FINAL REPORT

Port of Manzanillo: Climate Risk Management

September 2015

BID
Mejorando vidas

SCT
SECRETARÍA DE COMUNICACIONES Y TRANSPORTES

ESTADOS UNIDOS MEXICANOS

MANZANILLO
Coordinación General de Puertos y Marina Mercante

Cataloging-in-Publication data provided by the
Inter-American Development Bank

Felipe Herrera Library

Port of Manzanillo: climate risk management / Richenda Connell, Laura Canevari, Chris Coleby, Stewart Wright, John N. Robertson, Will Morgan, Antonio Cerezo, Alvaro Rivero, Guadalupe Ugarte, Robert Larson, Christopher Carr, Richard Washington, Eduardo Saucedo, Efrén Ramírez, Marcelo Olivera, Austin Becker, Joana Pascual, Melissa Barandiarán, Gmelina Ramírez, Amado Crotte, Ernesto Monter Flores, Juan-Pablo Martínez-Molina.

p. cm. — (IDB Monograph ; 434)

Includes bibliographic references.

1. Harbors-Environmental aspects-Mexico.

2. Coastal zone management-Mexico.

3. Climatic changes-Risk management-Mexico. I. Connell, Richenda. II. Canevari, Laura. III. Coleby, Chris. IV. Wright, Stewart. V. Robertson, John N. VI. Morgan, Will. VII. Cerezo, Antonio. VIII. Rivero, Alvaro. IX. Ugarte, Guadalupe. X. Larson, Robert. XI. Carr, Christopher. XII. Washington, Richard. XIII. Saucedo, Eduardo. XIV. Ramírez, Efrén. XV. Olivera, Marcelo. XVI. Becker, Austin. XVII. Pascual, Joana. XVIII. Barandiarán, Melissa. XIX. Ramírez, Gmelina. XX. Crotte, Amado. XXI. Monter Flores, Ernesto. XXII. Martínez-Molina, Juan-Pablo. XXIII. Inter-American Development Bank. Transport Division. XXIV. Series. IDB-MG-434

Key Words: Climate change, Mexico, Ports, adaptation, Manzanillo, transportation, susteinability

Jel Codes: Q54, R40, R42, Q56

Copyright © 2015 Inter-American Development Bank. This work is licensed under a Creative Commons IGO 3.0 Attribution-NonCommercial-NoDerivatives (CC-IGO BY-NC-ND 3.0 IGO) license (http://creativecommons.org/licenses/by-nc-nd/3.0/igo/legalcode) and may be reproduced with attribution to the IDB and for any non-commercial purpose. No derivative work is allowed.

Any dispute related to the use of the works of the IDB that cannot be settled amicably shall be submitted to arbitration pursuant to the UNCITRAL rules. The use of the IDB's name for any purpose other than for attribution, and the use of IDB's logo shall be subject to a separate written license agreement between the IDB and the user and is not authorized as part of this CC-IGO license.

Note that link provided above includes additional terms and conditions of the license.

The opinions expressed in this publication are those of the authors and do not necessarily reflect the views of the Inter-American Development Bank, its Board of Directors, or the countries they represent.

FINAL REPORT

Port of Manzanillo: Climate Risk Management

September 2015

Manzanillo, Mexico

CONSULTORIA TECNICA, S.C.

WorleyParsons

ACCLIMATISE building climate resilience

BID Mejorando vidas

SCT SECRETARÍA DE COMUNICACIONES Y TRANSPORTES

MANZANILLO COORDINACIÓN GENERAL DE PUERTOS Y MARINA MERCANTE

© 2015, Inter-American Development Bank

AUTHORED BY

Richenda Connell and Laura Canevari, Acclimatise Group Limited; Chris Coleby, Stewart Wright, John N. Robertson, Will Morgan, Antonio Cerezo, Alvaro Rivero, Guadalupe Ugarte, Robert Larson and Christopher Carr, WorleyParsons; Richard Washington, Universidad de Oxford; Eduardo Saucedo and Efrén Ramírez, Consultoría Técnica; Marcelo Olivera, Universidad Autónoma Metropolitana; Austin Becker, Universidad de Rhode Island.

We thank Inter-American Development Bank staff members Joana Pascual, Melissa Barandiarán, Gmelina Ramírez, Ernesto Monter Flores and Juan-Pablo Martínez-Molina for their comments throughout the development of this study.

The authors wish to thank the management and staff of API Manzanillo for their continuous support and cooperationin this study, especially Rosa Aurora Quiroz Dahas, Alejandro Abundis Santamaría, Roberto López Ceballos, Zayda Armenta, Berenice López, Juan Manuel de los Santos, Juan Carlos Córdova Estrada and Francisco Santana Roldán.

This report was produced with the support of the International Finance Corporation. The technical lead for the study was Vladimir Stenek, International Finance Corporation, World Bank Group.

The authors also wish to thank the following organizations for their contributions to this study.

Port community: APASCO, CEMEX, CONTECON, FRIMAN, GRANELERA, HAZESA, LA JUNTA, MARFRIGO, MULTIMODAL, OCUPA, PEMEX, SSA, TIMSA, USG, Capitanía de Puerto, Ayuntamiento de Manzanillo, FERROMEX.

State of Colima: Instituto para el Medio Ambiente y Desarrollo Sustentable del Estado de Colima (IMADES), Centro Universitario de Gestión Ambiental (CEUGEA, Universidad de Colima), Secretaría de Desarrollo Urbano del Estado de Colima.

Federal Government: Comisión Nacional del Agua (CONAGUA), Centro Nacional de Prevención de Desastres (CENAPRED), Comisión Nacional de Áreas Naturales Protegidas (CONANP), Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO), Instituto Nacional de Ecología y Cambio Climático (INECC), Instituto Mexicano del Transporte (IMT), Secretaría de Comunicaciones y Transportes (SCT), Secretaría de Marina (SEMAR), Secretaría del Medio Ambiente y Recursos Naturales (SEMARNAT), and Secretaría de Turismo (SECTUR).

DESIGNED BY

Ana Dorado Infodesign

RIGHTS AND PERMITS

The material in this publication is subject to copyright. Quote, copy and / or reproduction of any portion or all of this publication is permitted provided that the reference is mentioned.

Publication of this report was made possible through financial support provided by the IDB's Infrastructure Project Preparation Fund (INFRAFUND).

Forewords

Message from the Vice President for the Private Sector and Non-Sovereign Guaranteed Operations, a.i., at the Inter-American Development Bank

Hans U. Schulz

Ports are located in coastal areas that are increasingly susceptible to climate change impacts. By 2050, according to IDB estimates, rising sea levels, temperature increases and changes in rainfall patterns will result in an estimated annual cost of 2-4 percent of GDP for Latin America and the Caribbean (LAC)[1]. Climate change has already begun to affect the availability of resources, supply and demand of products and services, and performance of physical assets, making it urgent to strengthen public policy priorities on climate change. Financial returns as well as management of non-financial risks, such as economic development and environmental and social issues, may be affected if climate change is not taken into account in investment strategies. We estimate that the 340 extreme weather phenomena observed in 2007-2012 in LAC left at least 8,000 dead, affected more than 37 million people and led to economic losses of more than US$ 32 billion. Low-income people and women are disproportionately affected by climate change.

More than 80 percent of goods traded worldwide are transported by sea. Ports in developing countries handle more than 40 percent of the total containerized traffic, of which a significant portion relates to export of goods produced in the country[2]. Maritime infrastructure and transport sector is critical to trade growth in most of LAC. The region accounts for 41.8 million twenty-foot equivalent units (TEUs), about 7% of the world's total[3]. Within Latin America, Mexico represents 10.23 percent of total port traffic or third place.

As Mexico is a key operational hub for the logistics supply chain in LAC, it is critical to undertake an ex- ante assessment in collaboration with key logistics providers and or local governments to address vulnerability to climate change. Thus, while ports in Mexico could be impacted by climate change locally, changes to the supply chain and local infrastructure can create additional disruptions that require working collaboratively on a broader climate risk and adaptation strategy.

Specifically, in the case of the Port of Manzanillo, a climate change risk assessment conducted found that aspects of performance are likely to be significantly affected due to climate change, if no action is taken, specifically: (i) increased rainfall intensity causing greater surface water flooding of the internal port access road and rail connections; (ii) increased sedimentation of the port basin, reducing draft clearance for vessels and terminal access, due to increased rainfall intensity; and (iii) increased intensity of rainfall causing increased damage to infrastructure and equipment through surface water flooding.

The aim of this study is to analyze in depth the climate-related risks and opportunities facing the Port of Manzanillo in Mexico. The report also provides an Adaptation Plan for the port. The Port of Manzanillo becomes once again a pioneer, as this is the first climate risk management study performed on a full port in LAC.

1. Climate Change at the IDB: Building Resilience and Reducing Emissions –Inter-American Development Bank (IDB). http://publications.iadb.org/handle/11319/6692?locale-attribute=en#sthash.vTioHDnt.dpuf

2. Climate Risk and Business: Ports, Terminal Marítimo Muelles el Bosque –International Finance Corporation (IFC), World Bank Group. http://www.ifc.org/wps/wcm/connect/topics_ext_content/ifc_external_corporate_site/cb_home/publications/climaterisk_ports

3. According to the United Nations Economic Commission for Latin America and the Caribbean (UN ECLAC) statistic on transport: http://www.cepal.org/cgi-bin/getProd.asp?xml=/perfil/noticias/noticias/1/53131/P53131.xml&xsl=/perfil/tpl-i/p1f.xsl&base=/perfil/tpl/top-bottom.xsl

Message from the Director General of the Port Authority of Manzanillo

Vice Admiral Ruben Bustos Jorge Espino

I am pleased to announce that the participation of the Port Authority of Manzanillo in the study: Port of Manzanillo: Climate Risk Management, together with the Inter-American Development Bank, strengthens the objectives and actions set out in the Mexican National Development Plan 2013-2018 to address the adverse effects of climate change.

The content of this study will undoubtedly serve as a guide to determine priorities and programs to encourage best practices of climate change adaptation and mitigation to reduce emissions of greenhouse gases, more sustainable and environmentally friendly processes in the Manzanillo port community.

We commit to include this study as part of the strategy, plans and the daily actions of our performance.

We thank all the institutions, federal, state and municipal agencies, terminals and port service providers who made possible this study –first of its kind for a Mexican port, who generously and transparently shared information, experience and practices in the use of systems and technologies oriented to operation with low-carbon emissions.

Contents

List of acronyms

API Manzanillo	**Administración Portuaria Integral de Manzanillo S.A. de C.V.** Federal agency created in 1994 with a 50 year concession to administer, promote, build and maintain the Port of Manzanillo.
BAU	**Business as usual**
CAPEX	**Capital expenditure**
CENAPRED	**Centro Nacional de Prevención de Desastres** Supports risk reduction measures to protect the population against natural and anthropogenic disasters through research, monitoring, capacity building and knowledge diffusion.
CEUGEA	**Centro Universitario de Gestión Ambiental**, Universidad de Colima
CICC	**Comisión Intersectorial de Cambio Climático** Formed of 13 of Mexico's Federal Secretariats, its objective is to coordinate the formulation and implementation of national policies for mitigation and adaptation and to promote programs and strategies to ensure Mexico meets its obligations under the United Nations Framework Convention on Climate Change (UNFCCC).
CMIP5	**Coupled Climate Model Intercomparison Project 5**
CONAGUA	**Comisión Nacional del Agua** Its mission is to preserve national water, to ensure the sustainable use of the public goods and to guarantee water security. CONAGUA is also responsible for managing the National Meteorological Services and the National Catchment Network
CONABIO	**Comisión Nacional para el Conocimiento y Uso de la Biodiversidad** CONABIO's mission is to promote, coordinate and carry activities to support knowledge on biodiversity and to ensure its conservation and sustainable use.
CONANP	**Comisión Nacional de Áreas Naturales Protegidas** CONANP's mission is to ensure that the most representative ecosystems of Mexico and its biodiversity are preserved through a system of national protected areas and through other conservation instruments.
EBIDTA	Earnings before interest, taxes, depreciation, and amortization
EIA	**Environmental Impact Assessment**
GIZ	**Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH** A sustainable development service provider, set up to assist the German Government in achieving its objectives in the field of international cooperation.
HM	**Harbor Master**

IMADES — **Instituto para el Medio Ambiente y Desarrollo Sustentable for the State of Colima**
IMADES' key responsibilities include designing mechanisms to protect key ecosystems and to promote the sustainable development of the State's population.

IMT — **Instituto Mexicano del Transporte**
An SCT body dedicated to applied research, technological development, technical assistance, development of knowledge and transport regulation and capacity building and training.

INECC — **Instituto Nacional de Ecología y Cambio Climático**
Institute coordinated by SEMARNAT whose main objective is to generate and integrate scientific and technical knowledge and to support capacity building for the development, management and evaluation of public policies related to environmental protection and green growth, as well as mitigation and adaptation to climate change.

IOC — **Intergovernmental Oceanographic Commission**
A body with functional autonomy within UNESCO, and the only competent organization for marine science within the UN system. Its purpose is to promote international cooperation and to coordinate programs in research, services and capacity-building, to learn more about the nature and resources of the ocean and coastal areas and to apply that knowledge for the improvement of management, sustainable development, the protection of the marine environment, and the decision-making processes of its Member States.

IPCC — **Intergovernmental Panel on Climate Change**
The leading international scientific body for the assessment of climate change, established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) to provide the world with a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts.

INEGI — **Instituto Nacional de Estadística y Geografía.**
Federal institute responsible for the generation and dissemination of statistical and geographical information

IRR — **Internal rate of return**

LGCC — **Ley General para el Cambio Climático**

NAFTA — **North American Free Trade Agreement**

OPEX — **Operating expenditure**

PECC — **Programa Estatal de Cambio Climático**

PMDP — **Master Plan for the Port of Manzanillo**

List of acronyms

RCP **RCP 8.5** **RCP 4.5** **RCP 2.6**	**Representative Concentration Pathways** are scenarios of future concentrations of greenhouse gases, aerosols and chemically active gases in the atmosphere which are used to develop scenarios of future climate change. **RCP 8.5** is a high concentration pathway where radiative forcing reaches more than 8.5 W/m2 by the year 2100 relative to pre-industrial values. **RCP 4.5** is a scenario whereby radiative forcing is stabilized at 4.5 W/m2 shortly after the year 2100, consistent with a future with relatively ambitious emissions reductions. **RCP 2.6** is a scenario where radiative forcing reaches 3.1 W/m2 before it returns to 2.6 W/m2 by 2100. In order to reach such forcing levels, ambitious greenhouse gas emissions reductions would be required over time.
SAGARPA	**Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación** with the mission to promote, formulate and develop strategic projects for Mexico in the agricultural, livestock, fishing and food sector and in rural development
SCT	**Secretaría de Comunicaciones y Transportes** Federal government secretariat with the role of promoting safe, reliable and competitive transport and communication systems through the development of public policies and sectorial strategies that contribute to the sustainable growth of the economy.
SECTUR	**Secretaría de Turismo** Federal government secretariat with the role of directing the development of the tourism sector in the country.
SEGOB	**Secretaría de Gobernación** Federal government secretariat for internal affairs.
SEMAR	**Secretaría de Marina** National Military Institution with the role of defending the national territory from external threats and ensuring its internal safety. They monitor and record information on the marine environment, such as weather, climate and environmental variables.
SEMARNAT	**Secretaría del Medio Ambiente y Recursos Naturales** Federal government secretariat with the role of promoting the protection, restoration and conservation of ecosystems, natural resources and environmental services in order to ensure their sustainable use.
SENER	**Secretaría de Energía de Mexico** Federal government secretariat who mission is to drive Mexico's energy policy, to ensure energy supply is competitive, economically viable, sufficient, high quality, and environmentally sustainable.

SINACC	**Sistema Nacional de Cambio Climático.** Established following the LGCC, SINACC is composed of the CICC, INECC, the Consejo de Cambio Climático, federal entities, municipal authority associations; and the Congreso de la Unión.
SLR	**Sea level rise**
SuDS	**Sustainable Drainage Systems** Designed to reduce the impact of developments with respect to surface water drainage discharges, incorporating techniques such as source control; permeable paving; storm water detention; storm water infiltration; and evapo-transpiration (e.g. green roofs).
TEU	Twenty-foot equivalent unit, used to describe the capacity of container ships and container terminals.
UAB	Unidades de arqueo bruto (gross tonnage units), a measure of maritime vessel size
UNAM	**Universidad Nacional Autónoma de México**
UNFCCC	**United Nations Framework Convention on Climate Change**
VFD	**Variable Frequency Drive** An electronic device used to change the speed of electric motors

1. Study aims, approach and main findings

1.1. Study aims and audience

1.1.1.
Context and study aims

Ports have a critical role to play in the globalized and highly interconnected economy. They act as centers for national and international commerce, provide suitable environments for trading and support the economic development of countries. In Mexico, structural development policies have positioned trading (in particular with commercial partners in Asia) as an important national development priority.[1]

Additionally, ports are widely regarded as being highly vulnerable to the impacts of climate change. They are located in coastal areas and can therefore be affected by rising sea levels, and changes in storms and wave patterns. These climate-related variables, along with others such as changes in temperature and precipitation patterns, can damage port infrastructure and equipment, reduce operational capacity, compromise pollution control equipment and pose challenges for the health and safety of port workers. Taking these factors into account allows for the development of port adaptation plans, which should be seen as a priority both for ports, and for the economies of the countries where ports operate.

The Port of Manzanillo in the State of Colima, internationally renowned as one of the main containerized cargo ports globally, has an important role to play in this. It is considered Mexico's leading port in the Pacific and a critical node between the Pacific and the main national industrial belt (an area comprising the north, center and west of the country generating over 64% of GDP in Mexico)[2]. It has also been ranked as one of the ten largest and more important ports in the Americas and the second most important Latin American port in the Pacific[3]. The port is administered by Administración Portuaria Integral de Manzanillo S.A. de C.V., 'API Manzanillo', a federal agency created in 1994 with a 50 year concession to administer, promote, build and maintain it.

The Inter-American Development Bank ('IDB') has partnered with API Manzanillo on a Technical Cooperation to promote sustainability practices at the port. Recognizing the potential significance of climate change to ports, this Technical Cooperation includes the preparation of a study to assess climate-related risks and opportunities for the Port of Manzanillo, and to develop an Adaptation Plan.

The study aims to help build the capacity of the Port of Manzanillo to respond to potential challenges generated by climate variability and climate change and to foster associated opportunities stemming from early action and adaptation responses.

It aims to address the following questions:

1. What risks and opportunities does climate change present for the port?
2. What key climate-related factors should API Manzanillo take into account to maintain its competitiveness and develop its medium and long term business strategy?
3. How could the port manage climate risks and uncertainties in the most financially optimal way, taking account of environmental and social objectives?
4. How could climate-related opportunities be developed and exploited?
5. How should adaptation actions be prioritized and sequenced in an Adaptation Plan?
6. Where could API Manzanillo work in collaboration with other stakeholders to best manage climate risks and take advantage of opportunities?

Hence, based on the analysis of climate-related risks, opportunities and adaptation actions (points 1 to 4 above, addressed in Sections 2 to 4 of this report) an Adaptation Plan is put forward by the study (Section 5 of this report). The Adaptation Plan is the key outcome of the study.

As will be discussed in Section 1.5, the approach to the study is aligned with most of the requirements for State climate change programs set out in the SEMARNAT-INECC guidance document "Elementos Mínimos para la Elaboración de los Programas de Cambio Climático de las Entidades Federativas" (see box), within the limitations of the study scope (see Section 6).

1.1.2.
Audience for this report

This study is first and foremost aimed at supporting API Manzanillo and the terminals at the Port of Manzanillo to reduce risks and take advantage of opportunities generated by current and future changes in climate. The study helps identifying current and future challenges that could impair activities at the port, using a climate risks analysis of the port's value chain, proposing adaptation measures to ensure the port retains its current strategic position as one of the leading ports in the country. In doing so, it is a valuable reference to API Manzanillo and other actors in the port community of Manzanillo.

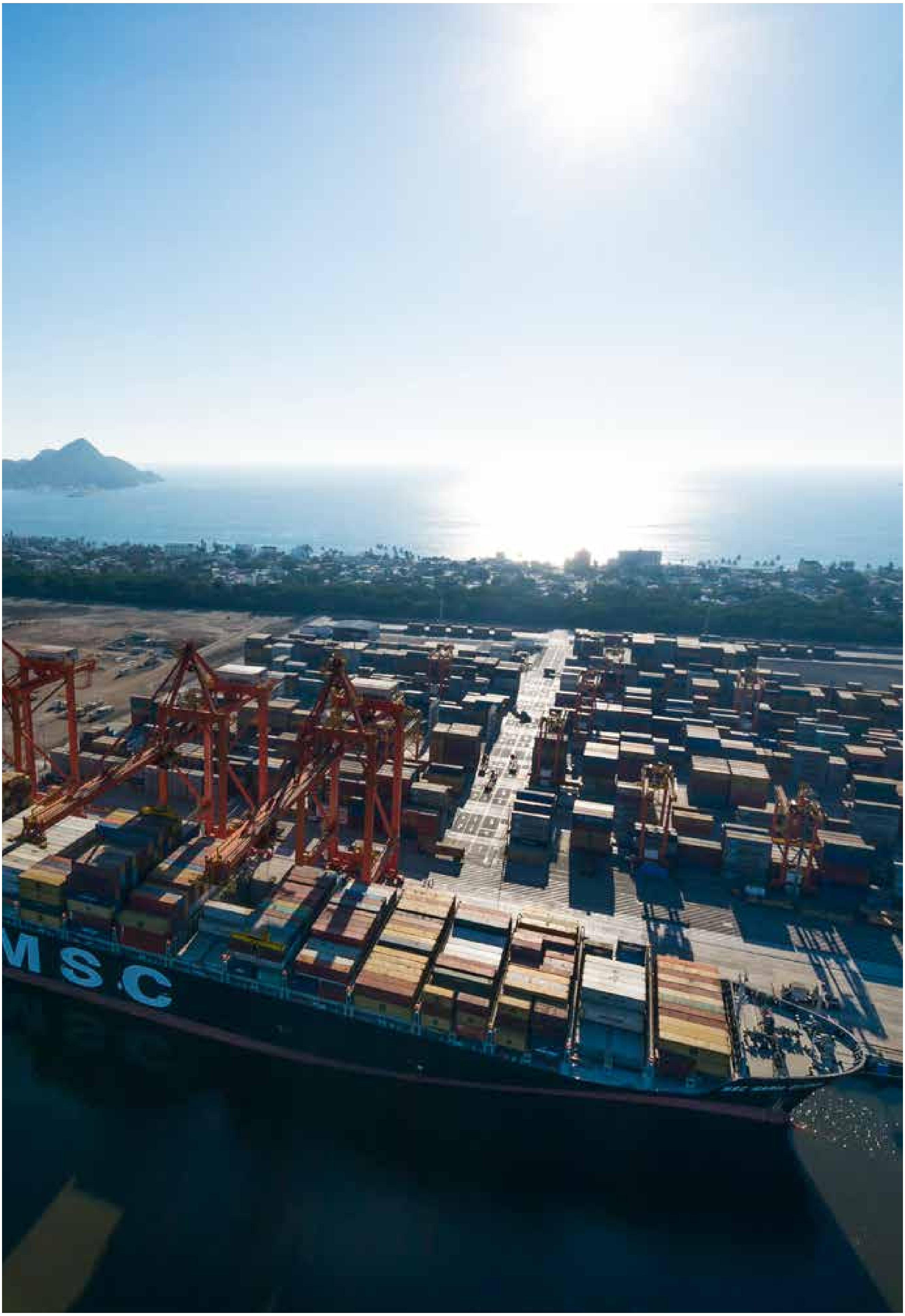
The study takes into account the latest climate change policy developments established at the federal, state and municipal level in Mexico (see Section 1.4) to ensure that adaptation actions at the port are in alignment with policy instruments that already exist in the country. In carrying out an assessment of climate risks for one of Mexico's largest ports and recommending concrete adaptation measures, this study responds to a national strategic objective set in the National Climate Change Strategy Vision 10-20-40, namely: "To reduce the vulnerability and increase the resilience of strategic infrastructure and productive systems in the face of climate change". Equally it responds to Objective 1 of the Special Program on Climate Change (PECC), namely: "Reduce the vulnerability of the population and of productive sectors and to increase their resilience, as well as the resilience of critical infrastructure". The study is therefore relevant to policy makers and government officials to evaluate how policy instruments addressing climate change challenges can be translated into specific adaptation actions for major strategic infrastructure in the country.

The study sets out an approach to climate vulnerability assessment, risk assessment and adaptation planning which can be considered by other ports in Mexico wishing to undertake similar assessments, taking into account the specifics of the climate and socio-economic conditions at each location.

Finally, the study brings together the latest scientific information from key national and international institutions, making use of the best available information, and providing a practical example on how climate change research and data can be used to assess risks and vulnerabilities, and develop concrete adaptation recommendations. In this sense, it is useful for research institutions and data providers interested in understanding and increasing the value of their climate services.

Minimum elements for elaboration of State Climate Change Programs according to SEMARNAT – INECC guidance[4]

- **Description of climate including:**
  - Current weather, climate variability and extreme events
  - Integration and spatial analysis of climate change scenarios
- **Diagnosis of:**
  - Potential climate change impacts on priority sectors and regions
  - Current and future vulnerability for priority sectors and regions, with a focus on territorial integration
  - Successful and unsuccessful adaptation processes, including: those that increase institutional capacity; those based on ecosystems; and mechanisms for monitoring and evaluation.
- **Proposals for adaptation which should:**
  - Be sustainable and address the specific problems identified through the diagnosis
  - Be feasible (considering institutional, financial, political, regulatory, technical and social capacity)
  - Include cost-benefit analysis and sources of potential funding for actions
  - Have clear synergies between mitigation and adaptation actions
  - Include analysis of positive impacts (co-benefits) and negative impacts
  - Align with mitigation and adaptation sectoral public policies, programs and government projects
  - Include indicators and monitoring and evaluation for adaptation actions and overall for the adaptation process
  - Adaptation measures must have the following characteristics:
    - Credibility
    - Equity
    - Reversibility
  - Prioritization of actions must be undertaken including short-, medium- and long timescales for implementation, consistent with the diagnosis of current and future vulnerability and the budget to implement them.



1.2. Overview of the Port of Manzanillo

The Port of Manzanillo is located in the Pacific coast of Mexico (19°03.45 N; 104°18.08 W) in the State of Colima (Figure 1.1). Established in the city of Manzanillo, the port has been an important center for maritime commerce since colonial times, acting as a departure and arrival point for maritime fleet explorations linking Asia with Central America. The geographic location of the Port of Manzanillo, its close proximity to the USA and its location in relation to maritime shipping routes in the Pacific have helped to develop the port into an important regional traffic hub.

In recent years, the port has positioned itself as the key port for the management of containerized cargo within Mexico, accounting for 60% of containerized cargo on the Pacific coast of Mexico and 46% within the entire country[5]. In addition to containerized cargo, the port provides services and facilities for the handling of other business lines, namely: mineral bulk, general cargo, agricultural bulk, petroleum products and vehicles. In terms of its zones of influence, the port trades goods to and from 17 out of 31 Mexican states[i] and maintains active trade relationships with over 14 countries worldwide.[ii] Further information on current and future cargo movements at the port, broken down by business line, and on the contribution of trade from specific countries and federal states is provided in Section 3.9.

FIGURE 1.1

Location of the Port of Manzanillo in the State of Colima, Mexico

Source: Report authors

There are 14 operating enterprises at the port, the terminals, which account for 100% of private capital invested (both national and international) and which together account for all cargo handled through the port. Each terminal has a contractual agreement with API Manzanillo. Among the facilities and services provided by the terminals, the following are of note:

- A total static capacity of over 49,000 TEUs[iii] and dynamic capacity of over 2 million TEUs
- There are two terminals specialized in mineral bulk with an overall capacity of 60,000 tons and which can load/unload up to 200 tons per hour
- The freezing compartments provided by the terminal specializing in fishing produce offer storage space of up to 3,500 tons
- The specialized terminal on containerized cargo operated by CONTECON Manzanillo, S.A. de C.V. can load/unload 3 vessels simultaneously with a maximum performance of 120 containers per hour per vessel
- The agricultural bulk installations offer five silos for storage, three providing up to 10,000 tons storage capacity and two providing 18,000 tons. Additionally, one of the agricultural bulk terminals, Comercializadora LA JUNTA S.A. de C.V., offers loading services of up to 1,000 tons per hour and storage space of up to 50,000 tons
- There are two multiple use areas, for the management of general and containerized cargo and two freezers for the storage of perishable goods with a total storage space of more than 6,000 tons of fresh produce
- There is one storage area for cement with a capacity of 25,000 tons, operated by Cementos APASCO S.A. de C.V.
- There are two storage spaces operated by CEMEX de México S.A. de C.V., one for the management of 50,000 tons of clinker and one for the management of 16,000 tons of cement bulk and general bulk

The layout of the port showing the locations of the terminals is presented in Figure 1.2. Further information on each of the terminals and their economic activities is provided in Table 1.1.

FIGURE 1.2

Layout of the Port of Manzanillo

1	Cruise ship terminal	
2	Pemex	*Specialized terminal*
3	Operadora de la Cuenca del Pacífico, S.A. de C.V.	*Multiple purposa facility (IUM)*
4	Cemex México, S.A. de C.V.	*Specialized terminal*
5	Cementos Apasco, S.A. de C.V.	*Specialized terminal*
6	Frigorífico de Manzanillo, S.A. de C.V.	*Port facility*
7	Corporación Multimodal, S.A. de C.V.	*Specialized terminal*
8	Terminal Internacional de Manzanillo, S.A. de C.V.	*Multiple purposa facility (IUM)*
9	Comercializadora La Junta, S.A. de C.V.	*Specialized terminal*
10	Granalera Manzanillo, S.A. de C.V.	*Port facility*
11	SSA México, S.A. de C.V.	*Specialized terminal*
12	Exploración de Yeso, S.A. de C.V.	*Specialized terminal*
13	Marfrigo, S.A. de C.V.	*Port facility*
14	Terminal Marítima Hazesa, S.A. de C.V.	*Port facility*
15	Contecon Manzanillo, S.A. de C.V.	*Specialized terminal*
16	Yard Nº3	*Port Authority*
17	Maneuver yard side "B"	
18	Maneuver yard side "C"	
19	Dock Nº14 backyard	*Maneuver yard*
20	Dock Nº15 backyard	*Maneuver yard*
21	Maritime customs	
22	Emergency center	

Source: API Manzanillo, 2014[6]

21
14
15
13
20
19
12
22
21
11
N
E
O
S
10
18
9
8
16
17
7
6
5
4
3
2
1

TABLE 1.1

Description of terminals operating at the Port of Manzanillo

Name of Terminal	Description
SSA México S.A. de C.V. (Stevedores Service of America)	SSA México, also known as Stevedores Service of America, operates one of the specialized container terminals (TEC I). SSA México is a subsidiary of the Carrix Group, the largest private capital port operator in the world. It has an area of 259,423 m^2 in the Port of Manzanillo from where it offers all types of container handling services.
CONTECON (Contecon Manzanillo, S.A. de C.V.)	CONTECON has an area of 724,200 m^2 of the port, for the second specialized container terminal (TEC II). Its capacity is projected to reach 2 million TEUs per year. TEC II was given under concession to CONTECON Manzanillo S.A., a subsidiary in Mexico of the Philippine International Container Terminal Services, Inc. (ICTSI), which is in charge of its operation.
OCUPA (Operadora de la Cuenca del Pacífico S.A. de C.V.)	Operadora de la Cuenca del Pacífico, known also as OCUPA, has an area of 84,477 m^2 at the port. It is a multipurpose facility dedicated to handling containers and general loose cargo.
TIMSA (Terminal Internacional de Manzanillo S.A. de C.V.)	Terminal Internacional de Manzanillo S.A. de C.V. (TIMSA) is a multipurpose facility for dispatching containers by land and sea, and it is also used for loading and unloading of general cargo, and mineral and agricultural bulk. It has an area of 84,957 m^2 at the port.
CEMEX (Cemex de México S.A. de C.V.)	CEMEX is a global construction company, offering products and services to clients and communities across America, Europe, Africa, Middle East and Asia. The company produces, distributes and commercializes cement, pre-mixed concrete, aggregates and other related products in 50 countries. It has a specialized facility for the management of its products, mainly cement. It has an area of 12,545 m^2 at the port.
APASCO (Cementos Apasco S.A. de C.V.)	Cementos Apasco is part of Holcim Group which produces and sells cement, aggregates, pre-mixed concrete and other products and services for the construction sector. It has significant presence throughout Mexico including 7 cement plants, more than 100 pre-mixed plants, 5 aggregate plants, 23 distribution centers and two maritime terminals, including the facility located at Manzanillo Port specialized in handling cement. It has an area of 17,440 m^2 at the port.
FRIMAN (Frigorífico de Manzanillo S.A. de C.V.)	Frigorífico de Manzanillo (FRIMAN) is a Mexican company operating at the Port of Manzanillo since July 2004. It has facilities for handling refrigerated goods with storage connections for 50 reefer containers and a cooled maneuvering platform with 18 gates, which are kept at a controlled temperature of -10 ° C to preserve the cold chain for goods being handled. It has an area of 16,426 m^2 at the port.

MULTIMODAL (Corporación Multimodal S.A. de C.V.)	Corporación Multimodal is a company dedicated to the handling of perishable goods, with facilities at the Port of Manzanillo for handling refrigerated products. It has an area of 8,915 m^2 at the port.
LA JUNTA (Comercializadora La Junta S.A. de C.V)	Comercializadora La Junta is a company dedicated to handling agricultural grains with an area of 35.090 m^2 in the port, including silos for storage of agricultural products. It has an area of 35,091 m^2 at the port
GRANELERA (Granelera Manzanillo S.A. de C.V.)	Granelera Manzanillo is dedicated to loading and unloading of agricultural bulk and has specialized facilities for handling and storing these goods in this business line. They also offer public weighing services. It has an area of 10,844 m^2 at the port.
USG (Exploración de Yeso S.A. de C.V.)	USG has specialized facilities for handling bulk minerals, with an area of 25,051 m^2 at the port.
MARFRIGO (Marfrigo S.A. de C.V.)	MARFRIGO is the port terminal dedicated to handling fishing products. The company has refrigerated facilities for storing and handling perishable goods, and an area of 4,000 m^2 at the port.
PEMEX (Pemex Refinación)	PEMEX Refining services include industrial refining processes, processing of petroleum and petroleum products, distribution, storage and sale. At the Port of Manzanillo it has a terminal for loading, unloading and handling oil and its derivatives. It has an area of 27,933 m^2 at the port.
HAZESA	HAZESA is a Multipurpose Terminal specialized in general cargo and mineral bulk.

Source: API Manzanillo

1.3. Overview of other main ports in Mexico

Of the Mexican ports, six can be considered the major ports of Mexico. Aside from Manzanillo, these are Ensenada and Lázaro Cárdenas on the Pacific coast, and Altamira, Tampico and Veracruz on the Atlantic coast (Figure 1.3).

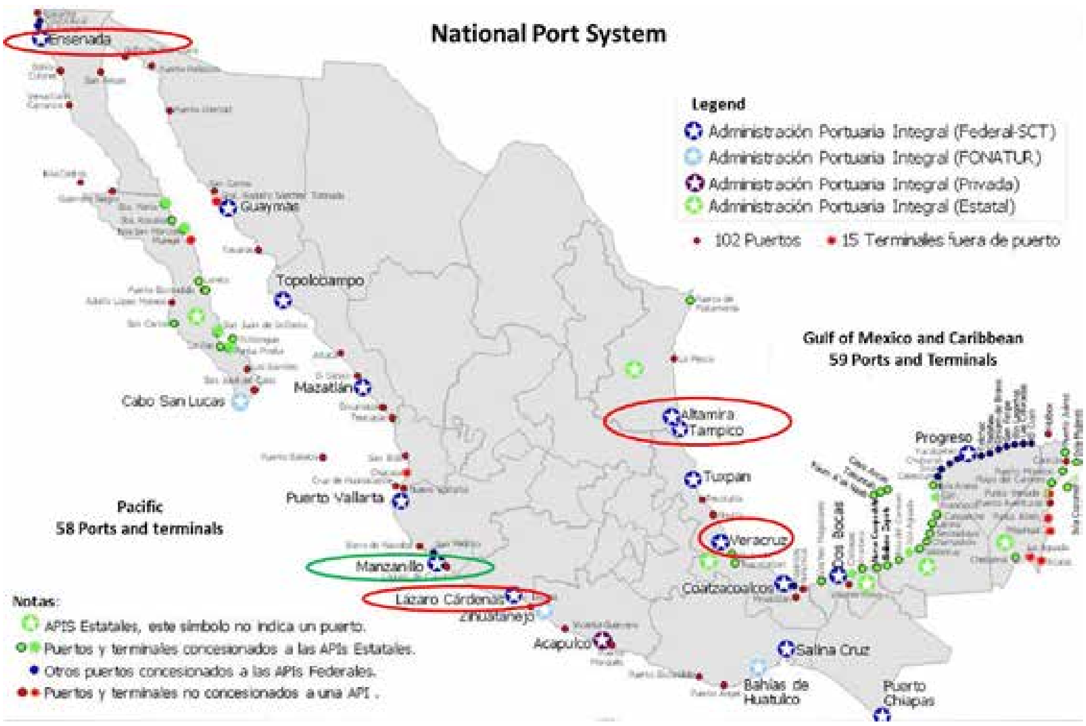
Most of these ports were selected by the Mexican Government in the late 1980s for major upgrades which specifically targeted the development of modern container handling facilities. This program was initiated to take advantage of the anticipated increase in trade due to the implementation of the North American Free Trade Agreement (NAFTA) of 1994. It was accompanied by a series of reforms of Mexican infrastructure by the Mexican Government including the privatization of ports under the Ports Law of 1993 and of the Mexican railroads in 1995.

Prior to privatization, Mexican ports were managed directly by the Department of Ports. After privatization, each port was placed under the control of an independent administrative body, or Administración Portuaria Integral ('API'). Major ports are nominally under the control of SCT but have considerable autonomy to enter into contracts with shipping companies and port operators, and are able to raise funds through port charges. Each port is independently operated and competes with the other Mexican ports for business and investment.

Since the 1990s these ports have considerably expanded their activities and their throughputs. While they compete with each other, they do not all handle the same commodities. Further, in addition to competing with each other, they are in competition with US ports, particularly Los Angeles and Long Beach which are reaching their limits for further development. Further information on the major ports is provided in Section 3.10.

FIGURE 1.3

Map of the national port system in Mexico. Main competitor ports in Mexico are highlighted in red.



Source: SCT, 2013 [7]

1.4. Climate adaptation policy frameworks and port policy frameworks at Federal, State and Municipal levels

Any climate change adaptation actions recommended in this study for the port must respond to the needs of the port to its current and future climate vulnerability, while at the same time working within the context of adaptation planning and port planning at the Federal, State and Municipal levels (see below). Thus, the development of the Port of Manzanillo's adaptation plan must take into account existing legislation at the Federal, State and Municipal levels.

This section provides a brief summary of the key policy instruments guiding the formulation and implementation of adaptation actions in Mexico at the Federal State and Municipal levels. It draws on a report developed in support of this study which describes the regulatory framework in more detail.[8] Further analysis of the relationships between the adaptation policy context in Mexico and the recommended adaptation plan for the Port of Manzanillo is provided in Section 5.

1.4.1. Federal level

Federal level climate adaptation policy frameworks

The Ley General de Cambio Climático (LGCC) released in 2012 is the underlying basis for climate change action in Mexico. It establishes the creation of institutions, legal frameworks and financing instruments to help support Mexico in responding to climate change challenges while moving towards a low carbon economy and represents a new benchmark for best practice in tackling climate change challenges worldwide. Following this law, Mexico established a Sistema Nacional de Cambio Climático (SINACC) which is supported by the Comisión Intersectorial de Cambio Climático (CICC). The SINACC is composed of: the CICC; the Instituto Nacional de Ecología y Cambio Climático (INECC); the Consejo de Cambio Climático; federal entities; municipal authority associations; and the Congreso de la Unión. Some of its key roles[9] are to:

1. Serve as a permanent mechanism for communication, collaboration, coordination and consensus on national climate change policy;
2. Promote the implementation of transversal national climate change policies in the short, medium and long term between the authorities of the three levels of government (Federal, State, Municipal), according to their scope and capabilities,
3. Coordinate the efforts of government entities at the federal, state and municipality levels for the implementation of adaptation, mitigation and vulnerability reduction measures in order to address the adverse effects of climate change through policy instruments provided by the General Law on Climate Change and others instruments derived from it; and
4. Promote coordination and consistency of programs, actions and investments between government entities at the Federal, State and Municipal levels and the National Strategy.

The CICC is formed of 13 of Mexico's Federal Secretariats[iv]. Its objective is to coordinate the formulation and implementation of national policies for mitigation and adaptation and to promote programs and strategies to ensure Mexico meets its obligations under the United Nations Framework Convention on Climate Change (UNFCCC).

Prior to the released on the General Law on Climate Change, Mexico already had a national response to climate change (the Programa Especial de Cambio Climático - PECC 2008-2012). However, the release of the LGCC is a key milestone that makes the objectives on climate change action legally binding. The three key policy instruments developed to support the LGCC are:

- The National Strategy on Climate Change Vision 10-20-40 (Estrategia Nacional de Cambio Climático – ENCC Visión 10-20-40), which sets out the focal areas for cross-sector climate policy, adaptation and mitigation. These are presented as a set of "eight axes of action" of which three are directly relevant to adaptation[v]:
    1. To reduce vulnerability and increase climate resilience of society to the effects of climate change;
    2. To reduce the vulnerability and increase the resilience of strategic infrastructure and of productive systems to the effects of climate change;
    3. To preserve and use in a sustainable way ecosystems and to ensure the maintenance of their ecological services.

- The Special Program on Climate Change (Programa Especial de Cambio Climático 2014-2018 - PECC), in response to the overarching objectives set out in the ENCC Visión 10-20-40, provides a framework for action under five key objectives, 21 strategies and over 150 lines of action. Of the five key objectives, three are directly relevant to adaptation[vi]:

- **Objective 1:** Reduce the vulnerability of the population and of productive sectors and to increase their resilience, as well as the resilience of critical infrastructure
- **Objective 2:** Preserve, restore and manage sustainable ecosystems, so as to guarantee the maintenance of their services for mitigation and adaptation
- **Objective 5:** Consolidate national policy on climate change through effective instruments and in coordination with federal entities, municipalities, legal institutions and society

- The State Programs on Climate Change (Programas Estatales de Cambio Climático - PECCs) support the design of sustainability policies and climate change strategies as the State and Municipal levels and is thus another important element of the climate change policy landscape in Mexico. In the case of the State of Colima, a draft final program is currently being reviewed by SEMARNAT. For the purpose of this study, information provided in the draft final version is drawn upon, noting that there may be changes to the program after its revision. Figure 1.4 and Figure 1.5 summarize the key elements setting the policy context for climate change action at the Federal level

According to the PECC 2014-2018, objectives under each of the strategies fall under the responsibility of one or multiple government agencies. Each of these entities must ensure that the lines of action described under each strategy are incorporated in the relevant sectoral plan in such a way that specific budget targets are set out against each line of action. Table 1.2 summarizes the key actors responsible for the implementation of climate change actions at the federal level[11].

Other federal level policy frameworks relevant to the Port of Manzanillo

In addition to the policy instruments directly addressing climate change, there is a more extensive list of instruments to be taken into account in the context of climate adaptation at ports. Drawing on the regulatory framework report[12] mentioned above, Table 1.3 summarizes information on other key federal level policy instruments that may affect the choice and implementation of adaptation measures at the Port of Manzanillo. While it is beyond the scope of this study to explain in further detail the role of each of these policy instruments, further information can be found in the regulatory framework report[13].

1.4.2. State level

State level climate adaptation policy frameworks

In response to requirements set out in the LGCC (2012), the State of Colima is in the process of developing its Programa Estatal de Cambio Climático (PECC)[vii]. The PECC draws on the guidance provided by Federal entities for the development of adaptation and mitigation instruments and includes a series of basic structural elements, as outlined in the “Elementos mínimos para la elaboración de Programas de Cambio Climático de las Entidades Federativas” developed by SEMARNAT and INECC[15]. Additionally the PECC is also being formulated in accordance with other State level policy instruments, in particular the Ley Ambiental para el Desarrollo Sustentable del Estado de Colima and the Ley de Protección Civil del Estado de Colima. Its objective is to establish the technical and programmatic basis required for the implementation of policies, strategies, lines of action and programs addressing climate change adaptation and mitigation actions. The Instituto para el Medio Ambiente y Desarrollo Sustentable (IMADES) is the entity responsible for the development and implementation of the Colima PECC, and is also responsible for the coordination of the CICC at the State level.

Other state level policy frameworks relevant to the port

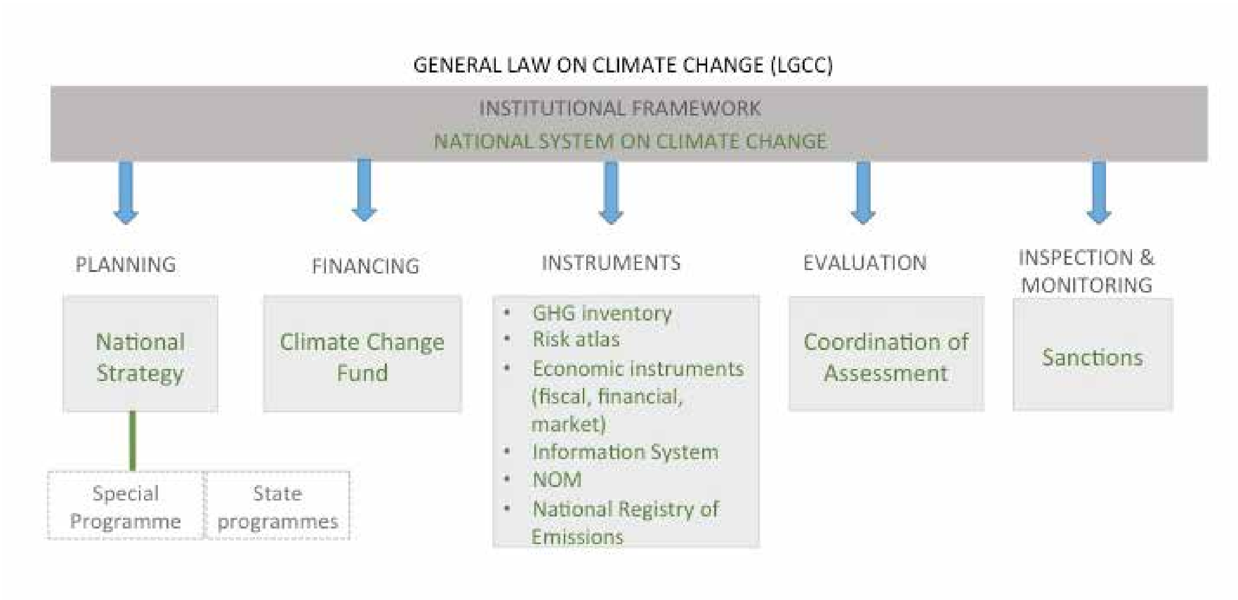
Other relevant policy instruments at the state level are listed in Table 1.4[viii].

