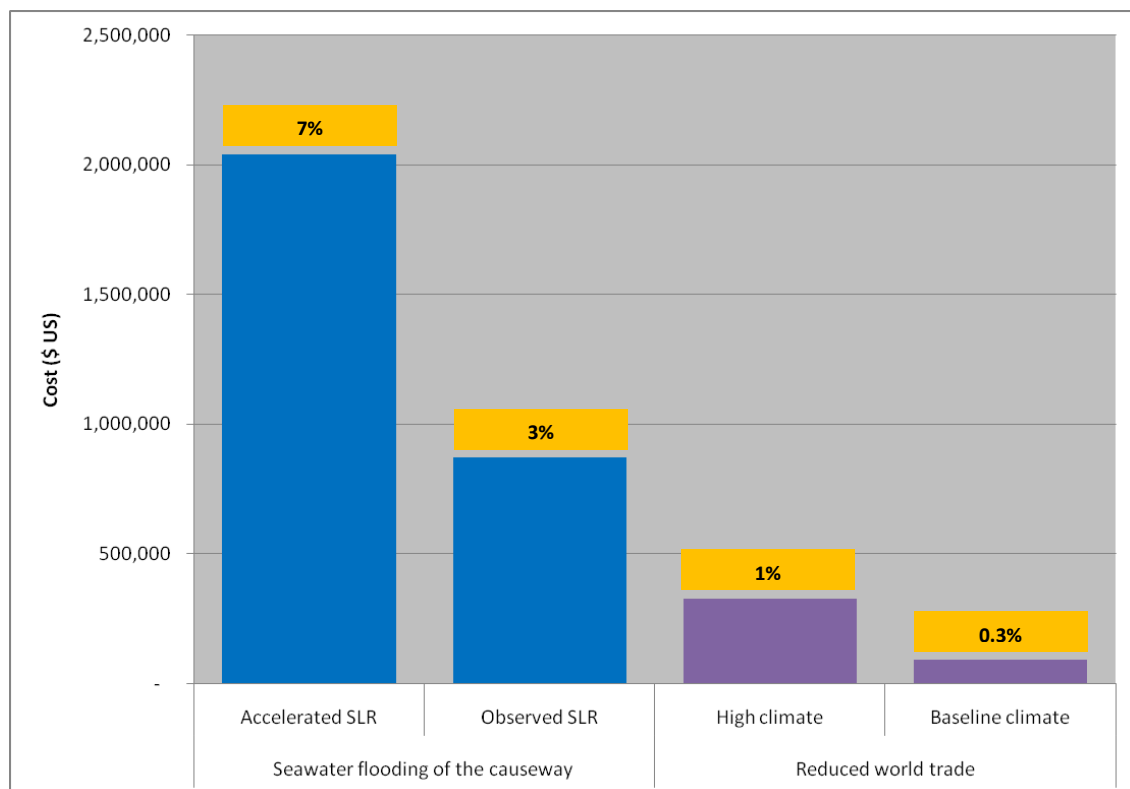


Figure 14-2 – Climate change impact costs in 2050 (undiscounted). The figures in the yellow boxes represent costs as a percentage of MEB’s projected EBITDA without climate change in 2050 (\$32,678,550). For further details see Section 5 and Section 6.

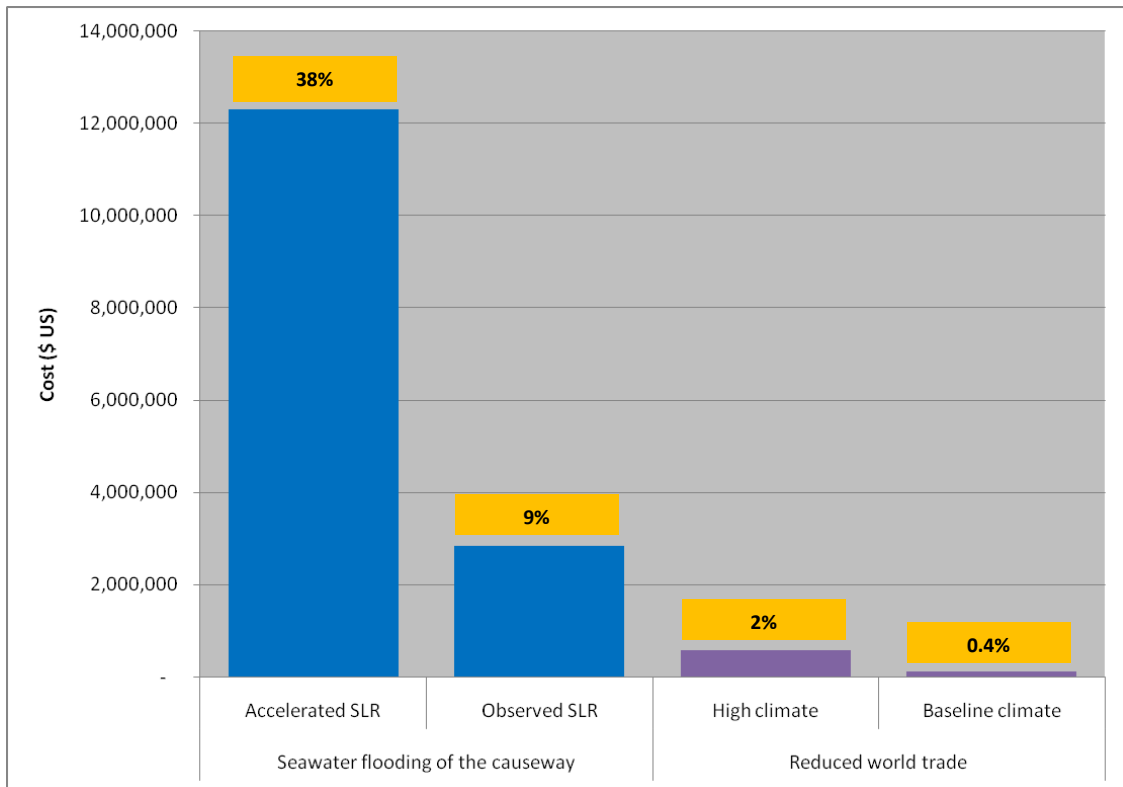
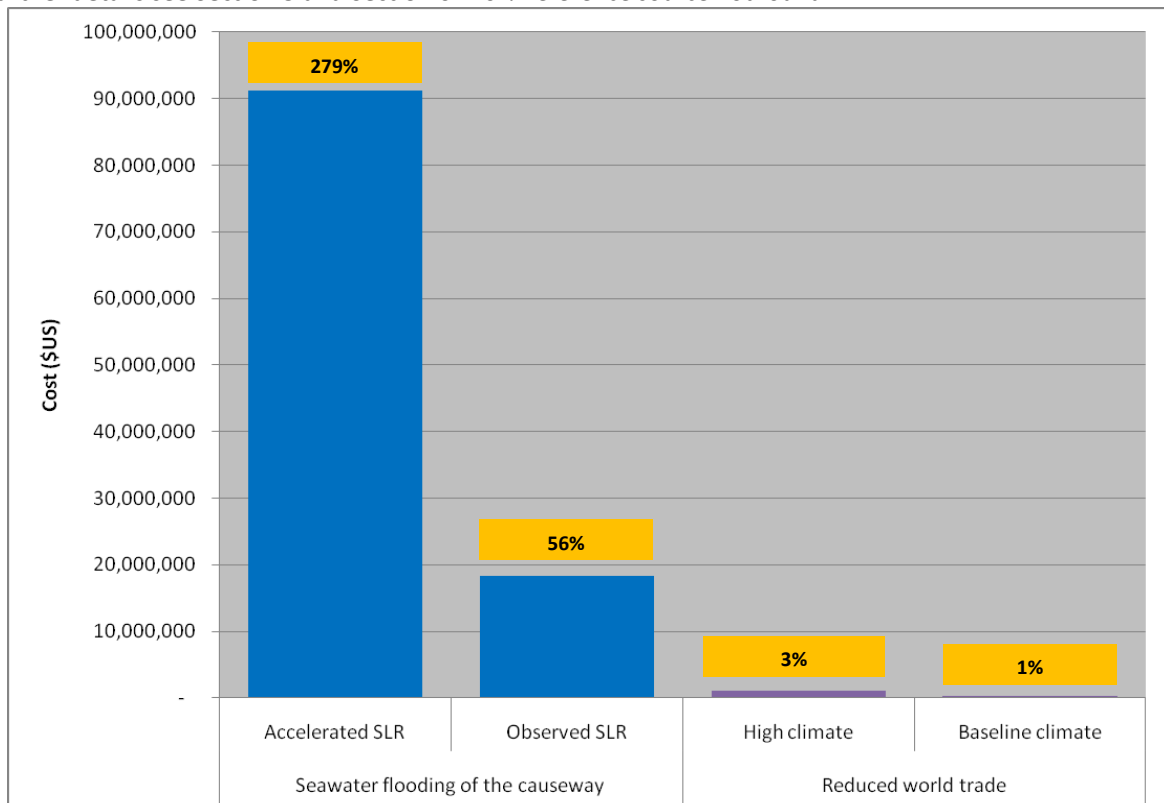