1.4.3. Municipal level

The municipalities of Mexico draw on a number of tools to support the development of climate change strategies at the municipal level[ix]. At present, the Municipality of Manzanillo is yet to develop its climate action plan, but has a Development Plan (‘Plan de Desarrollo’) and an Ecological and Territorial Planning Program. Neither of these documents currently accounts for climate change. However the Municipality of Manzanillo is working towards realigning these key policy instruments to incorporate climate change. As part of this process, new guidelines will be incorporated in the new Municipal Ecological and Territorial Planning Program (Plan de Ordenamiento Ecologico Municipal)(currently under development) which will account for climate change and will further highlight the importance of the port-

FIGURE 1.4

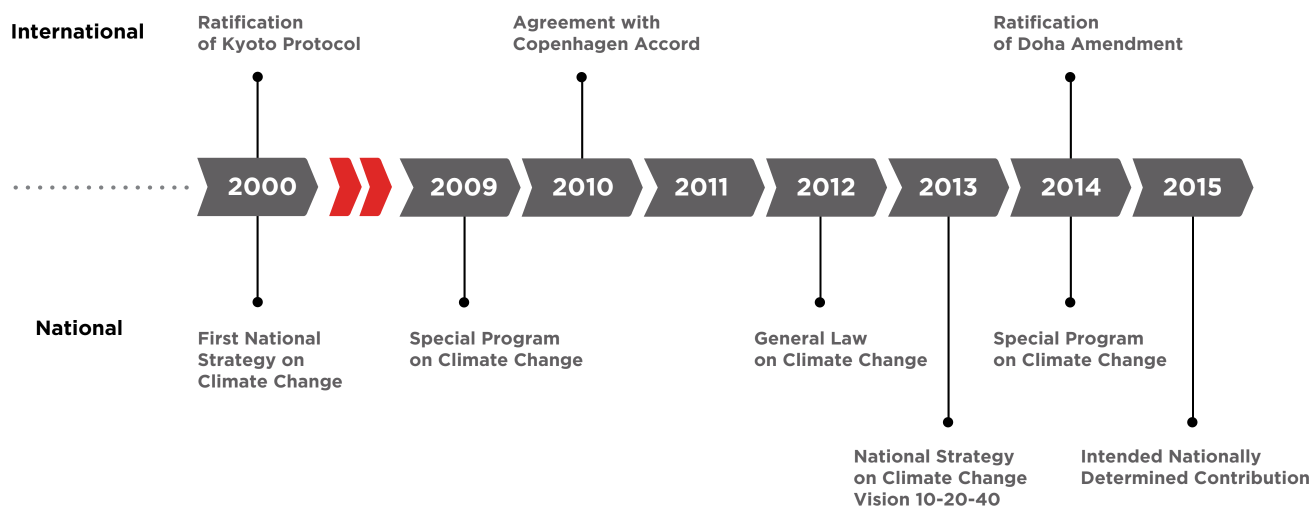
Policy instruments under the Ley General para el Cambio Climático (LGCC).



Source: Gobierno de la República, 2013 [10]

FIGURE 1.5

Pathway for the development of climate change adaptation policy instruments in Mexico



Source: Report authors

TABLE 1.2

Key adaptation actors at the federal level

Secretaría del Medio Ambiente y Recursos Naturales (SEMARNAT)	Government division responsible for the protection, restoration, conservation and sustainable use of ecosystems, natural resources and environmental services. SEMARNAT coordinates the CICC at the Federal level.
Instituto Nacional de Ecología y Cambio Climático (INECC)	Institute coordinated by SEMARNAT whose main objective is to generate and integrate scientific and technical knowledge and to support capacity building for the development, management and evaluation of public policies related to environmental protection, green growth, as well as mitigation and adaptation to climate change. INECC have an essential role in terms of climate change research in Mexico and coordinate the development of climate change scenarios and the National Vulnerability Atlas on Climate Change.
Secretaría de Comunicaciones y Transportes (SCT)	SCT is the Federal government secretariat with the role of promoting safe, reliable and competitive transport and communication systems through the development of public policies and sectorial strategies that contribute to the sustainable growth of the economy.
Secretaría de Marina (SEMAR)	National military institution with the role of defending the national territory from external threats and ensuring its internal safety. SEMAR monitor and record information on the marine environment, such as weather, climate and environmental variables. Of particular importance is the role of the Coordinación General de Puertos y Marina Mercante; Dirección General de Fomento y Administración Portuaria
Secretaría de Gobernación (SEGOB)	Within SEGOB the role of the Coordinación General de Protección Civil and Centro Nacional de Prevención de Desastres (CENAPRED) is particularly important. The first is in charge of the National System for Civil Protection whilst the second has more specific functions such as producing the Atlas Nacional de Riesgos.
Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación (SAGARPA)	Federal government secretariat with the role of promoting the sustainable development of rural areas, coast and oceans.
CONAGUA	Its mission is to preserve national water, to ensure the sustainable use of the public goods and to guarantee water security. CONAGUA is also responsible for managing the National Meteorological Services and the National Catchment Network
CONANP	CONANP's mission is to ensure that the most representative ecosystems of Mexico and its biodiversity are preserved through a system of national protected areas and through other conservation instruments.

Source: Report authors

city relationship on a number of topics including: civil protection, urban development, regional development, transport and health. Accordingly, climate change will be taken into account in the future Development Plan.

Other municipal level policy documents of relevance to the Port of Manzanillo are listed in Table 1.5.

While there is a strong and well integrated policy framework in Mexico able to support the implementation of adaptation measures, there is not currently a national methodology for evaluating and addressing climate change risks and adaptation specifically for ports. Additionally, there is little mention of climate risks and adaptation opportunities specific to ports within the existing instruments that have been developed at different scales of government. This study therefore offers a methodological approach specific to climate risks and adaptation for ports that can be considered for replication elsewhere in the country, which addresses the nature of port economic operations and assets while also taking into account existing policy instruments for adaptation in Mexico. Suggestions for how the approaches adopted in this study could be improved in future studies are provided in Section 6.

TABLE 1.3

National legal framework for ports

Topic	Law	Programs, regulations
Ports and Commercial Marinas	Ports Law Law on Navigation and Maritime Commerce	Sectoral Program on Communication and Transport 2013-2018 National Infrastructure Program 2014-2018 Rules of Operation of the Port of Manzanillo Master Plan of Port Development for the Port of Manzanillo (PMDP)
Natural Resources and the Environment	General Law on Ecological Equilibrium and Environmental Protection National Waters Law Federal Law on Environmental Responsibility General Law on Prevention and Management of Integral Waste NOM-022-SEMARNAT-2003 and NOM-059-SEMARNAT-2010,	Natural resources and the Environment Sectorial Program 2013-2018 Management Instruments (Environmental Impact Assessments, Marine-Terrestrial Federal Zones) Territorial ecological planning (General, Maritime, State and Local)
Marine	Federal Law of the Sea Law on Waste Disposal in Maritime Zones of Mexico	Sectoral Marine Program 2013-2018
Other topics	General Law on Communication Channels General Law of National Goods General Law of Civic Protection	

Source: Zorrilla Ramos, 2014 [14]

TABLE 1.4

State level policy instruments relevant to ports

- Civic Protection Law of the State of Colima
- Development Planning Law of the State of Colima
- Environmental Conservation Law of the State of Colima
- Human Settlements Law of the State of Colima
- Risk and Hazards Map of the State of Colima
- State Development Plan 2009-2015
- Transport and Road Security Law of the State of Colima
- Solid Waste Law of the State of Colima
- Free Municipalities Law of the State of Colima
- Ecological and Territorial Planning Program of the State of Colima
- Ecological and Territorial Planning Program for the Coast of the State of Colima
- Zoning Regulation of the State of Colima

Source: Report authors

TABLE 1.5

Municipal level policy instruments relevant to the Port of Manzanillo

- Municipal Development Plan of Manzanillo 2012-2015
- Local Ecological and Territorial Planning Program of the Municipality of Manzanillo
- Sub-Catchment Ecological and Territorial Planning Program for the Cuyutlán Lagoon
- Urban Development Program for the Population of Manzanillo, Colima

Source: Report Authors

1.5. Methodological approach to the study

1.5.1. Risk-based decision-making on adaptation

There are a number of methodological frameworks used to help decision makers appraise and respond to climate change adaptation needs and opportunities. The most complete frameworks generally include the same key guidance elements, covering:

- Appraisal of the problem;
- Definition of objectives and success criteria
- Evaluation of climate change vulnerabilities and risks;
- Identification of adaptation measures to help reduce climate risks or take advantage of emerging opportunities
- Appraisal of adaptation options;
- Implementation of selected adaptation measures; and
- Monitoring and evaluation of climate change adaptation actions and processes

These frameworks are commonly supported by tools and processes to help answering specific questions on the journey to developing an adaptation plan. They range from methodologies helping to appraise climate change vulnerability and risks[x] to those tailored to supporting the mainstreaming of climate change into policy and decision making processes.[xi] Many approaches have been developed to help users to understand adaptation needs, identify and appraise adaptation options, and plan, implement and monitor adaptation processes.[xii]

This study applies the UK Climate Impacts Programme (UKCIP) framework, a widely cited approach[xiii] that has been used as the theoretical foundation of many subsequent conceptual frameworks (see Figure 1.6). The framework is a decision support tool to assess vulnerabilities and risk from climate change and evaluate adaptation measures. In Steps 1 to Step 3 of the framework a "bottom-up" or "Vulnerability, Thresholds First" approach is applied. A similar approach is also advocated by the Intergovernmental Panel on Climate Change (IPCC)[16] and has been recently recommended by INECC as the most appropriate method for defining adaptation actions.[17] The approach also aligns well with recent SEMARNAT-INECC guidance.[18]

1.5.2. Analysis of risks, opportunities and adaptation actions for the port's value-chain

Within the overall conceptual framework presented above, the study analyzes how climate-related risks and opportunities could affect the various elements of the Port of Manzanillo's value chain, and identifies and quantifies (where possible) the key risks and opportunities. Figure 1.7 presents an overview of the port's value chain, showing the areas where climate-related risks and opportunities are analyzed.

Individual subsections in Section 3 of this report describe the various methods and analyses used to determine the level of present-day and future climate-related risk to each of the elements of the value chain and present the results from this analysis. Adaptation options are also identified and appraised in subsections of Section 3 and Section 5.2.

1.5.3. Approach to financial analysis

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 API Manzanillo and the terminals (blue line in Figure 1.8)
- 'Climate change cases' – estimate the financial implications of climate change impacts for a range of scenarios within the financial model i.e. future climate change impacts with no adaptation (green line in Figure 1.8)
- 'Climate change with adaptation cases' – assess the financial cost and benefits of adaptation options and identify economically optimal adaptation measures (red line in Figure 1.8)

The difference between the green line and red line in Figure 1.8 indicates the gross financial benefit of implementing adaptation measures. The green line shows that taking no action to adapt will result in increased impacts to the port's financial performance over time.

The study determines the financial benefit in implementing adaptation measures to address significant climate change risks to the port. Where appropriate, adaptation measures have been identified and costed in terms of operating costs and capital expenditure.

Figure 1.8 shows that taking no action on adaptation measures could result in increased impacts on the future financial performance of the port.

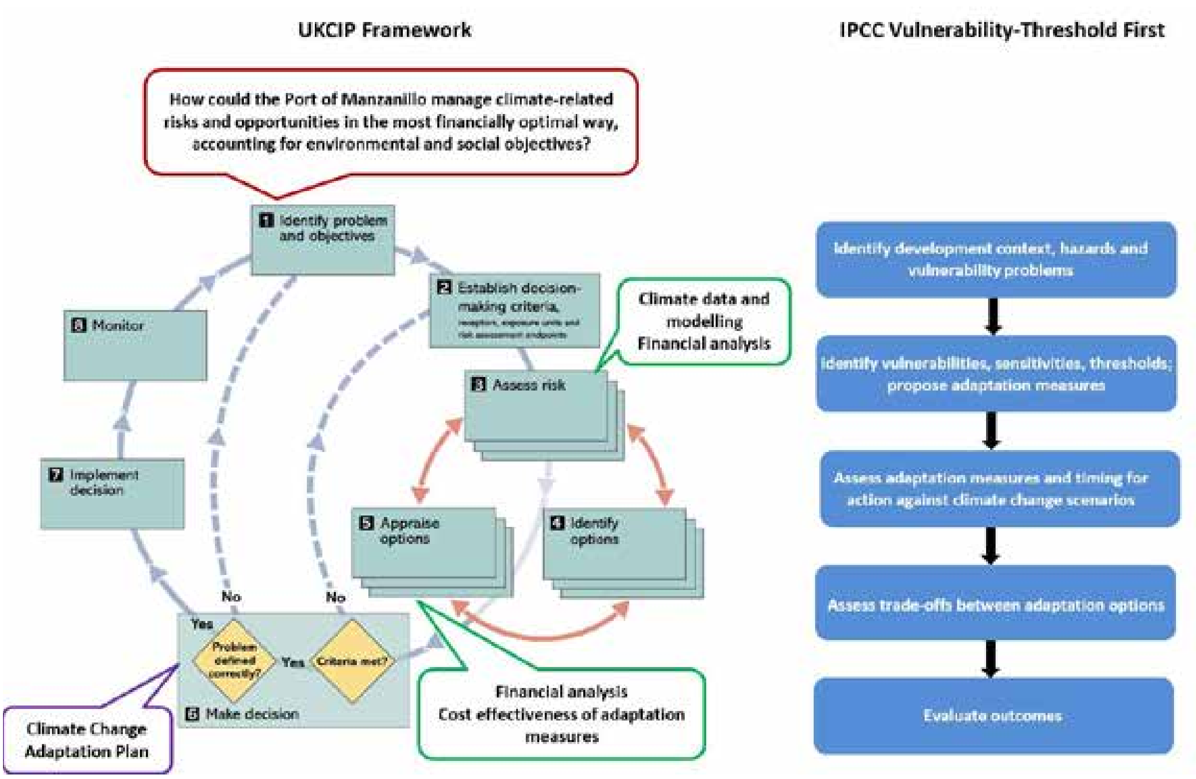
The baseline financial model is the business as usual scenario assuming no climate change. Projections are made into the future based on information provided by both API Manzanillo and the terminals. This information is described in this section under "Baseline financial model". This is based on their current view of future revenue.

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 the next section.

Information provided by API Manzanillo and the terminals included historical and projected gross cargo movements, revenue, high level operating costs and ongoing capital expenditure. Several accounting bench marks were available as well, including earnings before interest, taxes, depreciation, and amortization (EBITDA), and EBITDA as a fraction of revenue.

FIGURE 1.6

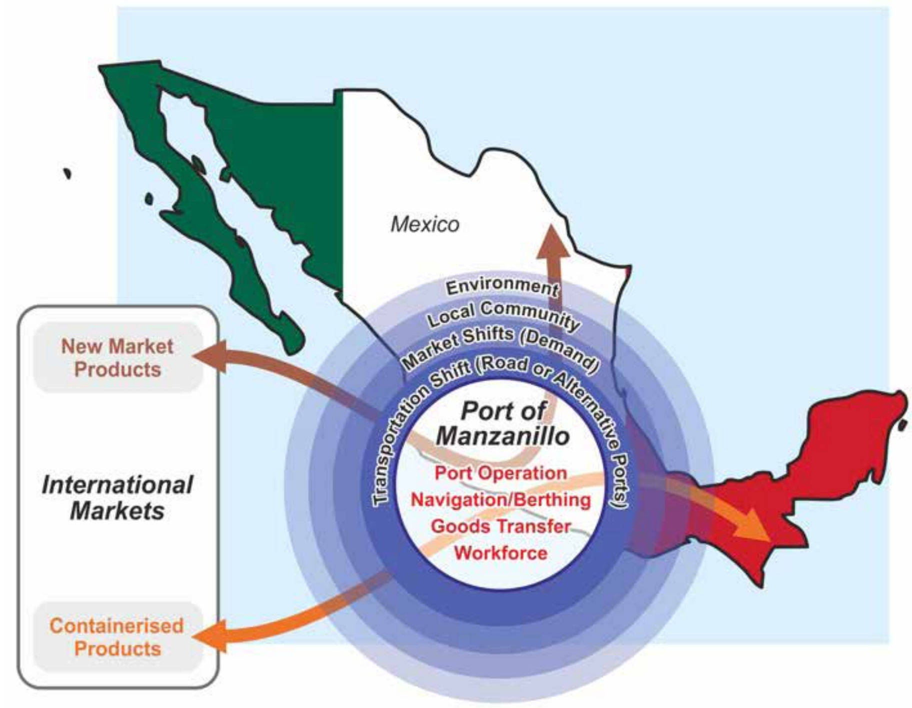
The UKCIP framework used as foundation of the methodological approach applied in this study (left hand figure) showing the key question to be answered by the study (red box), key study analyses (green boxes) and the Adaptation Plan (purple box). The IPCC 'Vulnerability-Threshold First' approach (right hand figure)



Sources: Willows and Connell, 2003[19] and IPCC, 2012[20]

FIGURE 1.7

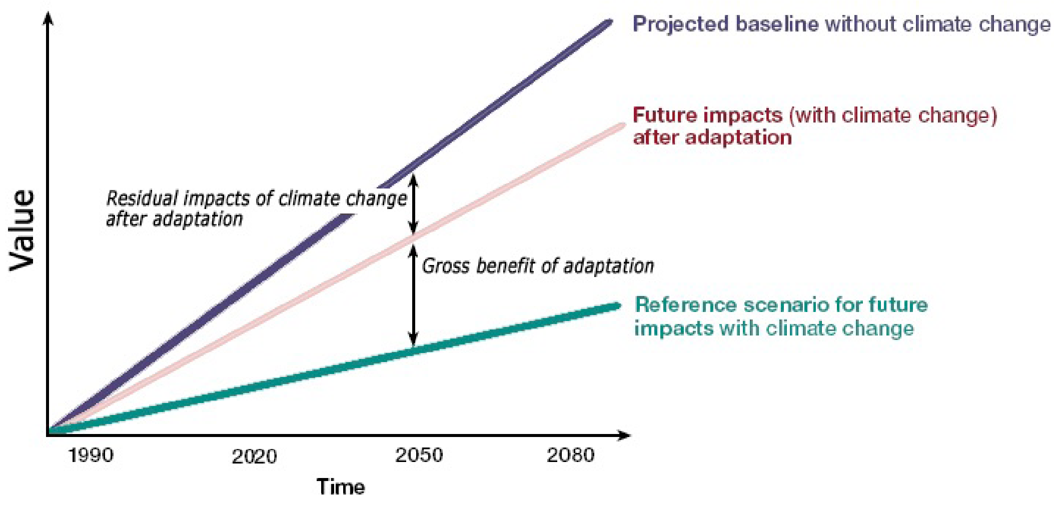
Schematic of the Port of Manzanillo value chain showing areas where climate-related risks and opportunities have been evaluated in this study.



Source: Report authors

FIGURE 1.8

Financial Model Schematic



Source: Metroeconómica, 2014 [21]

Assumptions

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 financial information. Furthermore, the simplicity of the model allows replication for other port facilities, because the analysis is not tightly tied into the financial accounts of API Manzanillo and the terminals. However, API Manzanillo and the terminals can take the relevant calculations and results and integrate them into a more detailed financial picture as appropriate.

The key assumptions are summarized as follows:

- Costs and benefits of climate change impacts and adaptation are analyzed in terms of their effect on revenue and EBITDA
- The only revenue sources for API Manzanillo are the fixed fees paid for port services and use of infrastructure, and the variable fees paid by the terminals dependent on cargo movements. 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 API Manzanillo and the terminals (or other ports) to include these factors as they see fit
- The financial model is expressed in Mexican Pesos (MXN)
- For the purposes of investment evaluation the baseline case discount rate is 10%, as recommended by API Manzanillo.

Using EBITDA rather than cash flow or profits, excludes interest, tax, depreciation, and amortization from consideration. 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. It is acknowledged that climate change can impact on depreciation rates, but to simplify analysis it is excluded from this study.

Discount rate

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 and there is a balance to be struck between investment and risk in order to find the optimal timing for adaptation investment. For example, improving the drainage system now will avoid future flooding impacts, but this action could also be put off into the future, if for example changes in rainfall intensity or sea level rise are slower.

A crucial parameter in adaptation decisions included in this study is the discount rate. The discount rate is a reduction (discount) to expenditures and revenues that occur 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, and invest in upgrades that provide revenue as early as possible. For example, say an issue with the port results in $100,000 of lost revenue per year. If a $500,000 investment this year can solve the issue and recover that $100,000 every year starting next year, it would pay back in 5 years without a discount rate. However, at a discount rate of 10%, it would take about 7.5 years to pay back the initial $500,000 (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 value of adaptation is defined as the discounted value of future adaptation investments in present year terms.

Baseline financial model

The primary aim of the study is to consider how climate change risks, opportunities and adaptation actions affect the performance of the port as a whole. Where possible this analysis has therefore incorporated both the financial impacts on API Manzanillo and the independently-operated terminals. This has been executed to the extent that information is available, and taking account of the nature of the climate risks associated with that information.

For example, as discussed in Section 3.1, some terminals have provided costs for refrigeration, which directly lend themselves to immediate analysis of future risks such as from increases in mean temperature. This, however is an issue for the terminals alone and will not significantly affect API Manzanillo's financial performance.

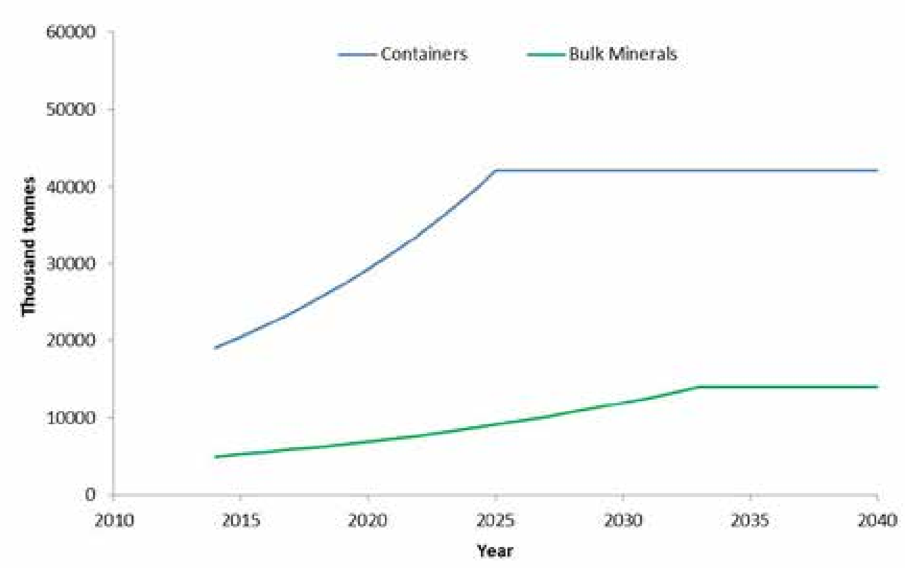
In contrast, as discussed in Section 3.2, certain goods handling financial risks are borne by the terminals, but will also have financial implications for API Manzanillo. The impact on API Manzanillo is determined by the individual contractual/lease relationships with each terminal.

API Manzanillo

Historical financial information (1994 to 2014) has been provided by API Manzanillo and includes the following:

FIGURE 1.9

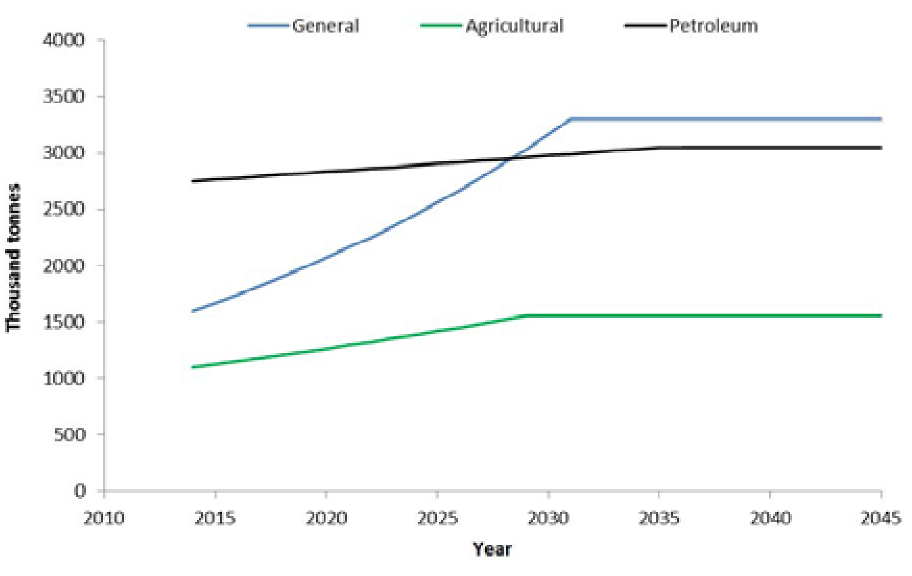
Projected containerized and bulk mineral cargo throughput and maximum capacity for intermediate business scenario



Source: API Manzanillo, 2015 [22]

FIGURE 1.10

Projected general, agricultural and petroleum cargo throughput and maximum capacity for intermediate business scenario



Source: API Manzanillo, 2015 [23]

- Revenue from
  - Berthing\docking\mooring
  - Loading and unloading
  - Wharfage
  - Port services
  - Storage
- Historical costs, including insurance and maintenance

Where possible, the study has incorporated the financial relationship between individual terminals and API Manzanillo by assessing both fixed and variable fees paid to API Manzanillo. The variable fees paid are dependent on the individual contractual relationships. Some variable payments cover common port services such as water; some variable payments are not currently specified in the data. They currently contribute an average 13.5% of API Manzanillo's revenue from assignments of rights contracts for the terminals.

The future projections of variable fees paid from each terminal to API Manzanillo are based on the future throughput of each cargo type. To calculate this, API Manzanillo has provided data on projected business demand, and current maximum throughput capacity for each major product line: containers, mineral bulk, general cargo, agricultural cargo and petroleum (Figure 1.9 and Figure 1.10). These are based on a market study of potential demand, in combination with statistical data for the last 10 years. No detailed analysis was undertaken on the port for this study to verify the maximum throughput capacity, as this was not an objective of the study. The analysis was done on the projected increases in cargo throughput of existing terminal infrastructure provided by API Manzanillo.

Three scenarios were developed by API Manzanillo, covering projections of current handling tonnage, 'intermediate' and 'optimistic' future business scenarios. For simplification, this study has incorporated the intermediate scenarios only. This acknowledges the potential for business growth, but avoids overly optimistic projections. Product line growth out to 2070 will be assumed to follow the trends shown in Figure 1.9 to Figure 1.10 until maximum capacity is reached.

This forecasted throughput of each cargo type has been converted to revenue, assuming that annual revenue growth is 70% of annual throughput growth, and revenue per unit cargo is constant throughout the study period. The figure of 70% was selected so that the resulting revenues for the years 2016-2020 were aligned with those projected by API Manzanillo in the current Port Master Plan. Table 1.6 summarizes the projected tonnage and revenue growth for each cargo type.

Figure 1.11 and Figure 1.12 provides a summary of the projected baseline (i.e. ignoring the effects of climate change) EBITDA for API Manzanillo. This incorporates all fixed and variable fees, revenue and operating expenses. This projection is derived from data provided by API Manzanillo, projected using the estimations for cargo throughput and maximum capacity.

The Terminals

With respect to projecting EBITDA for individual terminals, this was assessed by also using the projections for the future throughput of each cargo type and maximum capacities provided by API Manzanillo. Individual terminals were categorized under one of the cargo types and % increase projections made on the historical EBITDA figures provided.

API Manzanillo operating expenditure

There are a number of factors that affect the operating expenditure (OPEX) for API Manzanillo.

Fixed operating expenditure such as administration, as stated in the current port master plan is currently 5% of revenue. Variable operating expenditure, including costs such as maintenance of infrastructure is stated as 38%.

Therefore, in the financial baseline case, operating expenditure (fixed plus variable) is assumed to be constant at 43% throughout the study timescales.

1.5.4. Prioritization of risks

Prioritization of risks facing the port due to climate variability and change was undertaken by evaluating each identified risk against four key criteria, in line with good practice[27], namely where:

1. Current vulnerability is high
2. Projected impacts of climate change are large, in that they could significantly affect one or more aspects of port performance (operational, financial, environmental, social or reputational, see Appendix 1);
3. Adaptation decisions have long lead times or long-term effects (assessed in relation to the port's Master Planning cycles)
4. Large uncertainties mean that the scale of future risk is uncertain (but could be large)

Criteria 1 and 2 were further sub-divided into the following sub-categories of performance:

- Operational
- Financial
- Environmental
- Social;
- Reputational

TABLE 1.6

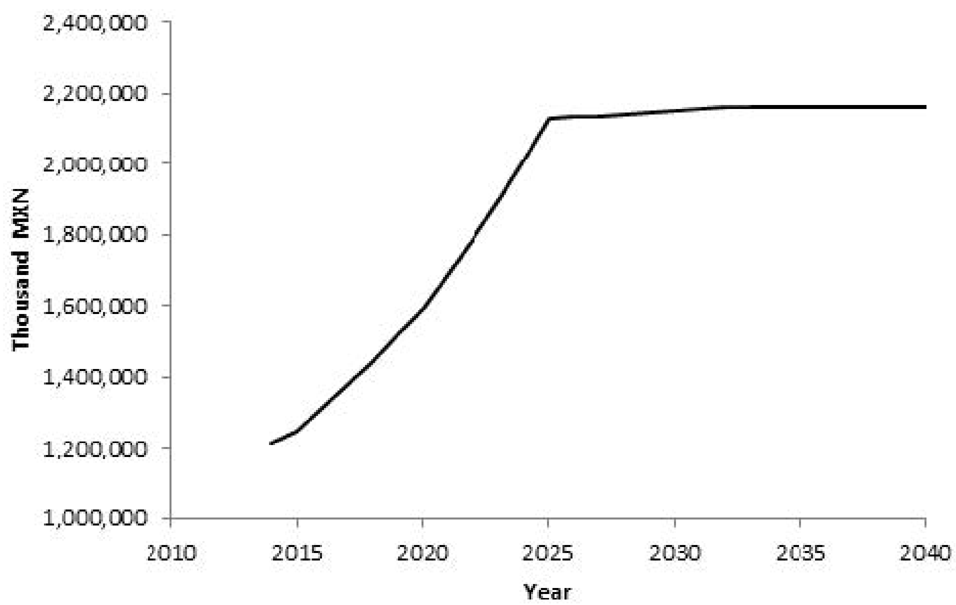
Summary of cargo volume assumptions for the baseline financial model

Cargo	2014 Thousand tonnes	Projected avg. annual tonnage growth rate 2014 to max capacity (Intermediate scenario)	Projected avg. annual revenue growth 2014 to max capacity (Intermediate scenario)
Containerized	19,000	7.5%	5.7%
Bulk Minerals	5,000	5.6%	4.4%
General	1,600	4.4%	3.3%
Agricultural	1,100	2.3%	1.7%
Petroleum	2,750	0.5%	0.4%

Source: API Manzanillo [24]

FIGURE 1.11

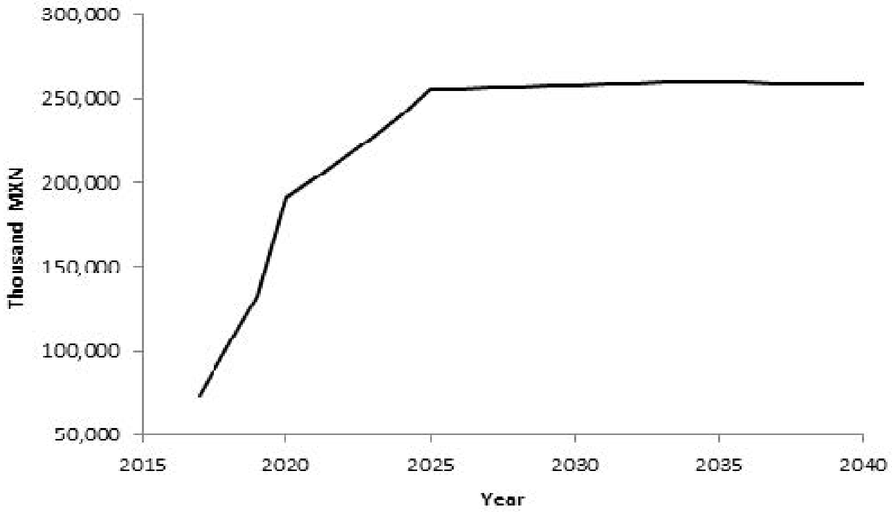
Projected annual baseline revenue for API Manzanillo



Source: API Manzanillo, 2015 [25]

FIGURE 1.12

Projected annual baseline EBITDA for API Manzanillo



Source: API Manzanillo, 2015 [26]

Identified risks were attributed a rating of low, medium or high for each criterion (see Appendix 1 for a full description of these ratings). Where a risk was rated 'high' against two or more of the criteria, the risk was identified as a high priority. Risks where current vulnerability was rated as 'high' were identified as a high priority, even if they did not score highly against other criteria. The priority risks are summarized in Section 1.6 and ratings for all risks are provided in Section 3.13.

1.5.5. Identification, prioritization and appraisal of adaptation measures

Identification and prioritization of adaptation measures was undertaken as follows by the study team:

1. First, adaptation measures were identified for each of the climate risks (whether high priority or not), under the following categories:
   - Building adaptive capacity: These include measures to create new information (e.g. data collection, research, monitoring and awareness raising) and measures to support governance of adaptation.
   - Delivering adaptation actions: These are actions that help reduce climate risks or take advantage of opportunities. These are further divided into four sub-categories:
     - Operational: changes in processes and procedures
     - Gray measures: engineer/hard structural solutions;
     - Green measures: ecosystem based adaptation
     - Hybrid: a combination of green and gray measures.
2. Adaptation measures were then prioritized as follows:
   - Measures that address priority risks were termed 'priority adaptation measures'.
   - Those that address medium and low priority risks are in turn, medium and low priority measures.
3. Within the set of priority adaptation measures, certain measures were identified that it is recommended should be undertaken first. These are measures that perform well in the face of future uncertainties about climate change, namely:
   - No regret measures: These are measures that are worthwhile now, delivering net socio-economic benefits which exceed their costs, and that continue to be worthwhile irrespective of the nature of future climate. They include 'soft' measures that build adaptive capacity through supporting better understanding of risks, and governance on adaptation.
   - Low regret adaptation measures: Measures for which the associated costs are relatively low and for which, bearing in mind the uncertainties in future climate change, the benefits under future climate change may potentially be large. They include operational measures that involve changes in processes and procedures.
   - 'Win-win' adaptation measures: These are actions that have other environmental, social or economic benefits as well as treating climate change.
   - Flexible or adaptive management options: These are measures that can be implemented incrementally, rather than through the adoption of 'one-off' costly adaptation solutions.
4. Priority adaptation measures (i.e. those that address priority climate risks) were appraised as follows:
   - 'Building adaptive capacity' measures, which are 'no regret', were not appraised further, as they are worthwhile, whatever the extent of future climate change.
   - Measures which 'deliver adaptation action' were appraised through a high level cost effectiveness analysis. This included operational, gray, green and hybrid priority measures. The approach used aligns with recent literature on cost effectiveness analysis of climate resilience measures[28].
   - Detailed quantitative analysis of the costs and financial performance of adaptation measures was undertaken for a small number of 'gray' measures (engineering solutions) that address the most financially significant climate risks facing the port. Within the scope and budget available for the study, it was not feasible to undertake detailed quantitative analyses for all the priority adaptation measures that deliver adaptation action

Further details on the adaptation measures are presented in Section 5.2.

It is worth noting that adaptation measures should ideally be identified and appraised in consultation with the stakeholders who will be responsible for implementing them, and involving other key stakeholders (see Section 5.5 for further details). This was not achievable within the study budget. As discussed in Section 5.6, API Manzanillo and the terminals will, in discussion with other stakeholders, wish to further evaluate the measures proposed in the Adaptation Plan (Section 5), to decide which to implement, and when. Guidance on identification and prioritization of adaptation measures, developed by GIZ and SEMARNAT can be utilized to inform this process[29].

1.5.6. Combining desk-based research with in-country consultations

The study was carried through a combination of desk-based research and analysis, and consultation meetings with key stakeholders in Mexico. A full list of the documents received from stakeholders and scientific papers utilized is provided in the references at the end of this report.

A two week mission to Mexico was carried out from February 9th to 20th, 2015. During Week 1, project team members attended meetings with personnel from API Manzanillo and the terminals, and examined the main port facilities. These helped to identify the port's climate-related vulnerabilities and to identify critical climate-related thresholds at the port. Meetings with external federal, state and municipal government authorities were held in Mexico D.F., Colima and Manzanillo respectively during Week 2. Appendix 2 provides a full list of the organizations consulted. Further telephone-based consultations were held with other organizations with expertise in climate change and adaptation following the mission.

Based on the discussions with API Manzanillo and the terminals about climate-related vulnerabilities at the port, a detailed data request (Excel-based) was prepared immediately following the mission (see Appendix 3). This was submitted to the terminals, and was completed, in whole or in part, by each of them. Their responses enabled terminal-specific and port-wide risk analyses to be undertaken, as described in Section 3. Individual data / information requests were also submitted to API Manzanillo divisions and federal, state and municipal stakeholders consulted during the mission. Together with the data received from the terminals, their responses provided highly useful information and data which was analyzed during the study.

1.6. Priority climate change risks, opportunities and adaptation actions identified for the Port of Manzanillo

This section briefly summarizes the high priority risks identified for the port through the climate risk assessment, and associated adaptation actions. Full analysis of climate-related risks, together with references, is provided in Section 3.

The high priority risks are summarized in Table 1.7 (see Appendix 1 for a full description of the risk prioritization process). These high priority risks are briefly discussed in turn below. A short discussion is also presented for two risks which did not emerge as 'high priority' through the risk rating: increased energy costs associated with rising temperatures, and climate change impacts on trade through the port. Higher energy costs emerge as a higher risk for specialist terminals. Climate change impacts on total trade, related to impacts on the global economy, are uncertain, but could be large.

1.6.1. Increased intensity of rainfall causes surface water flooding of the internal port access road and rail connections, causing disruptions to port operations

During periods of intense rainfall, surcharge of the drainage system entering the port causes surface water flooding and deposition of sediment at the port customs area and along the main internal access\egress road and rail connections. Surface water flooding occurs every other year on average, mainly during tropical storms. This can stop movement of trucks and trains for up to 3 days.

Hydrological analysis for this study shows that return periods for current peak flows into the drainage system will approximately halve by 2050, i.e. they will occur twice as frequently. Estimates show however that average loss of EBITDA per day for all terminals combined is approximately 9.9 million MXN. A 50% increase in the mean lifetime of maximum intensity of a storm will result in this increasing to an average of approximately 15 million MXN per day.

As the port effectively closes during these events, significant financial and reputational impacts are also borne by API Manzanillo. Maintenance and repair costs for internal roads and the customs area following a flooding event are 1% of API Manzanillo's annual OPEX. A 25% increase in the mean lifetime of maximum intensity of storms would increase the costs of road and customs maintenance by 1,000,000 MXN per year. A 50 % increase in the mean lifetime of maximum intensity of storms would increase the costs by 2,000,000 MXN per year.

Available adaptation options include:

- Upgrade the drainage system inside the port
- Review options for using Sustainable Drainage Systems (SuDS)
- Review flood early warning systems
- Review and update plans for business continuity during extreme events
- Adjust maintenance program to ensure that the maximum capacity of the existing drainage system inside the port is being achieved;
- Consider catchment level landscape planning and ecosystem based adaptation options for reducing risk of drainage overflow; and
- Implement traffic management measures to minimize bottlenecks during extreme events.

1.6.2. Increase in intensity of rainfall causing increased sedimentation of the port basin, reducing draft clearance for vessels and terminal access

Sedimentation at the port currently causes a reduction in draft clearance and disruption to vessel access for certain terminals. Risks are highest to the terminals closest to the Drain 3 discharge e.g. USG. Additional effects of this sedimentation include an increased requirement for maintenance dredging, which also disrupts terminal access due to the increased presence of the dredging vessel.

Peak flows into the drainage system will increase significantly by 2050, reflecting an increase in the 1 in 20 year 24-hour precipitation amount, of 8% by 2050[56]. This will lead to higher transport and deposition of sediment into the port basin.

Maintenance dredging costs in 2014 were 54 million MXN at 108 MXN per m^3. An assumed increase in 8% of sediment load would require an additional 8,000 m^3 of material to be removed per year by the 2050s, at an additional cost of 864,000 MXN per year. Mean sea level

TABLE 1.7

High priority climate risks for the Port of Manzanillo

Risk area for the port		Climate risk	Ccurrent vulnerability is high	Projected impacts of climate change are large
HIGH PRIORITY RISKS				
DAMAGE TO INFRASTRUCTURE, BUILDING AND EQUIPMENT		Increased frequency of intense rainfall events causes damage to infrastructure and equipment through surface water flooding	H	H
PORT SERVICES		Increase in intensity of rainfall causing increased sedimentation of the port basin, reducing draft clearance for vessels and terminal access	H	H
TRADE ROUTES	Loss of Port connectivity with land transport routes	Increased intensity of rainfall causes surface water flooding of internal access road and entrance, causing disruptions to port operations	H	H
		Increased intensity of rainfall causes surface water flooding of internal port rail tracks, causing disruptions to port operations	H	H

Source: Report Authors

Decisions have long lead times or long-term effects	Scale of future risk is uncertain (but could be large)	Comments (including terminals facing higher vulnerabilities / risks)
M	M	Current reputational risk high through international clients. Projected reputational high. All terminals affected
M	M	Current reputational risk high through international clients. Projected reputational high. All terminals affected
M	M	Current reputational risk high. Projected reputational risk high. All terminals affected
M	M	Current reputational risk high. Projected reputational risk high. All terminals affected

rise (SLR) would increase draft clearance somewhat, reducing these additional costs by between 86,400 and 108,000 MXN per year.

Available adaptation options include:

- Monitor levels of sedimentation and assessing trends in historic dredging frequencies and quantities
- Update dredging programs and schedules to reduce loss of draft clearance
- Upgrade sediment traps to improve performance; and
- Review and adjust frequency of sediment trap clearance to maintain efficiency

1.6.3. Increased frequency of intense rainfall events causes damage to infrastructure and equipment through surface water flooding

Due to surface water flooding, the maintenance and repair of internal roads and the customs area is the most significant component of API Manzanillo's annual maintenance costs (outside of dredging) and is a high priority adaptation action. API Manzanillo stated during discussion that flooding events can result in 30 cm depth of water and residual sediment. The port Master Plan estimated 6 million MXN in costs for 2015.

The magnitude of the 1 in 20 year 24-hour precipitation is estimated to increase by 8% by 205044 and return periods for current peak flows into the port drainage system will approximately halve by 2050, This will lead to greater frequency and size of flooding events, resulting in raised water levels and sediment damage.

The Port Master Plan includes a forecasted increase in road and customs maintenance costs of 5% per year. If assumed that the 8% increase in intense rainfall is applied on top of the 5% forecast, then additional costs of 3 million MXN per year by 2050 are estimated. These costs are covered by API Manzanillo.

Available adaptation options include:

- Upgrade the drainage system inside the port to increase maximum capacity and handle increased flow
- Retrofit infrastructure or assets that are vulnerable to flooding
- Review early flood warning systems
- Review options for using sustainable drainage systems (SuDS);
- Upgrade and improve sediment traps
- Adjust maintenance program to ensure that maximum capacity of the existing drainage system is being achieved (e.g. frequency of drain clearance); and
- Consider catchment level landscape planning and ecosystem based adaptation options for reducing risk of drainage overflow.

1.6.4. Increased average and peak temperatures cause increased refrigeration and freezing costs

Terminals running reefer containers e.g. CONTECON, SSA, TIMSA, OCUPA and specialist refrigeration and freezing warehouses e.g. MARFRIGO and FRIMAN are at risk of increased energy costs due to higher temperatures. Observed data shows a significant trend of 0.4 to 0.5˚C increase in mean temperature per decade at Manzanillo. Warming along the coast near Manzanillo is estimated at 2˚C in the dry season by the 2040s under a high greenhouse gas concentration scenario[xiv] (1.2°C under a medium greenhouse gas concentration scenario[xv]) and 3˚C by the 2070s under a high scenario[xvi] (1.8˚C under a medium scenario[xvii]).

Data provided by a representative terminal showed a significant ($P < 0.05$) positive relationship between mean temperature and mean monthly energy costs. A 1˚C increase in temperature was associated with a 5% increase in energy costs. Increases in costs were estimated to be an additional 9% per year by 2040 (17% by 2070) for a moderate temperature rise, and 14% (2040s) and 24% (2070s) for extreme temperature rises.

The findings show that for some terminals the overall energy costs for cooling are small, so increased temperatures are not a significant hazard across the port as a whole. However for specialist terminals such as MARFRIGO and TIMSA, the financial impact could be more significant and would warrant investment to mitigate the effects.

Available adaptation options include:

- Implement available technological improvements over time, increasing the efficiency of cooling / freezing equipment
- Review energy audits conducted under the 2015 Carbon Footprint study (ME-T1239) for the port in light of impacts of rising temperatures
- Review climate change impacts on potential alternative energy sources considered following the 2015 Carbon Footprint study[94] for the port
- Review pricing relationships between terminals and their customers i.e. evaluate whether some energy costs can be passed on to the customer; and

• Isolate electrical connections to reduce incidents of loss of power to reefers and consequent extra energy for re-cooling\refreezing

1.6.5. Impacts of climate change on total trade through the port

Revenues at the port are shown to be closely correlated with global GDP. Analysis demonstrates that a 1% reduction in world GDP leads to a 1.5% reduction in the revenue of the port. Climate impacts on the global economy can therefore be expected to affect trade through the port. Several key factors affect revenue at the port, so it is challenging to infer changes in port revenue from climate impacts on world GDP. There are also considerable uncertainties regarding the global economic impacts of climate change.

Nevertheless, based on estimates of climate change impacts on the world economy[30], projected revenue losses at the port as a whole range between -0.30% to -0.95% by the 2020s and between -0.38% and -1.88% by the 2050s. By the mid-2030s, the port could see annual revenue losses of 4,000,000 to 10,000,000 MXN, and 6,000,000 to 15,000,000 MXN by the mid-2040s (undiscounted). Adaptation options include:

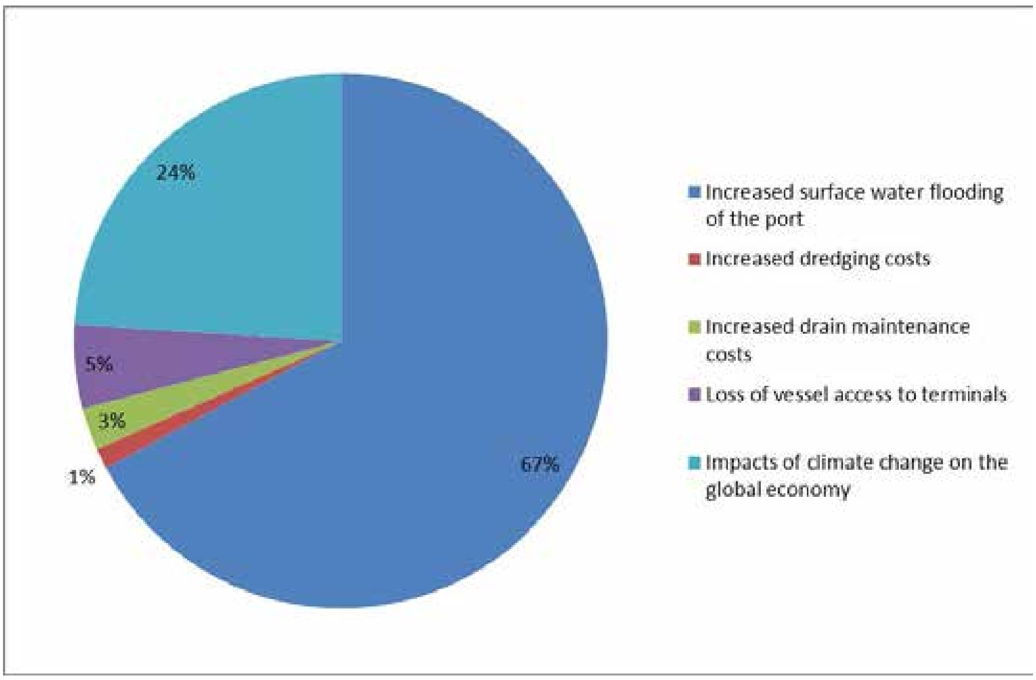
• Strategic actions to help spread the risk and manage future uncertainty, including diversification of trading partner countries and growing a broader range of business lines;
• Exploring opportunities to increase the trade of agricultural commodities, where there is high demand in Mexico and where domestic production may be adversely affected by climate change, in particular the trade of corn.

1.6.6. Summary of financial risks of climate change for the port

The study findings indicate that, if no action is taken, financial impacts will be borne by both API Manzanillo and the terminals for the key issues noted above. These are summarized in Figure 1.13. The impacts are not severe enough to pose risks to the continuity of business at the port over the medium or long term (2050s to 2080s).

FIGURE 1.13

Increase in annual costs or annual loss of revenue by 2050 for climate change risks with most important financial impacts at the port



Source: Report authors

1.7. Adaptation Plan for the Port of Manzanillo

The Adaptation Plan for the Port of Manzanillo recommends strategic and operational measures to be implemented by API Manzanillo and the terminals to reduce risks and take advantage of opportunities from climate change (see Section 5). The adaptation measures in the plan have been developed following internationally recognized principles. The recommended measures contribute to:

- Building adaptive capacity; or
- Delivering adaptation actions

As risks in this study are categorized as being either "high" or "medium to low" priority, so are the adaptation measures. They are classified as being "priority adaptation measures" (where they address high priority risks) or "measures addressing medium to low risks". Table 1.8 provides a summary of the priority adaptation measures presented in the Adaptation Plan.

To show how it fits with Mexico's adaptation policy frameworks, the Adaptation Plan outlines how specific measures align with policies and strategies at the federal, state and municipal levels. Similarly, and to facilitate its implementation, the Adaptation Plan highlights where the individual measures can be integrated into the Port Master Plan (PMDP) and into operational plans used by API Manzanillo and the terminals.

Since the adequate engagement of relevant stakeholders is a critical factor for the successful implementation of any adaptation plan, a Stakeholder Engagement Plan is provided, identifying key stakeholders that ought to be involved in the implementation process.

When API Manzanillo and the terminals have implemented adaptation measures, the port will be well positioned to cope with a changing climate on all aspects of its value chain, in the near term and over the coming decades.

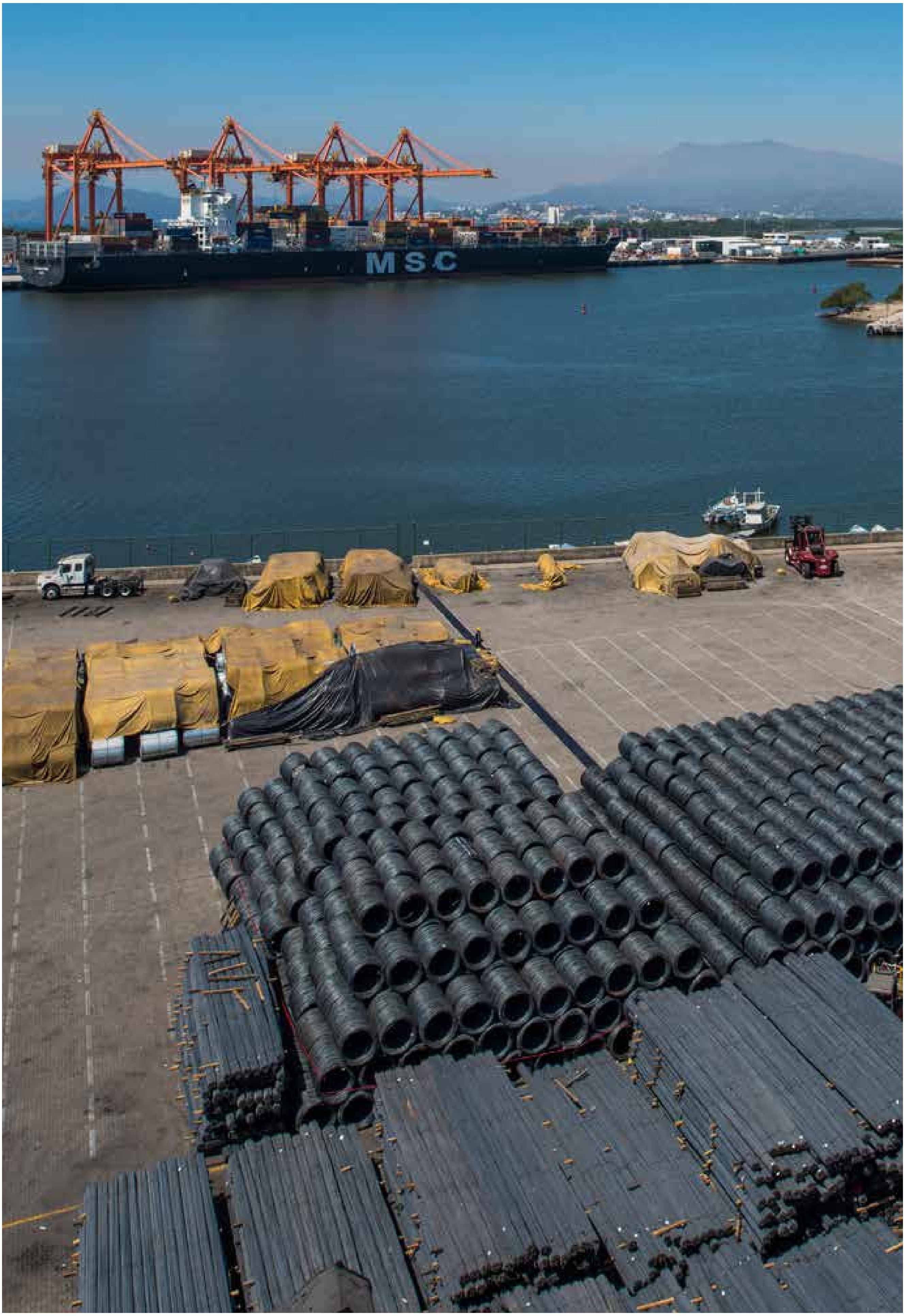

MSC

TABLE 1.8

Priority adaptation measures for the Port of Manzanillo[xviii]

(Color coding: Red = measures that Build Adaptive Capacity, (BAC); Blue = operational measures, (OP); Gray = engineered/ hard structural solutions (ENG); Green = ecosystem based adaptation measures (EBA); Purple = hybrid measures (HYB, a combination of gray and green)

Risk area for port	Adaptation objective	Adaptation measure
DAMAGE TO INFRASTRUCTURE, BUILDING AND EQUIPMENT	Increase resilience to floods and intense rainfall events	P1 Upgrade drainage system inside the port to increase maximum capacity and handle increased flow.
		P2 Retrofit infrastructure or assets that are vulnerable to flooding, in particular critical infrastructure (e.g. insulate electrical equipment, use water resistant materials)
		P3 Engage with stakeholders to plan landscape level flood management options
		P4 Review early flood warning systems and identify areas for improvement in light of increased risk due to climate change
		P5 Review options for using sustainable drainage systems (SUDS) taking into account potential for changes in precipitation
		P6 Upgrade and improve sediment traps
		P7 Undertake review and adjust maintenance program to ensure that maximum capacity of existing drainage system is being achieved e.g. frequency of drain clearance
		P8 Consider catchment level landscape planning and ecosystem based adaptation options for reducing risk of drainage overflow

Source: Report authors

Type	Cost	Effectiveness	Lead entity
ENG	H	H	API Engineering
ENG	L	M	API Engineering
BAC	No regret		API Engineering, API Ecology
BAC	No regret		API Engineering, API Ecology
HYB	H	M	API Engineering, API Ecology
ENG	M	M	API Engineering
OP	L	M	API Engineering
EBA	H	M	API Ecologia

TABLE 1.9

Priority adaptation measures for the Port of Manzanillo (continued).

Risk area for port	Adaptation objective	Adaptation measure
PORT SERVICES	Reduce risk of sedimentation	P9 Monitor levels of sedimentation and assess trends in historic dredging frequencies and quantities.
		P10 Update dredging programmes and schedules to reduce loss of draft clearance
		P11 Upgrade and improve sediment traps
		P12 Review and adjust frequency of sediment trap clearance to maintain efficiency
TRADE ROUTES Loss of Port connectivity with land transport routes	Increase resilience to floods and to intense rainfall events	P13 Upgrade drainage system inside the port to increase maximum capacity and handle increased flow
		P14 Review options for using sustainable drainage systems (SUDS) taking into account potential for changes in precipitation
		P15 Engage with stakeholders to plan landscape level flood management options
		P16 Review flood early warning systems and flood management plans and identify areas for improvement in light of increased risk due to climate change
		P17 Review and update plans for evacuation and business continuity during extreme events
		P18 Undertake review and adjust maintenance program to ensure that maximum capacity of existing drainage system inside the port is being achieved e.g. frequency of drain clearance
		P19 Upgrade and improve sediment traps
		P20 Consider catchment level landscape planning and ecosystem based adaptation options for reducing risk of drainage overflow
		P21 Implement traffic management measures to minimize bottlenecks during extreme events

Source: Report authors

Type	Cost	Effectiveness	Lead entity
BAC	No regret		API Engineering
OP	M	M	API Engineering
ENG	M	M	API Engineering
OP	L	M	API Engineering
ENG	H	H	API Engineering
HYB	H	M	API Engineering
BAC	No regret		API Engineering, API Ecology
BAC	No regret		API Engineering, API Ecology
BAC	No regret		API Operations
OP	L	M	API Operations
ENG	M	M	API Engineering
EBA	H	M	API Ecology
OP	L	M	API Operations

2. Current and future climate, hydrological and oceanographic conditions

Mexico sits astride the subtropics bringing the country under the dominant influence of subsiding air and therefore dry conditions for several months of the year. A monsoon system associated with tropical thunderstorms moves in from the south during the summer months. The west coast of Mexico is affected by tropical cyclones, the majority of which form in the Eastern Tropical Pacific which is one of the major basins for such storm development. Mexico is potentially sensitive to small adjustments to the large-scale climate system and potentially strongly exposed to future modifications to that system as a result of climate change.

This section outlines observed and projected future climate, hydrological and oceanographic conditions for Mexico in general and Manzanillo specifically.

2.1. Climate

2.1.1. Current climate conditions

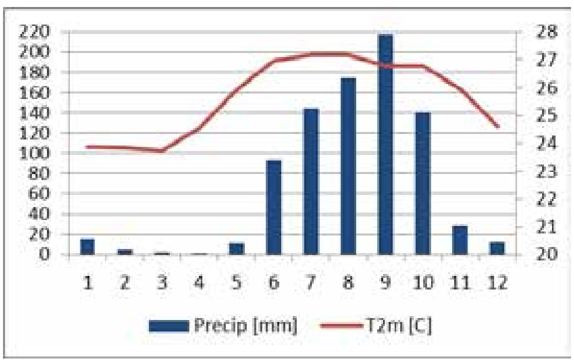
Mexico experiences a long dry season from December to May and a wet season from June to November. Tropical thunderstorms are responsible for most of the wet season rainfall. At Manzanillo temperatures reach about 27˚C in June to August but cool thereafter. Rainfall peaks in September but decreases sharply thereafter. Winds are generally light, except when a tropical storm or tropical cyclone is nearby.

Mexico experiences a dry season, here taken as December to May, and a wet season from June to November (Appendix 4, Figure 4.1 to 4.3). Satellite rainfall data[xix] reveals the extent of aridity in the dry season with less than 1mm/day over central and western Mexico. Tropical convection (thunderstorms) during the dry season occurs to the south over central and tropical South America. These rain-producing systems move north to bring rainfall in excess of 2mm/day to western and eastern Mexico with a swath of rainfall depressed to the south over central Mexico.

Details of the annual cycle of rainfall and temperature for Manzanillo are shown for reanalysis data (European Centre for Medium Range Weather Forecasts-Interim Reanalysis – ERA-I)[xx] and meteorological station data (Figure 2.1 and Figure 2.2 respectively). ERA-I data are shown because region-wide climate trends are later evaluated on the basis of these data in order to provide complete coverage of land and ocean. Near surface temperature (2 m) ranges from 24˚C in the dry, winter months of January to March inclusive, to near 27˚C in the months of rainfall onset (June to August). Temperatures cool slightly thereafter, before decreasing sharply in November and December. Rainfall in the ERA-I dataset peaks in September following a steady increase from June. Rainfall decreases rapidly from October to November. Station data at Manzanillo (Figure 2.2) mirrors the ERA-I data except for cooler temperatures in the dry winter months (21-22˚C) and a semi-annual cycle in rainfall peaking in July and September. Rainfall values in ERA-I and the station data are very similar in the peak month (ca. 220 mm). Winds at Manzanillo are generally light, except when a tropical storm or tropical cyclone is nearby. The predominant winds are from a south-westerly direction (Figure 2.3)[31].

FIGURE 2.1

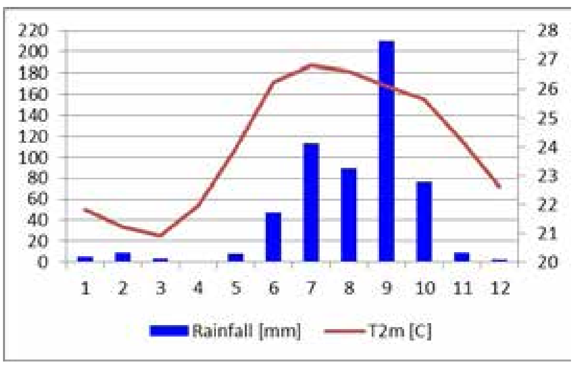
Annual cycle of rainfall (mm) and near surface temperature (˚C) for Manzanillo from ERA-I data



Source: Report authors

FIGURE 2.2

Annual cycle of rainfall (mm) and near surface temperature (˚C) for Manzanillo from met station data



Source: Report authors

Trends in historical climate: Seasonal means

Changes in climate observed over the period 1979-2012 are calculated for the broad region using data from the European Centre for Medium Range Weather Forecasts-Interim (ERA-I) reanalysis.

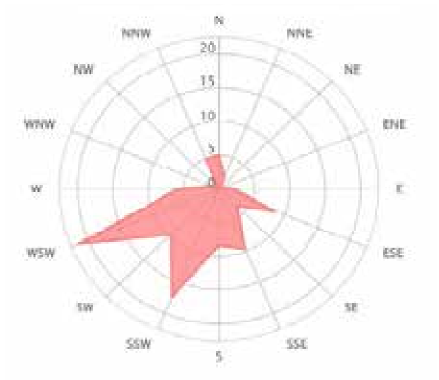
These data show widespread areas of decreasing mean rain over Mexico and the equatorial Pacific. In far western Mexico, including Manzanillo, rainfall is decreasing in the wet season (by up to 20mm per year) but this changed rainfall lies close to an area of increasing tropical rainfall immediately south of Manzanillo. Changes in extreme rainfall are very patchy. In July, there is a small decrease in the frequency of occurrence of days experiencing rainfall of 1, 2, 3 and 4 mm. There is an increase in the number of days in June experiencing heavy rainfall events, in excess of 10 and 20 mm.

The ERA-I data also show that Manzanillo is experiencing an increase in wet season maximum temperatures. There are no statistically significant temperature changes noted for the dry season.

Wind speeds above 1 m/s show an increase in August at a rate of 0.03 m/s for every year of the record. At 2 m/s winds decrease in March (0.08 m/s per year) but increase in December (0.15 m/s per year). Wind speeds above 3 m/s increase significantly in February, October and November, although the slopes of the significant trends are small (0.14, 0.1 and 0.07 m/s per year respectively). On the whole, these changes in wind speed are small and do not reflect the changes in individual weather systems but rather the overall background wind.

FIGURE 2.3

Frequency (%) of wind directions recorded at Manzanillo Airport meteorological station, 2004-2015. (Calm winds were recorded 6.1% of the time.).



Source: windfinder.com,2014 [32]

ERA-I data for 1979-2012 are used to assess significant trends in annual, dry season and wet season temperature, rainfall and wind speed. ERA-I data is used because the trends in climate can be assessed in detail over a broad area rather than at single points over some parts of the land. This is possible because ERA-I provides data for all points in a grid across the region. This spatially complete dataset is therefore useful to establish if Manzanillo is part of a broader region of trends or in an area bordering contrasting trends. ERA-I data were not yet available for the year 2014 when the study was done and data for 2013 had not been downloaded. Therefore only 1979-2012 was considered. Trends are calculated for mean, maximum (extreme) and, where possible given the assumptions of the method used to calculate the trend, minimum (extreme) rainfall. Trends in Manzanillo seasonal station data are also computed. Linear regression is used to establish trend slope and a t-test is used to establish statistical significance at the 0.05 level. Generally, only statistically significant trends are discussed. In other words, only those changes which can be detected in the data and are deemed not to have occurred by chance, are discussed.

Seasonal rainfall

The analysis shows that statistically significant trends occur in rainfall for ERA-I data (Table 2.1 and Table 2.2; also Appendix 4, Figure 4.4 to Figure 4.6):

- over widespread areas of decreasing mean rain over Mexico and the equatorial Pacific
- in a reduced area of decreasing mean rain (20mm per year) over far western Mexico (including Manzanillo) in the wet season (note however that there is an increase in tropical rain of 10-20mm per year immediately south of Manzanillo)
- as spatially incoherent trends for extreme rain

Station data from Manzanillo shows significant dry season decreases of 2.7 mm per year (which is slightly less than the ERA-I). Rainfall trends in the remaining seasons and for extremes are not significant.

Seasonal temperature

Statistically significant trends in temperature for ERA-I data (Table 2.3 and Table 2.4 also Appendix 4, Figure 4.7 to Figure 4.9):

- occur over widespread areas in all seasons and for all three measures for increasing temperature;
- are present at Manzanillo which is part of the significant increase in maximum wet season and mean annual temperature (about 0.4 to 0.5°C per decade) but not for any of the dry season measures

TABLE 2.1

Trends in Manzanillo dry season rainfall from ERA-I data 1979-2012

Season	Rainfall Type	Trend in mm per year	Is the trend statistically significant (is the trend non-random)?
December to May inclusive	Maximum rainfall	-0.005 mm per year (very small decrease in rainfall of 0.005 mm for every year of the record)	No
December to May inclusive	Mean rainfall	-2.670 mm per year (small decrease in rainfall of 2.670 mm for every year of the record)	Yes

Source: Report authors

TABLE 2.2

Trends in Manzanillo wet season rainfall from ERA-I data 1979-2012

Season	Rainfall Type	Trend in mm per year	Is the trend statistically significant (is the trend non-random)?
June to November inclusive	Maximum rainfall	0.434 mm per year (very small increase in rainfall of 0.434 mm for every year of the record)	No
June to November inclusive	Mean rainfall	1.101 mm per year (small increase in rainfall of 1.101 mm for every year of the record)	No
June to November inclusive	Minimum rainfall	Analysis not statistically viable owing to violation of regression assumptions	No

Source: Report authors

TABLE 2.3

Trends in Manzanillo dry season temperature from ERA-I data 1979-2012

Season	Temperature Type	Trend in °C per year	Is the trend statistically significant (is the trend non-random)?
December to May inclusive	Maximum temperature	0.002 °C per year (very small increase in temperature of 0.002°C for every year of the record)	No
December to May inclusive	Mean temperature	0.004°C per year (very small increase in temperature of 0.004°C for every year of the record)	No
December to May inclusive	Minimum temperature	0.022°C per year (very small increase in temperature of 0.022°C for every year of the record)	No

Source: Report authors

TABLE 2.4

4 Trends in Manzanillo wet season temperature from ERA-I data 1979-2012

Season	Temperature Type	Trend in °C per year	Is the trend statistically significant (is the trend non-random)?
June to November inclusive	Maximum temperature	0.014°C per year (very small increase in temperature of 0.014°C for every year of the record)	Yes
June to November inclusive	Mean temperature	0.009°C per year (very small increase in temperature of 0.009°C for every year of the record)	No
June to November inclusive	Minimum temperature	0.008°C per year (very small increase in temperature of 0.008°C for every year of the record)	No

Source: Report authors

For Manzanillo station data, wet season maximum temperatures are increasing significantly.

Seasonal winds

Statistically significant trends in wind speed for ERA-I data (Appendix 4, Figure 4.10):

- occur over widespread areas of the NE subtropical Pacific for increased mean winds and over a reduced area of the NE subtropical Pacific for an increase in low wind speeds
- are present at Manzanillo as part of the significant increase in mean winds in the wet season (0.2 m/s per decade) and is on the edge of the large expanse of increases in the dry season
- there are only sparse areas of significant trends in maximum winds in any of the seasons

Trends in historical climate: Thresholds of rain and wind from daily data

Operations at the Port of Manzanillo are sensitive to particular thresholds in rainfall and wind. It is valuable to quantify the observed (historical) trends in a range of rainfall and wind thresholds. Initially this analysis was attempted on daily station data for Manzanillo. However, there are considerable gaps in the station data, particularly prior to 2000 (Table 2.5 and Appendix 4, Figure 4.11). In no month in the record is station data complete. For some periods, e.g. 1994-1997, data is mostly absent at 00:00 and 12:00 hours. As a result, trend analysis based on thresholds of daily data is unreliable. Resulting trends can be calculated, but these tend to depend more on the missing data than they do on any real trend in the climate itself. As a result, further analysis of trends was conducted on ERA-I daily data. Both winds and rainfall were analyzed.

Wind thresholds from daily data

Trends in the number of days exceeding several thresholds in wind speeds were quantified using ERA-I daily data over the period 1980-2014. The wind thresholds are 1, 2, 3, 4, 5, 6, 7, 8 and 10 m/s. ERA-I generally underestimates high winds produced by systems such as tropical cyclones. The trends are shown in Table 2.6 (see also Appendix 4, Figure 4.7 to Figure 4.14). Wind speeds above 3m/s increase significantly over the historical period of analysis in February, October and November, although the slopes of the significant trends are small (0.14, 0.1 and 0.07 m/s per year respectively). The lower category of wind speed (2m/s) shows a decrease in March (-0.08) and an increase in December (0.15 m/s). There are no trends in the frequency of occurrence in any of the months at wind speeds higher than 3m/s.

Rainfall thresholds from daily data

Trends in the frequency of days exceeding specific thresholds in daily rainfall are shown in Table 2.7 (see also Appendix 4, Figure 4.7 to Figure 4.14) The thresholds assessed are 1, 2, 3, 4, 6, 7, 8, 9, 10 and 20 mm. For thresholds up to 6 mm, the results are dominated by modest decreasing trends in the frequency of oc-

TABLE 2.5

Availability of daily station data from Manzanillo January 1985 to January 2014

Time of data recording in UTC time	Comment on availability
00	Below 5 observations per month from 1994 to 1997, highly variable up to 1995
06	Varies between 5 and 25 observations per month in most years
12	Below 5 observations per month between 1992 and 1998
18	Varies between 5 and 25 observations per month from 1985 to 1999

Source: Report authors

TABLE 2.6

Trends in the frequency of occurrence of daily wind speeds in excess of specific thresholds (meters per second) from ERA-I data from 1979-2012

Threshold (meters per second)	Months showing statistically significant trend	Trend description
1	August	August: increase of 0.03 m/s for every year of the record
2	March and December	March: decrease of 0.08 m/s for every year of record December: increase of 0.15 m/s for every year of record
3	February, October, November	February: increase of 0.14 m/s for every year of record October: increase of 0.1 m/s for every year of record November: increase of 0.07 m/s for every year of record
4	None	
5	None	
6	None	
7	None	
8	None	
10	None	

Source: Report authors

TABLE 2.7

Trends in the frequency of occurrence of daily rainfall in excess of specific thresholds (mm per day) from ERA-I data from 1979-2012

Threshold (mm per day)	Months showing statistically significant trend	Trend description
1	July, November, December	July: decrease of 0.07 mm per day for every year of the record November: decrease of 0.21 mm per day for every year of the record December: decrease of 0.11 mm per day for every year of the record
2	January, July, November	January: decrease of 0.07 mm per day for every year of the record July: decrease of 0.2 mm per day for every year of the record November: decrease of 0.13 mm per day for every year of the record
3	July	July: decrease of 0.23 mm per day for every year of the record
4	July	July: decrease of 0.22 mm per day for every year of the record
5	None	
6	December	December: decrease of 0.03 mm per day for every year of the record
7	None	
8	None	
9	None	
10	June	June: increase of 0.06 mm per day for every year of the record
20	June	June: increase of 0.04 mm per day for every year of the record

Source: Report authors

currence – particularly so in the month of July (significant decreasing trends for 2 mm, 3 mm, 4 mm). The decreasing frequency of occurrence of days on which rainfall thresholds are exceeded is consistent with the decreases in rainfall projected for future decades over Mexico which are discussed next. At thresholds of 6 mm and above, there is a more mixed picture, with some months showing decreasing trends and others, increasing. There is a significant increasing trend for June 10 mm and 20 mm rainfall.

It is important to note that the trend analysis of thresholds of rainfall and wind summarized above derive from the reanalysis (ERA-I) data rather than observed station data sets. There is much to recommend reanalysis data sets, particularly the physical consistency of those data. However, they are a blend of modeled and observed data and therefore suffer from some of the problems models have in computing rainfall and weather systems. Important amongst these is the underestimation of wind extremes which comes about partly because some of the severe weather such as tropical cyclones and convective storms are not properly captured by reanalysis. It is arguably best to use the categories presented for the reanalysis work as a spectrum of data intervals rather than to treat the thresholds as absolute themselves. For example, if there is a trend in the frequency of days exceeding 20mm of rainfall, then that is best taken as a trend in the frequency of occurrence of high rainfall days rather than a definitive assessment of days with exactly > 20 mm of rainfall.

Interannual variability of climate

In addition to the description above of the mean state of the climate system, there is considerable variability in climate from one year to the next. Variability in rainfall and tropical cyclones are briefly discussed here (tropical cyclones are also discussed in further detail in Section 2.1.3).

Figure 2.4 shows a set of precipitation statistics for Manzanillo during the wet season. Whereas the previous section dealt with the mean climatology and trends in quantities and thresholds, it is clear from Figure 2.4 that there is considerable year to year variability in rainfall amounts and their extremes. Two years in particular stand out, namely 2008 and 2011 where the maximum rainfall is nearly a factor of four larger than that in most other years. Similarly, there is considerable variability in the year to year occurrence of tropical cyclones (see Section 2.1.3 on tropical cyclones).

2.1.2. Future changes in climate conditions for the Mexican Pacific Region and the Port of Manzanillo

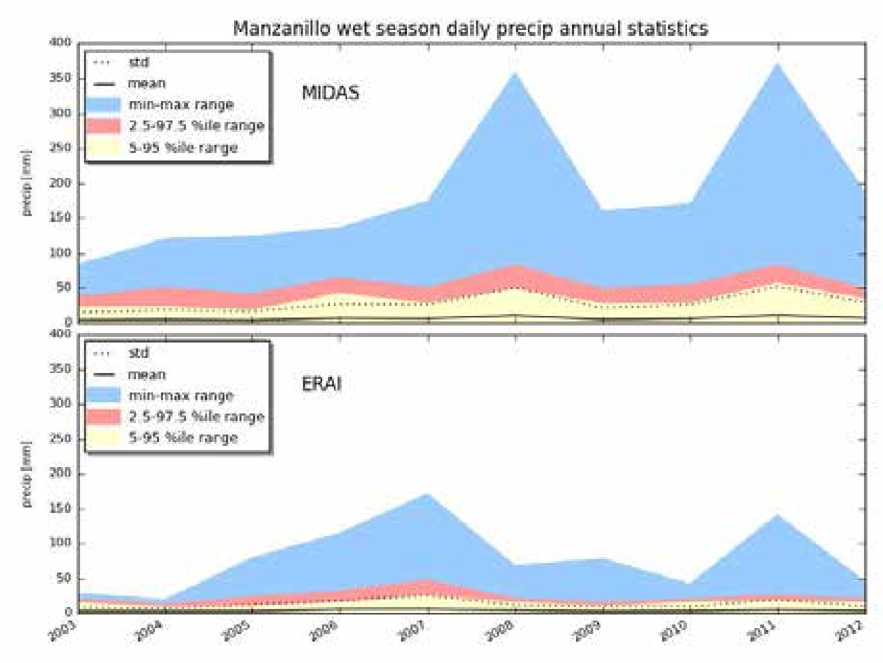
Mean rainfall over Manzanillo is projected to decrease in both the wet and the dry season in all future decades and under two different scenarios of future climate change forcing – namely RCP 8.5 and RCP 4.5[xxi]. Peak decreases are projected to be 0.7 mm per day for the 2070s during the dry season. Peak decreases are about 0.4 mm per day for the 2070s during the wet season. These changes are part of a broad trend covering a large part of Mexico and are consistent with the drying trends seen in the observed data described above. During the dry season, Manzanillo is projected to become drier in all three decades (-0.3 mm per day in 2020s, -0.5 in 2040s and -0.7 in 2070s under RCP 8.5). Wet season changes are also projected towards drying, though the decreases are smaller than those noted for the dry season for the 2020s and 2040s (0-0.1 mm per day in 2020s, -0.3 in 2040s and -1.9 in 2070s).

Extremes in rainfall have not been explicitly analyzed in this study. Daily data from regional model experiments would be necessary for this. Nevertheless it seems likely that extreme rainfall will increase in future, as climate change brings more energy in the form of higher humidity and higher temperatures in the first kilometer or two of the atmosphere. For the broader Central America / Mexico region, the IPCC estimates that 20-year return period values of annual maximum 24 hour precipitation could increase by around 8% by the 2050s[34].

In the 2020s under RCP 8.5, the mean temperature change in dry season months is typically 1.0˚C with a range of 0.5 to 1.5˚C (2.5 to 97.5 percentiles) in December to March, increasing to a change of about 1.1˚C and a range of 0.6 to 1.4˚C (2.5 to 97.5 percentiles) in April and May. Wet season months show an increase of temperature of 1.0 to 1.1˚C and a steady range of 0.6 to 1.4˚C (2.5 to 97.5 percentiles). In the 2040s under RCP 8.5, the mean temperature change in dry season months is typically 1.7˚C with a range of 0.7 to 2.6˚C (2.5 to 97.5 percentiles) in December to February, increasing to a range of 0.3 to 3.6˚C in April. For the dry season as a whole, the range across the 2.5 to 97.5 percentiles is 1.3 to 2.6˚C. Wet season months show an increase of temperature of 1.7 to 1.8˚C and a steady range of 1.3 to 2.6˚C (2.5 to 97.5 percentiles). In the 2070s, under RCP 8.5, the mean temperature change of dry season months is typically 2.9 to 3.1˚C with a range of 2.2 to 4.5˚C (2.5 to 97.5 percentiles) in February and March, increasing to a range of 2.2 to 5.5˚C in April and May. Wet season months show an increase of temperature of about 3.3˚C and a steady range of about 2.5 to 4.7˚C (2.5 to 97.5 percentiles).

FIGURE 2.4

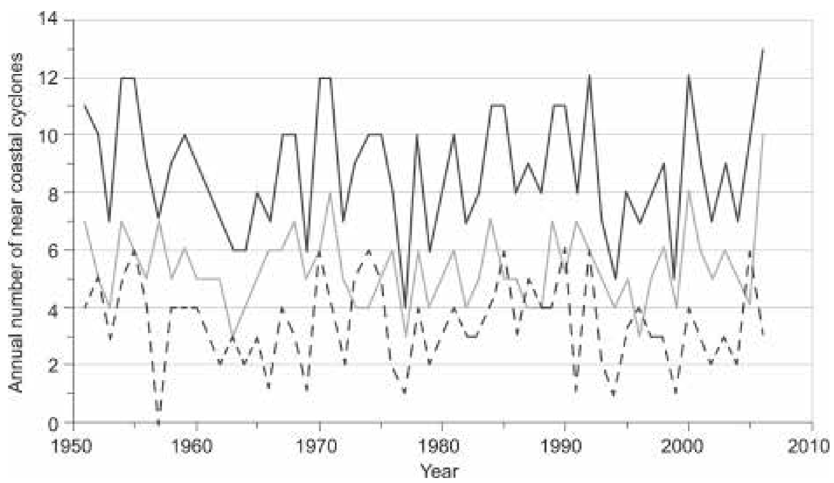
Manzanillo wet season daily precipitation statistics from 2003-2012 from meteorological station observations (top panel) and ERA-I reanalysis (bottom panel). Standard deviation (dotted line), mean (dotted line), min-max range (blue envelope), 2.5 to 97.5 percentiles (red envelope) and 5 to 95 percentile (yellow envelope).



Source: Report authors

FIGURE 2.5

Time series of tropical cyclones along the coast of North America (May to November, solid black; May to July, dashed; August to November, solid gray) 1951-2006



Source: Gutzler et al. 2013 [33]

Projected changes in Mexican wind speeds are typically very small. In both RCP 4.5 and 8.5, wind speed tends to decrease over the oceans and increase slightly over land. Increases in the dry season for RCP 8.5 along the west coast vary from +0.1 m/s in the 2020s to +0.2 in the 2070s. Increases under RCP 4.5 do not exceed +0.1m/s. In the wet season, wind speed tends to decrease by about -0.1 m/s in both the 2040s and 2070s in RCP 4.5 and RCP 8.5.

Tropical cyclones have been migrating poleward in recent decades. It is likely that this trend will continue, leading potentially to fewer tropical cyclones over Manzanillo, although this statement has low confidence. Tropical cyclones are expected to decrease in frequency of occurrence but the most intense phase of cyclones is expected to last longer. There is no method to predict changes in sub-basin scale cyclone tracks although it is noted that this metric is critical to evaluation of climate change impacts on Manzanillo port operations.

Some elements of climate change are likely to feature a 'slow onset', evolving gradually from incremental changes occurring over many years, or from an increased frequency or intensity of recurring events[35]. These include increases in temperature, changes in seasonal precipitation and mean sea level rise. There are also 'rapid onset' events, which are single, discrete events that occur in a matter of days or even hours, such as tropical cyclones and associated storm surges. Climate change can also affect these rapid onset events, for instance leading to changes to tropical cyclone tracks, intensity and frequency, particularly if bound up in decadal or near decadal oscillations of climate controlling these features. Evidence of such cycles is scarce, however, as are well accepted methods of predicting rapid onset changes. This section summarizes knowledge on the expected changes on both slow onset and rapid onset events, for Mexico in general and Manzanillo in particular.

To estimate climate change over the broad Mexican region, model simulations from the Coupled Climate Model Intercomparison Project 5 (CMIP5) were used. (See Appendix 4, Table 4.1, for a full list of the climate models used.) These data result from running coupled (ocean-atmosphere) climate models through both the historical period and, for most models, to the end of the 21st Century. For the historical period, the climate models are forced with reconstructed values of gaseous composition including ozone and greenhouse gases. For the future period, Representative Concentration Pathways (RCPs) are used. These present scenarios of radiative forcing on the atmosphere dependent on changing gaseous concentrations, notably of greenhouse gases. Two scenarios are used: RCP 8.5 and RCP 4.5 where 8.5 and 4.5 both indicate the forcing on the climate system in Wm-2 at the end of the 21st Century. More attention is given to RCP 8.5 here, as this RCP is commonly held to represent the 'business as usual' scenario.

Projected changes are shown for the 2020s (2020-2029), 2040s (2040-2049) and 2070s (2070-2079). Changes are shown with respect to the simulation of the historical period 1979-2000. For example, the changes for the 2040s are calculated based on the model ensemble mean of the period 2040-2049 minus the model ensemble mean of the period 1979-2000. In line with the analysis of the historical climate (Section 2.1.1) changes are shown for the dry season (December to May) and the wet season (June to November). Changes in temperature, rainfall and wind speed are covered. Changes over Mexico as a whole are evaluated in the first part of this assessment (Sections 2.1.2, chapters "Changes in mean Mexican rainfall for RCP 8.5 and RCP 4.5" to "Changes in mean Mexican wind speed for RCP 8.5 and 4.5"). Next, the changes specific to Manzanillo are assessed (Section 2.1.2, chapter "Changes in Manzanillo temperature, rainfall and wind"). For this more detailed analysis, individual months of the year are assessed. In the case of the RCP 8.5 results, a sample of 38 climate models is used to assess rainfall, 37 for temperature and 28 for wind. The varying number of models reflects data availability for RCP 8.5. Slightly fewer models are used for RCP 4.5. In most cases, roughly double the number of models is used here compared to the Mexican national climate change scenarios published by INECC[36] (which use 15 models). In the case of the Mexico-wide analysis, the ensemble mean of the climate models is shown. In the case of the site-specific Manzanillo analysis, individual climate model results are shown and the changes are reported in tabular form. In this case, any differences between the ensemble mean of the Mexican national scenarios and the ensemble mean of the ca. 30 model ensemble mean used in this analysis are noted. It is important to note that the changes in climate are projections based on scenarios of future forcing. They are not forecasts.

Changes in mean Mexican rainfall for RCP 8.5 and RCP 4.5

Changes to drier conditions are projected for wet and dry seasons over all, or most of Mexico in the future, with peak drying of up to 0.5 mm per day by the 2040s and 0.7 mm per day by the 2070s for RCP 8.5 in the dry season near Manzanillo (Appendix 4, Figure 4.32). Peak drying in the dry season shifts a few degrees of latitude north along the west coast of Mexico by the 2070s with increases of up to 0.7 mm per day. Manzanillo is part of a drying trend extending into the subtropical and equatorial Pacific in all three time periods during the dry season. Wet season decreases by the 2070s are about 0.5 mm per day along the west coast of Mexico (0.4 mm per day for Manzanillo). The center and far north east of Mexico are projected to experience modest increases in rainfall during the wet season by the 2070s.

There is a striking similarity in the spatial pattern of Mexican rainfall projections for the RCP 4.5 and 8.5 pathways. By the 2040s the RCP 4.5 peak dry season change is 0.3

TABLE 2.8

Projected changes in temperature (˚C) for Manzanillo from CMIP5 models

Season, RCP scenario	2020-2029	2040-2049	2070-2079
Dry season, RCP 8.5			
Mean of models used in Mexico national scenarios	1.0	1.6	3.0
Mean of all models	1.0	1.7	3.1
2.5 percentile all models	0.5	0.9	2.2
97.5 percentile all models	1.5	2.3	4.5
Wet season, RCP 8.5			
Mean of models used in Mexico national scenarios	1.1	1.8	3.3
Mean of all models	1,1	1.8	3.4
2.5 percentile all models	0.6	1.3	2.5
97.5 percentile all models	1.4	2.6	4.7
Dry season, RCP 4.5			
Mean of models used in Mexico national scenarios	0.9	1.3	1.9
Mean of all models	0.9	1.3	1.9
2.5 percentile all models	0.6	1.0	1.2
97.5 percentile all models	1.3	2.0	2.6
Wet season, RCP 4.5			
Mean of models used in Mexico national scenarios	1.0	1.5	2.1
Mean of all models	1.0	1.5	2.0
2.5 percentile all models	0.4	1.0	1.2
97.5 percentile all models	1.4	2.2	2.9

Source: Report authors

TABLE 2.9

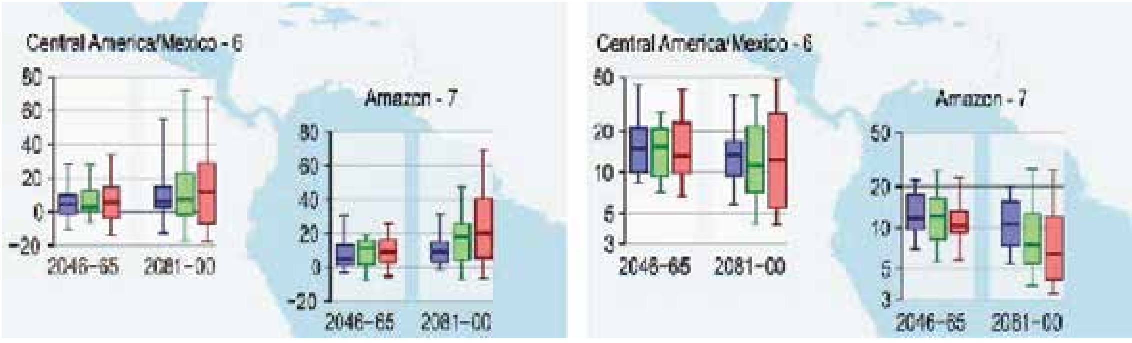
Projected changes in rainfall (mm/day) for Manzanillo from CMIP5 models

Season, RCP scenario	2020-2029	2040-2049	2070-2079
Dry season, RCP 8.5			
Mean of models used in Mexico national scenarios	-0.3	-0.4	-0.7
Mean of all models	-0.3	-0.5	-0.7
2.5 percentile all models	-1.0	-1.5	-1.5
97.5 percentile all models	0.1	-0.1	-0.2
Wet season, RCP 8.5			
Mean of models used in Mexico national scenarios	-0.1	-0.2	-0.4
Mean of all models	-0.1	-0.3	-0.4
2.5 percentile all models	-1.2	-1.4	-1.9
97.5 percentile all models	1.5	1.2	1.2
Dry season, RCP 4.5			
Mean of models used in Mexico national scenarios	-0.2	-0.3	-0.4
Mean of all models	-0.3	-0.3	-0.4
2.5 percentile all models	-1.3	-0.9	-1.1
97.5 percentile all models	0.1	0.3	0.2
Wet season, RCP 4.5			
Mean of models used in Mexico national scenarios	-0.3	-0.3	-0.4
Mean of all models	-0.3	-0.3	-0.3
2.5 percentile all models	-1.2	-1.7	-1.6
97.5 percentile all models	0.4	0.6	1.2

Source: Report authors

FIGURE 2.6

Left: Projected changes (%) in 20-year return values of annual maximum 24-hour precipitation by mid-century (2046-65) and end-century (2081-2100); Right: Projected return period (in years) of late 20th century 20-year return values of annual maximum 24-hour precipitation. Blue refers to emissions scenario B1, green to A1B and red to A2



Source: IPCC, 2012 [38]

mm per day (0.2 mm per day less than RCP 8.5) and lies along the west coast of Mexico near Manzanillo (Appendix 4, Figure 4.33). By the 2070s, the peak dry season drying also lies along the west coast but is half the amplitude of that for the RCP 8.5 scenario (0.3 compared with 0.7 mm per day). Similar proportional differences between RCP 4.5 and 8.5 are evident in the wet season.

Changes in extreme Mexican rainfall

For the analysis of extreme rainfall, the IPCC SREX report[37] analyzed two time periods (2046 to 2065 and 2081 to 2100) and two greenhouse gas emissions scenarios. Their key conclusions are that under all scenarios, the amount of rainfall in a 24 hour period with an expected return period of 20 years increases, and that the amount of extreme rainfall in any event increases with increasing greenhouse gas forcing. For Central America and Mexico, the report finds that 20-year return period values of annual maximum 24 hour precipitation could increase by around 8% by the 2050s and around 10% by the end of the century (Figure 2.6, left panel). Similarly, the present-day 1 in 20 year annual maximum 24-hour precipitation could occur 1 in every 15 years by the 2050s (Figure 2.6, right panel). This is a widespread response, common to many convective environments and relates to the energy available in the atmosphere to drive thunderstorms.

Changes in mean Mexican temperature for RCP 8.5 and 4.5

All models show an increase in temperature during both the wet and dry season for all forcing scenarios, including RCP 8.5 and RCP 4.5 (Appendix 4, Figure 4.34 and Figure 4.35). Warming is largest over central Mexico, aligned along a strong gradient perpendicular to the coastlines. Warming along the coast near Manzanillo reaches 2˚C in the dry season by the 2040s in RCP 8.5 (1.2˚C for RCP 4.5) and 3˚C for RCP 8.5 (1.8˚C for RCP 4.5) by the 2070s. Wet season temperature increases are similar to dry season increases except that the wet season increases are slightly lower than the dry season for each RCP scenario. It is likely that cloud in the wet season moderates the temperature increases by decreasing the warming effects of solar radiation.