Figure 14-3 – Climate change impact costs in 2100 (undiscounted). The figures in the yellow boxes represent these costs as a percentage of MEB’s projected EBITDA without climate change in 2100 (\$32,678,550). For further details see Section 5 and Section 6Error! Reference source not found..



Other climate change risks that are usually likely to affect ports (see Section 2) have been found unlikely to result in financial costs to MEB, though potential impacts cannot be totally excluded. These include:

- Navigation and berthing which appear climate resilient at MEB, due to the port's location in the bay, the height of MEB's quays and MEB's limited dredging requirements,
- Materials handling, which is not expected to be significantly affected by the heavy rain and high wind, (though there is a lack of information on future changes in extremes for these variables),
- Road maintenance costs which could be marginally influenced by climate change, though with no great confidence,
- Surface flood risk which is not expected to be affected by climate change due to MEB's drainage capacity,
- Transport of goods to and from MEB which could be affected by a climate-related deterioration in transport reliability outside MEB (for example, surface flooding in Cartagena),
- The mangrove around the port's causeway between MEB's island and mainland sites, which is expected to be affected by sea level rise. However, it is unlikely that MEB would be required to pay for mangrove regeneration (which could amount to \$95,000),
- Community relations which are not thought to be particularly sensitive to climate change, and
- Worker's health and safety which is not expected to be impacted by climate change.

The assessment also reveals that climate change could potentially bring some financial opportunities for MEB. These were more difficult to assess than the possible financial costs, because of lack of data, but illustrative assessments based on simple assumptions were undertaken:

- The increased draft caused by sea level rise (under the accelerated SLR scenario) would decrease the volume of material to be dredged and reduce dredging costs by between \$325,000 and \$400,000 by 2100 (for a 500m long and 50m wide sea channel),
- MEB's water use for spraying coke could be reduced, amounting to a saving of up to \$14,000 per year (assuming that water use and rainfall changes are directly and inversely proportional).

14.2 Costs and benefits of adaptation

To increase the resilience of the causeway to climate change, there is an obvious adaptation measure that stands up to scrutiny: raising its height. Compared to the cost of flooding (\$2,040,000 in the accelerated SLR scenario by 2030), the cost of raising the causeway is relatively low (for 20cm, \$380,000 without any discount rate) and is therefore worth undertaking before flooding occurs, especially as the astronomical tides and the annual variations in sea level are predictable within the timescales that it would take to implement adaptation⁴⁹. If the accelerated sea level rise scenario proves to be correct, adaptation will be required to ensure business continuity. Under the accelerated sea level rise scenario, adaptation will be necessary before the end of the current port concession in 2032.

Further, the additional costs of 'repeat adaptation' are also relatively small and therefore the raising of the causeway lends itself to adaptive management: the causeway can be raised several times during this century (as needed) and decisions to do so can be taken on relatively short time scales. Overall, the net present cost of the adaptive management option is below the net present cost of the 'one-off adaptation' option for discount rates above 0.2%.

Storm surges, which lead to less frequent and temporary flooding events, are not projected to increase in Cartagena. They can be dealt with by an ingress/egress insurance policy against business interruption. Insurance as an adaptation instrument is discussed in Section 17.2.7.

⁴⁹ By 2100 the total cost of climate change due to business interruption because of flooding of the causeway amounts to \$91,250,000 in the accelerated SLR scenario and to \$2,280,000 and \$2,130,000 respectively for the adaptive management and 'one-off' adaptation scenarios (without discount rate). The climate change cost figure is large because it assumes that MEB does not take action to prevent flooding; clearly this is hypothetical. For further detail, see Section 5.

In Section 7.6.2 various adaptation measures to prevent flooding of good storage areas are discussed. In this instance, the financial case for adaptation is less clear cut. MEB's customers would experience the financial impact of flood events, and may claim against MEB's liability insurance cover. Clearly, if this were to become a regular event, MEB's reputation and, hence, its market share, would suffer.

There may be areas of the port for which retreating may be preferable to trying to raise ground levels, although it seems unlikely as storage space is costly. Assuming sea level rise does not exceed the accelerated SLR scenario projections, insurance and minor revisions to the drainage system of the mainland patio area⁵⁰ are likely to be sufficient until the end of the current concession in 2032. Later in the century further adaptation will likely be required, for instance raising the patio to keep the mainland storage area usable under both the observed and accelerated SLR scenarios. The cost of raising the patio by 1.2m is estimated to be at least \$4.7m if undertaken all at once, which represents approximately 7% of MEB's projected earnings (EBITDA) by the 2040s onward. This is a conservative cost estimate, since costs could be significantly higher if structural works are required to support the increased height of the patio. At MEB's discount rate of 16%, the NPC of raising the patio by 20cm every 10 years between 2050 and 2100 is much lower than that of 'one-off' adaptation (approximately 60% of it).

Climate change risks stemming from the impact of increased temperature on refrigeration were found to have the least effect on MEB's earnings of the risks that could be quantified. Taking the most extreme climate model projections by the 2050s (a 6°C increase), higher average temperatures could cause an increase in MEB's annual electricity bill of \$65,000, which represents 0.2% of MEB's projected earnings in 2050. Adaptation options are available to MEB: for instance, it can pass the increased cost on to its customers through its storage fee rate. An adaptation option that MEB should consider is encouraging its customers to use more energy efficient reefers, as the financial impacts of climate change on refrigeration are directly tied to electricity consumption. Customer investment in more energy efficient refrigeration technology could result in immediate savings regardless of future temperature increases.

Reference

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⁵⁰ To prevent seawater ingress, the small drainage pipes on the mainland patio area should be upgraded and have valves fitted (see Section 7.2).

15 Adaptation gaps and barriers

15.1 Introduction

Making decisions in the face of uncertainty requires managing appropriately gaps in knowledge and data. For instance, climate projections over certain areas sometimes show a range of possible outcomes, especially with regards to precipitation which is influenced by small-scale climatic processes and natural decadal variability. However climate change knowledge is developing rapidly leading to better-evidenced and tested projections. Nevertheless, where data on the impacts of climate are limited, such as in this study, comparing estimates of the possible costs of climate change to the company's earnings and the cost and benefits of adaptation, can help to make high level and quick adaptation decisions.

The US Climate Change Science Program highlighted the following challenges to the assessment of climate change impacts on transport infrastructure: articulating data and information requests, identifying the most relevant climate information, integrating multiple environmental factors, and incorporating uncertainty (USCCSP, 2008). In this section, two kinds of gaps and barriers are presented and discussed: those affecting the quality of climate change risk assessments and those challenging decision-making on, and implementation of, adaptation options.

An assessment of climate change adaptation in Cartagena concluded that legislative, institutional and organizational barriers present serious constraints to the implementation of a climate change strategy in Cartagena (Invemar, 2005). Invemar concluded that the technical feasibility of achieving adaptation was low in Colombia, due to a combination of lack of technical capacity among Colombian institutions, scientific uncertainties, and lack of knowledge on climate change.

As with most climate change risk and adaptation assessments, the gaps and barriers identified in this study fall within the following categories:

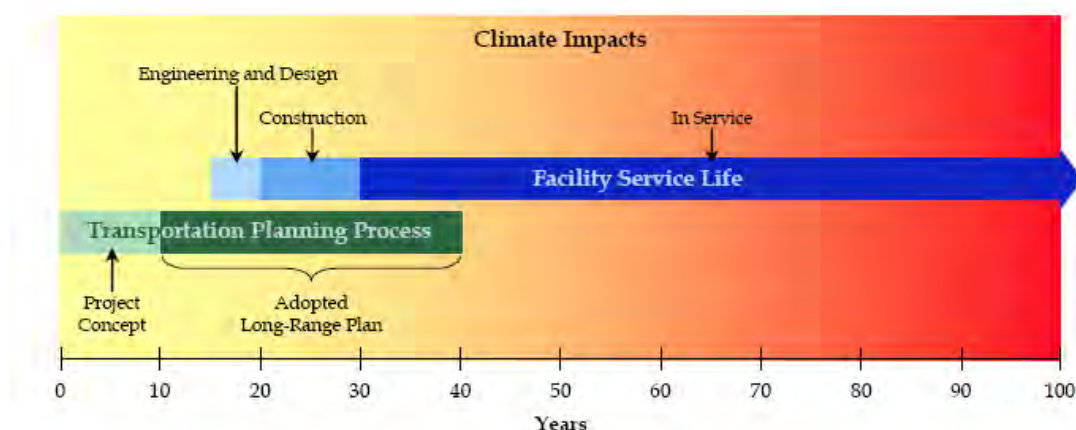
- Lack of quality localized data (such as LiDAR elevation datasets),
- Uncertainty in future climate projections, relative to climate change timescales,
- Lack of knowledge of existing climate risks and adaptation measures,
- Short time horizon for investment decisions, and
- Failure by other organizations to acknowledge climate change.

For instance, port infrastructure and equipment (including quays and materials handling equipment) is often designed for 20 to 50 years, which commits it to coping with several decades of a changing climate. However, existing infrastructure with many years of remaining lifetime can be difficult to retrofit (USEPA, 2008). Ports' actual planning horizons are even shorter, often between 5 and 10 years (USEPA, 2008). In the case of MEB, the concession will expire in 22 years time and the financial projections provided cover the next 8 years.

The information presented in this section is specific to the climate change risk and adaptation assessment done for MEB. Barriers to risk assessment and adaptation for other ports may differ.

However, one barrier to adaptation that is likely to apply to all ports is the lack of monitoring data. The conclusions of this study relating to the lack of long-term monitoring data on the impacts of climate-related events (such as floods) for ports are likely to apply to most ports around the world.

Figure 15-1. Timescales of port planning horizons, lifespan of port infrastructure and climate change impacts (USCCSP, 2008)



These constraints have been taken into account in this study when analyzing climate change risks to MEB and when recommending and appraising adaptation options. The key barriers to climate change risk assessment and adaptation are presented below for each risk area considered in this study.

15.2 Observed and future climate information

The availability of good quality and long-term climate observations is necessary for the development of both climate projections and impact models that capture interannual climate variability. In locations where natural decadal cycles are known to significantly influence climatic patterns, the use of long-term climate records is especially important. When such records are not available, sensitivity testing is necessary. In Colombia the El Niño Southern Oscillation (ENSO) is known to have an influence on precipitation; however, due to the considerable scientific uncertainty on ENSO-related precipitation, the impact of ENSO to MEB was not specifically assessed.

The level of agreement on future climate change between climate models and across different methods of projections determines the level of confidence that can be placed in risk and adaptation assessments. Generally, the level of confidence in rainfall and wind projections is lower compared with temperature projections, and a wide range of possible future scenarios needs to be considered. For instance, it is common for rainfall projections in a particular location to show both increases and decreases across a number of climate models. For example, projections of future changes in rainfall over MEB are complicated by Colombia's topography and the significant uncertainties over future tropical cyclones.

Projections of future extreme climate events (such as tropical cyclones) are also highly uncertain. This is because whilst climate models may be able to provide reasonably accurate forecast of trends in climate, such as seasonal or monthly averages, high resolution projections (for example hourly or daily) from GCMs are generally regarded as unreliable, unless comprehensive work has been done to evaluate whether the models are realistic.

With this in mind, following a threshold-based approach to risk assessment is often preferable where high resolution climate projections or projections of future extreme climate events are needed. This involves testing the vulnerability of key business thresholds to a range of future changes in climate.