Changes in mean Mexican wind speed for RCP 8.5 and 4.5

Projected changes in Mexican wind speed are typically very small (Appendix 4, Figure 4.36 and Figure 4.37). In both RCP 4.5 and 8.5, wind speed tends to decrease over the oceans and increase slightly over land. Increases in the dry season for RCP 8.5 along the west coast vary from +0.1 m/s in 2020s to +0.2 in 2070s. Increases under RCP 4.5 do not exceed +0.1m/s. In the wet season, wind speed tends to decrease by about -0.1 in both the 2040s and 2070s in RCP 4.5 and RCP 8.5.

Changes in Manzanillo temperature, rainfall and wind

Temperature and rainfall

The purpose of this section is to provide greater detail, including monthly information, on the projected changes in temperature, rainfall and wind at Manzanillo. It is also an opportunity to compare the results of an ensemble of the 15 models used in the Mexican climate change scenarios with those of a larger ensemble (>30 models) from CMIP5. Some of the changes within the long dry and wet seasons described above may mask shifts in climate on shorter (monthly) timescales within the annual cycle. For example, a wetter start to the wet season and a drier end to the wet season may lead to no change if only the entire season is considered. Such changes will however be evident on monthly timescales. The range of changes across the CMIP5 ensemble is reported as 2.5 and 97.5 percentiles.

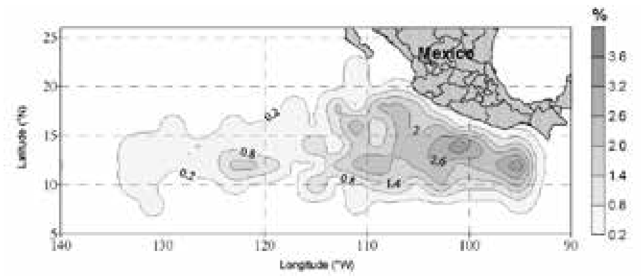
In the 2020s under RCP 8.5 (Table 2.8 and Appendix 4, Figure 4.38 and Figure 4.39), the ensemble mean temperature change in dry season months is typically 1.0˚C with a range of 0.5 to 1.5˚C (2.5 to 97.5 percentiles) in December to March, increasing to a change of about 1.1˚C and a range of 0.6 to 1.4˚C in April and May. Wet season months show an increase in temperature of 1.0 to 1.1˚C and a steady range of 0.6 to 1.4˚C (2.5 to 97.5 percentiles). Rainfall in the dry season months decreases (peak change of -0.8 mm/day in January, with range of -3.5 to 1.8 in December, January and February, decreasing to about -0.8 to 1.0 mm/day in April (Table 2.9 and Appendix 4, Figure 4.38 and Figure 4.39). The dry season as a whole shows a projected change in the mean model ensemble of -0.1 mm per day with a range across the 2.5 to 97.5 percentiles of -1.2 to 1.5 mm per day. There is no change in the ensemble mean rainfall in May. Rainfall in the wet season shows little change by the 2020s, although the spread in the ensemble is large, for example from -4.0 mm/day (2.5 percentile) to 4.5 mm/day (97.5 percentile) in September.

In the 2040s under RCP 8.5 (Table 2.8 and Appendix 4, Figure 4.40 and Figure 4.41), the ensemble mean temperature change of dry season months is typically 1.7˚C with a range of 0.7 to 2.6˚C (2.5 to 97.5 percentiles) in December to February, increasing to a range of 0.3 to 3.6˚C in April. For the dry season as a whole, the range across the percentiles is 1.3 to 2.6˚C. Rainfall in the dry season months decreases (peak change of -0.7 mm/day in December, with range of -3.5 to 1.8 in January and February decreasing to about -1.8 to 0.6 mm/day in April (Table 2.9 and Appendix 4, Figure 4.40 and Figure 4.41). As with the 2020s, there is no change in the ensemble mean rainfall in May. Wet season months show an increase of temperature of 1.7 to 1.8˚C and a steady range of 1.3 to 2.6˚C. Rainfall shows little change although the spread in the ensemble is large, for example -4.0 mm/day to 4.3 mm/day in August. The ensemble mean change is -0.3 mm per day for the wet season.

In the 2070s, under RCP 8.5 (Table 2.8 and Appendix 4 Figure 4.42 and Figure 4.43), the ensemble mean temperature change of dry season months is typically 2.9 to 3.1˚C with a range of 2.2 to 4.5˚CC (2.5 to 97.5 percentiles) in February and March, increasing to a range of 2.2 to 5.5˚C in April and May. Rainfall in the dry season months decreases (Table 2.9 and Appendix 4 Figure 4.42 and Figure 4.43) with a peak change of -1.0 mm/day in January and February, with range of -4.5 to 0.8 in January decreasing to about -1.0 to 0.2 mm/day in May. In January, February and March, few models in the ensemble simulate wetter conditions. In January only two models are wet and in February only one is wet. There is no change in the ensemble mean rainfall in April. Wet season months show an increase of temperature of about 3.3˚C and a steady range of about 2.5 to 4.7˚C. Rainfall shows little change although June and July is drier (-1.0 mm/day) and September and October wetter by about 0.6 mm/day. In June and July, only 4 and 3 models respectively show wetter conditions.

FIGURE 2.7

Climatology of tropical cyclone frequency in percentage of days per year over 39 years



Source: Romero-Vadillo et al. 2007 [40]

Wind

In common with the Mexico-wide analysis described above, projected changes in wind speed at Manzanillo are very small (Table 2.10). Ensemble mean changes in dry season and wet season wind speeds are +0.1 m/s at most, with a range of -0.3 to +0.3 m/s (2.5 to 97.5 percentiles).

How does the larger ensemble of CMIP5 models used here compare with those models used in the Mexican national scenarios? In the 2040s, the larger set of models used in this study produces slightly warmer conditions in 9 out of 12 of the months, and in the remaining months there is good agreement with the smaller ensemble used in the national scenarios. The larger ensemble is wetter than the model ensemble used in the national scenarios in 5/6 of the wet season months and drier in 3/6 of the dry season months. In the remaining months there is good agreement between the ensembles. On balance, the larger ensemble of models provides a more stable estimate of the changes. It certainly gives a more reasonable assessment of the range of change when extremes like the often-used IPCC 2.5 and 97.5 percentiles are examined. Calculating these percentiles from a small ensemble of 15 is probably misleading.

TABLE 2.10

Projected changes in wind speed (m/s) for Manzanillo from CMIP5 models

Season, RCP scenario	2020-2029	2040-2049	2070-2079
Dry season, RCP 8.5			
Mean of models used in Mexico national scenarios	0.0	0.1	0.1
Mean of all models	0.0	0.1	0.1
2.5 percentile all models	-0.1	-0.2	-0.2
97.5 percentile all models	0.1	0.2	0.2
Wet season, RCP 8.5			
Mean of models used in Mexico national scenarios	0.0	0.0	0.0
Mean of all models	0.0	0.0	0.0
2.5 percentile all models	-0.2	-0.2	-0.3
97.5 percentile all models	0.1	0.3	0.3
Dry season, RCP 4.5			
Mean of models used in Mexico national scenarios	0.0	0.0	0.0
Mean of all models	0.0	0.0	0.0
2.5 percentile all models	-0.1	-0.1	-0.2
97.5 percentile all models	0.1	0.1	0.1
Wet season, RCP 4.5			
Mean of models used in Mexico national scenarios	0.0	0.0	0.0
Mean of all models	0.0	0.0	0.0
2.5 percentile all models	-0.1	-0.2	-0.2
97.5 percentile all models	0.1	0.1	0.1

Source: Report authors

In the 2070s, the larger ensemble used in this study produces slightly warmer conditions in 7 out of 12 of the months and in the remaining months there is good agreement with the smaller ensemble used in the national scenarios. The larger ensemble is wetter than the model ensemble used in the national scenario in 2/6 of the wet season months and similar in all but one dry season months.

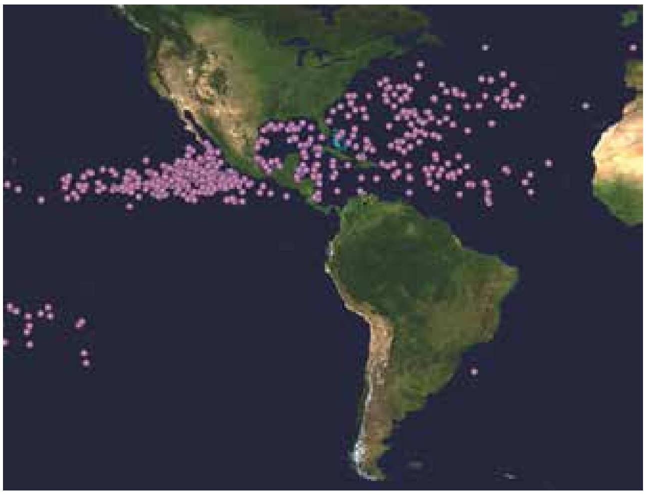
Changes in daily extremes

Ideally it would be extremely useful to know the changes in the frequency of occurrence of daily thresholds in rainfall, wind speed and temperature. To obtain such measures, daily data from several high resolution regional climate models would be needed. Regional climate model simulations for Mexico are available from 4 different models via the national climate change scenarios website[39]. However, only monthly rather than daily data are available via the website[xxii]. As a result, computing the trend in the frequency of occurrence of daily thresholds is not possible. It is plausible to run an ensemble of regional climate models and to store daily data with a view to analyzing changes in climate extremes. The process is computationally demanding but does yield data at higher spatial resolution which can provide more information. Regional models do, however, produce their own biases and these need to be carefully studied. Additionally, regional models run at grid-spacings greater than about 4km, like global climate models, require parametrization of convection which controls climate extremes. If run at grid-spacings finer than 4km, convection can be explicitly resolved. In cases where this has been done (e.g. over the UK), there are large jumps in the extremes simulated by the model compared with coarser resolution versions. The resources required for such a study are considerable and are beyond the scope of this study.

In the absence of the requisite regional climate model data, one plausible approach is to extrapolate the observed trends in the frequency of occurrence of daily thresholds into the future (as presented in Section 2.1.1, chapter "Trends in historical climate: Thresholds of rain and wind from daily data"), assuming that they continue in a linear fashion. This approach has been adopted in the analysis of risks to the port described in Section 3.

FIGURE 2.8

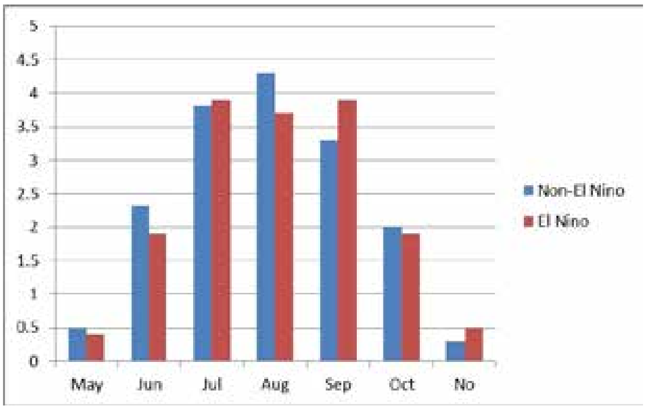
Distribution of tropical cyclones at their maximum intensities shown by dots



Source: Ramsay, 2014 [41]

FIGURE 2.9

Influence of ENSO on mean number of tropical cyclone occurring per month



Source: Romero-Vadillo et al. 2007 [42]

2.1.3. Tropical cyclones

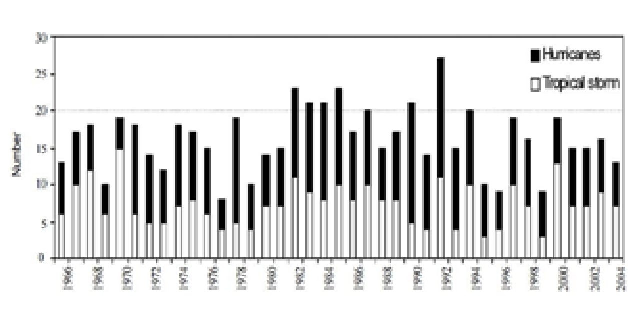
Tropical cyclones and tropical storms are known to disrupt operations at Manzanillo. At the same time, global climate models, the prime tool for climate prediction, are currently too coarse in spatial resolution to simulate these important features of the atmosphere. The changes in seasonal winds reported earlier from climate models reflect broad-scale changes to the tropical easterlies resulting from adjustments to such features as subtropical anticyclones and the equatorial trough, rather than to changes in the frequency, intensity and track of tropical storms. In this section, data are analyzed on operational disruption to the terminal at Manzanillo that is most sensitive to tropical cyclones, (namely PEMEX). Data from PEMEX were only provided for 2014. The purpose of this analysis is to gauge the nature of tropical storm intensity in relation to this disruption. This work is preceded by a general background on tropical cyclones in the North East Pacific.

The North East Pacific has the second highest annual frequency of tropical cyclones globally after the West Pacific. The west coast of Mexico has a greater frequency of hurricanes than the coast of Gulf of Mexico. The main area of tropical development in the tropical eastern Pacific Ocean is offshore in the Gulf of Tehuantepec, between 8 and 15°N (Manzanillo is 19oN, 104oW) (Figure 2.7 and Figure 2.8). In the broad region of the North East Pacific there is an average of 8.8 tropical cyclones and 7.4 tropical storms per year (based on 39 years of data). The annual cycle of frequency peaks in August but 7 of 8 most intense storms between 1966 and 2004 occurred at the end of September and beginning of October. Cyclone tracks are highly variable although about 50% of the tropical cyclones turn north to north-east, with few passing north of 30° N because of the cold California Current. The El Niño Southern Oscillation (ENSO) imposes a complicated pattern of tropical cyclone frequency with high frequency in September but lower frequency in the month of peak occurrence in August (Figure 2.9). Interannual and near-decadal variability of tropical storm and hurricane occurrence (Figure 2.10) in the North East Pacific is large. Extreme years differ by a factor >2.5. There are no clear trends in the frequency of occurrence.

Tropical cyclones have migrated poleward at a rate of about 50 km per decade over the 31 year period from 1982 to 2012[44] (Figure 2.11). It is likely that this trend will continue, leading potentially to fewer tropical cyclones over Manzanillo, although this statement has low confidence. These changes are thought to relate to the change in the mean meridional structure of wind shear linked to the general widening of the Hadley Circulation[xxiii].

FIGURE 2.10

Frequency of tropical cyclones (black) and tropical storms (white) in NE Pacific between 1966 and 2004. White bars represent tropical storms and dark bars represent hurricanes

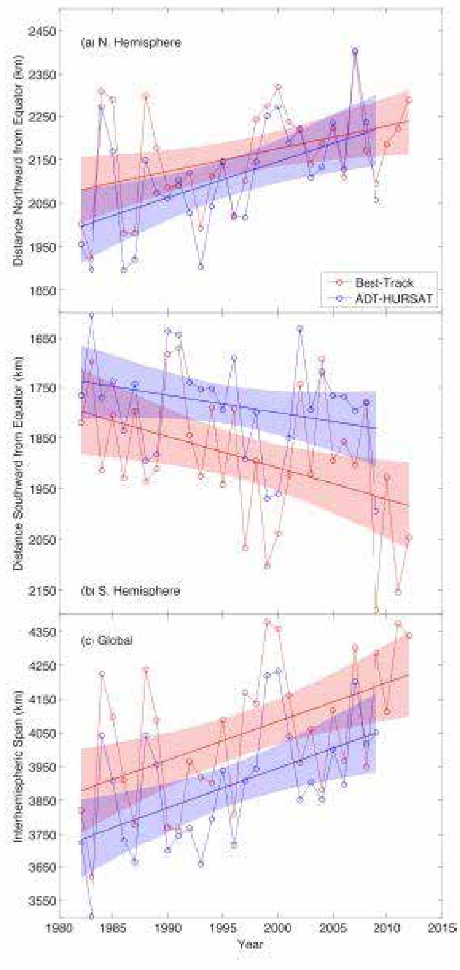


Source: Romero-Vadillo et al. 2007 [43]

In the Intergovernmental Panel on Climate Change Fourth Assessment Report[46] (IPCC AR4), high-resolution atmosphere models reproduced the frequency and distribution of tropical cyclones, but underestimated their intensity. Note these were 'atmosphere-only' models rather than the coupled ocean-atmosphere models normally used in climate prediction. Since the IPCC AR4, at least one global model (MRI-AGCM) at 20 km horizontal resolution simulates tropical cyclones as intense as those observed. But this model is unusual and climate change projections need more than one model, and models that are coupled. It is likely to be 5-10 years before a modest sample of global climate models with

FIGURE 2.11

Observed poleward migration of tropical cyclones since the 1980s



Source: Kossin et al. 2014 [45]

sufficient spatial resolution begins to simulate tropical cyclones sufficiently for the first scenarios of future tropical cyclone activity to emerge.

In lieu of the availability of such data, the 2014 season of disruption to operations at PEMEX has been investigated. In all cases, named tropical storms and tropical cyclones were responsible for the disruption. The tracks and intensity of the storms is shown in Figure 2.12. On the other hand, the tracks of named storms and cyclones in the North East Pacific which were not responsible for disruption are shown in Appendix 4, Figure 4.44. The winds, as simulated by the National Centers for Environmental Prediction (NCEP) numerical prediction model, are shown in Appendix 4, Figure 4.45. It is clear that the prime difference between those storms that led to disruption and those that did not, is the proximity of the storm to Manzanillo. Only those storms passing very close to Manzanillo and normally within a few tens of kilometers, led to disruption. As these affected operations at PEMEX, they are in effect defined as 'direct hits' at the port. The majority of storms, which are distant from the port, do not. It is also evident that even high resolution numerical weather prediction models with realistic assimilation of observed data are unable to simulate winds characteristic of tropical cyclones (Appendix 4, Figure 4.45).

For future projections of storms, the results of expert judgment on 4 tropical cyclone characteristics for the eastern north Pacific (for 2080-2100 relative to 2000-2019 under a medium greenhouse gas emissions scenario) show[47]:

1. A decrease in the annual frequency of tropical storms
2. An inability to comment on the frequency of Category 4 or 5 storms
3. An increase in mean lifetime of maximum intensity
4. An increase in precipitation rate within 200 km

There is currently no available method to assess how tropical cyclone storm tracks could change in the future. Although there is an observed poleward shift in the most intense phase of tropical cyclones, it is unclear whether the tracks would be longer and the storms would evolve in similar locations but move further poleward as well.

Nevertheless, it seems reasonable to plan for:

- Fewer storms
- Increased storm intensity and therefore winds, precipitation and storm surges from tropical storms

Based on the expert judgement statements noted above, sensitivity tests have been developed for potential future changes in tropical cyclones (Table 2.11). These tests are applied in Section 3 to allow assessment of risks to various aspects of port performance.

TABLE 2.11

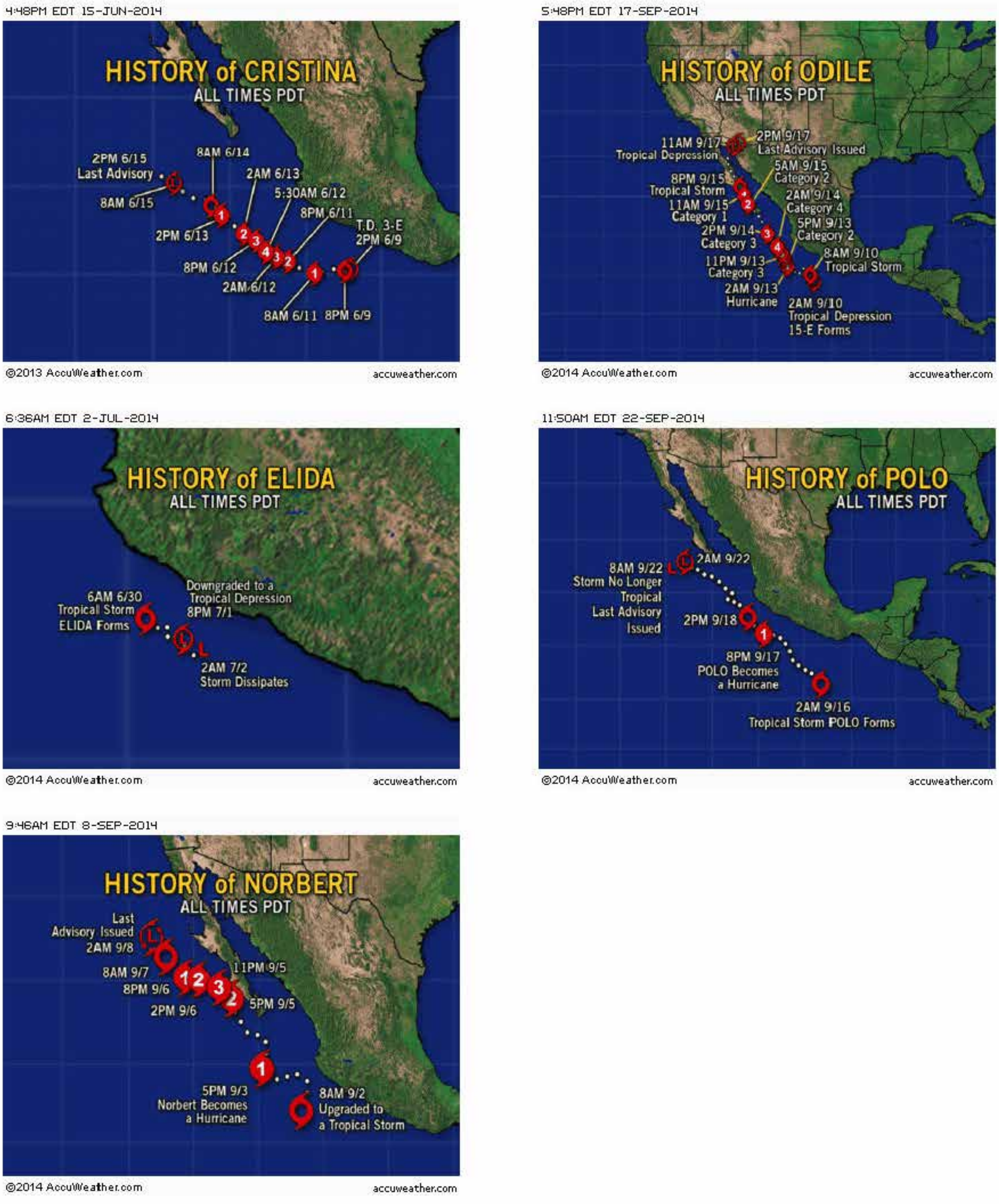
Sensitivity tests developed for this study for potential future changes in tropical cyclones affecting Manzanillo

Expert judgement statement	Sensitivity tests for changes by 2050s
A decrease in the annual frequency of tropical storms	25% decrease in frequency 50% decrease in frequency
An inability to comment on the frequency of Category 4 or 5 storms	25% increase in frequency 25% decrease in frequency
An increase in mean lifetime of maximum intensity	25% increase in mean lifetime 50% increase in mean lifetime
An increase in precipitation rate within 200 km	25% increase in precipitation rate within 200km 50% increase in precipitation rate within 200km

Source: Report authors

FIGURE 2.12

Tracks of tropical storms in 2014 responsible for limiting availability of facilities at PEMEX



Source: AccuWeather.com

2.2. Hydrology

2.2.1. Current

Manzanillo is situated in the central coastal region of Colima State. A recent study by the Mexican Institute of Environment for Sustainable Development (IMADES), incorporating the State Climate Change Program (Programa Estatal de Cambio Climático, PECC)[48] estimated the spatial distribution of the wettest days (99% percentile of daily precipitation) in the region at present (Figure 2.13). The coastal regions are shown to experience the most intense rainfall events.

Rainfall intensity is highest during tropical storms. Figure 2.14 shows the path and intensity of rainfall during Hurricane Jova in 2011. The State of Colima including the Port of Manzanillo experienced over 300 mm of rain between the 11th and 12th October 2011.

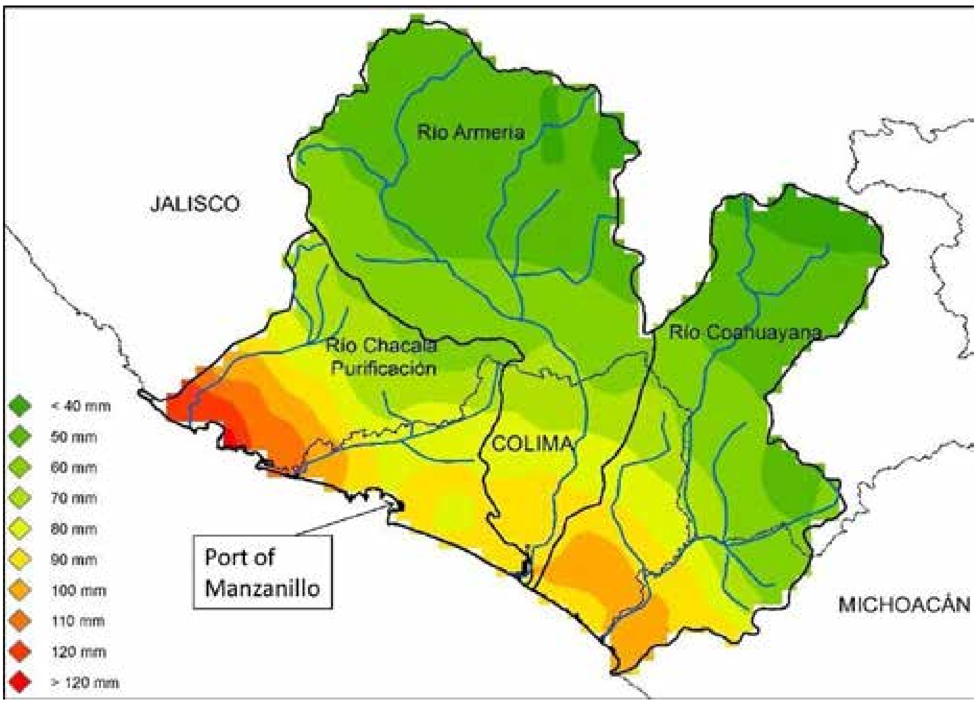
Due to the topography surrounding Manzanillo, the port is a focal discharge point for a number of drainage basins. Urbanization and development have modified this system further, increasing flow rates during intense rainfall events. Studies have shown that certain areas of the Port and the Laguna de las Garzas to its north are now subject to a high risk of flooding.

Discharges

For the purposes of this study, rivers, drainage channels and any other freshwater flows to the sea are termed 'discharges'. A 2008 study[51] and Comisión Nacional Del Agua (CNA) model[52] provided rainfall intensities and drainage discharge data that influence key areas of the Port of Manzanillo. These data were incorporated into a hydrological analysis conducted for this study (Appendix 5). A summary of key findings and data is presented below.

FIGURE 2.13

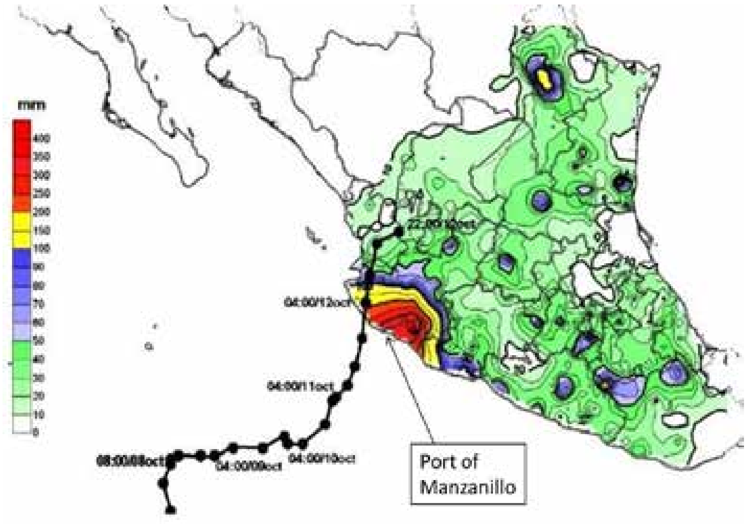
Spatial distribution of the 99 percentile of daily precipitation in river basins in the State of Colima



Source: IMADES, 2014 [49]

FIGURE 2.14

Hurricane Jova path and intensity of rainfall (mm) recorded between 8th and 12th October 2011



Source: IMADES, 2014 [50]

The blue lines on Figure 2.15 show the approximate borders of the separate catchment and drainage systems surrounding the Port. Zone (A) discharges directly into the Laguna de San Pedrito where the port is located. Zone (B) discharges separately into the Laguna de las Garzas which is connected to Laguna de San Pedrito through a 700 m channel.

The drainage route (Figure 2.16) that most frequently results in surcharge and flooding at the port is marked on Figure 2.17. The main discharge follows route 98 for the last 1.6 km into Manzanillo. This 1.6 km section is currently being enclosed in a concrete rectangular culvert. On reaching the port the discharge enters Drain 3 and runs under the terminal patio areas and exits under the quayside into the port basin. For the purpose of this study, this discharge route will be called the Arroyo Jalipa discharge.

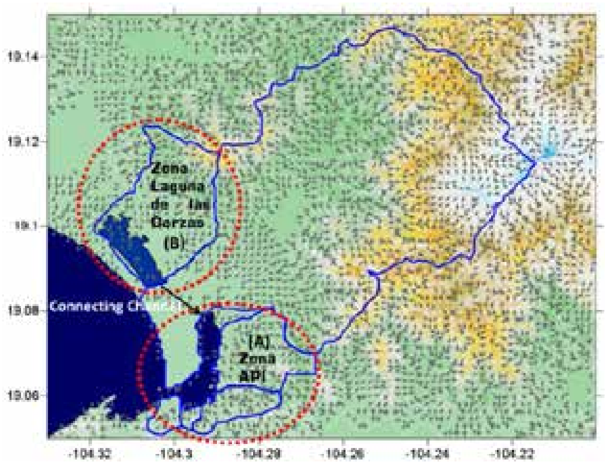
Surface water flooding

Due to debris accumulation in the drain from the municipality, insufficient drainage capacity and the impermeable nature of the port infrastructure (which increases storm water run-off), the main port entrance, customs and internal access/egress roads are subject to almost annual surface water flooding events (Figure 2.18).

To understand the relationship between current and future rainfall and surface water flooding events at the port, and the potential impacts of climate change on design flows, a hydrological analysis has been conducted. The findings are presented in Section 3.6.1, chapter "Surface flooding".

FIGURE 2.15

Zones discharging into the inner port harbor



Source: ERN, 2008 [53]

Sedimentation

Sedimentation from waters draining into the inner harbor results in a decrease in draft clearance for specific areas of the port. This has resulted in delays in vessels berthing, and affects the requirement for annual maintenance dredging.

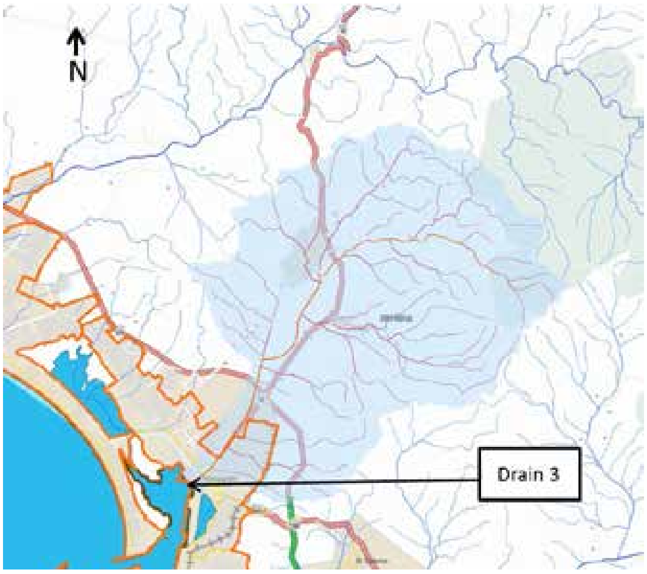
FIGURE 2.16

Arroyo Jalipa discharge route into the Port of Manzanillo being enclosed in concrete culvert

Source: Report authors

FIGURE 2.17

Catchment area and Arroyo Jalipa drainage route into the Port of Manzanillo The Jalipa discharge into the port is marked in yellow



Source: CONAGUA, 2014 [54]

The port has primary and secondary access channels, with two turning circles, serving the southern and northern areas. Sedimentation is reportedly focused on the shaded areas in Figure 2.20.

FIGURE 2.18

Customs area and primary internal access road subject to annual flooding

Source: API Manzanillo, 2015 [55]

These primary routes of sedimentation are caused by the two main drainage systems into the port basin (Zone A and B Figure 2.15). These two main systems result in the Arroyo Jalipa discharge route through Drain 3 (Zone A), and the channel connecting and receiving flow from the Laguna de las Garzas (Zone B).

Detailed hydrological data on the routes and levels of sedimentation from each source were not available for this study. However, total sedimentation currently results in 0.5 million m^3 of material per year entering the port basin. This has to be removed through the maintenance dredging program. The relationship between sedimentation and the requirement for maintenance dredging is discussed further in Section 3.4.

2.2.2. Future

Discharges

Flooding of the port can result from coastal flooding due to storm surges, heavy rainfall causing direct pooling of water, and\or heavy rainfall causing surcharge of the drainage system entering the port. Analysis of historical events showed no significant regular issues with coastal flooding and\or direct rainfall pooling. The most significant cause was heavy rainfall causing surcharge of the drainage system entering the port. The 'surface water flooding' analysis in the study therefore focuses on the relationship between rainfall intensity and the degree of flooding from this drainage system.


WAN HAI
EVERGREEN

TABLE 2.12

Estimated present day rainfall intensities and return period flows (QPeak) for the Drain 3 catchment

Return Period (years)	Intensity (mm/hr)	QPeak (m^3/s)
2	38	107
5	59	165
10	74	208
20	90	252
50	110	309
100	125	350
200	141	396

Source: Report authors

For the Central America\Mexico region, the IPCC 20-yr median return value for total 24-hr precipitation is projected to increase by approximately 8% for the period 2046-2065 (2050s) and approximately 10% for the period 2081-2100[58].

Changes in rainfall intensity are already being observed at Manzanillo: the analysis of ERA-I data for the period 1979-2012 found statistically significant increasing trends for 10 mm and 20 mm rainfall thresholds in June. Assuming that these observed trends will continue in the coming decades, the frequency of occurrence of observed daily rainfall events in excess of 20 mm for the wet season is estimated to increase by 57% by 2030[xxiv].

The hydrological analysis conducted for this study provides the present day rainfall intensities and estimated peak flows for various return periods for the Drain 3 catchment (Table 2.12).

The return period peak discharge values were then projected to increase by a proportion equivalent to the change in rainfall intensity, namely the IPCC estimates of 8% for the 2050s and 10% for the 2080s. Table 2.13 therefore compares the estimated return period peak discharges for the Drain 3 catchment for the various return periods and future time periods.

Surface water flooding

The estimated future increase in rainfall intensity discussed in Section 2.2.2, chapter "Discharges", will result in more frequent surcharge of the natural drainage features of the basins. Comparing the data in Table 2.13, the present-day 1-in-100 year peak flow (350 m^3/s) observed at Drain 3 is estimated to become twice as frequent (approximately the 1-in-50 year peak flow event) by the 2050s. Similarly, the present-day 1-in-50 year peak flow (309 m^3/s) is estimated to have a recurrence interval of approximately 25 years by the 2050s. This trend continues for the 2080s time period.

The results suggest that both the rainfall intensity and peak flows for the Drain 3 catchment will increase in both magnitude and frequency in the future under climate change. For the same return period, the volume of discharge entering the port will increase significantly. If current drainage capacity remains the same, then the likelihood of surcharge and flooding increases.

These findings are applied to the specific risks to the port in Section 3.6.1, chapter "Surface flooding".

Sedimentation

For this study there were no available estimates of sediment concentrations within the Drain 3 catchment; therefore, estimates on the potential for changes to sediment discharges under climate change are restricted to a qualitative discussion.

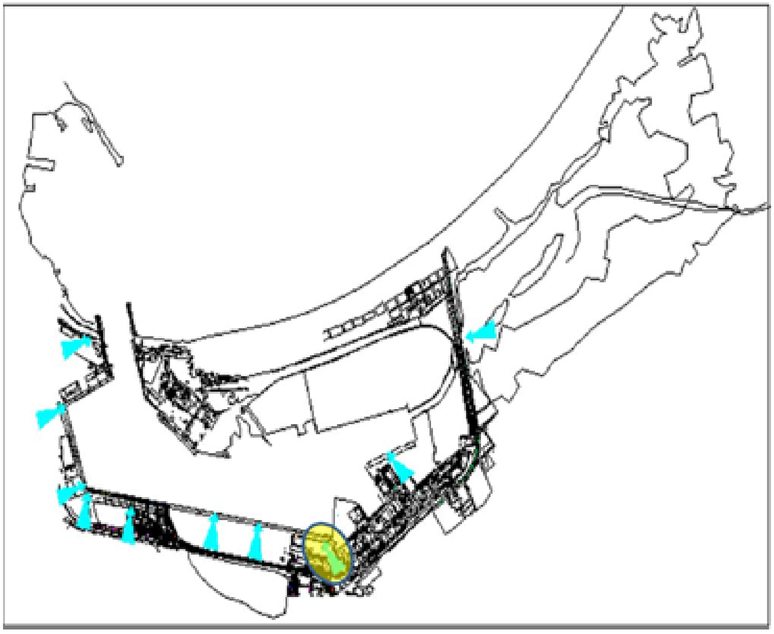
Sediment discharge varies proportionally with flow discharge. Based on the hydrological analysis, it is therefore likely that increasing peak flows will lead to increasing sediment loading.

However, it is challenging to predict what degree the increase might be. If changes in the Intensity-Duration-Frequency and peak flows do not affect sediment concentrations, then sediment loading could be expected to increase proportionally with peak flows. However, more frequent and higher-intensity rainfall events (IPCC estimates of 8% for the 2050s and 10% for the 2080s[59]) could have the effect of causing rain drops to dislodge a greater number of soil particles upon contacting the ground surface. This would increase sedimentation non-linearly. Similarly, higher peak flows could increase channel erosion non-linearly.

To allow for a degree of analysis, the increase in sediment load to the basin is assumed in this study to be related only to the increase in total flow. This issue and its effect on draft clearance, berthing and requirement for maintenance dredging is discussed further in Section 4.1.2.

FIGURE 2.19

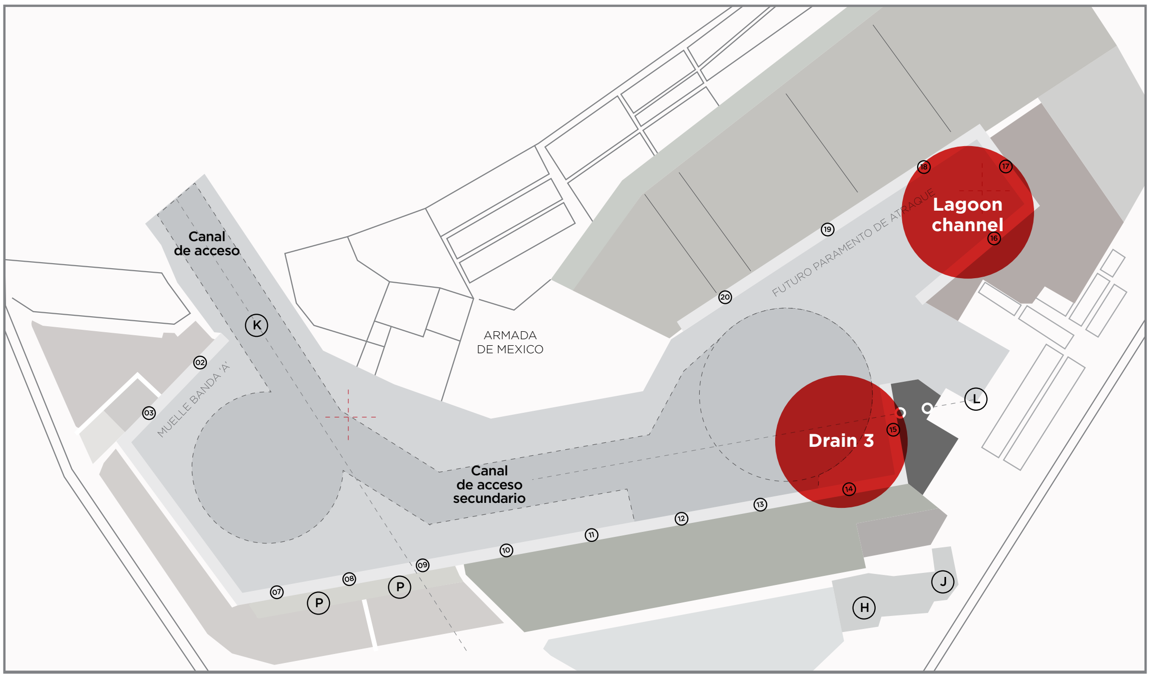
Location of drains discharging into the port basin; Arroyo Jalipa discharge marked in yellow



Source: CONSULTEC, 2013 [56]

FIGURE 2.20

Port primary and secondary access channels and areas of increased sedimentation



Source: API Manzanillo [57]

TABLA 2.13

Estimated return periods for rainfall intensity and peak discharge (Qpeak) for the present day, 2050s and 2080s for the Drain 3 catchment

Return Period (years)	Present day		2050s		2080s	
	Intensity (mm/hr)	Qpeak (m^3/s)	Intensity (mm/hr)	Qpeak (m^3/s)	Intensity (mm/hr)	Qpeak (m^3/s)
2	38.3	107	41	116	42	118
5	58.8	165	64	178	65	181
10	74.3	208	80	225	82	229
20	89.8	252	97	272	99	277
50	110.3	309	119	334	121	340
100	125.1	350	135	379	138	386
200	141.3	396	153	428	155	435

Source: Report authors

2.3. Oceanography

2.3.1. Current

The following key oceanographic parameters have been evaluated to understand current conditions:

- Mean sea level;
- Storm surge; and
- Wave climate.

Mean sea level and tide

For ports, sea level rise (SLR) is often the most significant climate change hazard. At a given location, sea level is affected by a number of long-term and short-term processes which are sensitive to climatic factors.

Long term SLR is driven by the combined effect of climate change, local land movements and groundwater depletion[60]. 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 2.21.

Observed SLR

To understand current SLR scenarios at Manzanillo, a number of data sets have been reviewed to establish potential minimum and maximum ranges. These can be projected into the future in a linear fashion to develop what will be termed the 'Observed' SLR scenario, as discussed in Section 3.2.3.

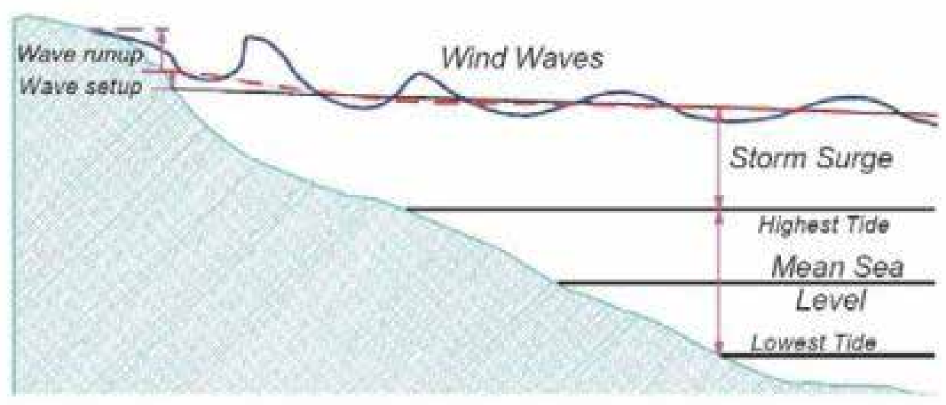
Manzanillo Global Sea Level Observing System

A readily available source of historical sea level data is the Manzanillo Global Sea Level Observing System (GLOSS buoy no 163) dataset. The GLOSS is an international program managed by the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) of the World Meteorological Organization (WMO) and the Intergovernmental Oceanographic Commission (IOC). Hourly data is available from 1953 to 1982 and 1992 to 2012. The US National Oceanic and Atmospheric Administration (NOAA) reports that the station was relocated in 1992 and the records were merged.

This dataset was used for an analysis of SLR for the CONTECON terminal technical due diligence report[62]. Based on these data a local trend in sea level rise of 3.28 mm/yr was presented. This figure of 3.28 mm/yr is also referenced in the Programa Estatales de Acción ante el Cambio Climático (PEACC), and Instituto Nacional de Ecología y Cambio Climático report on sea level rise

FIGURE 2.21

Factors contributing to sea level



Source: Hennessy et al., 2004 [61]

in the state of Colima (Figure 2.22). This matches the average annual global rate of SLR of 3.3 +/- 0.4 mm per year observed through satellite data from 1993 to 2009[63].

This GLOSS observed rate of SLR is on the lower end of the '3 to 6 mm/yr' category, under which NOAA classifies the majority of the eastern and western Mexican coastal regions[65]. Other regional examples show higher increases, for example a Caribbean-wide study estimated an increase of 5.6 mm per annum[66].

Instituto Mexicano del Transporte\ Secretaría de Marina

The Instituto Mexicano del Transporte (IMT) and the Secretaría de Marina (SEMAR) stated that their own data showed lower rates for SLR at Manzanillo than the GLOSS dataset. This was stated as due to plate tectonic activity in the region counteracting any rise in global mean sea level.

Data received from IMT included sea level records at Manzanillo from 2008 to 2014. The data was analyzed but showed no indication of sea level rise outside of natural variation. The relatively short time series of 6 years will require extension for confirmation of any significant trend.

Summary of implications of observed SLR datasets for future SLR

The GLOSS SLR data would result in approximately 12 cm of SLR by 2050 and 28 cm by 2100. In the context of a maximum tidal range of 0.3 m and 1:100 storm surge of approximately 1.5 m this would be a relatively small change.

The lower value from the IMT\SEMAR dataset is therefore of note, but will not significantly affect the overall risk of SLR flooding. This is discussed further in Section 3.2.3.

Tidal rise

Data from SEMAR shows that the tidal range at Manzanillo (the difference in height between the high tide and the succeeding low tide) is approximately 0.6 m and hence the difference between high tide and mean sea level is approximately 0.3 m (Figure 2.23).

Seasonal sea level

One of the clear signals in the sea level time-series is seasonal. There is an increase in sea level at Manzanillo between May and September (Figure 2.24). This can be caused by a number of regular fluctuations such as coastal temperatures, salinities, winds, atmospheric pressures and ocean currents (NOAA[68]).

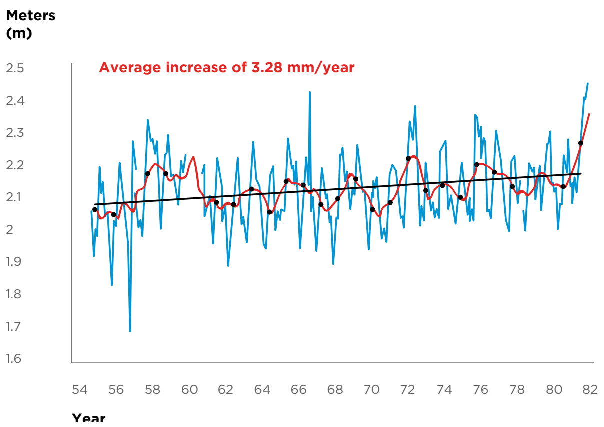
This seasonal rise in sea level visually correlates with average monthly precipitation, with the highest and lowest extremes of both being July to September and March to April respectively (Figure 2.25).

Storm surge

Storm surge is a rising of the sea as a result of wind and atmospheric pressure changes associated with a storm. Water level is increased due to the low pressure

FIGURE 2.22

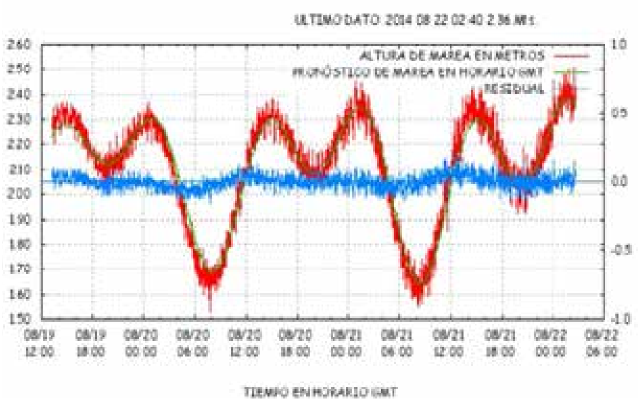
Historical mean sea level at Manzanillo reported in the PECC



Source: INECC, 2014 [64]

FIGURE 2.23

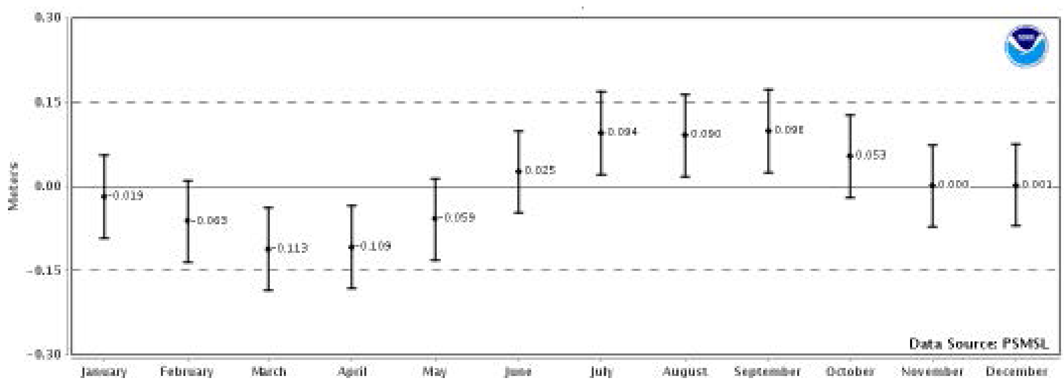
Typical tidal range recorded by SEMAR oceanographic buoy, Manzanillo (19 to 22 August 2014)



Source: SEMAR, 2015 [67]

FIGURE 2.24

Average monthly mean sea level Manzanillo (+/- 95% confidence interval)



Source: NOAA, 2015 [68]

at the center of the storm drawing water upward, and strong winds pushing water against the landmass. In addition, breaking waves in the surf zone cause increases in water level on the coastal fringe, due to a process called 'wave setup'. Together, these increases in water level are generally the most destructive component of storms (in comparison to wind), as illustrated by the extensive damage caused by Hurricane Katrina's storm surge in the Gulf of Mexico. Storm surge is separate from standard wind-related wave activity.

Manzanillo is in the path of yearly tropical cyclones developing in the Eastern Pacific. These events can have a significant effect on sea level at the port. A study51[69] developed storm surge return periods for the Manzanillo region. This was based on quantitative analysis of NOAA data, applied to the 52 cyclones passing within 150 km of the Port between 1949 and 2007. The categories of these 52 cyclones are given in Table 2.14.

The analysis shows that storm surge heights are potentially significant, with heights of the 1 in 250 year return period storm surge estimated at 2.52 m, and the 1 in 500 year event at 2.85 m (Table 2.15 and Figure 2.26).

Decadal cycles

There is also evidence for decadal cycles in sea level around Manzanillo, contributing to potential maximum sea level heights. Studies have shown sea levels in the Eastern Pacific during El Niño years to be raised by approximately 20 to 30 cm as warm water is drawn westwards across the Pacific over a period of months[73].

Sea level summary

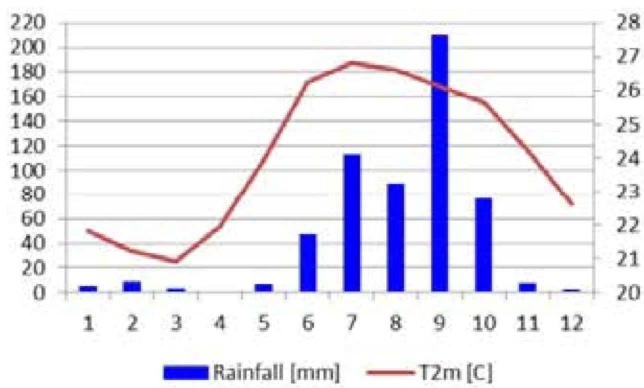
The various factors contributing to sea level at the Port of Manzanillo are summarized in Table 2.16.

Wave climate

Waves can form locally through the force of the wind acting on the surface (wind waves). These are typically more irregular waves with shorter wavelengths or periods. The wave period is the time that it takes for a single wave, i.e. from crest to crest, to pass a fixed point. Swell waves

FIGURE 2.25

Average monthly precipitation (mm) and near surface temperature (˚C) from Manzanillo met station data



Source: Report authors

TABLE 2.14

Number and category of extreme storms, Manzanillo region 1949-2007

Category	Number
H5	1
H4	3
H3	2
H2	7
H1	14
TROPICAL STORM	25

Source: ERN, 2008[70]

TABLE 2.15

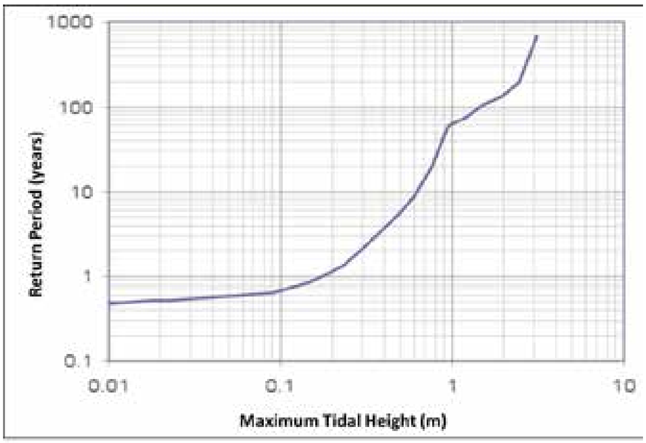
Storm surge return period and estimated maximum sea level at Manzanillo

Return Period (years)	Maximum Sea Level (m)
50	0.91
100	1.47
250	2.52
500	2.85

Source: ERN, 2008[71]

FIGURE 2.26

Return periods (years) of storm surge heights (m) for Manzanillo



Source: Source: ERN, 2008 [72]

are caused by regional storms in the Pacific, creating waves that travel into the local area. These are typically more regular and longer in wavelength and period.

With regard to wave exposure at Manzanillo, the main harbor is highly sheltered, with the possible exception of the penetration of very long period 'infragravity'[xxv] waves during occasional sustained periods of very high swells. Analysis for this study will therefore focus on the area immediately outside the port entrance where the PEMEX Terminal is located.

The PEMEX Terminal does have some wave exposure, but in general the protection offered from the shoreline configuration and the causeway / breakwater at the west end the Terminal offers wave shelter under most operating conditions. Downtime at the PEMEX Terminal is associated mainly with tropical storms and hurricanes. This is discussed further in Section 3.5.

2.3.2. Future

Mean sea Level

In the future, as the oceans warm and ice melts, sea level is expected to rise more rapidly. An upper estimate for SLR is difficult to pinpoint because there is little consensus among scientists as to what this should be. To assess risks at the port from SLR, multiple scenarios will therefore be explored.

Compared to the observed rate of SLR reported in the previous section, the incorporation of climate change model projections leads to a various higher rates of SLR over the coming century. These are termed the 'Accelerated SLR' scenarios for the purposes of this study. As with the Observed SLR scenario, a number of approaches have been investigated to understand potential minimum and maximum ranges.

IPCC scenarios

The IPCC Fifth Assessment Report (IPCC AR5) provides a range of SLR scenarios[74]. However many scientists have commented[75] that these exclude the potential for extreme sea level rises, so are potentially inappropriate for the management of high-risk coastal areas. They note that the IPCC AR5 scenarios[76] only cover the central range of possible sea level rise, which is generally not sufficient for coastal risk management. For example the IPCC AR5 scenarios indicate that, by 2100, global mean sea level is considered likely to rise within the range 0.28 to 0.98 m relative to 1986-2005 (Figure 2.27). This lower range of 28 cm is the same as the Observed SLR scenario recorded from the GLOSS Manzanillo data. The probability of staying within this central range is, however, estimated by the IPCC to be only 66 per cent.

Projections of climate change-induced accelerated SLR were incorporated into the CONTECON Due Diligence study[78], resulting in a worst case SLR of approximately 1.5 m by 2100.

Other studies and approaches give a wider range of values for global mean sea level rise by 2100, for example 1.15 m[79], 1.79 m[80] and 2.4 m[81]. Managing risks for the Port of Manzanillo requires an avoidance of major damage wherever possible, so some scenarios higher-end SLR beyond the IPCC range can considered more applicable.

Therefore, one Observed SLR rate and two IPCC SLR scenarios have been applied in this study as low, moderate and worst case. These are:

1. 'Observed' - assuming that sea level rise continues at the current estimated rate of 3.3mm/year;
2. 'Moderate' - using a rate of sea level rise based on IPCC scenario RCP2.6; and
3. 'Worst case' – using a rate of sea level rise based on IPCC Scenario RCP 8.5

The sea level rise for each of these scenarios from 2015 to 2100 is given in Table 2.17.

Additional extreme values are discussed to comment on all possibilities where appropriate in Section 2.3.2 and 3.3.4 where appropriate.

Storm surge

It is expected that in the coming years, tropical storms and hurricanes are likely to be less frequent, but intensity is likely to increase, with higher wind speeds, waves and storm surge (Section 2.1). However, changes in storm surge frequency and intensity under climate change are very challenging to predict.

Based on the potential for storm intensity to increase, it can be assumed that the likelihood of a larger storm occurring increases, and the 1:250 and 1:500 year storm surge heights can be used for the analysis of moderate to worst case SLR scenarios by 2100. Analysis for this study incorporates this increasing likelihood of higher storm surge over time.

In addition, analysis of historical storm data[82] reveals that over the last three decades a significant shift has occurred towards the poles in the average latitude at which tropical cyclones attain maximum intensity. However it is unclear whether the storms will actually

TABLE 2.16

Maximum contributions to sea level of individual components at Manzanillo

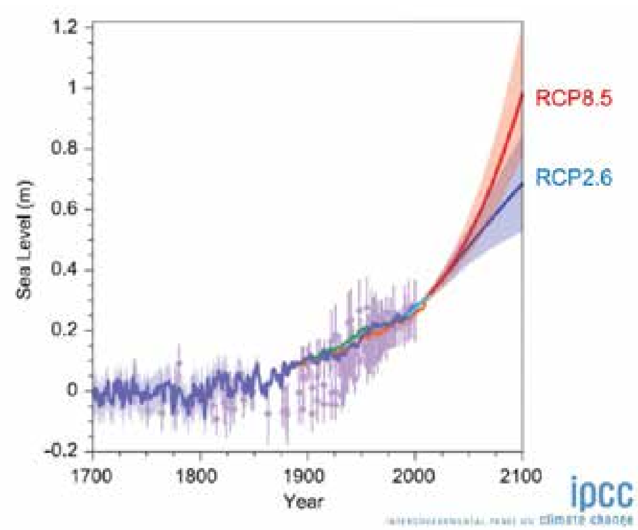
Sea Level Component	Approx. maximum contribution (m)
Observed mean SLR (GLOSS)	0.12 by 2050 0.28 by 2100
High tide	0.3
Seasonal variation	0.1
Decadal (El Niño)	0.3
Storm surge (1 in 100 yr)	1.47
Storm surge (1 in 250 yr)	2.52

Source: Report authors

evolve in similar locations, but with longer poleward tracks. Increased proximity of storms to Manzanillo is also considered in this study.

FIGURE 2.27

Range of IPCC SLR scenarios to 2100 (RCP 2.6[xxvi] to RCP 8.5)



Source: Church et al, 2013 [77]

Wind and waves

Studies indicate that maximum and average wind related wave height is likely to increase in the future in the tropical Eastern Pacific. Projected changes in the regional averaged annual means (Havg) and annual maxima (Hmax) of significant wave heights are provided in Figure 2.28[83]. Rises in sea level will compound these impacts.

To understand potential changes in wave height at Manzanillo, the analysis conducted for this report indicates only a modest increase in average winds speeds in the dry season, showing +0.2 m/s by the 2070s for RCP 8.5. Wet season wind speeds tend to decrease by about -0.1 m/s in both the 2040s and 2070s for both RCP 4.5 and RCP 8.5.

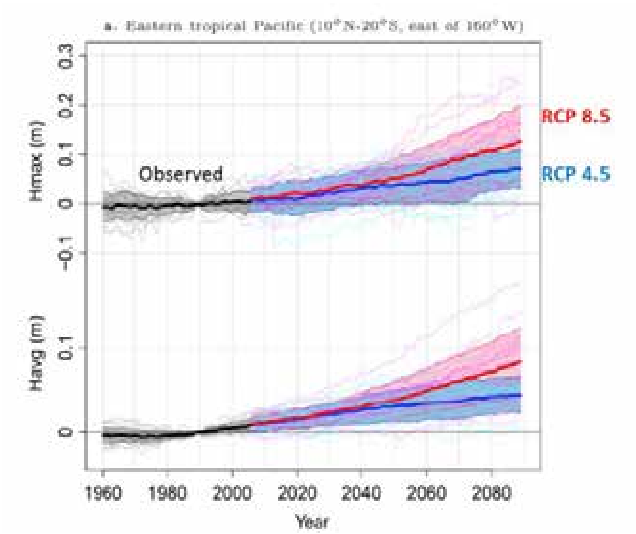
The ability to model future changes in the frequency occurrence of daily wind speed thresholds is limited, as discussed in Section 2.1.

Therefore the approach used in this study was to quantify the observed (historical) trends in a range of wind thresholds. For this, daily ERA-I data (1979-2012) was used, as considerable gaps occurred in the daily met station data. Analysis of the ERA-I data shows no historical trend in the frequency of wind speeds greater than 3 m/s in any month (Section 2.1). This slight increase would not significantly increase average wave heights.

However it is important to note that there is an underestimation of wind extremes when analyzing ERA-I data, partly due to extreme weather events such as tropical cyclones and convective storms not being captured by reanalysis.

FIGURE 2.28

Future changes in average and maximum wave height (m) for the tropical Eastern Pacific, under RC 4.5 and RCP 8.5 greenhouse gas concentration scenarios



Source: PICC, 2013 [84]

TABLE 2.17

Mean Manzanillo SLR for 3 scenarios 2015 to 2100

Scenario	Mean SLR by 2100
Observed	0.28 m
Moderate	0.36 m
Worst case	0.66 m

Source: Report authors


HMK 6507

3. Climate risks, opportunities and adaptation assessment for the Port of Manzanillo

This section evaluates climate-related risks, opportunities and adaptation actions for the port, considering all aspects of its value chain. In addition, an overview of climate risks, opportunities and adaptation actions for ports in general is provided in Appendix 6.

3.1. Goods storage

Summary of key points

- Operational sensitivities for reefers and warehouses e.g. energy costs, lifespan of equipment are temperature dependent.
- A significant relationship was found to exists between mean temperatures and mean monthly energy costs for a representative terminal. Each 1˚C increase in mean temperature was associated with an approximate 5% increase in annual mean energy costs for cooling.
- Climate projections indicate mean wet season temperature increases of 1.8˚C by the 2040s (3.4˚C by 2070s), with a range of increases from 1.1˚C to 2.9˚C by the 2040s (and 1.8˚C to 4.8˚C by the 2070s)
- This will result in significant increases in costs for specialist freezing terminals.
- Adaptation measures to consider include increasing the efficiency of cooling equipment, using alternative energy sources, avoiding loss of power to reefers, incorporating rising temperatures into energy audits and exploring options for passing energy costs on to customers.

3.1.1. Summary of Climate Risks

A summary of key goods storage climate risks information is provided in Table 3.1. Section 3.1.2 then provides a discussion of key risks to the terminals.

TABLE 3.1

Goods storage risks

Risk	Thresholds and Sensitivities	Current and future climate/ oceanographic variability and change	Risk Description
Increased average and peak temperatures cause increased refrigeration and freezing costs	• Operational sensitivities for reefers and warehouses e.g. energy costs, lifespan of equipment, are temperature dependent. • Increased energy is required for cooling at higher temperatures. • Dust and rain can cause problems with electric connections to the reefers, leading to power loss, and consequent extra costs to re-cool or refreeze reefers to their target temperature.	• Monthly mean temperatures range from 24°C (January to March) to 27°C June to August. • Observed data shows significant trend of 0.4 to 0.5°C increase per decade. • Warming along the coast near Manzanillo reaches 2°C in the dry season by the 2040s for RCP 8.5 (1.2°C for RCP 4.5) and 3°C by the 2070s for RCP 8.5 (1.8°C for RCP 4.5). • Wet season temperature increases are similar to dry season but slightly lower for each respective RCP pathway.	• Increases in temperature will result in increased refrigeration and freezing costs. • 1°C increase in temperature was associated with a 5% increase in energy costs for a representative terminal. • Degree of impact will be mitigated by technological improvements over time, increasing the efficiency of cooling equipment. • Specialist refrigeration / freezing terminals are most at risk: MARFRIGO and FRIMAN. • Other reefer handling terminals also affected: CONTECON, OCUPA, TIMSA, MULTIMODAL, SSA

Source: Report authors

3.1.2. Terminals

The Port of Manzanillo includes terminals dedicated to the storage and handling of refrigerated and frozen produce e.g. fish and agricultural with the largest specialist terminal providing over 100,000 m^3 of freezing warehouse space. Costs of freezing and maintaining low storage temperatures can be significant, contributing up to 5% to the end product price.

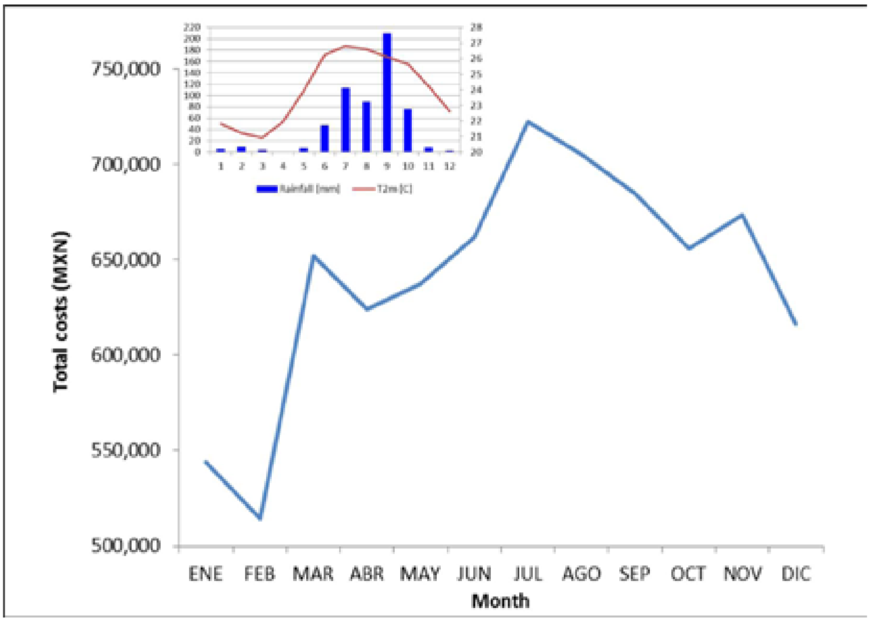
From data provided by a representative terminal, a pattern can be observed between seasonal temperatures and energy costs for freezing (Figure 3.1). Both warmer ambient temperatures, and increased amounts of seasonal produce held within the warehouses during agricultural harvesting and fishing seasons, will requirelead to greater energy requirements to maintain the required low temperatures. Average costs per month for 2010 to 2014 were lowest in the coolest months of January to February, and highest in the hottest months of July and August. June to September are the warmest months of the year (inset Figure 3.1).

Container terminals with reefers will also experience additional costs for cooling, though these will be less significant than for specialist terminals storing refrigerated and frozen produce in warehouses. An example terminal reported an increase in reefer energy use during the hotter months of the year, ranging from 8kw/hr in January/February to 12kw/hr in August during the hottest months.

Data on average monthly freezing costs was compared to available observed temperature data over the period January 2009 to May 2013 for this representative terminal. These data showed a significant ($P < 0.05$) positive relationship between mean monthly temperature over the five year period and mean monthly energy costs (Figure 3.2). However no significant ($P > 0.05$) relationship was observed when comparing all individual monthly temperatures to individual monthly energy costs.

FIGURE 3.1

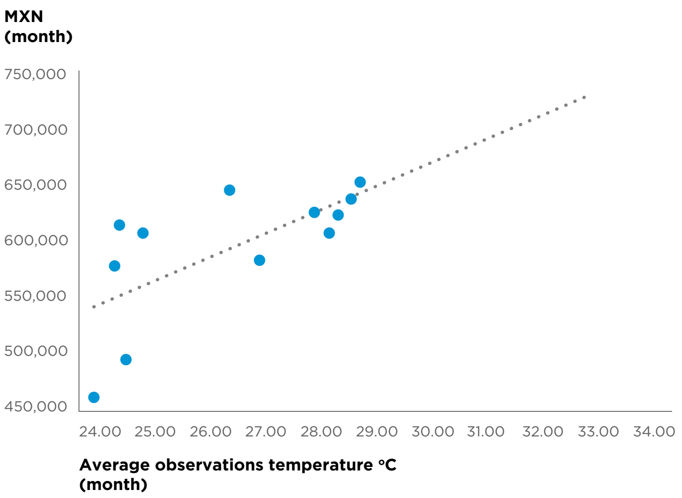
Average monthly energy costs (MXN) for freezing for a representative terminal, 2010 to 2014 (Inset: annual mean rainfall and temperature at Manzanillo 1979 to 2012).



Source: Report authors

FIGURE 3.2

Relationship between observed monthly mean temperatures and monthly energy costs for freezing (MXN), for a representative terminal 2009 to 2013



Y 21305X + 25713 **R²** 0.4601

Source: Report authors

TABLE 3.2

Mean temperature increases at Manzanillo (RCP 8.5)

Scenario	Temp increase DRY SEASON (°C)			Temp increase WET SEASON (°C)		
	2020s	2040s	2070s	2020s	2040s	2070s
Low (2.5th percentile)	0.5	0.7	2.0	0.5	1.1	1.8
Mean	1.0	1.7	3.0	1.1	1.8	3.4
High (97.5th percentile)	1.6	2.6	4.7	1.6	2.9	4.8

Source: Report authors

TABLA 3.3

Potential increases in average seasonal energy costs for affected terminals (RCP 8.5).

Scenario	Average costs increase DRY SEASON (MXN per year)			Average costs increase WET SEASON (MXN per year)		
	2020s	2040s	2070s	2020s	2040s	2070s
Low (2.5th percentile)	-	-	314,644	-	-	283,179
Mean	-	267,447	471,965	-	283,179	589,216
High (97.5th percentile)	251,715	409,037	814,505	251,715	456,233	831,835

Source: Report authors

TABLE 3.4

Potential increases in average annual energy costs for affected terminals (RCP 8.5).

Scenario	TOTAL ANNUAL costs increase (MXN per year)		
	2020s	2040s	2070s
Low (2.5th percentile)	-	283,179	658,536
Mean	330,376	606,547	1,109,113
High (97.5th percentile)	554,557	953,145	1,646,341

Source: Report authors

These data are of particular use as the terminal's overall freezing space remained constant over this period. Their annual energy requirements (though not their unit energy costs) can therefore be viewed as consistent relative to other terminals, which experience fluctuations in the number of reefers through variations in customer demand.

Rising temperatures due to climate change can be expected to lead to increased energy costs. Projections of temperature increases under the RCP 8.5 scenario were presented in Section 2.1 and are summarized iin Table 3.2 for both wet and dry seasons. These include the 2.5 percentile, the mean and 97.5 percentile ranges of temperature increases, to evaluate low, moderate and high impact scenarios.

Based on the observed relationship between ambient temperature and energy costs presented in Figure 3.2, Table 3.3 provides average increases in annual energy costs for affected terminals at the Port. Data from three terminals was used when calculating these averages. To incorporate the range of costs across the port as a whole, these included both specialist freezing warehouses and container terminals with reefers with less significant energy requirements.

The costs presented acknowledge the materiality of impact and prioritization, whereby any increases in costs

below 150,000 MXN are considered "not meaningful" and are not provided. The figure of 150,000 MXN was selected as an average representative significantmeaningful figure, with respect to all terminals' annual EBITDA.

Dry and wet season costs are combined to present total annual increases in Table 3.4.

In addition to ambient temperature and energy usage, terminals also reported increased energy use associated with interruption of energy supply, as maintenance of temperatures within reefers that are already cooled requires considerably less energy than cooling down reefers which have warmed up due to power outages. Increases in dust and moisture can also affect the electrical contacts between the power supply and the reefers, resulting in a loss of power until fixed. Furthermore, electricity blackouts to the port were reported to occur around twice a year for up to two hours at a time. This presents a risk to terminals without a dedicated backup power supply for their reefers.

3.1.3. Adaptation

Increase the efficiency of cooling equipment

The sensitivity to rising temperatures and energy costs for refrigeration and freezing varies between terminals. The EBITDA of the specialist cold storage terminals is highly dependent on the percentage of operating expenditure related to energy costs. The specialist container terminals are less sensitive (1% to 5% of containers are reefers) but energy costs are still significant.

There are currently 1,000,000 reefer containers installed globally. The reefer market is growing and undergoes a compound annual growth rate of 5% per annum[85]. In view of rising fuel prices and growing concerns over greenhouse gas emissions and a constantly growing fleet, the transport sector is under pressure to increase fuel efficiency. There is therefore a strong emphasis on improving the energy efficiency of reefer units, primarily by software solutions and hardware improvements[86;87].

There is a significant difference in energy consumption between newer units and older, less well-maintained ones. The primary method of reducing reefer energy consumption is therefore to ensure units are modern and running up-to-date hardware and software management systems.

Modern reefers possess many added functions including: air quality control systems, atmosphere control, humidity control and very fine temperature controls. For example the Maersk QUEST II adapted reefer can reduce energy by up to 65%, and associated CO_2 emissions related to power generation[88]. It is estimated the implementation of QUEST II has saved 350,000 metric tons of CO_2 equivalent emissions a year for Maersk. Due to the reduced energy costs, vessels can now take onboard more reefer containers than before for a single transit.

The choice of reefer does not lie with API Manzanillo or the terminals. However it could be in the port's interest to reflect increasing energy costs in its charge-out rates for storing reefers.

The lifecycle and upgrade of containers can be a slow process. For instance, shipping companies can typically operate a reefer unit for 15 to 17 years[89]. While certain models of reefers can be made energy efficient by a simple software upgrade, other models will have to finish their operational lifecycle and be replaced before energy savings are possible.

For the refrigerated and frozen warehouses of MARFRIGO and FRIMAN, new technologies are available to reduce cooling costs, such as Variable Frequency Drives (VFDs, electronic devices used to change the speed of motors) and evaporator controls[90]. Studies have shown that efficiency gains of up to 30% can be made on large cold stores through the implementation of new technologies[91].

Investment in new warehouse technologies and equipment would be borne by MARFRIGO and FRIMAN. However the Return on Investment (ROI) has been shown to be quick elsewhere. For example, case studies have shown that investments in VFDs can have a ROI within 6 months[92]. Similarly, installation of energy-saving solid state LED lights inside a warehouse, which produced less heat, has been shown to have a ROI in less than two years[93]. Subsidies for new technology may be available as part of national efforts to improve energy efficiency[94].

Alternative energy sources

A 2015 study investigated the carbon footprint of the port[95] and made a number of recommendations for how to reduce CO_2 emissions and associated energy costs. The use of alternative renewable energy sources at the port was stated as viable. To encourage private participation in the generation of electricity from renewable sources, institutions such as the Secretaría de Energia de Mexico (SENER) provide a number of incentives.

For the port the most appropriate renewable energy sources recommended in the carbon footprint study were solar and wind energy.

Solar power, whilst not advised to be installed over areas of valuable land within the port, can be configured on the roofs of buildings, ships or other appropriate pre-existing installations. The study[96] calculated a ratio of investment of 30,000 MXN per kilowatt installed with an ROI of approximately 10 years.

In the coastal region of Manzanillo wind is predominantly from a south westerly direction (Section 2.1) with a low average speed of 2.5 m/s. However ROI on wind power is considered possible in the carbon footprint study, and was recommended for assessment.

Maintenance of power supply

When the supply of electricity to reefers is lost, additional energy is required for re-cooling, once the supply is re-established. The majority of terminals have a backup energy supply so it is a priority issue, however electrical connections can be isolated to reduce exposure to water and dust and incidents of power loss.

Energy audit review

An energy audit of the port has been conducted for the 2015 carbon footprint study[97] to identify potential areas for reducing overall energy consumption. This audit can be reviewed in light of impacts of rising temperatures and additional opportunities for reducing energy consumption in line with findings can be considered.

Passing on electricity costs to customers

A terminal stated that approximately 5% of the end product price is attributable to cold store energy costs. This implies that other terminals with high energy costs could review their pricing models with their customers, which could allow for increasing costs associated with higher temperatures to be passed on.

3.2. Goods Handling

SUMMARY OF KEY POINTS

- For a number of terminals, even light rain can suspend handling operations e.g. vessel hatches are closed as the product quality can be affected.
- Container crane and forklift operations are halted during heavy rain due to a reduction in visibility for the crane and forklift operators.
- If observed trends continue, the port will experience a 6% reduction in wet season daily rainfall events (<1mm) by 2020 and a 23% decrease by 2040.
- If observed trends continue, the port will experience a 23% increase in wet season daily intense rainfall events (>20 mm) by 2020 and a 90% increase by 2040.
- Drier conditions overall represent a positive impact for the port through decreased loading\unloading downtime.
- Average % monthly operational downtime during the wet season for an example specialist container terminal was 0.2% in 2014. This translates to approximately 33,000 MXN of EBITDA per month. Increased losses of 7,500 MXN EBITDA per month are expected by 2020, and 30,000 MXN EBITDA per month by 2040.
- Adaptation options include increased covered handling areas, review of handling materials in adverse conditions e.g. consolidation operations and loading onto trucks and railcars.

3.2.1. Summary of Climate Risks \Opportunities

One of the key factors which determine the number of ships that can dock at the Port of Manzanillo, and the rate at which cargo can be transferred through the port, is the efficiency and operability of the goods handling equipment. A summary of goods handling climate risks and opportunities identified for the whole port is provided in Table 3.5. A breakdown of key risks to individual terminals is then given where appropriate. Where an individual terminal is not discussed, no significant specific risk to goods handling was identified.

3.2.2. Rain causing stoppage of handling operations

Risk analysis

The issue of rain stopping of handling operations has two main dimensions:

1. For a number of terminals, even light rain can suspend handling operations as the product quality can be affected, so, for instance vessel hatches are closed; and
2. Container crane operations are halted during heavy rain due to a reduction in visibility for the crane and forklift operators

Light rain suspending loading\unloading operations

To investigate the potential future changes in delays from any rainfall stopping loading\unloading operations, analysis of significant historical changes in rainfall from daily ERA-I data was projected forward assuming the same linear trend continues into the future (Figure 3.3).

This issue is a factor of any rainfall event occurring, rather than the degree of rainfall intensity. Therefore the significant decreasing trends in low rainfall threshold exceedances i.e. 1 mm were assessed up to the 2020s and 2040s for the wet season (July) and dry season (December).

Assuming these observed trends continue, the port will experience a 6% reduction in July daily rainfall events by 2020 and a 23% decrease by 2040 (Figure 3.4). This presents a positive benefit to the port from overall drier conditions and hence reduced disruptions to good handling. Figure 3.4 shows that dry season rainfall events are likely to be insignificant by 2040.

Intense rain stopping container handling operations

Intense rain can halt container handling operations due to a reduction in visibility for crane and forklift operators. Stopping crane and forklift operations due to rain is a qualitative decision based on operational safety.

To investigate the potential future changes in delays from intense rainfall stopping loading\unloading of containers, analysis of significant historical changes in rainfall from daily ERA-I data was projected forward, assuming the same linear trend continues into the future.

This issue is a factor of intense rainfall events. Therefore the significant increasing trends in high rainfall threshold exceedances i.e. 20 mm were assessed up to the 2020s and 2040s. June was the only month that showed a significant increase in intense rainfall events over time (Figure 3.5).

If these observed trends continue, the port will experience a 23% increase in June daily rainfall events greater than 20 mm by 2020 and a 90% increase by 2040. This presents an increased risk to the port from container handling downtime.

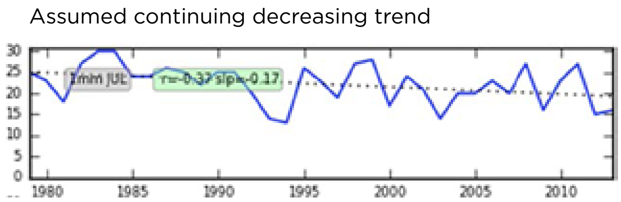
As a representative example of the current risks to container handling, information was provided by a container terminal on the percentage operational downtime due to suspension of crane operations due to weather in 2014 (Figure 3.6). There is a marked increase in suspensions during the rainy season months of July to September. The estimated 90% increase in the number of rainy days >20 mm by 2040 has been applied to the data to show the potential increase in downtime for each month.

Financial analysis

For terminals where any rain event can suspend handling operations, it is unclear how the forecast reduction in rainfall frequency will translate into increased revenues for API Manzanillo. While these terminals may see a marginal increase in throughput, they represent a small fraction (<10%) of the total value of goods transported through the port. Furthermore, it is not known if rain delays are a limiting factor in current throughput of these terminals, and even if it is, the terminals may well continue to plan conservatively for rain delays for the foreseeable future.

FIGURE 3.3

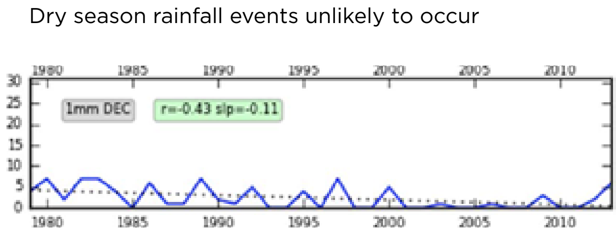
Trends in the frequency of occurrence of observed daily rainfall (July) in excess of 1 mm (1979-2014). (See Appendix 4).



Source: Report authors

FIGURE 3.4

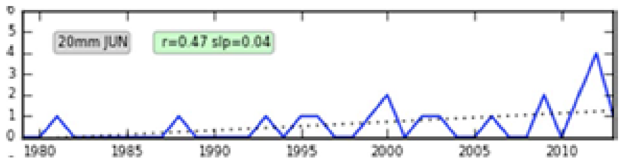
Trends in the frequency of occurrence of observed daily rainfall (July) in excess of 1 mm (1979-2014)



Source: Report authors

FIGURE 3.5

Trends in the frequency of occurrence of observed daily rainfall (June) in excess of 20 mm (1979-2014).



Source: Report authors

TABLE 3.5

Goods handling risks

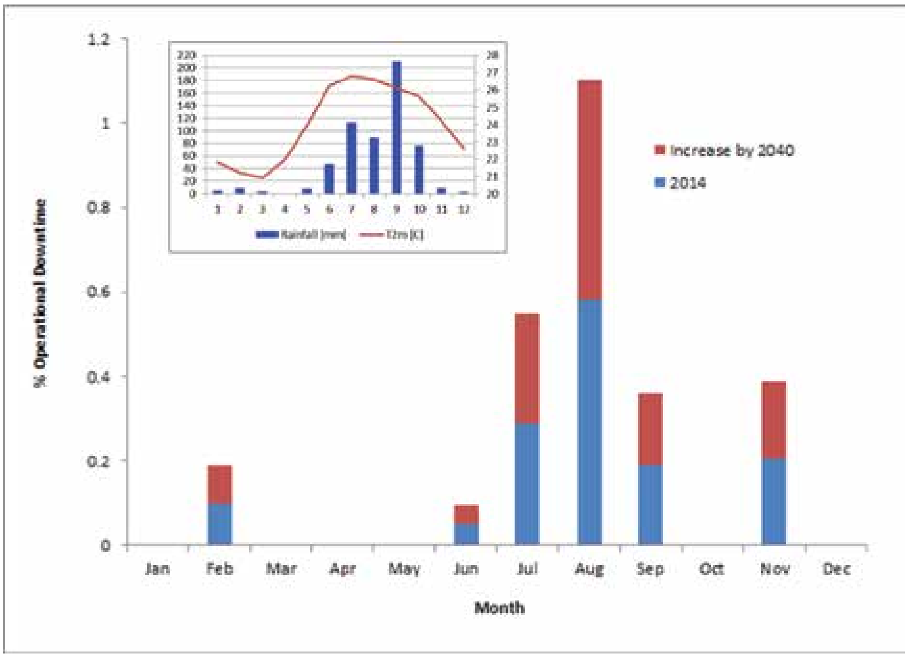
Risk/ Opportunity	Thresholds and Sensitivities	Current and future climate/ oceanographic variability and change	Risk Description
Increased intensity of rainfall events causes increased stoppages to handling equipment	• Crane and forklift handling of containers can be stopped during intense rainfall due to visibility issues. This is a qualitative judgement by the crane / forklift operator.	• Significant increasing historical trend for Manzanillo ERA-I data (June) for higher rainfall threshold exceedances e.g. 10 mm and 20 mm • Future changes in Mexican extreme rainfall indicate that the amount of rainfall in a 24 hour period with an expected return period of 20 years increases[98] • Increase in average duration of storm maximum intensity and precipitation rate within 200 km.	• Intense rainfall events causing stoppages to the use of goods handling equipment is an issue for the port. • Example increased losses of 7,500 MXN EBITDA per month by 2020, and 30,000 MXN EBITDA per month by 2040 for one container terminal, due to increase in heavy rainfall. • Container handling terminals are most at risk e.g. SSA, CONTECON, OCUPA
Decreased number of rain days reduces delays from rain to vessels loading\ unloading	• Mineral and grain handling operations are suspended during any rainfall as the ship cannot be opened. • High moisture content of mineral product can affect materials flow within handling belts. • Mineral bulk is also tested for moisture content prior to loading onto the vessel; if the threshold is exceeded then loading is stopped. • Wetting of cement product during quay side handling can result in clinker which cannot be loaded and requires recycling. Vessels will close hatches and stop cement loading operations under any rain conditions.	• Dry months January to March. • Rainfall increases from June, peaks in September. • Observed data shows significant dry season decrease of 2.7 mm per year • Analysis on historical changes in rainfall from daily ERA-I data shows modest decreasing trends in low threshold exceedances e.g. 1 to 4 mm	• Drier conditions will represent a positive impact for the port. • Delays when vessels cannot open their hatches due to any rain will decrease. • An example terminal experiences 5% average delays per year at a loss of > 1million MXN EBITDA. • This terminal faces an estimated reduction of EBIDTA losses of 250,000 MXN per year by the 2040s • Affects terminals handling mineral and agricultural products, multipurpose terminals, namely CEMEX, APASCO, FRIMAN, LA JUNTA, GRANELERA, USG, MARFRIGO, FRIMAN, HAZESA, TIMSA, OCUPA, MULTIMODAL

Sea level rise combined with storm surge causes flooding of the port resulting in goods handling stoppages	• All quay heights are +3.1 m above mean sea level apart from MARFRIGO (+2.1 m). • Associated courtyards and adjacent areas are +4.1 m, except CONTECON (3.4 to 3.7 m). • Minimum safe quay height for goods handling is +2 m for Panamax vessels, +2.5 m for post Panamax. • Thresholds exist between mean sea level and height of goods handling equipment e.g. for USG this is 14 m	• Observed SLR scenario = 0.17 m by 2065[59] • Under the RCP 2.6 scenario, SLR by 2065 = 0.16 m • Under the RCP 8.5 scenario, SLR by 2065 = 0.23 m • Combined tidal\seasonal \ decadal maximum contribution = +0.70 m • Current 1 in 250 year return period storm surge height = +2.52 m • Current 1 in 500 year return period storm surge height = +2.85 m	• Maximum sea level rise scenarios combined with storm surge presents a limited risk of seawater flooding to port within the next 50 years. • • MARFRIGO at increased risk due to lower quay height. Significant flooding (depths in excess of 30 cm) could occur by 2040 under the RCP 2.6 SLR scenario combined with a 1 in 250 year surge event.
Increased maximum intensity and duration of maximum intensity of tropical cyclones causes increased handling downtime	• Container terminal cranes have automatic cut-off thresholds for high wind speeds e.g. CONTECON\SSA auto cut-off at 25 m/s • Grain and mineral handling equipment\conveyors also have defined wind speed thresholds. High winds can also affect operations through increased dust generation e.g. thresholds for USG are 22 to 28 m/s • PEMEX terminal operational thresholds for offloading are wind speed of 17 m/s and wave height of 1.8 m. • Harbor master is likely to close the port before wind speeds approach these thresholds. Threshold for closure by Harbor master is 18 m/s (35 knots).	• Tropical storms known to cause handling downtime at PEMEX. • Analysis shows that the proximity of the storm to Manzanillo is the key factor. Only those storms passing within a few tens of kilometers lead to disruption. • Future increases are indicated in intensity and mean lifetime of storm maximum intensity.	• Considered a risk to goods handling primarily due to the severity of impact when the port is closed. • Not a frequently reported cause of stoppages for individual terminals inside the harbor. • Cost of port closure to API Manzanillo is 0.12% of annual income per 24 hours. • 50 % increase in mean lifetime of maximum storm intensity could result in >2,500,000 MXN per year increased lost revenue to API Manzanillo. • Affects all terminals during port closure. • PEMEX is at increased operational risk due to its exposure to the open sea

Source: Report authors

FIGURE 3.6

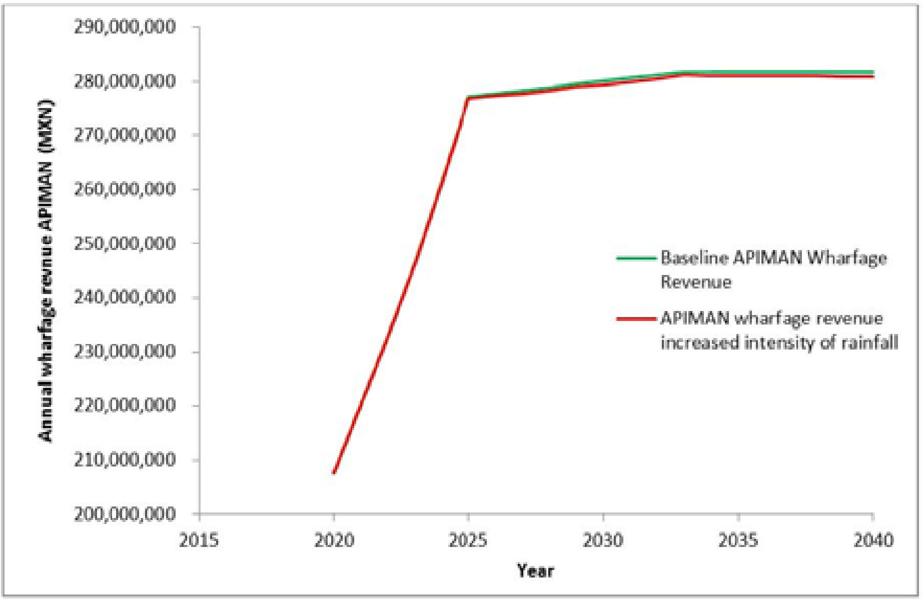
Observed (2014) and estimated future increases in monthly operational handling downtime due to intense rain for an example container terminal. (Inset: annual mean rainfall and temperature at Manzanillo 1979 to 2012)



Source: Report authors

FIGURE 3.7

API Manzanillo lost wharfage revenue due to increased intense rainfall events, based on linear trend from 2015 to predicted 2040 downtime (undiscounted). Data are representative of an overall trend, not a forecast for each year



Source: Report authors

The estimated increases in operational downtime for containerized cargo handling due to intense rainfall amounts to an annual increase from 0.11% at present to 0.22% by 2040. The effect of this increase on the terminals will be minor, assuming that delays correlate directly with loss of revenue. For API Manzanillo the effect is insignificant, as the variable fees they receive based on container cargo throughput are only a small fraction of the revenue the terminals receive. The financial loss to API Manzanillo is calculated to be only 0.045% of their income per annum in 2040 (Figure 3.7).

Terminals

The estimated future reduction in days with rain and the increase in intense rainfall can be applied to the current financial impact of disruptions to goods handling experienced by the terminals.

For the decrease in days with rain, data has been provided by API Manzanillo's statistics department on the monthly delays recorded for vessels offloading due to rain over the last 5 years.

The terminals most notably affected include APASCO, CEMEX, FRIMAN, GRANELERA, MULTIMODAL, OCUPA, TIMSA and USG. (Data were also provided by LA JUNTA, but this showed results exceeding the maximum possible hours in a year. Their data have therefore not been considered further.)

The total annual delays due to rain days for all significantly affected terminals between 2010 and 2014 are provided in Table 3 6. The results show a notable increase in reported delays between 2010 and 2014.

A summary of the average delays - due to days with rain for all significantly affected terminals - is presented in Figure 3.8. Average annual operational stoppage across the terminals was 2.8%.