15.3 Demand, trade levels and patterns

Quantifying the risks and opportunities posed by a changing climate to trade at MEB is difficult due to the uncertainties in evaluating future climate change impacts on international trade and national economies. Climate change is one of many factors which will drive international trade, and it is hard to disentangle one effect from another. Additional research effort in this area would be beneficial.

Other barriers to generating a robust, quantitative analysis of this issue include the lack of data on MEB's revenue and its response to changes in global/national GDP over the long-term, the difficulty of translating climate change impacts on crop suitability to impacts on crop export, and finally, the economic assumptions required in this analysis (such as the assumption that grain imports to Colombia will experience persistent growth).

15.4 Navigation and berthing

Availability of quality data on sea levels, water depths, sea currents and tidal movements, and quay elevation is critical to assessing climate risks to navigation and berthing. MEB's particular 'sheltered' position in the Bay of Cartagena and the fact that it only has limited dredging requirements, explains the absence of significant climate-related risks to navigation and berthing. However, for other ports these issues are likely to be significant.

Adaptation measures associated with navigation usually involve actions outside of the port boundaries and jurisdiction. Liability and cost, for example in relation to dredging, can often be difficult to assign, as there may be multiple users of a channel which comes under a port authority. Adaptation actions to manage risks to navigation in the face of climate change will require coordination between the public and private sector. Further discussion on this is provided in Section 9.

15.5 Goods handling

Assessing the climate change risks associated with bulk handling poses a number of challenges, primarily associated with the availability of high-resolution data. For such assessment, it is often necessary to use hourly data (e.g. on rainfall) to test operational and safety thresholds. In situations where hourly data are unavailable, a threshold-based approach can help to assess the vulnerability of materials handling to different levels of future changes.

Modeling climate change risks to materials handling is also challenging due to climate uncertainties in projecting future wind and rainfall, as discussed in Section 15.2. This is accentuated by the fact modeling the distribution of individual weather events which dictate extreme wind speed and precipitation is not possible with our current understanding and technology. Two consecutive months with very similar average wind speeds or average rainfall can correspond to very different conditions of operability, possibly resulting in delays, if for instance rainfall in one month is confined to high intensity storms.

Because wind speed and heavy rainfall were not reported as an issue for MEB currently and climate projections did not indicate changes likely to challenge materials handling equipment thresholds, monthly average rainfall and wind data for Cartagena were used for in this study. Where extreme climate-related events are likely to occur and affect materials handling (such as in Buenaventura or more East of the Caribbean coast of Colombia), the use of hourly data may be necessary to assess risk.

For ports in areas where storms have a direct impact on bulk handling equipment, adaptation may be constrained by the equipment that is used. In many cases, adaptation may require significant capital expenditure as port equipment can be very costly.

15.6 Vehicle movements inside the port

Because vehicle movement on ports can be restricted or suspended by flooding, causing business interruption losses, accurately assessing flood risk is key to climate change risk assessments.

Necessary information to do so includes: long-term records of sea level (including storm surge heights), land movement observations and a comprehensive digital elevation model (DEM) or indeed a reliable source of elevation data for all areas of the port. Crucially, the two datasets need to be fixed to the same datum, to enable comparisons.

In this study, the sea level that served as the reference for the port plan datum was not provided and had to be estimated using a calibration parameter. Further, the existence of comprehensive flood records for ports is essential so that the results of flood risk analyses can be validated against real observations of the impacts of flood events.

In cases where flood risk is highly uncertain (for example because of the low level of confidence in future changes in waves and storm surges), and because adaptation to flooding often requires large capital expenditure, the following considerations are often taken into account:

- When possible, aligning adaptation actions with asset replacement timetables,
- Monitoring changes, and, where possible,
- Implementing adaptation actions incrementally (if it is not too costly compared to a single adaptation intervention).

15.7 Goods storage

Similar to the discussion above, accurate elevation data and high quality climate projections (over a range of climate change scenarios of GHG emissions) are needed to provide a reasonable degree of certainty in flood risk assessments for goods storage. Flood records are also necessary to assess damage to buildings, equipment and goods stored on ports due to flood events.

Monitoring of climatic factors and consequent impacts on ports can help to understand how costs are changing over time with changes in climate. This is of particular importance for high risk factors such as flooding. For other less significant risk areas (such as the cost of refrigeration or coke spraying in the case of MEB), ports may decide that the cost of increased recording is not worthwhile.

The primary barrier to adaptation aimed at reducing flood risk affecting storage areas relates to the costs of raising large areas of the port. In addition to the required capital expenditure, these kinds of investments would constitute major disruptions to port operations while construction works are undertaken.

15.8 Inland transportation beyond the port

Reliable inland transportation is essential for ports. However, there are difficulties in assessing this risk for MEB, because of a lack of information on the impacts of climate-related events. For instance, in this assessment, the elevation of the road outside of MEB was estimated based on existing aerial photographs, and was assumed to be the same as the elevation of the port. Similarly, while information on the effects of heavy precipitation on flooding in Cartagena is available, the effects that flooding has on the roads used directly by MEB and their customers have not been appraised in depth. In addition, the effects that rubbish and debris may have on municipal drainage are unclear. These same gaps in knowledge apply to the wider road network throughout Colombia more generally. This emphasizes the importance of joint working between the public and private sectors to understand and manage climate change risks, as further discussed in Section 16.2.

Any adaptation upgrades to transport systems or new investments in transportation will fall outside the financial responsibility of ports and concern local or national public authorities. The costs associated with transforming the transport system, is also a significant barrier to adapting transport networks.

15.9 Environmental performance

This assessment faced a number of gaps in existing information (for example the biodiversity value of the mangrove located around the causeway road between the island and the mainland sites of MEB), which are covered in Section 8.3.1.1. Difficulties in assessing climate change impacts to MEB's environmental performance were also due to the lack of clarity on MEB's existing and future responsibilities in relation environmental performance and conservation.

Without regular monitoring data on environmental conditions around ports, adaptation will continue to prove difficult. The principal barrier to adaptation of environmental management systems is the lack of regular

monitoring: for example although MEB have had an Environmental Monitoring Program in place since 1998, monitoring has been infrequent. For instance, the potential uses of the mangroves around the Bay of Cartagena are not clearly defined, which makes it difficult to assess climate change risks.

Further investigation is also required to determine the right approach to support the adaptation of ecosystems, such as mangroves.

15.10 Social performance

It is considered that the population around MEB will not face any significant changes in risks associated with MEB's activities due to climate change. However evidence for this is mostly anecdotal.

The main barrier to the assessment of the climatic vulnerabilities of MEB staff is the lack of complete information on the general health of MEB staff and on whether certain causes of staff absenteeism, such as influenza, are influenced by climatic factors.

15.11 Insurance

Complete knowledge of insurance terms and conditions and of best practice insurance cover is important to assess whether climate risks are or should be insured.