Where financial data have been provided by terminals, the estimated average beneficial financial impacts associated with a future decrease in the total number of rainy days (>1mm) are given in Table 3 7. Average loss of EBITDA for the terminals is provided, together with a minimum and maximum range of the data to show the variation in risk for individual terminals.

To provide a representative indication of impact, it is assumed that the percentage of delays equals the same percentage loss of EBITDA.

Adaptation

Light rain suspending loading\unloading

Options for reducing this risk through adaptation are limited. For example GRANELERA and LA JUNTA share a vessel-to-silo conveyor that is open, as this makes the

TABLE 3.6

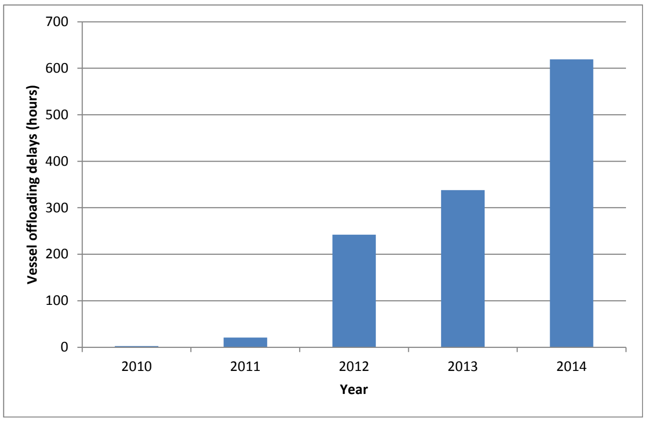
Total annual hours of vessel offloading delays recorded due to days with rain for significantly affected terminals.

YEAR	Total delay (Hours)
2010	20
2011	166
2012	1938
2013	2704
2014	4953

Source: Report authors

FIGURE 3.8

Influence of ENSO on mean number of tropical cyclone occurring per month



Source: Romero-Vadillo et al. 2007 [66]

TABLE 3.7

Estimated reduction in total annual losses due to vessel offloading delays on rainy days in 2020 and 2040 compared to the present day

(MXN)			
Annual mean losses due to delays (EBIDTA)	**Average**	**Minimum**	**Maximum**
Present-day	2,712,436	64,877	9,632,655
2020	2,549,690	60,984	9,054,696
2040	2,088,576	49,955	7,417,145

Source: Report authors

conveyor more mobile. Closed conveyors are available on the market but they are still exposed to the elements at some point in transfer. In addition, completely sealed product transfer or covered handling areas are not applicable or cost effective to all terminals subject to this kind of disruption.

The decision to halt loading\unloading is also often taken by the vessel captain. For example CEMEX maintain second maneuver operations longer than other terminals during rain events, due to their having an extensive covered handling area. However the vessel hatches cannot be opened during any rain so operations still stop.

As there is already an observed trend towards drier conditions, this can be marketed as a business opportunity that can result in less disruption to handling of mineral and agricultural bulk.

Intense rain stopping handling operations

Increased covered handling areas can provide a benefit in some sensitive handling processes at the port, for example wetting of concrete, and consolidation of containers and loading onto trucks e.g. MULTIMODAL.

However limited options exist for modifications to container handling by cranes. If visibility is reduced beyond a certain point then operations have to stop. Nevertheless, procedures for handling materials under adverse climatic conditions can be reviewed e.g. consolidation and loading, to investigate where operations can be maintained longer.

3.2.3. Seawater flooding

Risk analysis

Seawater or ‘coastal flooding’ is where normally dry, low-lying land is flooded by sea water. It is caused by a number of elements that can combine to increased effect, such as mean SLR, storm surge, high waves, high tides and tsunamis. The extent of a coastal flood is determined by a number of factors, such as the existence of natural protection such as mangroves and the topography of the land exposed to flooding.

For this study, a significant seawater flood is considered to be an exceedance of port infrastructure height e.g. quay heights exceeded by 30 cm for any time period. If seawater flooding of the port occurs, this has the potential to halt goods handling, for example crane and forklift operations.

Climate change will enhance coastal flood risks at Manzanillo because of two factors:

1. Long term mean sea level rise; and
2. Higher storm surge levels expected to occur during more intense tropical storms.

SUMMARY OF KEY POINTS

- If seawater flooding of the port occurs, this has the potential to halt goods handling, for example crane and forklift operations.
- Low (3.3 mm/yr), moderate (IPCC RCP 2.6) and worst case (RCP 8.5) mean sea level rise scenarios combined with maximum tidal, seasonal and ENSO ranges showed no risk to the port by 2100. Extreme SLR values of 2.4 m by 2100 as proposed by some scientists[99] would result in regular flooding of the MARFRIGO terminal, but are considered very unlikely by most scientists at present.
- Risks do exist when mean SLR is combined with storm surge. Significant flooding risk (flood depths in excess of 30cm) for MARFRIGO (+2.1 m AMSL) could occur by 2040 under the RCP 2.6 SLR scenario combined with a 1 in 250 year surge event.
- Seawater flooding of the other terminal quays (+3.1 m AMSL) is potentially an issue by the 2070s when the RCP 2.6 SLR scenario is combined with a 1 in 250 year storm surge. General inundation of all port patio and upland areas would occur only for the 'worst case' SLR scenario combined with a 1 in 500 year storm surge event, with an average inundation depth of 0.11 m by 2100.
- Although the MARFRIGO quay could experience seawater flooding by 2040 under the RCP 2.6 SLR with a 1 in 250 year event, MARFRIGO fees represent a relatively small part of API Manzanillo's total revenue from terminals.
- Since the likelihood of flooding of all terminal quays (with the exception of MARFRIGO) is virtually non-existent until 2070, at which point the likelihood of a flooding event is still limited, the expected loss of revenue for API Manzanillo is near zero.
- The losses and damages associated with extreme coastal flood events would be covered by insurance. However, there are physical and operational adaptation options to be considered. Physical options include raising the quay heights (which proves to be very costly), implementing flood management strategies, upgrading sensitive infrastructure and equipment (e.g. insulating electrical equipment and using water resistant materials), as well as maintaining natural coastal flood protection provided by mangroves. Operational measures include improved flood early warning systems and emergency response plans.

Increases in average wave heights due to wind are not considered a major factor in determining coastal flood risk at Manzanillo. Analysis of the ERA-I data shows no historical increasing trend in the frequency of wind speeds greater than 3 m/s in any month so increases in average wave heights are likely to be minor with respect to items 1 and 2 above.

Mean Sea Level Rise

The following three mean SLR scenarios have been selected for analysis:

1. 'Observed' - assuming that sea level rise continues at the current estimated rate of 3.3mm/year;
2. 'Moderate' - using a rate of sea level rise based on IPCC scenario RCP2.6; and
3. 'Worst case' - rate of sea level rise based on IPCC Scenario RCP 8.5

More extreme SLR projections are discussed below; however the selected scenarios are considered a reasonable range to inform the need for adaptation with respect to the medium-term future e.g. 2050s. To assess maximum possible sea level, mean SLR is combined with the +0.7 m of components that are unaffected by climate change, namely astronomical tide (+0.3 m), seasonal water level fluctuations (+0.1 m, and multi-year fluctuations (El Nno effect +0.3 m).

Table 3.8 shows the extrapolation of these data out to 2100, for the observed SLR scenario, and the 'moderate' and 'worst case' scenarios from the IPCC estimates for RCP 2.6 and RCP 8.5 (Section 2.3.2, Figure 2.27).

Figure 3.9 shows these scenarios plotted as a non-linear regression for RCP 2.6 (y = 2E-05x2 - 0.0853x + 84.275) and RCP 8.5 (y = 7E-05x2 - 0.3x + 301.64). The 'observed rate' projection is linear.

A digital elevation model was not available for the study, but to provide an estimation of future seawater flood risk, using information provided by API Manzanillo and other studies, the following is assumed:

TABLE 3.8

Low, moderate and worse case SLR scenarios (meters) at Manzanillo

Year	Observed	Moderate (RCP 2.6)	Worst case (RCP 8.5)
2015	0.7	0.7	0.7
2040	0.78	0.79	0.82
2065	0.87	0.86	0.93
2085	0.93	0.99	1.19
2100	0.98	1.06	1.36

Source: Report authors

TABLE 3.9

Mean SLR, tidal variation and flood risk by 2100 at Manzanillo

SLR Component	Scenario 1 Low	Scenario 2 Moderate	Scenario 3 Worst case
Mean SLR by 2100 (m)	0.28	0.36	0.66
High tide relative to MSL (m)	0.30	0.30	0.30
Seasonal fluctuation (m)	0.10	0.10	0.10
ENSO (m)	0.30	0.30	0.30
Total by 2100 (m)	0.98	1.06	1.36
Flooding of MARFRIGO (+2.1m MSL)	None	None	None
Flooding of quays (+3.1m MSL)	None	None	None
Flooding of patios\upland area (+4.1 MSL)	None	None	None

Source: Report authors

- The MARFRIGO quay height is +2.1 m above present-day mean sea level
- All other quay heights are +3.1 m above present-day mean sea level; and
- Rear patio and handling areas are + 4.1 m above present-day mean sea level[51]

Specific elevation data were available for the CONTECON terminal patio handling areas (3.4 to 3.7 m).

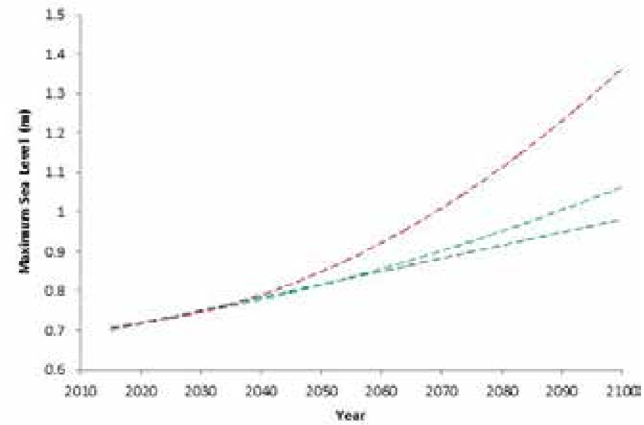
The water level components for the low, moderate and worst case scenarios are summarized in Table 3.9 including the components that are unaffected by climate change.

The data show that for the three SLR scenarios, mean SLR plus tidal, seasonal and ENSO fluctuations do not present a risk of flooding to the port out to 2100.

More extreme potential SLR scenarios from other studies, of +1.79 m[100] and +2.4 m[101] by 2100 combined with tidal, seasonal and ENSO would provide maximum sea levels of +2.16 m and +2.77 m above MSL by 2100. This would result in regular flooding of the MARFRIGO terminal by 2100, but nowhere else at the port. These more extreme scenarios do not present a risk of flooding due to mean SLR alone to any terminal by 2050.

FIGURE 3.9

Low, moderate and worst case maximum sea level scenarios (MSLR plus tidal, seasonal and ENSO fluctuations) up to 2100



Source: Report authors

Storm surge

To investigate the influence of increasing storm surge heights combined with SLR, three coastal flood scenarios have been selected up to 2100:

- Case 1 – observed rate of sea level rise + 100-year Return Period (RP) storm surge
- Case 2 – RCP2.6 sea level rise + 1 in 250-year Return Period storm surge; and
- Case 3 – RCP8.5 sea level rise + 1 in 500-year Return Period storm surge

As discussed in Section 2.3.2, chapter "Storm surge", based on the potential for storm intensity to increase it can be assumed that the likelihood of a larger storm surge event occurring increases over time. For example, the 1 in 250 storm surge height is more likely to occur in 2100 than in 2015; with the chance of the 1 in 250 event steadily increasing as we move towards 2100.

It is important to capture this steady increase in likely storm surge height due to climate change. Table 3.10 shows the approach taken to reflect this. Table 3.10 shows the 1 in 100 yr event (+1.47 m) as the baseline expected scenario for 2015. This value of +1.47 m therefore steadily increases to the more expected 1 in 250 year event in 2100 (+2.52 m). This steady increase is also shown for the 1 in 500 year event up to +2.85m.

These values were then combined with the mean SLR and tidal, seasonal and ENSO components (Table 3.9) to show maximum potential sea level over time (Table 3.10 and Table 3.11).

It is assumed that flood levels within the enclosed harbor will be the same as those occurring along open coast (apart from local wave setup effects). There is free hydraulic connection between the ocean and the interior harbor, and whatever tide and storm surge level occurs at the entrance will also occur within the harbor. The harbor prevents the penetration of short period wind waves and swells, but not long period waves such as tides, surges, and tsunamis.

Actual flood levels within the harbor may be somewhat different (either higher or lower) than the coastal water levels, but detailed hydrodynamic modeling studies beyond the scope of the present study would be needed in order to estimate these effects accurately. From a practical standpoint the assumption of water levels being the same within the harbor and outside it seems reasonable and is probably conservative.

The results show that minor flooding of the +2.1 m MARFRIGO quay could occur at present with a 1 in 100 storm surge event (1.47 m) combined with maximum tidal plus seasonal and El Nino sea levels (+0.7 m). A significant flooding risk for MARFRIGO e.g. > 30 cm

TABLE 3.10

Gradual increase in the likelihood of storm surge height over time (2015 = 100 yr event likelihood +1.47 m, 2100 = 250 yr and 500 yr events +2.52 and +2.85 m).

Year	Increasing likelihood of 250 yr RP scenario (m)	Increasing likelihood of 500 yr RP scenario (m)
2015	1.47	1.47
2040	1.73	1.73
2065	1.94	1.95
2085	2.32	2.50
2100	2.52	2.85
y =	6E-05x2 - 0.2513x + 246.08	0.0001x2 - 0.5991x + 600.22

Source: Report authors

TABLE 3.11

Maximum potential sea level scenarios and associated flooding for quay and patio areas

Year	Observed + 1 in 100 RP	RCP 2.6 + 1 in 250 yr RP increase	RCP 8.5 + 1 in 500 yr RP in-crease
2015	2.17	2.17	2.17
2040	2.25	2.52	2.54
2065	2.34	2.80	2.88
2085	2.40	3.31	3.69
2100	2.45	3.59	4.21
Key	Flooding MARFRIGO >30 cm	Flooding all quay heights	Flooding patio\upland areas

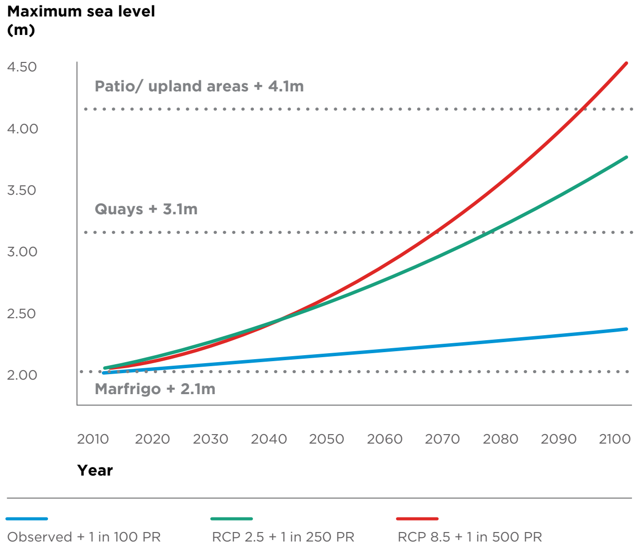
Source: Report authors

could occur by 2040 under the RCP 2.6 SLR scenario with a 1 in 250 year event. Seawater flooding through storm surge of the remaining terminal quays (+3.1 m) is potentially an issue by the 2070s, under the RCP 2.6 SLR scenario with a 1 in 250 year event. General inundation of all port patio and upland areas (+4.1 m) would occur only for the 'worst case' scenario of mean SLR IPCC RCP 8.5 to 2100 combined with a 1 in 500 year return period storm surge/ Even in this case the extent of flooding would be relatively minor (average inundation level of 0.11 m by 2100).

These results show that seawater flooding is not an immediate significant risk to the port, but it is an issue for MARFRIGO by 2040, with respect to extreme storm surge events combined with mean SLR and tidal variation (Figure 3.10). Figure 3.11 and Figure 3.12 show a graphical representation of the potential areas of the port at risk in different future time periods overlaid with the three storm surge flooding scenarios. Assumptions have been made as to the elevation heights (m) of the various areas of the port. These figures are not technically accurate and are representative only.

FIGURE 3.10

Maximum potential sea level to 2100 (mean SLR + tidal\seasonal\El Nino + storm surge) for low, moderate and worst-case SLR scenarios combined with various storm surge return periods



Source: Report authors

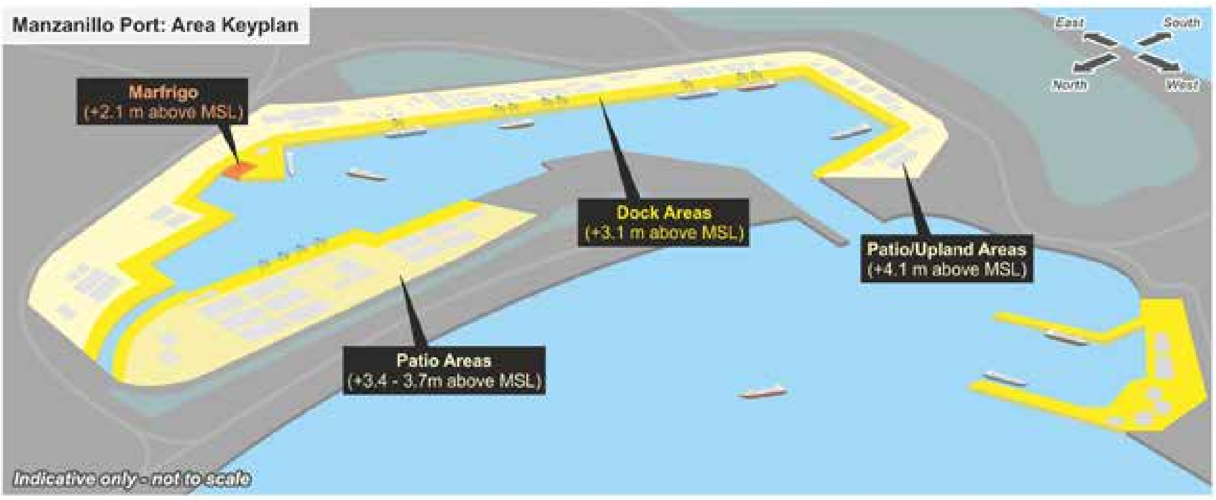
Financial analysis

A seawater flooding incident would incur the same cost to API Manzanillo as a full port closure. Depending on the severity of the flooding, the port could be closed from 1 to 7 days to clean and repair the quays. However, since the risk of flooding to all terminal quays (with the exception of MARFRIGO) is virtually non-existent until about 2075, at which point the likelihood of a flooding event is still very small, the expected cost to API Manzanillo is near zero.

Although the MARFRIGO quay could experience seawater flooding by 2040 under the RCP2.6 SLR scenario with a 1 in 250 year event, MARFRIGO fees to API Manzanillo are a relatively small part of API Manzanillo's total revenue from the terminals.

FIGURE 3.11

Elevation heights of key areas of the port



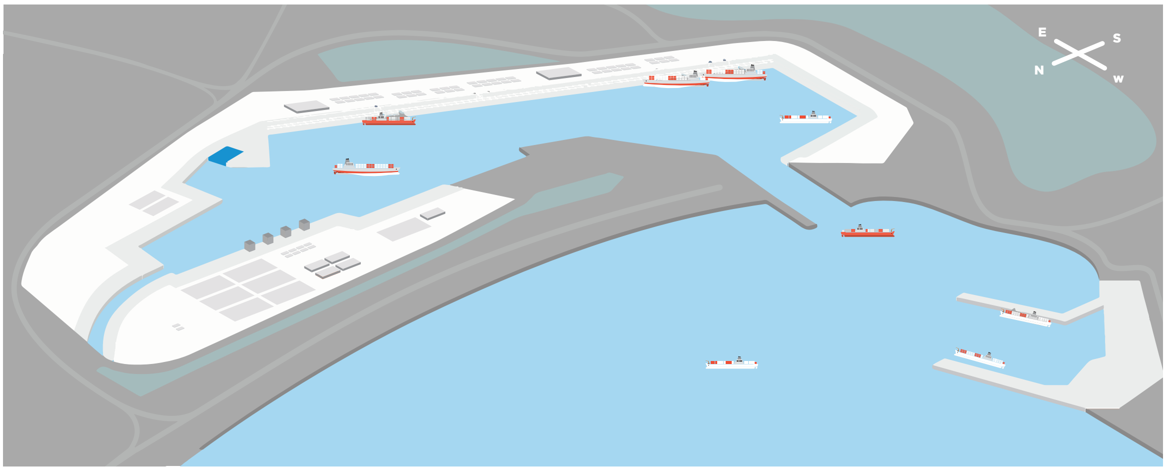
Source: Report authors

FIGURE 3.12

Storm surge flooding scenarios 2040s, 2070s and 2100. Areas experiencing flooding under each scenario are shaded in dark blue

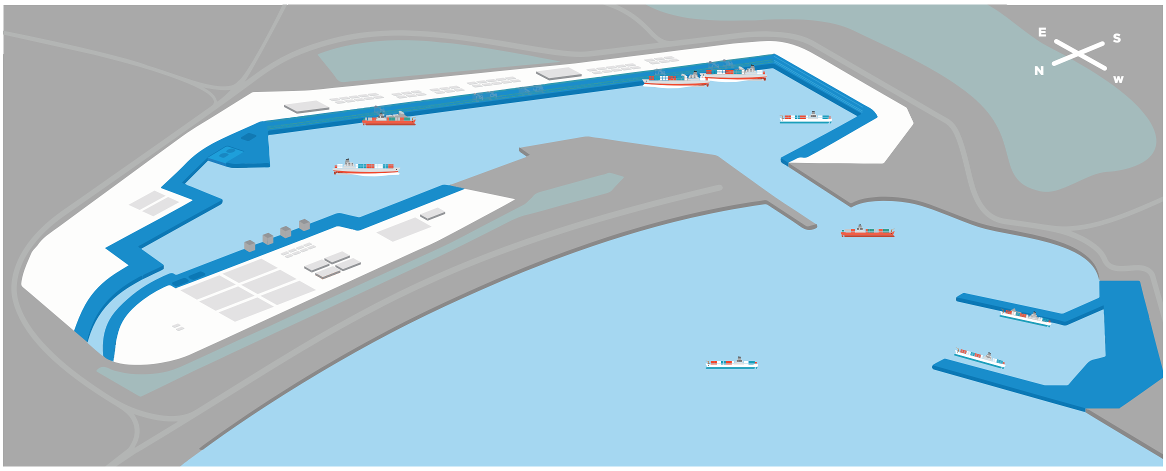
Scenario One - 2040s
Observed SLR (3.3 mm/yr) + 1 in 100 storm surge

Indicative only - not to scale



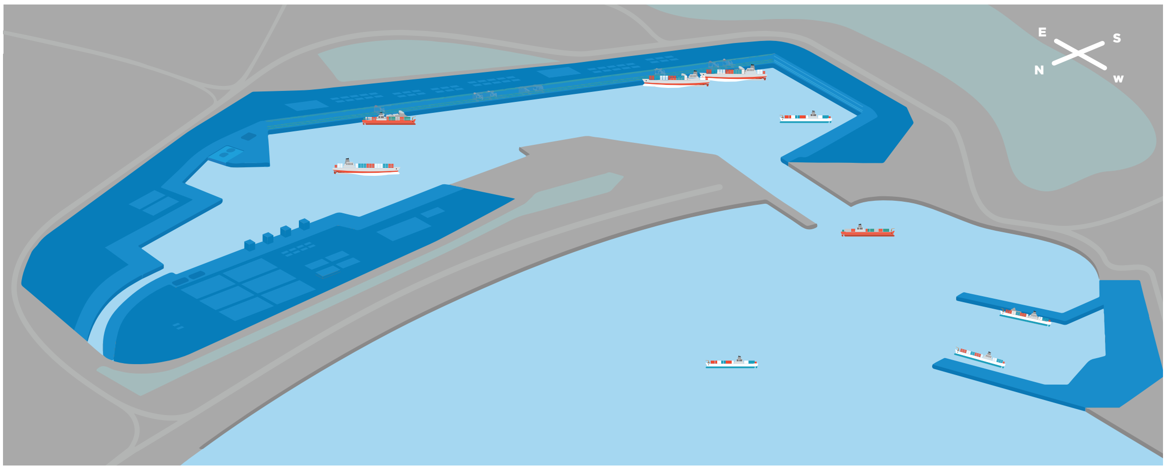
Scenario Two - 2070s
RCP 2.6 + 1 n 250 storm surge

Indicative only - not to scale



Scenario Three - 2100
RCP 8.5 + 1 in 500 storm surge

Indicative only - not to scale



Source: Report authors

Adaptation

Raise quay height

It has been shown that the only significant risk of seawater flooding is when mean SLR is combined with an extreme storm surge event. Under these circumstances, potential financial impacts are mitigated primarily by insurance. Significant investment in infrastructure upgrades is therefore not a primary adaptation option unless mean SLR increases greatly. However as additional extreme SLR scenarios are considered possible by scientists[102;103], example costs of increasing the heights of the quays are provided below (Table 3.12).

The costs are considered with an accuracy of -20/+40 %. They have been prepared based on typical costs for raising quay heights for similar port infrastructure[xxvii]. They have been tabulated for two conditions based on relevant flooding scenarios: a 0.6 m raise in quay heights to address the moderate SLR scenario for 2100 (RCP 2.6) combined with the 1 in 250 RP storm surge, and a 1.2 m raise to address the worst case SLR scenario for 2100 (RCP 8.5) combined with the 1 in 500 RP storm surge).

Two construction schemes were considered: constructing plinths under the containers; or applying a concrete/HD Poly overlay over the entire yard. The values for the plinths include allowances for Rubber Tyred Gantry Crane (RTGC) runways and truck lanes. Indirect costs including contingency and IVA tax are also included in both schemes as appropriate for a high-level Association for the Advancement of Cost Engineering (ACE) Class 4) cost estimate

The estimated costs for raising the terminal decks are significant. For Scheme 1, raising the decks by 60mm costs more than API Manzanillo's 2015 revenue, and for Scheme 2 the costs are around five times API Manzanillo's 2015 revenue. However, a detailed elevation model was not available for the port. Some of the terminal areas may be at higher elevations, reducing the overall costs.

In addition, smaller engineering designs and upgrades tailored to the sensitivities of each terminal can be considered. USG already have a plan in development to protect them from surface water flooding, for instance, informed by a specific topographic analysis of their low-lying areas. Development of such individual adaptation options should be coordinated between all the terminals and API Manzanillo to achieve greater cost-effectiveness.

Review flood response plans

Operationally, emergency response plans for flooding can be reviewed and areas for improvement identified in light of increased risk due to climate change. The plans should direct equipment and resources to lessen the duration and severity of flooding, and minimize operational downtime at the port.

TABLE 3.12

Cost estimates for raising the quay heights of all terminals.

Cost to Raise Deck Height for ALL TERMINALS	Scheme 1 - Concrete Plinths				Scheme 2 - Concrete/Poly Overlay			
	Raise 600mm		Raise 1200mm		Raise 600mm		Raise 1200mm	
Area (m^2)	Cost (2015 MXN, 000, 000's)	Cost (% of API Manzanillo estimated Revenue 2015)	Cost (2015 MXN, 000, 000's)	Cost (% of API Manzanillo estimated Revenue 2015)	Cost (2015 MXN, 000, 000's)	Cost (% of API Manzanillo estimated Revenue 2015)	Cost (2015 MXN, 000, 000's)	Cost (% of API Manzanillo estimated Revenue 2015)
1,470,337	1,729.5	138.3%	2,596.8	207.6%	6,054.0	484.1%	12,109.7	968.4%

Source: Report authors

Equipment upgrades

In addition to reducing the likelihood of seawater flooding, the severity of its impact can be reduced. This can be done by upgrading sensitive infrastructure, assets or equipment that are vulnerable to flooding e.g. by insulating critical electrical equipment and using water resistant materials.

Coastal flood protection

The main driver of seawater flood risk at the port has been shown to be extreme storm surges. Mangroves are proven to act as coastal protection from flooding due to storm waves, surges and tsunamis[104] and have been used as coastal protection measure elsewhere for a number of years[105]. Mangrove primarily protects against short-term events by absorbing a wave's energy and acting to reduce its height. However, mangroves also provide protection from mean sea level rise, by stabilizing morphological features such as sand bars that act as flood protection barriers.

The remaining mangrove habitat on the western perimeter of the port, and to the north and south in the Laguna de las Garzas and Laguna de la Cuyutlan can act as important coastal protection features from coastal flooding. API Manzanillo's ongoing mangrove management program should ensure the distribution, diversity and health of species, acknowledging the effect of species succession due to changing salinities. This is discussed further in Section 3.7.

3.2.4. Extreme wind speeds resulting in port closure

Risk Analysis

A number of goods handling operational thresholds were provided by terminals related to wind speed; for example container cranes have an automatic cutoff at 25 m/s. However it was reported by all terminals that the Harbor Master (HM) will close the port before these threshold wind speeds are reached. Therefore the issue of extreme wind speed in this study is discussed with respect to total port closure and not individual terminals' handling equipment.

As all goods handling operations for all terminals are halted when the decision is taken by the HM to close the port, the climatic factors driving this decision are critical issues. From discussion with the HM during the site visit, the port is closed 8 to 12 hours before a hurricane will cause exceedance of agreed safe operating thresholds, and typically for 3 to 4 days after. Recent incidents include closure in 2011 for Hurricane Jova (Figure 3.13) and in 2014 as a preventative measure for Hurricane Bud, which resulted in wind gusts of up to 25 m/s in Manzanillo.

This critical decision pathway is as follows:

- The HM is first notified of potentially severe storms by meteorological data supplied by SCT. Once identified as a potential threat, the storm starts to be tracked by the HM and API Manzanillo and the terminals are informed
- When the storm reaches 900 km distance from the port, first actions are taken dependent on its predicted direction, and using data on locally-observed wind and wave conditions e.g. from vessel pilots. If it is tracking toward the port, the HM holds regular

SUMMARY OF KEY POINTS

- Goods handling operational thresholds were provided by terminals related to wind speed, However it was reported by all terminals that the Harbor Master (HM) will close the port before these threshold wind speeds are reached.
- The HM has a defined protocol for closing the port. It is closed 8 to 12 hours before a hurricane will cause exceedance of agreed safe operating thresholds, and typically for 3 to 4 days after.
- The operational financial impact to API Manzanillo from a port closure is not significant (0.12% of annual income per 24 hours of closure), as the majority of costs are borne by the terminals.
- Goods handling adaptation to extreme wind speeds is not a priority as the port will close before thesholds are reached. Upgrades in equipment thresholds should focus on wind speeds that cause damage to equipment (see Section 3.3).
- If the current threshold for port closure (18 m/s) was adjusted by the harbour master then a review of operating thresholds for critical handling equipment would be required.

FIGURE 3.13

Track and Intensity of Hurricane Jova 2011

Source: Wunderground, 2015 [106]

meetings with API Manzanillo, which become more regular as the storm gets closer. Hurricane tracking data are taken from a number of sources e.g. NOAA, SEMAR and CONAGUA

- At 500 km distance a 'general alert' is sounded, the whole port begins to consolidate risk areas e.g. container stacks are reduced in height. If the storm continues towards the port and is likely to hit the area, vessels are sent outside the port to take refuge offshore. The stated wind speed threshold for closure is 18 m/s (35 knots). The decision to close is taken in the context of a review of all local conditions
- Storm strength along with track determines the decision to close. For example Hurricane Odile in 2014 was 150 km offshore at its nearest point, but was strong enough nevertheless to cause closure and damage to the port.

Financial analysis

The operational financial impact to API Manzanillo from a port closure is not significant, as the majority of costs are borne by the terminals. Variable fees due to cargo throughput will reduce, for example for containers, and API Manzanillo's other revenues from berthing, wharfage, and other services will be affected; however, these costs are not large with respect to API Manzanillo's overall EBITDA.

Financial analysis estimates the cost of port closure to API Manzanillo to be 0.12% of annual income per 24 hours of closure. An estimated 15% of vessel traffic (in terms of cargo value) through the port is comprised of vessels less than 500 UAB[xxviii] (gross tonnage units); therefore the cost of a partial closure, for vessels of this size only, would be 0.018% of API Manzanillo's annual income per day of closure.

It is important to note that these figures represent only lost revenue and do not account for additional maintenance or repair costs that API Manzanillo could incur due to tropical storms. These costs are covered in Section 3.4.

The following sensitivity analyses have been applied to show the potential loss of revenue for API Manzanillo due to storm related port closures (Table 3.13).

Adaptation

The port is closed and handling operations stop before operating thresholds for equipment are reached. Adaptation of goods handling for extreme wind speeds is therefore not a priority. Upgrades in equipment thresholds should focus on wind speeds that cause damage to equipment (see Section 3.3).

If the current threshold for port closure (18 m/s) was adjusted by the harbour master, then a review of operating thresholds for critical handling equipment would be required. Any required upgrade of equipment can be incorporated into the maintenance and renewal schedule.

3.2.5. Terminals

In discussions, the terminals reported a variety of goods handling risks, dependent on the handling equipment used and products moved. A summary is provided in Table 3.14. Additional detail on risks for each terminal is then provided in Sections 3.2.6 to 3.2.19.

3.2.6. OCUPA

The critical bottleneck for handling operations for OCUPA is slow entry and exit of trucks from the north port entrance (discussed in Section 3.1). Climate-related goods handling risks for OCUPA include downtime of crane operations caused by heavy rainfall, and vessels delays due to rain. Wind was not stated as a factor for handling as the HM will close the port before wind speeds reach those levels.

If observed trends continue, the port and OCUPA will experience a 23% increase in wet season daily intense rainfall events (>20 mm) by 2020 and a 90% increase by 2040.

TABLE 3.13

Sensitivity tests for lost revenue for API Manzanillo due to potential future changes in tropical storms causing partial and full port closures.

Lost Revenue for API Manzanillo Due to Port Closures as a Result of Tropical Storms	2015 (Expected Based on Historical Average)	25% decrease in frequency	50% decrease in frequency	25% increase in mean lifetime of maximum intensity	50% increase in mean lifetime of maximum intensity
Total Downtime (All vessels)	1.4 days / 0.4%	1.1 days / 0.3%	0.7 days / 0.2%	1.8 days / 0.5%	2.1 days / 0.6%
Total Downtime (Vessels <500 UAB)	13.4 days / 3.7%	10.0 days / 2.7%	6.7 days / 1.8%	16.7 days / 4.6%	20.1 days / 5.5%
Estimated annual lost revenue (MXN)	5,241,752	3,931,314	2,620,876	6,552,190	7,862,628

Source: Report authors

TABLE 3.14

Summary of goods handling climate risks for each terminal

Terminal	Climate risks
OCUPA	Heavy rainfall events halting handling operations due to a reduction in visibility for crane and forklift operators. Rainfall causes vessel loading\offloading delays due to rainfall due to potential wetting of product
CEMEX	Rainfall causes vessel loading\offloading delays due to rainfall due to potential wetting of product
FRIMAN	Forklift operations halted during heavy rainfall Rainfall caused vessel loading\offloading delays due to rainfall due to potential wetting of product
TIMSA	Container consolidation operations halted during heavy rainfall Rainfall causes vessel loading\offloading delays due to rainfall due to potential wetting of product
CONTECON	Heavy rainfall events halting handling operations due to a reduction in visibility for crane and forklift operators
PEMEX	Downtime in handling due to loss of berthing availability due to wind and waves
APASCO	Rainfall causes vessel loading\offloading delays due to rainfall due to potential wetting of product
MULTIMODAL	Heavy rainfall events halting handling operations due to a reduction in visibility for crane and forklift operators Rainfall causes vessel loading\offloading delays due to rainfall due to potential wetting of product
LA JUNTA	Rainfall causes vessel loading\offloading delays due to rainfall due to potential wetting of product
GRANELERA	Rainfall causes vessel loading\offloading delays due to rainfall due to potential wetting of product
SSA	Heavy rainfall events halting handling operations due to a reduction in visibility for crane and forklift operators
USG	Rainfall causes vessel loading\offloading delays due to rainfall due to potential wetting of product
MARFRIGO	Rainfall causes vessel loading\offloading delays due to rainfall due to potential wetting of product
HAZESA	Rainfall causes vessel loading\offloading delays due to rainfall due to potential wetting of product

Source: Report authors

3.2.7.
CEMEX

CEMEX is a specialist import cement handling terminal, handling bulk cement product and are therefore subject to climate-related goods handling risks from rainfall and/or humidity. (Cement is a hydroscopic product, sensitive to wet and humid conditions.) If wetting of the product occurs, compacted clinker can develop which then requires treatment and recycling before use. 100% can be recovered but at a financial cost to the terminal.

CEMEX have the largest amount of covered handling areas in the port, they can therefore maintain second maneuver operations longer than other terminals. However offloading from vessels is suspended during any rainfall as the ship cannot be opened. This decision is taken by the ship captain.

If observed trends continue, the port and CEMEX will experience a 6% reduction in wet season daily rainfall events (<1mm) by 2020 and a 23% decrease by 2040.

3.2.8.
FRIMAN

The critical bottleneck for handling operations for FRIMAN is slow entry and exit of trucks from the north port entrance. The key climate-related goods handling risks for FRIMAN are forklift operations being halted during intense rainfall events and delays to vessels offloading during rain.

If observed trends continue, the port and FRIMAN will experience a 23% increase in wet season daily intense rainfall events (>20 mm) by 2020 and a 90% increase by 2040.

3.2.9.
TIMSA

The key climate-related goods handling risk for TIMSA is rainfall. For example even under light rain offloading of general cargo is halted, and in heavy rain containers cannot be opened for consolidation. From extrapolation of observed June daily rainfall data, TIMSA can expect an approximate 6% reduction in delays to offloading by 2020 and a 23% decrease by 2040.

3.2.10.
CONTECON

The main climate-related goods handling risk for CONTECON is from intense rainfall events halting handling operations due to a reduction in visibility for crane and forklift operators. If observed trends continue, the port and CONTECON will experience a 23% increase in wet season daily intense rainfall events (>20 mm) by 2020 and a 90% increase by 2040.

3.2.11.
PEMEX

The PEMEX terminal outside the main harbor entrance is subject to operational downtime due to wind and wave activity. This is considered a risk primarily to berthing availability and is discussed in Section 3.5.

3.2.12.
APASCO

APASCO is a specialist cement handling terminal, handling bulk cement product and are therefore subject to climate-related goods handling risks from rainfall and/or humidity. (Cement is a hydroscopic product, sensitive to wet and humid conditions.) If wetting of the product occurs, compacted clinker can develop which then requires treatment and recycling before use. 100% can be recovered but at a financial cost to the terminal.

The key climate-related goods handling risk for APASCO is rainfall and/or humidity. APASCO are an export-only terminal, and vessel captains will halt loading operations in any rain conditions. From extrapolation of observed June daily rainfall data, APASCO can expect an approximate 6% reduction in delays from loading by 2020 and a 23% decrease by 2040.

3.2.13.
MULTIMODAL

The key climate-related goods handling risk for MULTIMODAL is rainfall. They cannot load merchandise onto uncovered trucks when it rains as this risks damage to the product. Also crane and forklift operations are halted during heavy rain due to a reduction in visibility for the operators. Stopping operations due to rain is a qualitative decision based on operational safety and visibility.

During intense rainfall events, there is standing water in areas below the raised warehouse loading platforms. This requires pumping out and can stop operations for between 2 to 4 hours. This reportedly occurs 2 to 3 times a year.

If observed trends continue, the port and MULTIMODAL will experience a 23% increase in wet season daily intense rainfall events (>20 mm) by 2020 and a 90% increase by 2040.

3.2.14. LA JUNTA

The critical bottleneck for handling operations for LA JUNTA was identified as the supply and efficiency of rail transport. The key climate-related goods handling risk was reported as rainfall. Offloading of grain from vessels to terminal operations is suspended during any rainfall as the ship cannot be opened. Loading of grain from the terminals to trains is not affected by rain as the conveyors are covered.

From extrapolation of observed June daily rainfall data, LA JUNTA can expect an approximate 6% reduction in delays from loading by 2020 and a 23% decrease by 2040.

3.2.15. GRANELERA

The critical bottleneck for handling operations for GRANELERA was identified as the supply and efficiency of rail transport. Some 14,000 tons per day can be discharged from the vessels, but only 5,000 tons per day can be transferred out of the silos by train. This can result in vessels being delayed outside the port waiting to offload.

Offloading of grain from vessel to terminal is suspended during any rainfall as the vessel-to-silo conveyor is uncovered. Disruptions due to rain can last from 15 minutes to 1 day. The decision to halt the unloading is taken by the vessel captain. Rain can also halt loading from the silos onto the trains as the 300 ton carriages lose traction and cannot move.

From extrapolation of observed June daily rainfall data, GRANELERA can expect an approximate 6% reduction in delays from loading by 2020 and a 23% decrease by 2040.

3.2.16. SSA

The critical bottleneck for handling operations for SSA was identified as entry and exit of trucks from the north port entrance.

A climate-related handling risk for the SSA terminal is downtime to crane operations. This is primarily caused by heavy rainfall halting operations due to a reduction in visibility by the crane operators. Stopping crane operations due to rain is a qualitative decision based on operational safety. If observed trends continue, the port and SSA will experience a 23% increase in wet season daily intense rainfall events (>20 mm) by 2020 and a 90% increase by 2040.

3.2.17. USG

USG is the only specialist bulk mineral handling terminal at the port. It is capable of receiving vessels of up to 100,000 tons of mineral bulk, with a reported maximum operating capacity of 2,000 tons per hour per shipping operation[107]. In discussion, USG reported achieving approximately 850 tons per hour.

Rainfall can affect handling operations at USG in two ways:

- High moisture content of mineral product can also affect materials flow within the handling belts, producing blockages in chutes between conveyors; and
- Mineral handling operations are suspended during any rainfall as the ship cannot be opened

There are multiple sources of moisture entering mineral bulk during the supply chain, starting with the level of the water table at the source of the mining operation. Due to the complexity in understanding how changing climate conditions affect the whole supply chain, it has not been possible to quantify these climate risks in this study.

Due to their location close to the main port entrance and the main drainage discharge entering the port, USG are also subject to surface water flooding inside the terminal during heavy rains, which can affect handling operations. They have already started to take action to protect against future flooding. They reported undertaking a topographic risk analysis and are already developing a plan to protect low lying areas. It is intended that this adaptation study can inform and guide any climate risk management actions being taken by individual terminals such as USG's flood management plans. Furthermore, a coordinated approach by the terminals, supported by API Manzanillo will achieve greater cost-effectiveness.

USG also stated there is a minimum safe height of 14 m between sea level and their handling equipment. The analysis presented on seawater flooding (Section 2.2) shows that the maximum projected rise in mean sea level by 2050 (RCP 8.5 scenario) used in this study is +0.16 m. This change will not result in exceedance of the 14 m minimum safe handling height for USG.

3.2.18. MARFRIGO

The key handling risk for MARFRIGO is rainfall. They cannot take fish out of boats even in light rain as it can affect the product. From extrapolation of observed June daily rainfall data, they can expect an approximate 6% reduction in delays from offloading by 2020 and a 23% decrease by 2040.

3.2.19. HAZESA

The HAZESA terminal is yet to open so could not provide historical data on handling issues related to weather. They did report they will not operate during any rain when handling mineral bulk. This is due to the potential wetting of the product when loading onto vessels. Too much moisture in the product results in increased movement of the product in the vessel during transit.

There are multiple sources of moisture entering mineral bulk during the supply chain, starting with the level of the water table at the source of the mining operation. Due to the complexity in understanding how changing climate conditions affect the whole supply chain, it has not been possible to quantify these climate risks in this study. When operational HAZESA can expect an approximate 6% reduction in delays from loading by 2020 and a 23% decrease by 2040 compared to 2015.

3.3. Damage to port equipment, buildings and infrastructure

3.3.1.
Summary of Climate Risks

A summary of key climate risks for port equipment is provided in Table 3.15. A breakdown of key risks to individual terminals is then given where appropriate. Where an individual terminal is not discussed, no significant specific risk was identified.

3.3.2.
Surface water flooding resulting in damage to equipment and infrastructure

As discussed in Section 3.6.1, chapter "Surface flooding", surface water flooding of the port's main entrance and internal access\egress road occurs almost annually. The

SUMMARY OF KEY POINTS

- Damage to port equipment and infrastructure at Manzanillo can mainly occur through surface water flooding e.g. internal roads. This is considered in the maintenance section.
- Due to their height (50 m approx.), CONTECON, SSA and OCUPA container handling cranes have the potential to be subject to damage from extreme wind speeds. CONTECON provided specific design thresholds for their cranes of 56 m/s.
- Damage due to wind speeds beyond these limits can range from local yielding of bracing members, to catastrophic loss of structural integrity and collapse of the crane structure.
- Fewer storms are expected at Manzanillo in future, but the potential of experiencing a Category 4 (63 to 78 m/s) or Category 5 (>78 m/s) tropical cyclone is likely to increase.
- Cost of replacing bracing members and repairing connections is relatively modest, but a collapse of the crane would likely render it beyond economic repair, resulting in significant financial cost for replacement.
- Adaptation options include improvements to the cranes' tie-down systems, estimated as 750,000 MXN to 2,250,000 MXN depending on the design and age of the crane and the adequacy of its existing tie-down system. Improvements to the cranes' braking systems and wind speed prediction systems.
- Seawater flooding also has the potential to damage buildings, equipment and infrastructure through water damage and increased corrosion.
- The risk is low however and not considered a priority. Possible when mean SLR is combined with tidal, seasonal and ENSO maximums and storm surge. Current risks are highest for the MARFRIGO terminal with a quay height of +2.1 m above MSL (risk of flooding by 2040s with 1 in 250 year storm surge).
- Adaptation options for seawater flooding are as discussed in Section 3.2.3, namely physical upgrading of quay heights and handling areas, maintenance of soft coastal defenses provided by mangrove habitat, and retrofitting critical equipment / infrastructure that is vulnerable to increased flood risk e.g. electrical equipment.
- Additional informational and operational measures include: updating design standards for equipment and infrastructure, taking into account design life and potential impact of future climate change; and
- Account for sea level rise when doing inventories for replacement and refurbishment of equipment and infrastructure.