The impact that the increased knowledge of climate risks by insurers may have on insurance availability and pricing is unknown, though there are indications that it could have material effects.

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16 The Role of the Public Sector

16.1 Nationally

A range of national government ministries, departments and institutes in Colombia are taking actions to assess and manage climate change impacts. A brief summary of their activities, based on meetings conducted during the site visit and highlighting the issues of most relevance to MEB, is provided below⁵¹.

16.1.1 Ministerio de Ambiente, Vivienda y Desarrollo Territorial (MAVDT)

MAVDT is the government department responsible for developing climate change policy, covering both mitigation of greenhouse gas emissions and adaptation. Its work on climate change adaptation has four main themes: risk assessment, spatial planning, food supply and ecosystems.

In relation to risk assessment and spatial planning, MAVDT are planning a project with three components: development of tools and guidance for including climate change in spatial planning; development of a working group on risk assessment and climate change; and organization of so-called 'regional nodes' on adaptation, by working with the Corporación Autónoma Regional (CAR), the regional government organizations in Colombia who link to municipalities. The CARs are autonomous, and MAVDT is developing guidance for them on adaptation, to help develop their knowledge and capacity, though it cannot mandate what they do.

MAVDT has also recognized that the country's ecosystems are essential elements of its climate change resilience, and is trialing an 'ecosystems approach' to adaptation planning.

MAVDT notes that one of its key objectives in relation to climate change is to strengthen the capacity of IDEAM (see below). MAVDT also wants to work more closely with the private sector on adaptation.

16.1.2 Departamento Nacional de Planeación (DNP)

DNP are working to strengthen institutional capacity within the Government and supporting institutions, to help Colombia manage climate change risks more effectively. CONPES, the National Economic and Social Policy Council, is the advisory agency for economic and social development in Colombia. Its members include Ministers and the heads of DNP, with DNP acting as the CONPES executive. They intend to publish a high-level political directive stating that Colombia will have a national adaptation plan. This CONPES directive will address institutional arrangements for adaptation.

DNP is currently undertaking a study to assess the economic impacts of climate change on Colombia. The study is applying a General Computable Equilibrium (GCE) model, and is assessing impacts on 15 economically important sectors.

DNP expressed an interest in understanding the outcomes of this assessment of climate change risks to MEB, recognizing that ports are particularly vulnerable to climate change, and are important to Colombia's economy.

16.1.3 Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM) and Instituto de Investigaciones Marinas y Costeras (INVEMAR)

IDEAM and INVEMAR are the key institutes in Colombia developing knowledge about climate change, its impacts and adaptation. Colombia published its First National Communication on Climate Change, developed under the leadership of IDEAM, in 2001. Its Second National Communication on Climate Change (2NC) was

⁵¹ It should be noted that climate change actions by government are ongoing, and additional initiatives may have been undertaken since the site visit.

reported to be almost complete in November 2009, but has not yet been made publicly available⁵². Among other issues, the 2NC assesses the vulnerability of Cartagena to flooding from sea level rise. This element of the assessment was undertaken by the Instituto de Investigaciones Marinas y Costeras (INVEMAR), who produced maps showing areas of Cartagena that would be inundated by sea level rise, and assessed the consequent economic impacts by district.

The 2NC also has two adaptation components: the 'Proyecto Integrado de Adaptación Nacional' (Integrated National Adaptation Plan, INAP) and a program entitled, 'Integración de Ecosistemas y Adaptación al Cambio Climático en el Macizo Colombiano' (Integrating Ecosystem and Adaptation to Climate Change in the Colombian Massif). INAP is focused on high mountain ecosystems, Colombia's Caribbean islands and human health. It is a five-year project, which started in 2006. It aims to support Colombia's efforts to define and implement pilot adaptation measures and policy options, and is supported by the Global Environment Facility (GEF). The Macizo program aims to help mainstream climate change into national policies, supporting sustainable development. It is also strengthening the capacity of institutions and organizations involved in local planning to implement adaptation actions. It is a pilot program, aimed at validating transferable technologies and methodologies.

IDEAM is the official source of climate change data in Colombia and has been working with scientific experts in Colombia to develop regional climate projections, using the UK Hadley Centre's PRECIS modeling system, driven by the Hadley Centre's Global Climate Model (see Appendices 2 and 3). As noted in Appendix 1, the Hadley model projections for future changes in precipitation in Colombia are quite different from the projections of the majority of other Global Climate Models. For the 2NC, IDEAM has also made use of output from a high resolution regional climate model developed in Japan.

16.1.4 Centro de Investigaciones Oceanográficas e Hidrográficas de la Dirección General Marítima (CIOH)

CIOH has a Digital Elevation Model (DEM) of Cartagena, produced using LiDAR (Light Detection and Ranging) and has used this dataset to undertake flood mapping of Cartagena. As highlighted in Section 11.2.1, it is highly valuable for assessing flood risk and should be made widely available.

CIOH has been measuring sea level at Cartagena for more than 50 years, and shares these data with IDEAM. CIOH also has a regional oceanographic model of the Caribbean Sea, which it has linked to climate model output. CIOH also has a meteorological station in Cartagena.

It is clear that CIOH has modeling and monitoring capabilities covering oceanographic and climatic variables that are of significant interest to MEB, and interaction between the two organizations will help to ensure that MEB's adaptation planning is informed by the best-available local data.

16.1.5 Ministerio de Agricultura y Desarrollo Rural

The Ministerio de Agricultura y Desarrollo Rural (Ministry of Agriculture and Rural Affairs) has a large program of research, investigating climate change impacts on various aspects of agriculture. They organized a major conference on climate change and its impacts on agriculture in November 2009, which brought together the leading scientific experts in the country for the first time. Following on from the conference, the ministry is establishing an ongoing network to facilitate continued information exchange between researchers and policy-makers working on climate change and food security, entitled 'Red Interinstitucional de Cambio Climático y Seguridad Alimentaria'. Given that agricultural imports and exports are important to MEB's revenue, it may be useful for MEB to be aware of this research network.

The ministry is also promoting expansion of a number of agricultural crops in Colombia, and it may be useful for MEB to be aware of these, to see if they offer opportunities for the company to develop new lines of business.

⁵² Correct as of June 2010.

16.1.6 Instituto Colombiano Agropecuario (ICA)

At the request of the Ministerio de Agricultura y Desarrollo Rural, ICA is undertaking a study to investigate the impacts of climate change on phytosanitary issues. This is investigating whether pests of coffee, sugar cane, fruit, potato and flowers could become more common as the climate changes. If pests are exported from Colombia in agricultural produce or flowers, this can lead to quarantine of the affected produce at ports in receiving countries, and, in extreme cases, to the loss of permission to export a particular crop. ICA also monitors ports in Colombia, to check that they are not importing pests from overseas.

16.2 In Cartagena

The national policy and plans on climate change will be implemented at a local and regional level by the Corporación Autónoma Regional. In the case of Cartagena, it is the Corporación Autónoma Regional del Canal del Dique (CARDIQUE). During a meeting with CARDIQUE, they explained that they are focused on existing environmental protection issues, as explained in Section 8.1, and are not currently undertaking any work associated with climate change (although they are aware of the issue).

Climate change adaptation is being evaluated by the municipality of Cartagena (through the 'Secretaria de Infraestructura') via their master planning process (POT). It is understood that climate change will be incorporated in POT in 2010, though no information on who will be undertaking this work and what it will consist of could be obtained.

The master planning process does include actions to address the current flooding issues. For instance, the University of Cartagena has been contracted to assess current flooding problems throughout the city. The focus of these efforts is on improving the city drainage system to alleviate flooding due to precipitation. Examples are discussed in Section 11.2.1.

In the short term, the master planning process is focused on current flooding issues in Bocagrande, Castillogrande and the city centre in particular. The municipality is considering the building of a dyke around Bocagrande to keep the sea out, as well as pumping stations to discharge rainwater. One of these potential options is shown in Figure 16-1.

Further schemes to protect sections of Cartagena's coastline are also being considered (University of Cartagena, 2009). There are a number of rock groins that have been placed along the beach at Bocagrande to try to protect it, which can be seen in Figure 16-2. However, there has not been a comprehensive study of coastal processes to design coastal protection measures and therefore the groins are rather haphazard and may be accentuated by reducing the natural source of sediment to the south of Bocagrande. Similarly, it may be that the building of large coastal structures such as the harbour wall at Barranquilla has reduced the supply of sediment to Cartagena, which then means that the shoreline is not replenished and it retreats (Andrade, 2009).

These coastal protection schemes will make little or no difference to MEB. To offer any protection to MEB from sea level rise, the scheme would have to control the flow in from the Bocachica and Bocagrande or at least into the inner harbor. Such schemes are starting to be discussed (Andrade, 2009). However, the cost would be very high and due to navigation requirements, a flood barrier such as the Oosterscheldekering in the Netherlands or the Thames Barrier which protects London (see Figure 16-3) would be required. Both of these barriers are designed to protect against storm surge rather than mean sea level rise and protecting Cartagena against flooding may be more of a challenge. It will be crucial for the private sector in Cartagena to work with the public sector on coastal protection.

More challenging long-term schemes to reduce water flows into the bay via Bocachica and Bocagrande have also been discussed at the municipality level, although they have not been formally reported based on the meetings held during the site visit.

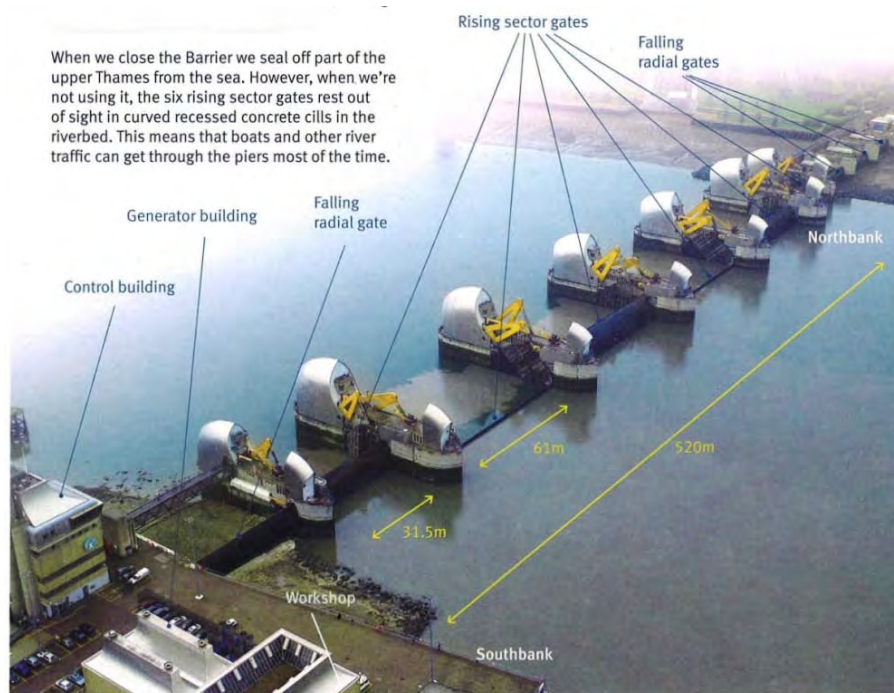
Figure 16-1– Potential flood prevention scheme for Bocagrande and Castillogrande



Figure 16-2 – Beach protection measures along Bocagrande. Source: Invemar, 2005



Figure 16-3 – The Thames Barrier. Source: Environment Agency of England and Wales)



References

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17 Summary of results and conclusions

This report presents the potential risks of climate change for MEB and recommends a number of adaptation options that MEB can consider to prevent or reduce adverse climate change impacts, or to exploit opportunities.

17.1 Summary of risks, opportunities and uncertainties

A preliminary analysis of MEB led to defining a set of risk areas which are likely to be affected by climate change, namely:

- Demand, trade levels and patterns affecting total trade through the port,
- Navigation and berthing,
- Goods handling,
- Vehicle movements inside the port,
- Goods storage,
- Inland transport beyond the port,
- Environmental performance,
- Social performance, and
- Insurance.

Each of these risk issues can encompass implications of the following nature:

- Financial (e.g. if climate change affects earnings),
- Operational (e.g. if climate change has implications for operation and equipment efficiency),
- Health and safety (e.g. if climate change has effects on worker health and productivity),
- Local community (e.g. if climate change has implications for community relations),
- External stakeholders (e.g. if climate change adaptation requires cooperation, funding or buy-in of governments),
- Environmental (e.g. if climate change influences environmental performance), and
- Reputation (e.g. if climate change affects clients' views of the reliability and quality of the port facility).

Table 17-1 summarizes the significance of climate change risks and opportunities according to the categories listed above, assuming no adaptation. Risk significance is evaluated by scoring the two dimensions of risk, namely the likelihood of a hazard and the magnitude of its consequence. Table 17-2 and Table 17-3 provide the consequence and likelihood ratings, which are scored from 1 (low) to 5 (high). Note that, where relevant, the risk assessment considered the implications of climate variability as well as average changes in the future climate. Note also that almost all of the risks have potential financial consequences, but only one risk category has been assigned to each risk in Table 17-1.

When considering these conclusions, MEB will need to consider its attitude to risk (or risk aversion), and make decisions about adaptation measures accordingly.