TABLE 3.15

25 Port equipment risks

Risk	Thresholds and Sensitivities	Current and future climate/ oceanographic variability and change	Risk Description
Increased frequency of intense rainfall events causes damage to infrastructure and equipment through surface water flooding	• Flooding and residual sedimentation of the main access road into and out of the port occurs annually, with waters reaching up to 30 cm depth. • Water damage to surrounding buildings has occurred during these events e.g. customs area • Customs automatic scanning equipment required replacement due to water damage in 2011.	• Currently, annual flooding occurs during the rainy season from overflow of the Arroyo Jalipa discharge route directly into the port. • Changes in Mexican extreme rainfall shows, the amount of rainfall in a 24 hour period with a return period of 20 years increases[58] • Increasing trend has been observed (ERA-I data) (June) for higher threshold exceedances e.g. 20 mm	• Heavy rains causing surcharge of the drainage system into the port is a risk to port equipment and infrastructure, such as the internal access road and customs area. • For example flooding events occurred in 2011, 2012 and 2014. • Costs primarily borne by API Manzanillo under its maintenance budget. • Terminals closest to Drain 3 discharge are at increased risk e.g. USG
Extreme storm event wind speeds damaging handling equipment	• Container cranes have a maximum design threshold for wind speed before damage is expected. • For example the CONTECON terminal cranes have a maximum wind speed of 56 m/s. • When wind speeds reach 22 m/s the cranes are tied down with anchor pins to improve stability. • No damage thresholds were provided for other handling equipment such as conveyor bands. Wind speeds of 42 to 56 m/s are likely to result in damage.	• Manzanillo experiences hurricane events and extreme wind speeds e.g. Hurricane Jova 2011. • Future increases in peak wind speeds mean lifetime of maximum storm intensity are likely.	• Increased extreme wind speed is likely to result in increased damage to port equipment and infrastructure. • Potential for category 4 (63 to 78 m/s) and Category 5 (>78 m/s) tropical cyclones to become more frequent. • The potential for this effect is mitigated by warnings from the Harbor Master, allowing preparation and consolidation of port equipment. • Container crane operating terminals most at risk e.g. SSA, CONTECON

Sea level rise combined with storm surge causes flooding of the port resulting in damage to port equipment and infrastructure	• All quay heights are +3.1 m above mean sea level; apart from MARFRIGO (+2.1 m). • Associated courtyards and adjacent areas are +4.1 m. CONTECON heights are 3.4 to 3.7 m.	• Observed SLR scenario = 0.17 m by 2065[62] • Under the RCP 2.6 scenario, SLR by 2065 = 0.16 m • Under the RCP 8.5 scenario, SLR by 2065 = 0.23 m • Combined tidal\seasonal \decadal maximum contribution = +0.70 m • Current 1 in 250 year return period storm surge height = +2.52 m • Current 1 in 500 year return period storm surge height = +2.85 m	• Maximum sea level rise scenarios combined with storm surge presents a limited risk of seawater flooding within the next 50 years. • MARFRIGO at increased risk due to lower quay height. Significant flooding (depths in excess of 30 cm) could occur by 2040 under the RCP 2.6 SLR scenario combined with a 1 in 250 year surge event.

Source: Report authors

terminals closest to the main entrance and discharge route are also subject to surface water flooding inside the terminal boundaries during heavy rains.

The level of water and sediment deposited during this surface water flooding can affect port equipment and infrastructure. It was reported that the customs infrastructure and scanning equipment required repair following a flooding event in 2011. Repeated flooding will eventually result in degradation of the road surface, also requiring more frequent repair. These are considered as maintenance issues for API Manzanillo and financial impacts are discussed in Section 3.6.1, chapter "Surface flooding". Recommended adaptation to prevent surface water flooding is as discussed in Section 3.6.1, chapter "Surface flooding", namely:

- Upgrade drainage system to increase maximum capacity and handle increased flow
- Create Sustainable Drainage Systems (SuDS) taking into account potential for changes in precipitation;
- Undertake review and adjust maintenance program to ensure that maximum capacity of existing system is being achieved e.g. frequency of sediment trap clearance
- Consider catchment level landscape planning and ecosystem based adaptation options for reducing risk of drainage overflow;
- Review of early flood warning systems and identification of areas for improvement, in light of increased surface water flood risk

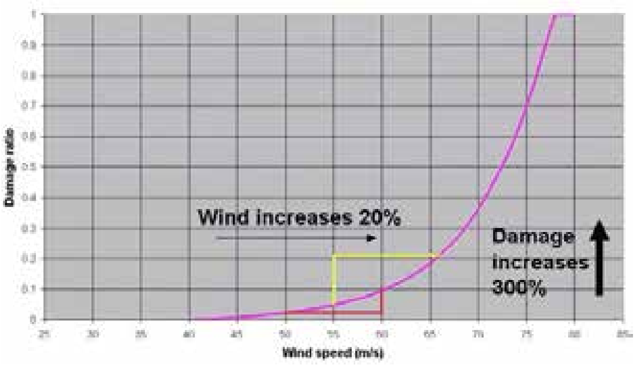
3.3.3. Extreme wind speeds damaging handling equipment

Due to their height (50 m approx.), CONTECON, SSA and OCUPA container handling cranes have the potential to be subject to damage from extreme wind speeds. CONTECON provided specific design thresholds of 56 m/s before damage may occur. Although data were not available, other older cranes at the port owned by other terminals will potentially have lower design thresholds and perform less well during extreme wind conditions. In general, with increasing knowledge, more attention is paid to the design of cranes and tie-downs for wind than in the past.

Due to Manzanillo's location, and potential future changes in the mean lifetime of maximum intensity of tropical cyclones[108], the port is potentially subject to wind speeds in excess of 56 m/s.

FIGURE 3.14

Graphical representation of the variation of wind damage with wind speed



Source: Australian Government of Meteorology, 2015 [109]

Accurately quantifying future changes in storms is currently beyond scientific method. However fewer storms are predicted, though the likelihood of experiencing a Category 4 or 5 tropical cyclone is likely to increase. Category 4 tropical cyclones e.g. Hurricane Daniel, which occurred in the eastern Pacific in 2006 are characterized by sustained wind speeds of 63 to 78 m/s. Category 5 tropical cyclones exceed 78 m/s.

The level of increased damage from higher wind speeds is not linear. As wind speed increases the power of the wind to do damage increases exponentially (Figure 3.14). Hence a Category 5 hurricane has the potential to do around 250 times the damage of a Category 3 severe tropical cyclone (with wind gusts of 46 m/s). Potential increases in Category 4 or 5 storms have the potential for significantly increased damage to handling equipment.

No terminals provided data indicating their cranes, conveyors and other equipment were subject to damage in the past due to extreme winds. Wind speed thresholds were provided, but the Harbor Master will close the port before these thresholds are reached, stopping all operations and helping to protect the equipment. As no historical data has been provided to assess risks, no detailed analysis for the current or future situation for the port as a whole has been undertaken. Example background information for risks to cranes is provided below.

CONTECON

Data provided by the CONTECON terminal shows their cranes have a graded operational threshold to increasing wind speed:

- At 19 m/s an alarm sounds but normal operations continue
- At 22 m/s a crane reduces speed, moves into its parking position and gets tied down by anchor pins. This tie down and stopping of operations helps prevent damage to the crane; and
- At 25 m/s cranes stops operating automatically

Although data was not available, the other older cranes at the port e.g. SSA potentially will have lower thresholds before operations are affected. Stated example wind speeds for port operations[110] indicate that crane operations cease at 11.5 to 14.0 m/s rather than the higher 22 m/s given for CONTECON.

The behavior of cranes in severe storm or hurricane conditions is dependent on the skill of the designer and the adequacy of the tie down anchorages. In general then it is expected that more modern cranes will perform better in wind conditions than older cranes, but this is by no means always the case.

The cranes are typically designed with load factors and material strength reductions factors to allow for uncertainties in design loads, material strength variations and construction deficiencies. Typically a crane structure is designed to withstand wind loads of up to 35 to 50% above specified maxima, equivalent to wind speeds of 15 to 22 % above maxima. Damage due to wind loads increasing beyond these limits can range from local yielding of some bracing members, to catastrophic loss of structural integrity and collapse of the crane structure.

Providing definitive repair costs for crane damage due to winds above their design wind speed is difficult. The cost of replacing bracing members and repairing connections is relatively modest, but a collapse of the crane would likely render it beyond economic repair, resulting in significant financial cost for replacement. Typically, a collapse occurs in extreme hurricane conditions when one or more of the tie downs to the wharf structure fail.

Adaptation options to prevent damage to cranes from extreme wind speeds include:

- Improvements to the cranes' tie-down systems. A ductile link system would assist in improving the load distribution to the various components of the tie-down system and prevent failure of one or more tie-downs. Approximate costs for this improvement would be of the order of 750,000 MXN to 2,250,000 MXN depending on the design and age of the crane and the adequacy of its existing tie-down system; and
- Improvements to the cranes' braking systems and wind speed prediction systems. These systems ensure that as wind speeds approach operational limits, there is sufficient braking capacity to prevent run-away of the crane down the rails, and time to get it to safe position and install the tie-downs.

3.3.4. Sea level rise combined with storm surge causes flooding of the port resulting in damage to port equipment and infrastructure

As discussed in Section 3.2.3, the likelihood of seawater inundation above current dock heights is low and not considered a priority risk. It is only considered possible when mean SLR is combined with tidal, seasonal and El Niño maximums and storm surge. Current risks are highest for the MARFRIGO terminal with a quay height of +2.1 m above MSL.

Seawater flooding has the potential to damage buildings, equipment and infrastructure through water damage and increased corrosion. These are considered primarily a maintenance issue for API Manzanillo and are discussed in Section 3.4.

Adaptation options for physical and ecosystem-based prevention and mitigation for seawater flooding are as discussed in Section 3.2.3, namely physical upgrading of dock heights and handling areas, and maintenance of soft coastal defenses provided by mangrove habitat. Upgrading of dock heights, as discussed there, are costly, and API Manzanillo and the terminals have insurance coverage for damage caused by extreme events.

Additional informational and operational measures to prevent increased future damage to equipment and infrastructure include:

- Updating design / management guides for equipment and infrastructure, taking into account design life and potential impact of future climate change; and
- Account for sea level rise when doing inventories for replacement and refurbishment of equipment and infrastructure.

3.4. Implications of climate change impacts on maintenance costs

SUMMARY OF KEY POINTS

- Maintenance costs at the port are primarily borne by API Manzanillo. Key maintenance issues affected by climate change are:
  - Maintenance dredging;
  - Maintenance of the drainage system and sediment traps;
  - Clear-up and repair of infrastructure e.g. roads following flooding events.
- The estimated increase in sediment load to the port basin under climate change is assumed to be directly proportional to the 8% increase in IPCC 20-yr median return value for 24-hr precipitation by the 2050s (10% by 2080s). An 8% increase in sediment deposition would require an additional 8,000m^3 of material to be removed per year by the 2050s, at an additional cost of 864,000 MXN per year.
- However, SLR would increase draft clearance somewhat, reducing these additional costs by 86,400 to 108,000 MXN per year (RCP 2.6 to 8.5 SLR scenarios).
- Total annual costs in 2014 for drain clearance were 19,489,444 MXN (4.5% of API Manzanillo's total operating expenditure). Costs associated with clearance of sediment and waste from the drainage system could increase, in line with increases in the frequency of intense hydrological events and changes in storm activity. An 8% increase in sedimentation by 2050 will result in additional annual costs of 1,559,155 MXN per year (0.4% OPEX). A 50% increase in the intensity of tropical storms could result in total annual costs for drainage maintenance of 6.75% of OPEX.
- Increased maintenance costs for internal roads and customs area are assumed to be directly proportional to increased intensity of rainfall causing surface water flooding events. An 8% increase in intense rainfall by the 2050s will result in an increase in these costs of approximately 3 million MXN.

3.4.1. Summary of Climate Risks

A summary of key climate risks for climate change impacts on maintenance costs the port is given in Table 3.16.

Both API Manzanillo and the terminals take responsibility for differing maintenance activities and associated costs at the port. Where information has been provided on costs these are summarized below, with respect to how they will be affected by climate change.

3.4.2. API Manzanillo

The majority of significant maintenance costs at the Port of Manzanillo lie with API Manzanillo. Significant costs affected by climate change include:

- Maintenance dredging
- Maintenance of the drainage system
- Clear-up and repair of infrastructure following flooding events e.g. access road

API Manzanillo's Finance Department reported that their system of recording maintenance costs has changed, so the overall record is fragmented. However from figures provided, apart from significant expenditures in 1997 and 2008, maintenance costs for API Manzanillo have shown a degree of consistency, at an annual average of 11,300,000 MXN (Figure 3.15).

A forecast of the API Manzanillo maintenance program and related costs for the period 2012 to 2017 is also included in Section 5.3 of the current Port Master Plan (PMDP) (Table 3.17). This demonstrates the various aspects of maintenance for which API Manzanillo is responsible. No clear trend over time can be seen from these projections. However Table 3.17 show an increase in 2013 and 2014, related to the internal roads and drainage system. This is likely due to the planned construction works of the navigation channel, CONTECON terminal and other associated works.

TABLE 3.16

Maintenance costs risks

Risk	Thresholds and Sensitivities	Current and future climate/oceanographic variability and change	Risk Description
Increase in intensity of rainfall causing increased sedimentation of the port basin, reducing draft clearance for vessels and terminal access	Sedimentation at the port currently causes a reduction in draft clearance and disruption to vessel access. Risks highest to terminals closest to drain 3 discharge e.g. USG. Maintenance dredging costs in 2014 were 54 million MXN at 108 MXN per m^3 Secondary effect of dredging vessel presence stopping terminal access.	Rainfall intensity is expected to increase. 8% increase in 20-yr median return value for 24 hr precipitation by 2050. Increase in sedimentation assumed to be proportional to the increase in total hydrological flow. Hydrological analysis shows an approximate doubling of frequency of drain surcharge by 2050	Increase in sediment load would require an additional 8,000m^3 of material to be removed per year by the 2050s, at an additional cost of 864,000 MXN per year. Mean SLR will have moderate mitigating effect. Maintenance dredging costs covered by API Manzanillo. Increased maintenance dredging will result in higher operational downtime for all terminals due to vessel.
Increase in intensity of rainfall requiring increased maintenance of the port drainage system.	Sedimentation and collection of material within the port drainage system currently occurs. Significant contributing factor to surcharge of the drainage system. Total annual costs 2014 19,489,444 MXN. 4.5% of API Manzanillo's total operating expenditure in 2014.		A proportional 8% increase in sediment deposition would result in additional costs of 1,559,155 MXN per year. This equates to a 0.4% increase in overall OPEX for API Manzanillo. Costs covered by API Manzanillo
Increased frequency of intense rainfall events causes damage to infrastructure and equipment e.g. internal roads through surface water flooding	Due to surface water flooding, the maintenance and repair of internal roads and the customs area is the largest component of API Manzanillo's annual maintenance costs (outside of dredging). Port master plan estimated 6 million MXN in 2015.		Port Master Plan includes a forecasted increase in road maintenance costs of 5% per year. If assumed that 8% increase is applied on top of 5% forecast, then additional costs of 3 million MXN per year by 2050. Costs covered by API Manzanillo

Source: Report authors

Issues most likely to be affected by climate change in Table 3.17 are those affected by flooding such as internal roads, customs facilities, and drainage and drinking water networks. Projected impacts from climate change on these costs are discussed below.

Increased maintenance dredging

Section 5.4 of the Port Master Plan includes an investments forecast for API Manzanillo from 2013 to 2017. Information is provided on future dredging costs covering both construction and maintenance dredging (Figure 3.16). The costs are consistent apart from a significant increase in 2014. This 2014 increase is likely due to the expected increase in construction dredging for the Laguna de Las Garzas connecting channel and other planned works. The average estimated annual costs excluding 2014 are 22.5 million MXN.

The standard maintenance-dredging program occurs once a year, starting in November when the rainy season ends. API Manzanillo Engineering Department stated the current volume of maintenance dredging is 0.5 million m^3 per year. However this was stated by API Manzanillo to reduce to 0.1 million m^3 per year after 2017, due to removal of historical sedimentation.

API Manzanillo stated 'actual' total maintenance dredging costs in 2014 were 54 million MXN. For 0.5 million m^3 this works out as approximately 108 MXN per cubic meter. Construction dredging costs in 2014 were 96 million MXN. The 0.5 million m^3 of maintenance dredging represented 12% of API Manzanillo's total operating expenditure in 2014.

Risk analysis

Although Manzanillo is to experience drier conditions overall, the frequency of intense rainfall events is expected to increase. These intense periods of rain are the main cause of increased carriage of sediment into the port basin. This will therefore result in an increased requirement for maintenance dredging.

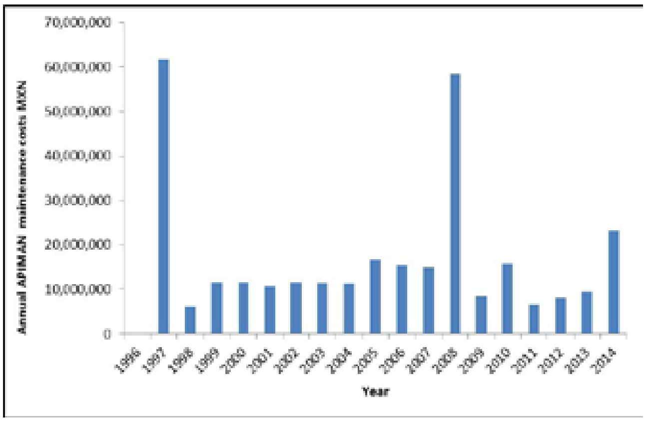
To allow for analysis, the potential increase in sedimentation under climate change is assumed here to be proportional to the increase in total hydrological flow. With additional data and focus on this specific issue, future work outside this study can refine these estimates, taking account of sediment discharge varying dis-proportionally with flow.

The potential increase in sediment load to the port basin under climate change is therefore related to the 8% increase in IPCC 20-yr median return value for 24-hr precipitation for the 2050s (10% by 2080s).

Taking the figure of 0.1 million m^3 per year for maintenance dredging after 2017, a proportional 8% increase in sediment deposition would require an additional 8,000m^3 of material to be removed per year by the 2050s, at an additional cost of 864,000 MXN per year. This equates to a 1% increase in overall OPEX for API Manzanillo.

FIGURE 3.15

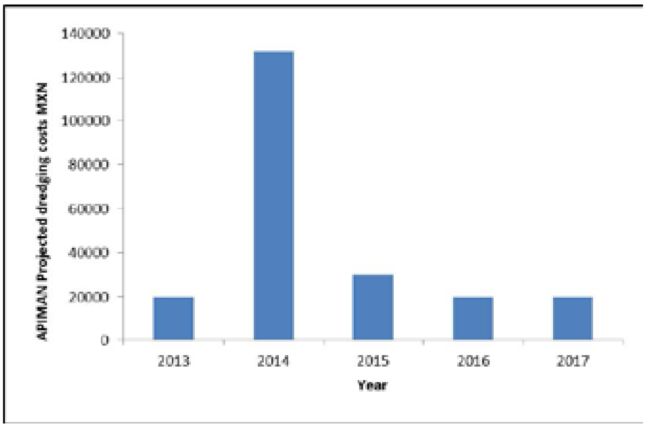
Annual maintenance costs (MXN) for API Manzanillo over the period 1996 to 2014



Source: Report authors

FIGURE 3.16

Annual estimated dredging costs API Manzanillo. Costs are indicated in thousands of MXN



Source: Report authors

TABLE 3.17

Projections of maintenance costs 2012 to 2017 (MXN/1000) (Source: Port Master Plan, 2012[111]). (Issues most likely to be affected by climate change are shaded in gray).

API Manzanillo maintenance responsibility	2012	2013	2014	2015	2016	2017
Internal roads	3,792	2,886	5,000	3,859	4,052	4,254
API general facilities	4,030	4,714	6,000	4,410	4,631	4,862
Customs facilities	2,317	0	1,000	2,205	2,315	2,431
Navigational aids	302	1,000	1,500	1,654	1,736	1,823
Electrical equipment	572	1,600	2,000	1,103	1,158	1,216
Fencing	458	1,400	2,000	551	579	608
Drainage and drinking water networks	495	7,150	8,000	551	579	608
Horizontal and vertical signaling system(roads)	302	1,100	3,000	551	579	608
Laydown areas	1,154	0	0	1,103	1,158	1,216
Docks	1,493	5,150	1,500	1,654	1,736	1,823
Total	14,915	25,000	30,000	17,641	18,523	19,449

Source: Report authors

Emergency dredging following storm events

The main factor causing extreme hydrological events and significant drainage into the port are tropical storm events. These storm events can result in a significant increase in the amount of sediment deposited in the port, and can require an immediate response from API Manzanillo outside the standard maintenance schedule to maintain access to the terminals.

To illustrate potential risks, Table 3.18 provides a sensitivity analysis to show the potential effects of a decrease in the frequency of storms and an increase in the mean lifetime of maximum intensity (duration). A figure of 10,000 m^3 of material (10% of annual program) is used as representative of an immediate dredging volume requirement following a storm at present.

Increased draft clearance through sea level rise

At noted in the section above, dredging requirements are expected to change due to increased rainfall intensity and changes in tropical storms. However, the issue of draft clearance will be mitigated somewhat by sea level rise, though the effect is expected to be limited. Mean SLR by 2050 for the moderate scenario (RCP 2.6) is 0.13 m; and for the high scenario (RCP 8.5) is 0.17 m. This would increase draft clearance by 0.8% and 1% in the 16 m deep port basin.

Maintenance dredging (estimated by API Manzanillo as 0.1 million m^3 per year in 2017) would therefore be reduced by 800 to 1,000 m^3 (assuming that the reduction in the depth of dredging required is equal to the projected sea level rise). The saving would be 86,400 to 108,000 MXN per year (RCP 2.6 to 8.5).

Summary of climate change impacts on maintenance dredging

The overall impact of climate change is therefore an increase in maintenance dredging over time, due to increased rainfall intensity (and possible increases in tropical cyclone impacts) counteracted somewhat by a trend of increased mean sea level.

Vessels that can currently dock at Manzanillo have a maximum draft of 14 m. To accommodate sixth generation New Panamax vessels the port will have to increase draft clearance further, which will increase the maintenance dredging commitment further, and overall costs.

Drainage maintenance

Financial data on costs for drain maintenance and clearance at the port was available for 2014 only. Work took place in four months, March, August, September and December. Figure 3.17 shows the highest costs to be in December after the wet season ends. The total annual figure for 2014 was 19,489,444 MXN. Drain maintenance represented approximately 4.5% of API Manzanillo's total operating expenditure in 2014.

As with maintenance dredging, the level of costs associated with clearance of sediment, waste and other materials washed into the drainage system can be related to increases in the frequency of intense hydrological events and changes in storm activity (Table 3.19).

The potential increase in sediment load to the drainage system under climate change can be related to the 8% increase in IPCC 20-yr median return value for 24-hr precipitation for the 2050s (10% by 2080s).

Taking the total annual 2014 figure of 19,489,444 MXN, a proportional 8% increase in sediment deposition would result in additional costs of 1,559,155 MXN per year. This equates to a 0.4% increase in overall OPEX for API Manzanillo.

A sensitivity analysis shows the potential effect of changing storm scenarios on drainage maintenance costs, as increased sediment and waste enters the port drainage system.

TABLE 3.18

Sensitivity tests for changes in tropical storms affecting the requirement for immediate dredging

Immediate Dredging	Immediate dredging (m^3)	25% decrease in storm frequency	50% decrease in storm frequency	25% increase in mean lifetime maximum intensity	50% increase in mean lifetime maximum intensity
Amount of material (m^3/year)	10,000	7,500	5,000	12,500	15,000
Total average annual costs (MXN)	1,080,000	810,000	540,000	1,350,000	1,620,000
% of operating expenditure	0.24	-0.18	-0.12	0.30	0.36

Source: Report authors

TABLE 3.19

Sensitivity tests for changes in tropical storms affecting the requirement for maintenance of the port drainage system

Maintenance of Port Drains	2014	25% decrease in storm frequency	50% decrease in storm frequency	25% increase mean lifetime of maximum intensity	50% increase mean lifetime of maximum intensity
Total average annual costs (MXN)	19,489,444	14,617,083	9,744,722	24,361,805	29,234,166
% of operating expenditure	4.50	3.38	2.25	5.63	6.75

Source: Report authors

Adaptation

Adaptation costs for physically upgrading the drainage system, including improving the prevention of sediment and material entering the drains are provided below. The overall cost effectiveness of these measures is then discussed.

The engineering rationale for the design increase in the maximum capacity of Drain 3 and upgrade of the sediment traps is provided in Appendix 7.

Costs

The costs for the upgrade of Drain 3 and installing additional sediment traps in all drains were estimated using quantities and procedures provided by WorleyParsons engineering specialists, based on conceptual designs. Pricing is based on unit rates for earthwork, concrete, and other construction activities from other projects in the region, modified using productivity factors applicable to work at the port. Indirect costs including contingency are also included as is appropriate for high-level (AACE Class 4) cost estimates. The total costs used in the financial analysis include tax (IVA) and are in 2015 MXN. A summary of each estimate is presented in Table 3.20 and Table 3.21 below.

The cost of installing additional traps was estimated first for the main drain, and subsequently for the other drains using the unit cost, based on the area of the drain inlet.

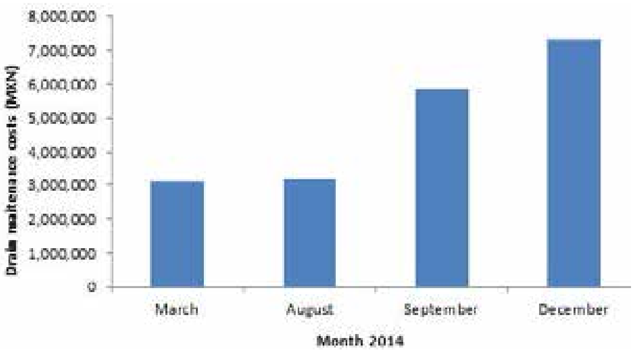
Effectiveness

These two engineering adaptation measures combined can provide a high level of effectiveness against both surface water flooding and sedimentation of the port basin. Increasing the drain capacity and upgrading the traps will both reduce the risk of surface water flooding, by accommodating increased peak flows, and by preventing material entering the drain, thus maintaining maximum capacity over time. Upgrading the sediment traps will also reduce sedimentation of the port basin. This will maintain draft clearance and overall terminal access, and reduce the need for maintenance dredging.

The savings for API Manzanillo that would result from these projects were therefore compared to total costs for surface water flooding (port closure), maintenance dredging and drains maintenance combined. Quantifying the exact changes in drainage flow patterns for

FIGURE 3.17

Year 2014 API Manzanillo costs for maintenance of port drainage system



Source: Report authors

TABLE 3.20

Cost estimate for upgrade of Drain 3

1 - DRAIN 3 UPGRADE				
ACTIVITY	**Quantity**	**Units**	**Unit price (MXN)**	**Value (MXN)**
Demolitions				
Demolition of pavement	1,696.80	m^3	122.00	207,010
Earthworks				
Excavation without water table drainage	18,835.20	m^3	161.00	3,032,467
Excavation with water table drainage	4,708.80	m^3	280.00	1,318,464
Backfilling	12,092.50	m^3	83.00	1,003,678
Transportation of surplus of excavation to dump site	11,451.50	m^3	12.00	137,418
Structure				
Vertical formwork (bottom slab & walls)	5,101.20	m^2	1,575.00	8,034,390
Horizontal formwork (top slab)	3,270.00	m^2	2,205.00	7,210,350
Lean concrete	559.20	m^3	2,335.00	1,305,732
Concrete(fck=30MPa)	3,341.90	m^3	3,951.00	13,203,847
Reinforcement	267,352.00	kg	24.00	6,416,448
Waterproofing				
Water stop PVC joint	1,308.00	m	311.00	406,788
Bituminous coating	3,008.40	m^2	178.00	535,495
Pavements				
Pavement reconstruction	1,696.80	m^3	593.00	1,006,202
Direct Cost				43,818,289
Overhead	25%			10,954,572
Profit	10%			4,381,829
Contingency	35%			20,704,142
TOTAL				79,858,832
IVA	16%			12,777,413
TOTAL + IVA				92,636,245

Source: Report authors

TABLE 3.21

Cost estimate of trap upgrades (for protection against sedimentation and waste)

2 - TRAPS UPGRADE				
ACTIVITY	**Quantity**	**Units**	**Unit price(MXN)**	**Value (MXN)**
MAIN DRAIN				
Excavation without water table drainage	337.50	m^3	174.85	59,011.90
Excavation with water table drainage	337.50	m^3	227.50	76,781.30
Transportation of surplus to dump site	675.00	m^3	12.61	8,511.80
Pour concrete	11.25	m^3	143.65	1,616.10
Grates	1,080.00	kg	78.00	84,240.00
Structural steel (galvanized)	7,536.00	kg	85.41	643,649.80
Direct Cost				873,811
Overhead	25%			218,453
Profit	10%			87,381
Contingency	35%			412,876
TOTAL				1,592,521
IVA	16%			254,803
TOTAL + IVA				1,847,324
Main Storm Drain Inlet Size	54.00	m^2		
TOTAL UNIT COST INCL. IVA/M2				34,210
ADDITIONAL DRAINS				
Drain 1	9.00	m^2		307,887
Drain 2	9.00	m^2		307,887
Drain 3	9.00	m^2		307,887
Drain 4	9.00	m^2		307,887
Drain 5	9.00	m^2		307,887
Lagoon Drain "I" (2 Cell)	18.00	m^2		615,775
Lagoon Drain 2 (3 Cell)	27.00	m^2		923,662
Lagoon Drain 3 (3 Cell)	27.00	m^2		923,662
Secondary Drain	15.00	m^2		513,146
Additional Drain	13.50	m^2		461,831
Drain G	16.25	m^2		555,908
TOTAL ALL DRAINS INCL. IVA				7,380,745

Source: Report authors

TABLE 3.22

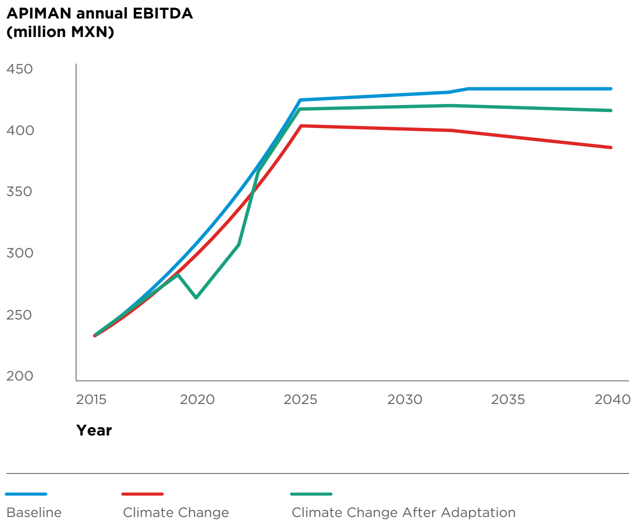
Scenarios studied for financial analysis of drain upgrades and installation of sediment traps

Scenario	Description	Sand Trap Installation	Drain Upgrades
Base Case	A baseline scenario where traps are installed beginning in 2016 and drain upgrades begin 4 years later in 2020	Takes place over 3 years from 2016 to 2018	Takes place over 3 years from 2020 to 2022
Adaptive Management	Projects are spread out over longer periods	Takes place in 3 phases, in 2016, 2018 and 2020	Takes place in 3 phases in 2021, 2025, and 2029
5 Year Delay	Same as Base Case, except all projects are delayed by 5 years	Takes place over 3 years from 2021 to 2023	Takes place over 3 years from 2025 to 2027
10 Year Delay	Same as Base Case, except all projects are delayed by 10 years	Takes place over 3 years from 2026 to 2028	Takes place over 3 years from 2030 to 2032

Source: Report authors

FIGURE 3.18

Effects of climate change impacts and adaptation measures on annual API Manzanillo EBITDA (2015 MXN). (Note: 'EBITDA – baseline' refers to future projections for API Manzanillo's EBITDA ignoring the effects of climate change)



Source: Report authors

these measures is beyond the scope of this study, so it is assumed the upgrades could offset 75% of these cost increases.

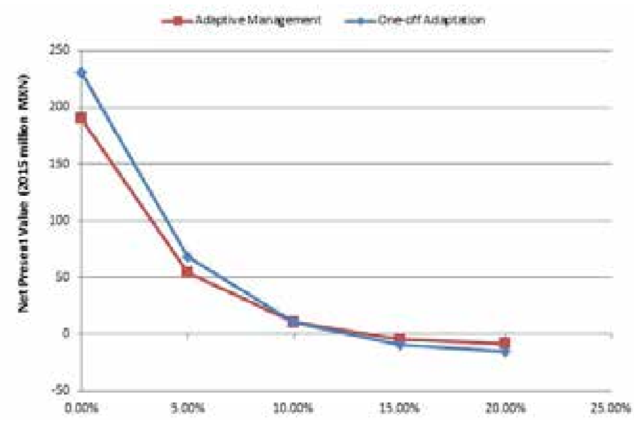
Given that installation of the sediment traps is substantially less expensive and less likely to interfere with port activities than drain upgrades, it is recommended that installation of the sediment traps is completed first. Since it is not known exactly how effective sand/waste traps will be at preventing obstruction of the drainage channels, the drainage upgrade project can be revised, delayed, or started sooner depending on the results. It is expected that each project can be undertaken in phases, with the work taking place over several years.

The aim of this analysis is to determine the net present value (NPV) of these two adaptation measures over a 25 year period (2016-2040). Four different scenarios for implementation of these adaptation measures were studied to explore how the economics are affected by completing the projects in phases or delaying the projects. The scenarios are described in Table 3.22 below.

The results of the analysis are presented in the tables and figures below. For the base case scenario, Figure 3.18 presents the effects of climate change and adaptation on API Manzanillo's annual projected EBITDA. It can be seen that undertaking the drainage upgrade leads to a

FIGURE 3.19

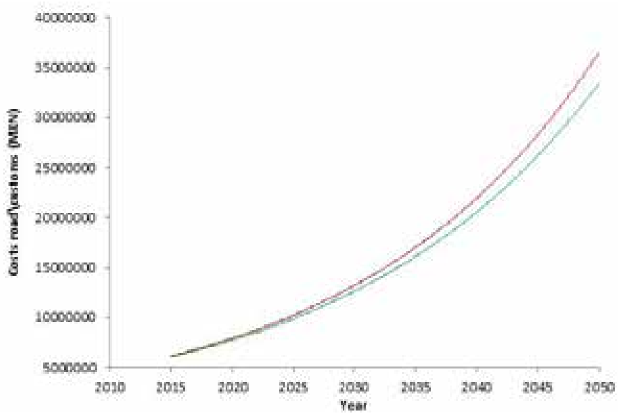
NPV of adaptation measures at various discount rates (2015 MXN)



Source: Report authors

FIGURE 3.20

Potential effect of increase in annual intensity of rainfall on road\customs maintenance costs (Baseline costs (i.e. ignoring the effects of climate change) in green; Costs of increased rainfall intensity due to climate change in red)



Source: Report authors

noticeable reduction in API Manzanillo's EBIDTA 2019 to 2023 (green line). From 2023 onwards, EBIDTA with the adaptation measures in place is greater than EBIDTA without adaptation (red line), as the impacts of climate change are reduced. The slight decline in EBIDTA beyond 2033 with adaptation measures in place (green line) is based on the assumption that the measures will offset 75% of the costs of climate change, rather than 100%.

Figure 3.19 compares the NPV of the base case ("one-off adaptation") with the adaptive management scenario. At API Manzanillo's discount rate of 10%, the NPV is roughly equal for both scenarios, whereas lower discount rates favor the base case, and higher discount rates favor adaptive management.

Table 3.23 compares the financial performance of the four scenarios studied. Delaying the projects, either through waiting to implement them or implementing them in phases (adaptive management) lowers the net cash flow (because it leaves the port exposed to climate change impacts for longer) but improves the rate of return on the investment (as evaluated by "internal rate of return" [IRR], the discount rate for which NPV = 0).

Internal roads\customs area

Due to flooding, the maintenance and repair of internal roads and the customs area is the largest component of API Manzanillo's annual maintenance costs. Since Manzanillo is expected to experience more intense rainfall events, the required maintenance of these areas could increase.

The Port Master Plan includes a forecasted increase in all maintenance costs of 5% per year from 2015 to 2017. Climate change impacts will be superimposed on this. It is assumed that the 8% increase in IPCC 20-yr median return value for 24-hr precipitation for the 2050s will translate into an equivalent (8%) increase in road and customs maintenance costs by the 2050s, on top of the 5% annual increase forecast by API Manzanillo (Figure 3.20). Hence, instead of the forecast 5% annual increase, the increase will be around 5.5% a year.

3.4.3. Terminals

In discussions, the terminals generally reported that weather was not a strong factor affecting their requirements for maintenance. They reported various maintenance requirements, such as for:

- Patios and docks
- Electrical equipment
- Cranes
- Transportation equipment
- Buildings and silos
- Belts and scales; and
- Railways and internal roads

TABLE 3.23

Financial results of scenarios studied for adaptation measures (2015 MXN)

Scenario	Net Cash Flow	NPV @ 10%	IRR
Base Case	230,836,553	10,578,466	11.98%
Adaptive Management	189,723,889	10,311,169	12.89%
5 Year Delay	182,400,249	12,447,622	14.89%
10 Year Delay	105,656,579	5,770,751	15.38%

Source: Report authors

TABLE 3.24

Historical maintenance costs for terminals (MXN

Terminals	2009	2010	2011	2012	2013	2014
Total	44,864,955	71,313,287	85,772,211	94,723,421	117,549,994	168,546,210
Average	11,216,239	17,828,322	21,443,053	18,944,684	19,591,666	28,091,035

Source: Report authors

Compared to the maintenance requirements for API Manzanillo, these are minor costs. However the individual terminals were asked to provide costs for maintaining equipment, buildings and operational areas.

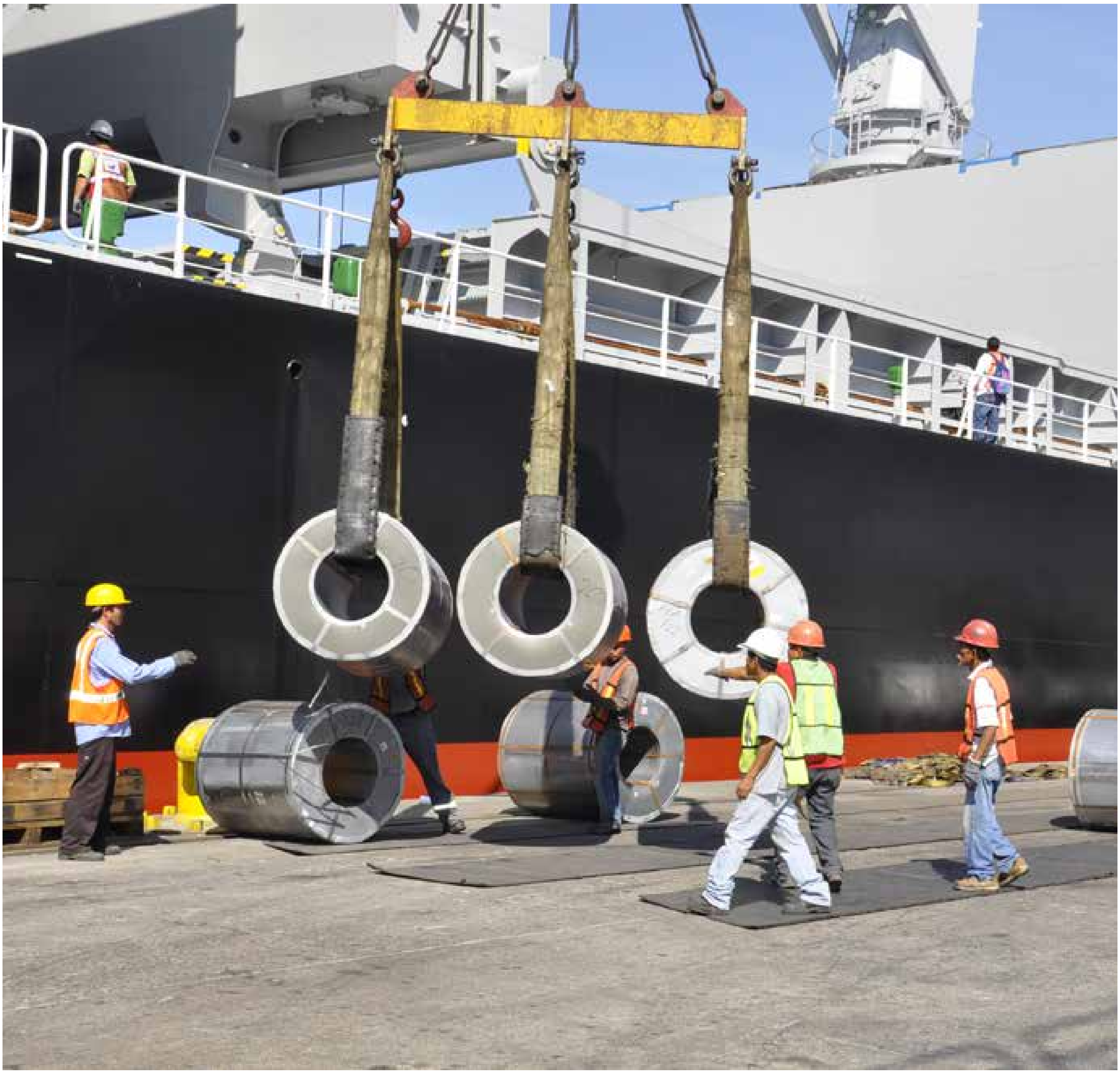
Table 3 24 provides a summary of the information available on total and average maintenance costs from six terminals who provided data from 2009 to 2014. Maintenance costs for the terminals as a percentage of operational expenditure varied from an average of 1% to 7%.

The highest costs are typically borne by the specialist container terminals, likely due to their higher working area, cargo throughput and infrastructure e.g. cranes, patio areas, buildings.

The influence of climate on terminal maintenance costs is limited. Some minor climate-related maintenance issues were nevertheless identified, including:

- Airborne dust increasing maintenance requirements for equipment filters (OCUPA)
- High humidity in bulk mineral product causing increased wearing of chutes (USG)
- Dust and rain causing increased maintenance of electrical connections to reefers (MULTIMODAL)

Climate change is likely to result in an increase in maintenance costs for terminals, but additional data collection beyond the scope of the present study would be needed in order to estimate accurately these effects, on a terminal by terminal basis.



3.5. Port services

3.5.1. Summary of Climate Risks

The port provides 437 hectares of water, docks and storage warehouses[112]. The general availability of the natural harbor of Manzanillo to vessels, and its base services of navigation and berthing are critical to all operations at the port. A summary of key navigation and berthing risks is provided in Table 3.25. A breakdown of key risks to individual terminals is given where appropriate. Where an individual terminal is not discussed, no significant specific risk to port services, access and berthing was identified.

3.5.2. Sedimentation reducing draft clearance and increasing drain maintenance

It was reported that during the rainy season, sedimentation from waters draining into the inner harbor results in a decrease in draft clearance for specific areas of the port. This has resulted in increased maintenance dredging and delays in vessels berthing.

In addition, the collection of sediment and other materials inside the drains is an important issue contributing to surcharge of the drainage system at the port. As the drains become blocked, their capacity is reduced and the likelihood of flooding is increased.

Adaptation

To accurately manage increasing levels of sedimentation, a program can be initiated to more closely monitor sedimentation levels in the port throughout the year. The results can be reviewed with respect to assessing the frequency of the current maintenance dredging program. As a low cost operational measure, the financial impact to API Manzanillo is not considered here.

If vessel access issues are shown to occur at regular times through the year, then where possible the dredging program can be adjusted to be proactive in preventing decreases in draft clearance. In addition, the traps that prevent sediment entering the harbor can be upgraded, and more frequently cleared to ensure they are always operating at maximum efficiency.

The potential increase in sediment load to the port basin under climate change is assumed to be proportionally related to the 8% increase in IPCC 20-yr median return value for 24-hr precipitation for the 2050s (10% by 2080s). These assumptions are discussed in Section 2.2.2, chapter “Sedimentation”. Sedimentation in the

SUMMARY OF KEY POINTS

- Increased intensity of rainfall will result in increased sedimentation of the port basin, reducing draft clearance for vessels and requiring increased maintenance dredging.
- The potential increase in sediment load to the port basin under climate change is proportionally related to the 8% increase in IPCC 20-yr median return value for 24-hr precipitation for the 2050s (10% by 2080s). This is considered in the maintenance section.
- Additional maintenance dredging also affects terminal operations. For example an increase in time of 33% to unload a cargo for one representative terminal. In 2011, the same terminal lost 168 hours of operational time due to dredging operations.
- If dredging requires port closure, then in addition to the costs to API Manzanillo for operating the dredging vessel, their revenue is estimated to be reduced by approximately 0.005% (67,000 MXN in 2015) per hour.
- Wind and wave activity affects berthing operations outside the port harbor at the PEMEX terminal. Operational thresholds for offloading were stated as a maximum wind speed of 60 km/hr (16.7 m/s) and wave height of 1.8 m. Proximity of storms is main factor determining downtime.
- PEMEX is most exposed to operational downtime due to storms, owing to its location outside the main harbor entrance and it is uncertain whether this will increase or decrease in future.
- Adaptation measures for PEMEX include a review of operating conditions e.g. cargo loads and vessel size to maintain berthing availability and performance standards.

TABLE 3.25

Port services risks

Risk	Thresholds and Sensitivities	Current and future climate/ oceanographic variability and change	Risk Description
Increase in intensity of rainfall causing increased sedimentation of the port basin, reducing draft clearance for vessels	• Sedimentation of berthing positions, particularly at terminals 12 and 13 occurs following periods of heavy rain. • Reduction of draft clearance for vessels, increased requirement for maintenance dredging. • Currently dredging 0.5 million m^3 of material per year. These are large volumes due to accumulation of sediment over time. Estimated reduction to approximately 100,000 m^3 per year by 2017[113].	• Sediment load is related to discharge flow rates linked to rainfall. • Higher rainfall intensity expected in future. • Increase in precipitation rate of storms within 200 km • 23% increase in >20mm daily rainfall events by the 2020s. • Maximum 24 hour precipitation rates rise 8% by 2050[114]. • These factors are likely to lead to increased sedimentation at Manzanillo.	• Sedimentation of the port basin and drainage traps is considered an important climate risk which will likely worsen due to climate change. • Influences the requirement for maintenance dredging, terminal availability and damages the port's reputation if not addressed. • 8% increase in sediment load by 2050s. • For this, an additional 8,000m^3 of material needs to be removed per year, at an additional cost of 864,000 MXN per year. • Drain clearance in 2014 was 4.5% of API Manzanillo's OPEX. • While API Manzanillo incurs the costs of dredging, all terminals are subject to downtime due to the presence of the dredging vessel stopping access. • Terminals closest to the point of sediment discharge are at increased risk of reduction of draft clearance and delays in berthing i.e. USG and HAZESA
Increase in intensity of rainfall requiring increased maintenance of the port drainage system.	• Collection of sediment and other materials inside the drains is an important issue contributing to surcharge of the drainage system at the port. • Reduces drainage capacity and increases the likelihood of flooding.		
Wind and wave activity affecting berthing operations	• The PEMEX terminal outside the main harbor entrance is subject to operational downtime due to wind, waves and storm surge affecting berthing availability. • PEMEX reported six operational closures of the terminal in 2014 due to weather events.	• Possible future decrease in annual frequency of tropical storms. • Possible future increase in maximum intensity and mean lifetime of maximum intensity of storms.	• Proximity of storms to Manzanillo is key factor affecting berthing availability at PEMEX terminal. • Operational downtime from storm activity may increase in the future. • Considered an important climate risk for PEMEX; a lower risk for terminals inside the harbor.