Table 17-1 – Climate change risk assessment for MEB over the 21st Century, assuming no adaptation

Risk	Risk category	Likelihood (1-5)	Consequence (1 - 5)	Risk level
Vehicle movements inside the port (Section 5)				
Increased seawater flooding of port areas (observed SLR scenario)	Operational	5	4	VERY HIGH
Increased seawater flooding of port areas (accelerated SLR scenario)	Operational	3	5	HIGH
Increased maintenance of port unpaved areas	Operational	3	1	Low
Demand, trade levels and patterns (Section 6)				
Reduction in total trade at MEB	Financial	3	3	MEDIUM
Reduction in grain imports at MEB	Financial	2	3	MEDIUM
Reduction in agricultural exports at MEB	Financial	3	1	Low
Better relative performance of MEB compared to other ports	Reputational	4	n/a	OPPORTUNITY
Increase in certain agricultural exports at MEB	Financial	1	n/a	OPPORTUNITY
Goods storage (Section 7)				
Goods damage or loss due to seawater flooding (accelerated SLR scenario)	Reputational	5	4	VERY HIGH
Goods damage or loss due to seawater flooding (observed SLR scenario)	Reputational	4	4	VERY HIGH
Goods damage or loss due to surface flooding	Reputational	1	4	MEDIUM
Increased customer energy costs for refrigerated containers, affecting customers' views of MEB	Reputational	2	1	Low
Grain spoilage in storage facilities	Reputational	3	2	MEDIUM
Reduced water use for spraying coke	Financial	4	n/a	OPPORTUNITY
Environmental performance (Section 8)				
Mangrove degradation around the causeway	Environmental	4	3	HIGH
Failure to comply with EMP as a result of climate change	Legal	2	3	Low
Reduced dredging requirements	Environmental	4	n/a	OPPORTUNITY
Use of mangrove regeneration as an adaptation measure	Environmental /Operational	3	n/a	OPPORTUNITY

Risk	Risk category	Likelihood (1-5)	Consequence (1 - 5)	Risk level
Navigation and berthing (Section 9)				
Difficulties with berthing due to increased height of vessels berthed relative to quay and material handling equipment	Operational	5	1	MEDIUM
Reduced berth operability because of higher wave height	Operational	1	1	Low
Reduced navigability in the Bay of Cartagena	Operational	1	2	Low
Opportunity for larger draft vessels to berth at MEB	Operational	1	n/a	OPPORTUNITY
Reduced dredging requirements	Financial	2	n/a	OPPORTUNITY
Goods handling (Section 10)				
Increased crane downtime during periods of high winds	Operational	2	2	MEDIUM
Periods of heavy rainfall prevent the loading or unloading of certain goods	Operational	3	3	MEDIUM
Inland transport beyond the port (Section 11)				
Increased surface flooding of the roads in Cartagena	Reputational	4	2	MEDIUM
Increased seawater flooding of the road outside MEB	Reputational	2	3	MEDIUM
Increased climate-related hazards on roads across Colombia	Operational	3	2	MEDIUM
Increased river flows on Colombia's waterways	Operational	3	n/a	OPPORTUNITY
Social performance (Section 12)				
Increased congestion or mud on the local road network	Local community	2	2	Low
Increased discontent because of coke dust and soda ash blowing	Local community	1	2	Low
Increased employee absenteeism	Health and safety	1	2	Low
Insurance (Section 13)				
Increased insurance premiums or degradation in insurance terms reflecting future climate change risks.	External stakeholders	4	2	MEDIUM

Table 17-2 – Risk matrix defining the categories of risk and the system for scoring levels of impacts

Risk category	Consequence rating				
	1	2	3	4	5
Legal	No evidence of compliance.	Non-compliance & imposition of regulatory or contractual conditions.	Failure to meet legislative, regulatory or contractual conditions.	Possibility of prosecution & fine.	Possibility of imprisonment.
Financial	Incurs slight increases in costs & liabilities or slight reductions in revenues but not enough to affect EBITDA.	Incurs costs & liabilities or reductions in revenues. EBITDA is slightly reduced.	Incurs costs & liabilities or reductions in revenues. EBITDA is moderately reduced.	Incurs costs & liabilities or reductions in revenues. EBITDA is significantly reduced. Irreversible loss of market shares.	EBITDA is negative.
Local community	Minor community opposition. Need to improve relationship.	Local community complains and minor actions are needed to resolve complaints.	Widespread local community opposition & high level of complaints.	Project requires major social programme and large-scale resettlement action plans.	Project cannot go ahead due to widespread objections that are accepted by the regulators/politicians or funders.
External stakeholders	Need for discussions to avoid objections.	Possible objections by stakeholders requiring additional actions or small studies.	Possible strong objections by stakeholders that will require major studies to address.	Delay to approvals and sign-off by major stakeholders. Changes to contractual conditions.	Project likely to be denied approval or sign-off by major stakeholders.
Environment	On-site release that is containable with minimal damage.	Off-site release with no significant damage and remediation in terms of weeks.	Major off-site release with medium term damage and remediation needed in terms of months.	Major off-site release, long term damage and remediation needed in terms of years.	Permanent damage to an ecosystem with irreversible effects. Permanent damage to a site of high ecological value that is legally protected and/or of particular vulnerability.
Operational	No impact or slight reduction of operations or equipment efficiency.	Interruptions to operations in the order of hours (e.g. due to flooding restricting movements on the port) or reduced equipment efficiency causing slight delays.	Interruptions to operations in the order of days. Damage to buildings or equipment.	Project likely to be mothballed.	Project unable to proceed.
Health & safety	Local treatment with short recovery and minor short-term effects. No absenteeism.	Medical treatment required or short-term acute health effects. Short-term absenteeism.	Lost time injury and short/medium term health effects. Absenteeism of a week or more.	Extensive injuries or chronic health issues. Absenteeism of a month or more or very recurrent absenteeism over several months.	Single fatality or permanent disability implying long-term or quasi-permanent absenteeism.
Reputational	Clients suffer minor disruptions.	Clients suffer disruptions, delays or loss.	Clients suffer significant disruptions, delays or loss.	Clients consider using another port.	Clients use another port.

Table 17-3 – Definition of risk ratings as a combination of likelihood and impact scores

			CONSEQUENCE RATINGS				
LIKELIHOOD RATINGS			1	2	3	4	5
Almost certain	5	Recurrent events - expect this event almost annually. Single event - highly likely (>90% probability).	Medium	High	Very High	Very high	Very High
Probable	4	Recurrent events - expect this event several times in your career. Single event - more likely to occur than not (50-90% probability).	Medium	Medium	High	Very high	Very High
Possible	3	Recurrent events - expect this event to occur once in your career, at any time. Single event - less likely than not, but still appreciable chance of occurring (10-50%).	Low	Medium	Medium	High	Very High
Unlikely	2	Recurrent events - event hasn't occurred during your career yet, but could occur at some time. Single event - unlikely but not negligible (1-10%).	Low	Low	Medium	Medium	High
Rare	1	Recurrent events - event has occurred elsewhere, but in exceptional circumstances. Single event - not expected to occur, but possible (<1%).	Low	Low	Low	Medium	Medium
RISK LEVELS		DESCRIPTION OF RISK / ACTIONS REQUIRED					
Very High		Very high risks are unacceptable to MEB. Where possible and when it makes economic sense, implement adaptation options to avoid, reduce or transfer risk.					
High		Implement 'no regret' and 'low cost' adaptation options. Discuss the need to implement adaptation options requiring significant expenditure.					
Medium		Medium risks can be tolerated if 'no regret' and 'low cost' adaptation options can turn them into residual risks.					
Low		Low risks are acceptable.					
Opportunity		Consider actions that could optimize benefits while increasing climate resilience.					

17.2 Summary of recommended adaptation options for MEB

This section summarizes the key adaptation options which the study recommends MEB should consider to manage the climate change risks identified.

17.2.1 Raise the height of the causeway road

The financial analysis of adaptation costs to raise the causeway road between the island and the mainland is presented in more detail in Section 5 of the report.

Since the causeway road between the Isla del Diablo and the mainland is a gravel track it is both quick and easy to raise, although the cost of the business interruption caused by the construction works would be a factor to consider.

By 2032 the (undiscounted) annual cost of flooding of the causeway is expected to be between 3% and 7% of MEB's projected earnings in the observed and accelerated SLR scenarios respectively. Under the accelerated SLR scenario, it is projected that all of MEB's earnings are wiped out from the 2060s onward. Using a discount rate of 16% (the rate suggested by MEB), the NPC of raising the height of the causeway in both adaptation scenarios to 2100 is expected to be below \$100,000 and below \$200,000 in the observed and accelerated SLR scenarios respectively (which represents less than 1% of MEB's earnings by 2100).

Interestingly, Section 5 illustrates that the difference between the net present value of adaptation under the observed and accelerated sea level rise scenarios is very small, meaning that across a range of climate change scenarios the benefits of raising the causeway consistently exceed their costs. Finally, the lowest discount rate presented here is 8%. If one were to use the Stern rate of 1.4%, the net present value of interruptions to vehicle movements would clearly be a lot greater, and may justify raising the causeway before 2020.

17.2.2 Pave the port's unpaved areas

Currently, the average cost of maintaining unpaved areas stands at \$154,000 per annum. Paving these areas would require a capital expenditure of \$2.5m, which, using MEB's discount rate of 16%, would take approximately 16 years for the investment to payoff.

Due to the lack of confidence in the impacts of climate change on road maintenance and the relatively long payback time for paving, it cannot be solely justified by climate change risks. However, when additional benefits to paving the road are taken into account – for example, to minimize dust production, improve health and safety on the port, ensure business continuity and reduce vehicle wear and tear – the rationale for paving the road is stronger. MEB have stated that this is a measure they intend to implement, regardless of climate change.

17.2.3 Improving drainage

Because of the uncertainty of future extreme precipitation projections, and given the existing drainage capacity, it is not expected that it will be necessary for MEB to undertake any adaptation to reduce the risk of surface flooding in the short to medium term.

If MEB decides that action is needed to manage drainage then there are a number of steps that can be taken, including:

- Maintaining pavements and grates to ensure that the maximum potential drainage capacity is achieved,
- Fitting valves to all drainage outlets, and
- Making sure that regular inspections are made of all drainage areas to identify potential risks before they result in high-cost repairs.

These are all changes that can be implemented almost immediately and at low cost. It is also thought that these changes will bring benefits to MEB under climate change as rainfall intensity is expected to increase. Therefore, these actions would be beneficial to undertake in the short term, while a medium to long-term strategy is being formulated.

Toward the end of the century, it may be necessary to raise the drainage outlets, especially if the accelerated sea level scenario is realized. The cost has not been estimated but is expected to be significant as it would require significant changes to the quay walls. As a result, it is recommended to align any works with the date by which the quays are expected to expire (approximately 2050). Under the observed SLR scenario, the drainage channels will still be 0.1m above mean sea level by 2050, but will be 0.2m below it under the accelerated sea level rise scenario.

In addition, MEB could consider increasing the diameter of the small drainage pipes on the outside wall of the mainland port, to avoid surcharge due to seawater ingress (this risk was not assessed in the study due to the lack of data on the drainage system of the mainland site).

17.2.4 Develop knowledge of and/or trade in climate resilient commodities

If climate change begins to show adverse effects on some of the crop varieties that MEB currently transports, then MEB may wish to focus some business development effort in attracting producers of those crops that will grow favorably in a climatically changed future. In the Colombian context these would include sesame, bananas, coconut, plantain and sorghum.

In addition, it may be helpful to contact ICA (Instituto Colombiano Agropecuario) who is doing research on climate change impacts on pests and diseases (see Section 16.1.6).

17.2.5 Managing energy costs for refrigeration

There are two adaptation options for ensuring that energy cost increases, driven by rising temperatures, are managed by MEB:

- Reduce energy consumption and/or
- Ensure that the cost is passed on to customers.

There is a general move to more energy efficient reefers in the market. However, the choice of reefer does not sit with MEB but with its customers. One option is for MEB to charge its customers for electricity use outside the storage flat rate, if that is not already the case.

17.2.6 Protect goods from seawater flooding

There are four adaptation options to protect the storage areas against seawater flooding. These are presented in order of increasing capital cost as follows:

- Reorganize storage to ensure that perishable cargo is stored in less vulnerable port areas,
- Provide emergency flood protection to warehouses and storage areas,
- Increase the height of the wall around the patio, and
- Increase the height of the patio itself and the warehouses.

However, there is little room in the current port confines within which to reorganize storage to less vulnerable areas, so providing flood protection to warehouses and storage areas may be the first adaptation option available. Increasing the wall height would be costly and would require an overhaul of the drainage system, so if this option were to be considered it should be part of a plan to replace the drainage system in general.

17.2.7 Contract additional insurance

MEB's insurance cover does not extend to the costs of business interruption arising from:

- Climate-related hazards affecting customers, and
- Flooding, strong winds or heavy rainfall affecting the access to and from the port or vehicle movement at the port (ingress/egress).

Ensuring that future insurance policies take some of these considerations into account could be part of MEB's long-term business plan in the light of climate change.

It should also be noted that some insurers could be willing to offer lower insurance premiums for companies that undertake actions which reduce climate risks. Therefore, a renegotiation of MEB's insurance terms would be best discussed in conjunction with the adaptation options discussed above.

17.3 Transferability of the conclusions

MEB is in a relatively good position relative to some other ports, especially in Colombia. For instance, it is located in a sheltered bay which protects it from wave action and storm surges, it does not suffer from the high levels of precipitation experienced at Buenaventura and is not as exposed to storms as other ports in the Caribbean. For these reasons, there are various climate change risks which are generally significant to ports but have not been explored in depth in this assessment. Examples of these risks at other ports are presented in Section 2.

In other port locations there may also be better quality observed and future climate information, for example higher confidence across climate models of future precipitation changes. This means that the quality of climate change risk analyses will vary port to port depending on location and available information. Nevertheless, the climate change risk and adaptation assessment approach that was followed in this assessment can be applied to any sea port.



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