Source: Report authors

port basin and the drainage system is considered a maintenance issue for API Manzanillo. Further assessment including financial analysis was provided in Section 3.4.

3.5.3. Terminal downtime due to dredging vessel movements

In addition to a reduction in draft clearance due to sedimentation, movements of the maintenance dredging vessels can also prevent vessel access to all terminals, effectively stopping operations for the whole port.

API Manzanillo distribute the dredging schedule in advance, allowing the terminals to plan their operations around this. However it can still cause delays and stop vessel access. For example a terminal routinely operates from Band B. When dredging operations occur they are required to move to Band A, which is further away from their handling center. This results in a typical increase of 50% (10 hours to 15 hours) to unload a vessel cargo.

Information was available from only a single terminal on downtime due to dredging vessel operations. This terminal stated that in 2011, 168 hours of operational time was lost due to dredging operations at a cost of 2,806,650 MXN (16,706 MXN per hour). This represents less than 1% of average annual EBITDA for the terminal. No downtime was reported for other years, which suggests this single record represents a notable sedimentation event related to a tropical storm.

The level of costs associated with terminal downtime due to dredging vessel movements can be related to the level of maintenance dredging that occurs. The potential increase in sediment load to the port basin under climate change can be related to the 8% increase in IPCC 20-yr median return value for 24-hr precipitation for the 2050s (10% by 2080s).

If 16,706 MXN per hour is taken as an average representative figure for a terminal at the port, then total costs for all terminals (16,706 x 14) is 233,884 MXN per hour. An 8% increase in delays and associated costs is estimated by the 2050s. A sensitivity analysis shows the potential effect of changing storm scenarios and sedimentation on dredging requirements and terminal downtime due to vessel movements.

TABLE 3.26

Sensitivity tests for changes in tropical storms affecting the loss of terminal access due to dredging vessel operations, all terminals

Loss of terminal access due to dredging vessel	Current downtime	25% decrease in storm frequency	50% decrease in storm frequency	25% increase in mean lifetime maximum intensity	50% increase in mean lifetime maximum intensity
Current costs per hour all terminals (MXN per Hour)	233,884	175,413	116,942	292,355	350,826

Source: Report authors

TABLE 3.27

2014 PEMEX operational closures due to unavailability of berthing due to weather events.

Closed	Opened	Cause	Hours Closed	Average wave height (m)	Highest wave height (m)
07-May	09-May	Tropical disturbance in the Pacific	40	1.4	1.8
10-Jun	13-Jun	Cristina	72	1.9	2.5
30-Jun	03-Jul	Elida	83	1.7	2.3
02-Sep	05-Sep	Norbert	66	2.5	3.3
10-Sep	15-Sep	Odile	114	2.5	5.5
17-Sep	20-Sep	Polo	99	2.7	4.4

Source: Report authors

Adaptation

Adaptation should focus on ways to reduce the frequency of required maintenance dredging. This can be achieved through prevention of sedimentation via the physical upgrade of traps and increased frequency of trap clearance. This is discussed further in Section 3.4.2, chapter "Drainage maintenance".

3.5.4. Wind and wave activity affecting berthing operations

Increases in storm driven wind and wave activity could adversely impact port operations, primarily at the PEMEX terminal.

In general, increased wind speeds can cause more operational downtime for berthing at ports. The extent of the impact depends on the threshold operational wind speed and the increase in occurrence of winds exceeding that threshold. For a container terminal, the berthing operating limit is typically in the range of 13 to 15 m/s.

Increased downtime for pilot assisted entry into a port can also increase under stronger wind and wave conditions. For tug assisted entry, safe operating limits for wave height is typically in the range of 2.0 to 2.5 m. With regard to wave exposure at Manzanillo, the main port harbor is highly sheltered, with the possible exception of the penetration of very long period 'infragravity' waves during occasional sustained periods of very high swells.

Berthing problems from wind and wave activity were not reported as an issue by terminals in the inner harbor. However the PEMEX terminal sits outside the main harbor entrance and is subject to greater impact from wind and waves.

PEMEX

In 2014, adverse weather conditions resulted in six closures of the PEMEX terminal. Operational thresholds for offloading were stated as a maximum wind speed of 60 km /hr (16.7 m/s) and wave height of 1.8 m. Each period of downtime can be directly linked to a regional storm event (Table 3.27).

Wind and waves

To understand this effect of wind and waves on PEMEX, a review of conditions during periods of operational downtime in 2014 was conducted. Data reviewed included wind and wave data provided by IMT, regional Wave Hindcast data[xxix] and regional meteorological data[xxx].

The IMT wind and wave data did not include records for the May to September period of 2014 downtime. The Hindcast data however showed high wave conditions during the downtime events, with the average wave height exceeding PEMEX's 1.8 m threshold for all except one event.

Wind speed appeared less of a factor; for example in September 2014, the highest measured wind speed at the airport was 16 m/s (Sept 18th) which is slightly less than the 17 m/s wind speed threshold for stopping berthing at PEMEX.

Studies indicate that maximum and average wave height is likely to moderately increase in the future in the Eastern Tropical Pacific[75]. An increase in maximum wave height of approximately 0.12 m is expected by 2100 for RCP 8.5 (0.6 m for RCP 4.5). An increase in average wave height of 0.08 m is expected by 2100 for RCP 8.5 (0.04 m for RCP 4.5). These increases would not present a significantly increased risk to PEMEX.

Tropical storms

The PEMEX record (Table 3.27) clearly demonstrates that tropical storms are the main factor driving downtime. The features of the storms that led to these disruptions at PEMEX were analyzed in Section 2.1. The most important characteristic was shown to be their location, rather than their intensity or duration. Only storms passing very close to Manzanillo (and normally within a few tens of kilometers) led to disruption.

Accurately estimating how tropical storm tracks could change in the future is currently beyond scientific method. Analysis of historical storm data[115] reveals that over the last three decades a significant shift has occurred towards the poles in the average latitude at which tropical cyclones attain maximum intensity. In general for Manzanillo, tropical cyclones are expected to decrease in frequency of occurrence but are expected to be more intense.

Changes in downtime at the PEMEX terminal are therefore a possibility.

Flooding

The site elevations for the PEMEX terminal are similar to the main port, so the coastal flood risks are also similar. However, the potential for seawater flooding is slightly higher along the west side of the Terminal since it is located along the open coast and therefore prone to wave setup effects from high breaking waves (Figure 3.21). In addition, the causeway / breakwater structure along the west side of the PEMEX terminal will be much more prone to wave overtopping events in the future due to the effects of mean sea level rise.

Adaptation

An IMT study[116] made a detailed analysis of waves outside the port, with a focus on the more exposed PEMEX terminal. They made a number of recommendations for physical measures that would reduce wave reflection around the piers, and improve berthing availability. These included:

- Construction of a 2:1 rock fill embankment; and
- Concrete drawers in areas exposed to high waves.

Even following the implementation of such measures, a 50% increase in storms affecting PEMEX might require them to adjust operational targets. Potential operating conditions e.g. cargo loads and vessel size (<> 500 UAB) could have to be changed to maintain berthing availability performance. Customer responses to future changes in berthing restrictions would have to be monitored and acknowledged.

In light of the potential for increased downtime, it is recommended that PEMEX considers an operability assessment to understand berthing and offloading thresholds in light of potential changes in tropical storms. However, given the significant uncertainties about future changes, it is recommended that PEMEX does not take action beyond such an assessment. Rather, PEMEX is advised to monitor closely progress in scientific knowledge about how climate change could affect tropical storms in the north east Pacific, along with its ongoing record keeping on events that have affected operations.

FIGURE 3.21

Sensitivities to climate and oceanographic conditions at the PEMEX terminal

Source: Report authors

3.5.5. Effects of changes in sea level on maneuvers and berthing

Safe berthing of vessels implies that the fenders have to be in contact with the straight part of the vessel's hull. A minimum height of 0.5 m between sea level and the dock is therefore proposed as a conservative minimum requirement for all terminals[xxxi].

At the port, all terminal dock heights are currently +3.1 m above sea level, apart from MARFRIGO (+2.1m). A combined mean sea level of +2.6 m (i.e. mean SLR plus tidal, seasonal and El Niño) can therefore be considered a threshold above which safe berthing of vessels can be affected. For MARFRIGO, the threshold would be a combined mean sea level +1.6 m.

The analysis presented on seawater flooding (Section 3.2) shows that the maximum projected rise in mean sea level used in this study is +0.66 m by 2100 (relative to 2015). This is within the operating range of the port's dock heights, including MARFRIGO. Hence mean sea level rise will not present a hazard to berthing.

3.6. Trade routes

3.6.1. Loss of port connectivity with land transport routes

Summary of Climate Risks

Inland transportation networks are essential for the port to move goods to and from major economic centers that it serves. Road and rail infrastructure inside and immediately surrounding the port are therefore key sensitivities for operations.

Congestion on the port access road and through customs, together with the quality of the rail service are already recognized as two of the main weaknesses of the port, and they affect its reputation. These weaknesses were noted in the SWOT (FODA) analysis of the current Port Master Plan (PMDP). This states that there is consensus across among port clients and the port community on these issues, and that a diagnostic study for the 'Marca de Calidad' (Quality Guarantee) cited low satisfaction ratings among port users for: low efficiency in third maneuver operations, saturation of the customs area and lack of access to the port[117]. Any climate-related impacts on road and rail infrastructure can therefore act as additional stressors on an already overloaded system, and lead to greater reputational risks.

A summary of climate-related risks for land transport connectivity is provided in Table 3.28.

Road connections

The Port contains 10.77 km of internal roads and is 2.4 km from the freeway to Guadalajara and Mexico D.F. The principal external roads leading to the main port entrance are commonly congested. This situation has been exacerbated by the increased traffic from the Zona Norte expansion. A significant program to alleviate congestion is underway, through the construction of a dedicated elevated distributor road (Figure 3.22). The aims are to improve traffic flow, prioritizing the safety of users, remove train interference and segregate heavy goods traffic from local urban traffic.

FIGURE 3.22

Manzanillo Port elevated roadway building program

Source: SCT, 2008 [119]

The pace of development of the port has resulted in notable impacts on the efficient movement of goods along the main internal access\egress roads. During consultations undertaken for this study, this factor was cited by all terminals as a bottleneck for goods handling, due to limited space, heavy traffic and delays due to customs.

A 2008 SCT study[120] investigated access and movement of vehicles to and from the quays, involved in both primary and secondary maneuvers. Their findings showed that at peak demand, the port's existing road design significantly affected the efficient movement of goods in and out of the port. A number of key sensitivities were stated, such as access to CEMEX and OCUPA, and quays 9 and 10 (SSA). When flooding of the port's internal roads occurs, problems due to pre-existing congestion immediately increase, with limited options for re-routing internal traffic to and from the terminals.

To start addressing the issue of congestion, the road and customs area is to undergo a significant redevelopment, increasing from 4 to 9 inspection modules with 10 lanes, and from 30 to 50 inspection spaces[121].

Rail connections

The Port has 29.51 km of internal railways[122] and is connected by rail to Guadalajara, Mexico D.F., Irapuato, Silao, Querétaro, Aguascalientes, Chihuahua, Torreón, Sinaloa, Monterrey, Altamira and Ciudad Victoria.

In general, Ferrocarril Mexicano (Ferromex) serves all ports and terminals; however tracks at Manzanillo Port are subject to a complicated set of regulations. All tracks leading to the port are owned and operated by Ferromex; API owns public tracks within the port that Ferromex maintains; and terminals have private tracks that they maintain.

Some terminals reported existing problems with train availability, frequency, dispatch capacity and reliability. Individual terminals have provided data on the number of days and financial impact due to limitations on rail services. This is linked to the road congestion, as both road and rail share space through Manzanillo. A number of projects are being considered to improve rail connections into the port, including relocating rail lines away from Manzanillo center, via a tunnel through the mountains behind the city. This would connect to existing rail lines by the Cuyutlán lagoon[123].

Surface flooding

As discussed in Section 2.2, a key climate risk for the port is the annual surface water flooding and transport of sediment that occurs outside the principle northern entrance and along the main internal access\egress road. Some 1000 to 1500 vehicles per day use the access road at peak demand.

Due to the surrounding topography, the north eastern area of the port is a focal point of the surrounding drainage basins. Up to 30 cm of water and sediment can collect at the main exit. After Hurricane Bud in 2012, these impacts led to the access road being closed for three to four days. In 2013, it was closed for two days.

Most train tracks outside the port are elevated on embankments, so floods that stop trucks do not stop trains. Certain tracks outside the port however run directly through Manzanillo, crossing main roads at street level (Figure 3.23). These are sensitive to disruption from flooding. It was also reported that locomotives cannot pull heavier loads (e.g. agricultural bulk) during rain, due to a loss of traction.

Some tracks inside the port, specifically those closest to terminals 12 and 13 were reported as sensitive to disruption from surface flooding during heavy rain.

Hydrological analysis has been conducted to investigate changes in future rainfall intensity and their effect on peak flows into the port drainage system. A review of

SUMMARY OF KEY POINTS

- Surface water flooding of the internal access road and rail connections occurs almost annually at the port, mainly due to heavy rainfall during tropical storms causing the drainage system to overflow. This can stop movement of trucks and trains for up to 3 days, due to more than 30 cm depth of water and residual sediment.
- Tropical storm maximum intensity and mean lifetime of maximum intensity is expected to increase by the 2050s.
- Analysis for this study shows that return periods for current peak flows will approximately halve by 2050 (Section 2.2). The magnitude of the 1 in 20 year 24-hour precipitation is estimated to increase 8% by 2050[124] leading to greater frequency and magnitude of flooding events.
- Average current downtime for terminals due to surface water flooding is 1 to 2 days per year, every other year. If it is assumed that the percentage of downtime leads to an equivalent percentage loss of EBITDA then impacts are currently <1% EBITDA per annum for all terminals.
- Significant financial and reputational impacts are borne by API Manzanillo due to surface water flooding as the port effectively closes. Maintenance and repair costs for internal roads and the customs area following a flooding event are 1% of annual OPEX. A 25%/50% increase in mean lifetime of maximum intensity of storms could increase this by 1 million to 2 million MXN per year.
- Available adaptation options include physical upgrade of the drainage system, sustainable drainage systems (SuDS), catchment level landscape planning, internal traffic management and improvement of early warning systems.

TABLE 3.28

Land transport connectivity climate-related risks

Risk	Thresholds and Sensitivities	Current and future climate/ oceanographic variability and change	Risk Description
Increased intensity of rainfall causes surface water flooding of internal access road and entrance, causing disruptions to port operations	• Flooding and residual sedimentation of the main access road into and out of the port already occurs, up to 30 cm depth. • 1,000-1,500 vehicles per day on access road and surrounding urban roads during peak demand. • Terminal operations disrupted due to flooding of the access road in 2011, 2012 and 2014.	• Dry months January to March. • Rainfall increases from June, peaks in September. • Observed data shows significant dry season decrease of 2.7 mm per year. • Changes in Mexican extreme rainfall shows the amount of rainfall in a 24 hour period with an expected return period of 20 years is to increase[118]. • Significant increasing historical trend for Manzanillo ERA-I data (June) for higher threshold exceedances e.g. 10 mm and 20 mm • Future increase in mean lifetime of storm maximum intensity and precipitation rate within 200 km.	• Heavy rains causing surcharge of the drainage system into the port is already a significant climate risk to the main port entrance and internal access road. • Example average costs for one terminal are 38,000 MXN per hour. • All terminals using road connections are affected
Increased intensity of rainfall causes surface water flooding of internal access road and entrance, causing disruptions to port operations	• Ferromex experiences occasional disruptions on the rail network due to rain, heat, wind, or some combination. • Terminal operations disrupted due to flooding of the port rail connections in 2011, 2012 and 2014. • Locomotives cannot pull heavier loads during rain due to a loss of traction.		• Heavy rains are a risk to rail connectivity through surface water flooding of tracks and loss of traction. • Lower risk compared to road connections as tracks are raised on embankments. • Flooding outside the port can affect rail movement of goods on tracks at street level within Manzanillo. • Example costs for one terminal are 16,000 MXN per hour. • All terminals using rail connections affected

Increased storminess causes flooding in major rail and road routes connecting the port to its area of influence	• Ferromex has experienced disruptions of up to 17 consecutive days in the past years on the rail network due to flood events associated to tropical cyclones.		• Tropical cyclones and flooding can cause disruptions in the broader rail and road network connecting the port and result in delays and interruptions affecting the port's users. • All terminals using rail connections affected.
Higher temperatures lead to reduced train speeds	• Temperatures above 42°C can cause delays in the rail network, as trains are forced to reduce their speeds. This has the potential to cause delays in transport of goods to/from the port.	• Observed data shows increases in mean, maximum and minimum temperatures across Mexico. • Future projections suggest an increase in mean temperature of around 1˚C by the 2020s and 2˚C by the 2040s in western and central Mexico (compared to baseline period 1971 to 2000).	• For the Ferromex route connecting the port to Guadalajara and Mexico D.F., the likelihood of temperatures exceeding 42°C by mid-century is evaluated to be low.
Increased disruption to regional and international maritime transport from tropical storms	• In 2014, 25% of vessels at Manzanillo originated from South East Asia. The port receives 68% of its cargo from the Mexican Pacific. • Typhoon and tropical storm activity is a factor determining vessels moving to and from Manzanillo. • Average annual loss of access during tropical storm season at Manzanillo for large vessels (>500 UAB) is 0.4%; smaller vessels (<500 UAB) is 6.6%.	• The NE Pacific has the second highest annual frequency of tropical cyclones globally after the W Pacific. • Future increase expected in mean lifetime of storm maximum intensity and precipitation rate within 200 km.	• Accurately quantifying future changes in storms is currently beyond scientific method. • However, fewer South East Asia typhoons and East Pacific storms are predicted but with increased intensity and duration of maximum intensity, and closer to Manzanillo. • Increased impacts on maritime traffic are expected when a storm\ typhoon occurs. • Affects all Port operations

Source: Report authors

how these changes will affect flooding of the internal port access road and internal rail connections is presented here.

Risk analysis

To establish the current risks from flooding, the terminals were asked to provide specific dates between 2009 and 2014 when the access road and internal rail connections were flooded sufficiently to stop the movement of trucks and goods. Data on the dates and hours of interruption and financial impact were provided by a representative terminal, and are given in Table 3.29.

No rainfall was recorded in the Manzanillo meteorological station data on or before the March 12th, 2011. This incompatibility between the results suggests an inaccuracy in the flooding record, or the 2011 met data is unreliable. The 2011 incident therefore has not been referenced further.

The 2012 Manzanillo meteorological station data showed that 36 mm fell on May 25th and 23 mm on May 26th resulting in flooding of the access road (Figure 3.24). When compared to the mean rainfall for May (inset), this level of rainfall is extreme and can be attributed to Hurricane Bud, which developed from May 20th to May 26th.

In regard to identifying a rainfall threshold for surcharge of the drainage system, the rainfall records from Manzanillo met station show 24 hour values higher than 36 mm which did not result in flooding. For example 93 mm fell on June 18th 2012 though there was no reported extreme storm event at that time; and no reported operational downtime of the access road by API Manzanillo or the terminals.

FIGURE 3.23

Tracks running through Manzanillo

Source: LBJ 2009 [125]

The flooding events are therefore considered likely to be a factor of extreme weather events (tropical storms) and unlikely to occur under standard convective rainfall conditions. For example the September 2014 flooding event noted in Figure 3.24 is aligned with the dates for Hurricane Polo.

Increase in peak flows

This study has shown that the estimated 8% increase in IPCC 20-yr median return values for total 24-hr precipitation will result in a significant increase in peak flows into the port drainage system. As discussed in Section 2.2, the 1-in-100 year peak flow observed historically at Drain 3 is estimated to become the approximate 1-in-50 year peak flow event by the 2050s. Similarly, the current 1-in-50 year peak flow is estimated to have a recurrence of approximately 1-in-25 years by the 2050s. Figure 3.25 shows the peak flow discharges for three time periods. These increases in flow due to more intense rainfall will likely result in an approximate doubling in the frequency of surcharge of the Drain 3 catchment by 2050.

Financial analysis

Surface water flooding has a significant financial impact for individual terminals. The overall operational financial impact to API Manzanillo is limited, but high maintenance costs and reputational impacts for API Manzanillo occur.

Three terminals provided data on downtime due to surface water flooding of internal port roads.

To show the effect of the approximate doubling in frequency of surcharge of drain 3 by 2050 shown by the hydrological study, a sensitivity analysis has been applied to the data. As the degree of flooding is also shown to be a factor of storm activity, additional sensitivity analyses (as presented in Section 2.1) have also been applied (Table 3.30).

As financial impacts to API Manzanillo from surface water flooding are primarily a maintenance issue, these are discussed in Section 3.4.

Financial impact of road closure

For the application of sensitivity tests, it is considered that the 25/50% reduction in the annual frequency of tropical storms, and the 25/50% increase in mean lifetime of maximum intensity as discussed in Section 2.1 are applicable. Data from three representative terminals was available for 'annual hours' downtime for road closure' and ' financial impact of road closure' (MXN). Average figures for these three terminals are provided in Table 3.31.

TABLE 3.29

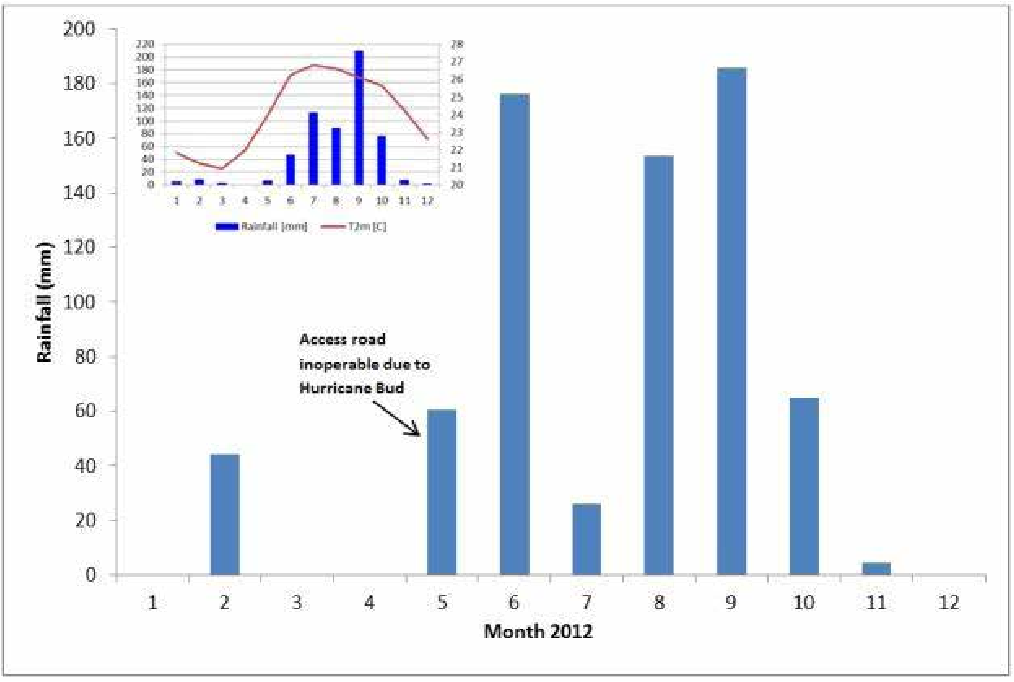
Record of operational downtime from one terminal due to flooding of the internal access road and rail connections

Terminal	2011	2012	2014
Number of hours downtime - road	36	22	22
Number of hours downtime - rail	36	22	22
Date of downtime	12 March 2011	25 May 2012	18 September 2014

Source: Report authors

FIGURE 3.24

Rainfall recorded at Manzanillo met station data in 2012 (Inset monthly mean rainfall and temperature at Manzanillo, 1979 to 2012).



Source: Report authors

TABLE 3.30

Sensitivity tests applied to surface water flooding analysis.

Expert judgment statements	Sensitivity tests
"A decrease in the annual frequency of tropical storms"	25% reduction in frequency 50% reduction in frequency
"An increase in mean lifetime of maximum intensity"	25% increase in mean lifetime of maximum intensity 50% increase in mean lifetime of maximum intensity

Source: Report authors

TABLE 3.31

Sensitivity tests for changes in tropical storms affecting Manzanillo, average of three terminals.

TERMINALS	Current flooding events	Doubling of frequency of drain surcharge	25% decrease in storm frequency	50% decrease in storm frequency	25% increase mean lifetime max intensity	50% increase mean lifetime max intensity
Average annual hours downtime due to road closure	41	82	31	21	52	62
Average financial impact of road closure (MXN)	434,742	869,484	326,057	217,371	543,428	652,113

Source: Report authors

All Terminals

When a surface water flooding event occurs, loss of port connectivity to road and rail connections affects all terminals. To understand the potential financial impact of this, the following high level estimates have been developed from available financial data:

- Over the period (2009 – 2014) for which data on disruptions were requested from the terminals, the three terminals who reported stated that surface water flooding had stopped movements in 3 of the 5 years. Therefore we estimate that disruption from flooding occurs approximately every other year.
- The average duration of disruptions for the two terminals that provided data were 22 hours and 30 hours (the third terminal did not provide the duration; this was estimated from lost revenue). Hence we estimate the average duration is approximately 1 day.
- Total annual EBITDA across all terminals has been calculated as approximately 3,625,396,000 MXN. This has been derived from a sum of data provided by the terminals. Where data has not been provided, then terminals with similar business lines e.g. container and agricultural cargo are assumed to have similar EBITDA.

Estimated loss of EBITDA per day due to surface water flooding disruption for all terminals at present is therefore:

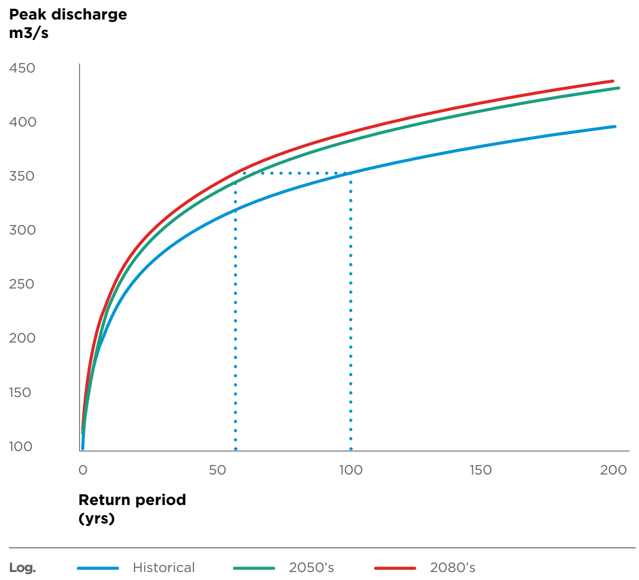
Equation 1: (Average number of events per year) x (average duration of events in days) x (total annual EBITDA/365 days)

This equates to: 0.5 * 1 *3,625,396,000 / 365

Based on this calculation, the loss of EBITDA across all terminals is approximately 10,000,000 MXN.

FIGURE 3.25

Peak discharge flows (m^3/s) for return periods up to 1 in 200 year, based on historical data and IPCC 20-yr median return values for 24-hr precipitation for the 2050s and 2080s



Source: Report authors

For the sensitivity tests with doubling of frequency of surcharge and changing storm scenarios the future potential daily losses for all terminals are given in Table 3.32.

TABLE 3.32

Sensitivity tests for changes in tropical storms affecting Manzanillo, ALL TERMINALS

ALL TERMINALS	Current flooding events	Doubling of frequency of drain surcharge	25% decrease in storm frequency	50% decrease in storm frequency	25% increase mean lifetime max intensity	50% increase mean lifetime max intensity
Total financial impact of flooding event for ALL terminals (EBITDA per day, MXN)	9,932,592	19,865,185	7,449,444	4,966,296	12,415,740	14,898,889

Source: Report authors

Adaptation
Upgrade of drainage system

To reduce the likelihood and severity of surface water flooding in the future, the drainage system of the port can be upgraded. There are two elements API Manzanillo can consider that will provide multiple benefits:

- Increase in drain capacity. Upgrades to the capacity of drainage system would reduce the risk of surface water flooding through intense rainfall events. Additional capacity should accommodate the estimated changes in peak flows and return periods discussed in Section 2.2.2.
- Trap upgrade. API Manzanillo has advised that one of the issues that significantly increases the risk of surface water flooding, is the high build-up of sediment, waste and other solids in the drainage channels. API Manzanillo stated the port does not currently have adequate traps to prevent this build-up. By upgrading these traps, maximum capacity can be maintained, further reducing the risk of surcharge. An additional benefit is the further reduction of sedimentation in the port basin, reducing the requirement for maintenance dredging and loss of terminal access by ships.

As surface water flooding is considered a priority risk for the port, costs for upgrading the drainage system and their relative benefits with respect to climate change impacts have been assessed in detail and are presented in Section 3.4.2, chapter "Drainage maintenance".

Sustainable Drainage Systems (SuDS)

An option is to create smart Sustainable Drainage Systems (SuDS) at the port, taking into account potential changes in precipitation. SuDS are designed to reduce the potential impact of new and existing developments with respect to surface water drainage discharges, incorporating the following techniques:

- source control
- permeable paving such as pervious concrete
- storm water detention
- storm water infiltration; and
- evapo-transpiration (e.g. from a green roof)

Unlike traditional urban storm water drainage systems, SuDS can also help to protect and enhance ground water quality, and they are increasingly promoted as a modern, sustainable solution in many countries. It is suggested that the port should consider the feasibility and benefits of installing SuDS.

Drain clearance

An operational measure that can help reduce surface water flood risk is to review and adjust the drainage maintenance program e.g. increasing the frequency of drain clearance to ensure that the maximum capacity of the existing system is maintained at all times. This increased frequency of maintenance will have a financial cost to API Manzanillo (Section 3.4).

Ecosystem-based adaptation

Catchment level landscape planning and Ecosystem Based Adaptation options (EBA) can also reduce the risk of drainage overflow outside and inside the port. As this is an issue that involves action beyond the port perimeter, it can only be implemented through engagement with stakeholders in the municipality. For example, the ecosystem services provided by riparian zones can be better integrated with land use planning undertaken by the municipality. For instance, the establishment of plant cover in river basins can be used as a way of increasing infiltration and reducing runoff[126]. Grassed filter strips help reduce runoff and erosion by slowing water velocities in the vegetated areas[127].

Traffic control

To mitigate impacts within the port following a flooding event, traffic management measures can be implemented to minimize bottlenecks, promote rapid site evacuation and maintain business continuity during extreme events.

Early Warning Systems

A review of flood early warning systems can identify potential areas for improvement, in light of increased surface water flood risk. A successful early warning of a potential flood at the port could help mitigate impacts through:

- Early implementation of traffic management measures;
- Site evacuation and contingency planning; and
- Preparation and closure of water-sensitive infrastructure and storage areas

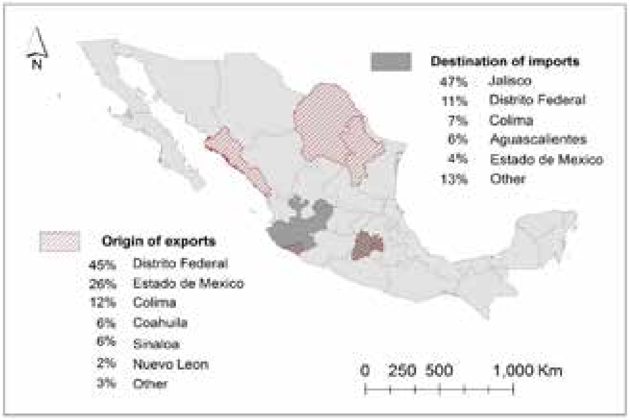
3.6.2. Land transport on wider network

Key characteristics of the road and rail network connecting the port to its areas of influence

Goods entering and exiting the port are transported either through the national road network or the Ferromex rail network. At present, the road network carries around 80% of total cargo to/from the Port and the rail network carries 20%. Of the goods imported through the port, 65% are destined for Jalisco (47%), Mexico D.F. (11%) or Colima (7%), whilst 83% of the goods exported have

FIGURE 3.26

Key areas of influence for the Port of Manzanillo



Source: API Manzanillo, 2012 [132]

FIGURE 3.27

Map of rail network

Source: Ferromex, 2012 [133]

SUMMARY OF KEY POINTS

- Key routes connecting the port to Colima City, are the Carretera Federal 98 and the Carretera Federal 100. From Colima City, goods are transported onwards to Guadalajara, the capital of Jalisco. This route is the key entry/exit node connecting Manzanillo to its wider market.

- In 2011, road expenditure in Colima due to damages caused by extreme weather was over 410 million Mexican pesos[128]. These damages are attributed to Hurricane Jova which hit the state in October 2011.

- According to Centro Nacional de Prevención de Desastres (CENAPRED's) risk atlas, 30% of main roads between Manzanillo and Guadalajara used by trucks can be significantly affected by tropical cyclones, with 13% being at high risk and 17% at medium risk.

- Ferromex is the only provider of transport services via rail. There is one rail route connecting Manzanillo to Guadalajara, via Colima. Therefore good rail conditions and low levels of interruptions on this section of the track is key for the sustainable and reliable transport of port shipments by rail.

- CENAPRED´s risk atlas estimates that less than 1% of the rail network connecting Manzanillo to Mexico D.F. and Guadalajara is currently at high risk from tropical cyclones. Most of the area at risk is in the near vicinity of the port.

- Major damage caused by the overflow of the River Armeria due to Hurricane Jova in 2011 led to interruption of rail services to the port lasting 17 days, causing major disruption to the dispatch and delivery of goods via rail.

- Due to significant uncertainty over future changes in tropical cyclones it is not possible to provide estimates of on how future changes in cyclones and subsequent incidence of floods may disrupt transport networks. API should monitor scientific advances in this area for better information to support these predictions.

- Adaptation planning should begin with closer monitoring of the effect of transport network disruptions on the revenue at the port, and impacts on customer satisfaction levels. API Manzanillo should work in closer collaboration with the Municipality and the State of Colima in the development of intermodal networks that increase the resilience of land transport systems.

their origin in D.F. (45%), Estado de Mexico (26%) and Colima (12%) (see Figure 3.26). Adequate connectivity and reliability in the transport system connecting these origins and destinations is thus of extreme importance for the commercial viability of the port.

Currently, the key road access routes to the port are the Carretera Federal 98 (exit to the North route) and the Carretera Federal 100. Both of these roads connect the Port of Manzanillo to the capital of the State (Colima), which can also be reached via Tecoman using the Carretera 200D. From Colima, goods are transported to Guadalajara (Jalisco) which is the key entry/exit node connecting Manzanillo to its key areas of influence.

Transport via the rail network is provided by Ferromex. Key rail routes to Manzanillo offer high capacity lines for trains of up to 120 carriages capable of carrying up to 16,000 tonnes of materials[129] (Figure 3.27). While at present only around 20% of moving cargo from the port is carried by rail, Ferromex has ambitious goals to increase its share to 35% in the next 3 years, by working with the terminals to increase its efficiency in the delivery and dispatch of cargo.[130] It is estimated that a train loaded with agricultural bulk has the same capacity as 300 trucks travelling by road.[131] Rail transport therefore offers a suitable, environmentally friendly alternative to road transport.

Currently all of the rail cargo is delivered via Guadalajara and from there to its different destinations (or from its different origins). As it can be noted in Figure 3.27 there is only one main rail route connecting Manzanillo to Guadalajara via Colima. This means that good rail condition and lack of interruptions in this section of the rail track is key for the sustainable and reliable mobility of goods by train in and out of the port.

Observed climate-related factors affecting the road and rail networks

Extreme hydrometeorological events including flooding, snow and extreme high temperatures can cause interruptions and delays in the delivery and dispatch of goods traded through the port, affecting the reliability and safety of its internal trade routes.[134]

Data are available from CENAPRED on the length of the road network damaged by extreme events over the period 2000 to 2010. In the state of Colima, between 2000 and 2010, 1,100km of roads were recorded to have been affected by hydrometeorological events.[135] These damages were all recorded in the year 2006 and were associated with the effects of Hurricane Lane. The Government of Colima estimates that the total cost of road reconstruction and repair in that single year equated to over 91 million MXN (29 million on the main state roadway and 62 million on rural roads).[136]

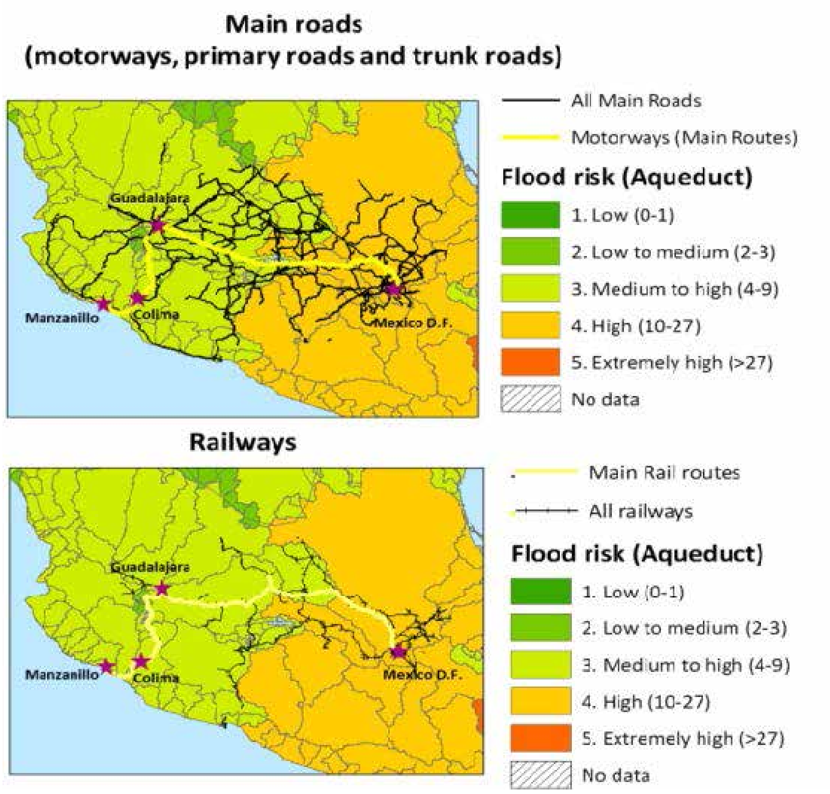
In 2011, road expenditure in Colima due to damages caused by extreme weather equated to over 410 million MXN[137]. These damages are attributed to Hurricane Jova, which hit the state in October 2011. Coastal areas affected during the hurricane experienced winds of up to 157 km/h (44 m/s) (category 3 on the Brennan scale) and storm surges of 1.5m above mean sea level.[138] From 11-12 October, within less than 24 hours, a total of 416 mm of rain were recorded at the meteorological station at Minititlan, between the Armeria and Chapala river catchments. As a result of the heavy rains the rivers Armeria, Colima, Marabasco and Salado overflowed, causing significant damage to infrastructure. The rail bridge in the Armeria River located between Manzanillo and Colima was partially destroyed. Although data are not available on the costs incurred by Ferromex in repairing the bridge, it has been noted that reconstruction works resulted in an interruption of rail services for the port lasting 17 days, causing major disruption in the dispatch and delivery of goods traded via the rail network.[139] During normal rain conditions Ferromex can execute preventative measures which allow it to continue its operation, such as adding sand on top of the rails to increase friction. However, events such as Hurricane Jova in 2011 show that the rail network can be subject to major damages due to unforeseen extreme hydrometeorological events and result in major disruptions in the transport of goods via land transport.

Guided by in-country consultations and based on available historic data, an analysis has been undertaken to evaluate the present-day level of exposure of the rail and road networks to cyclones and floods. The analysis is focused on the two key routes through which most of the goods are transported: The route from Manzanillo to Guadalajara and Guadalajara to Mexico D.F. From Manzanillo to Guadalajara there is only one railway route and two main road routes. This means that in the event of a disruption in the railway route there are no options for the transport of goods by rail, and that if one of the roads is disrupted, the other could become oversaturated. This makes transport from Manzanillo to Guadalajara highly susceptible to interruptions and delays in the event of a disruption.

As can be seen from Figure 3.28 based on data from the Aqueduct Water Risk Atlas[140], exposure to flooding is medium to high across most of the network used by the port. According to data from CENAPRED, the risk of cyclonic activity in the coastal zone is also medium to high, reflecting the high exposure of the municipality of Manzanillo to tropical cyclones (see Figure 3.29). Due to the lack of alternative rail routes to transport goods to and from Guadalajara, if the rail network is affected by extreme hydrometeorological events, the entire rail transport system has to stop, causing major disruptions in the dispatch and arrivals of goods by rail. The disruptions experienced by Ferromex in 2011 provide

FIGURE 3.28

Present-day flood risk of the road and rail networks. Yellow and black lines represent the main road and rail routes. The underlying map provided illustrates flood risk according to data provided by Aqueduct displaying flood occurrence between 1985 and 2011.[141]



Source: Report authors

an illustrative example of the high exposure of the rail network to tropical cyclones and this is further supported by this analysis. If Ferromex's plans to increase the share of cargo from the port transported by rail are realized, this would increase the vulnerability of cargo movements to weather-related disruption.

A more detailed analysis has been undertaken for both roads and rail between Manzanillo and Guadalajara, and from Guadalajara to Mexico D.F. This indicates that 60km of main roads utilized by truck traffic between Manzanillo and Guadalajara can be significantly affected by tropical cyclones, with 25 km (13%) being at high risk and 35 km (17%) at medium risk (see Figure 3.29). The route from Guadalajara to Mexico D.F appears to be at much lower risk. According to the analysis, less than 1% of the rail network connecting Manzanillo to Mexico D.F. and Guadalajara is at high risk to tropical cyclones. Most of the area exposed is in the near vicinity of the port.

Potential impacts of future climate change

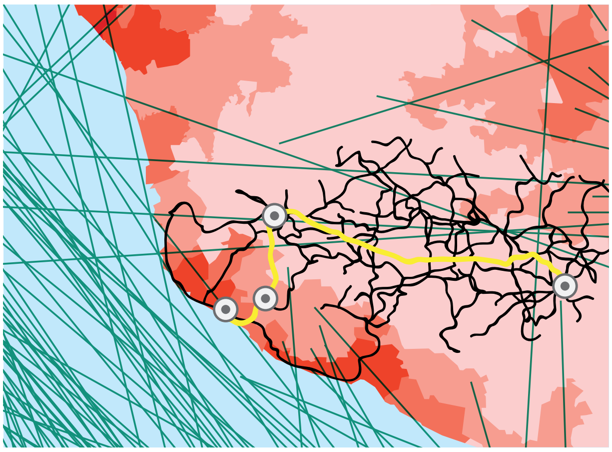
In the long run, if the observed climate-related events which have affected the road and rail network are significant and/or they worsen due to climate change, this could affect the port's reputation and competitiveness. As noted earlier, flooding, snow and extreme high temperatures are the main climate-related factors causing damage, interruptions and delays. There are few studies which have investigated the impact of extreme weather events and/or climate change on the transport network of Mexico. The Third National Communication (TNC) from Mexico to the United National Framework Convention on Climate Change (UNFCCC)[143] reports that national transport links are increasingly being identified as at high risk to climate impacts, particularly those in the coastal zone. The TNC also notes that if no action is taken this will lead to greater economic damage in the future as a result of extreme hydrometeorological events.[144] This is in accordance with the conclusions of the latest IPCC findings, which also highlight the potentially negative impacts of climate change-related extreme events on road and rail networks.[145]

FIGURE 3.29

Present-day exposure of road and rail network to tropical cyclones. Yellow and black lines represent the main road and rail routes. Lines in green represent cyclone tracks recorded between 1969 and 2009. The underlying map provided on a red scale spectrum is a map of tropical cyclone threat prepared by CENAPRED (2013) showing risk levels (from very low to very high) for all municipalities across Mexico.[142] On the left hand side, information on exposure of key motorways and rail network is provided in km.

ROADS

Summary level of threat | **Routes** | **Tropical Cyclone Risk Level**



Motorway route 1

Total length:
197 km
25 km high risk
(13%)
35 km medium risk
(17%)
43 km low risk
(22%)
94 km very low risk
(48%)

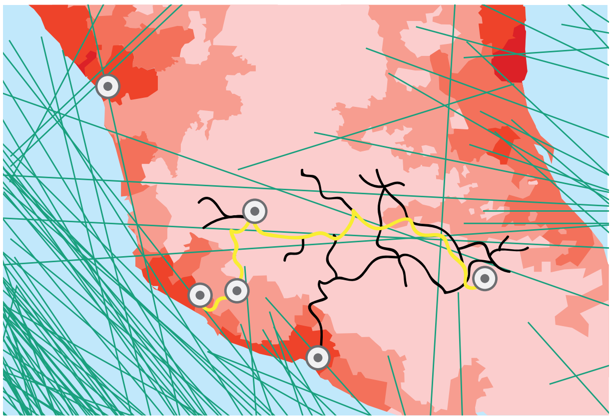
Motorway route 2

Total length:
514 km
04 km low risk
(<1%)
510 km very low risk
(>99%)

Routes: Urban Areas; Motorways (Main Routes); All main roads (Primary and Trunk Roads); Tropical Cyclones Tracks (**CAT 1** 1969-2009)

Tropical Cyclone Risk Level: Very low; Low; Medium; High; Very High

RAILWAYS



Main rail route

Total length
875 km
06 km high risk
(<1%)
19 km medium risk
(2%)
146 km low risk
(17%)
705 km very low risk
(81%)

Routes: Urban Areas; Main Rail Routes; All railways; Tropical Cyclones Tracks (**CAT 1** 1969-2009)

Tropical Cyclone Risk Level: Very low; Low; Medium; High; Very High

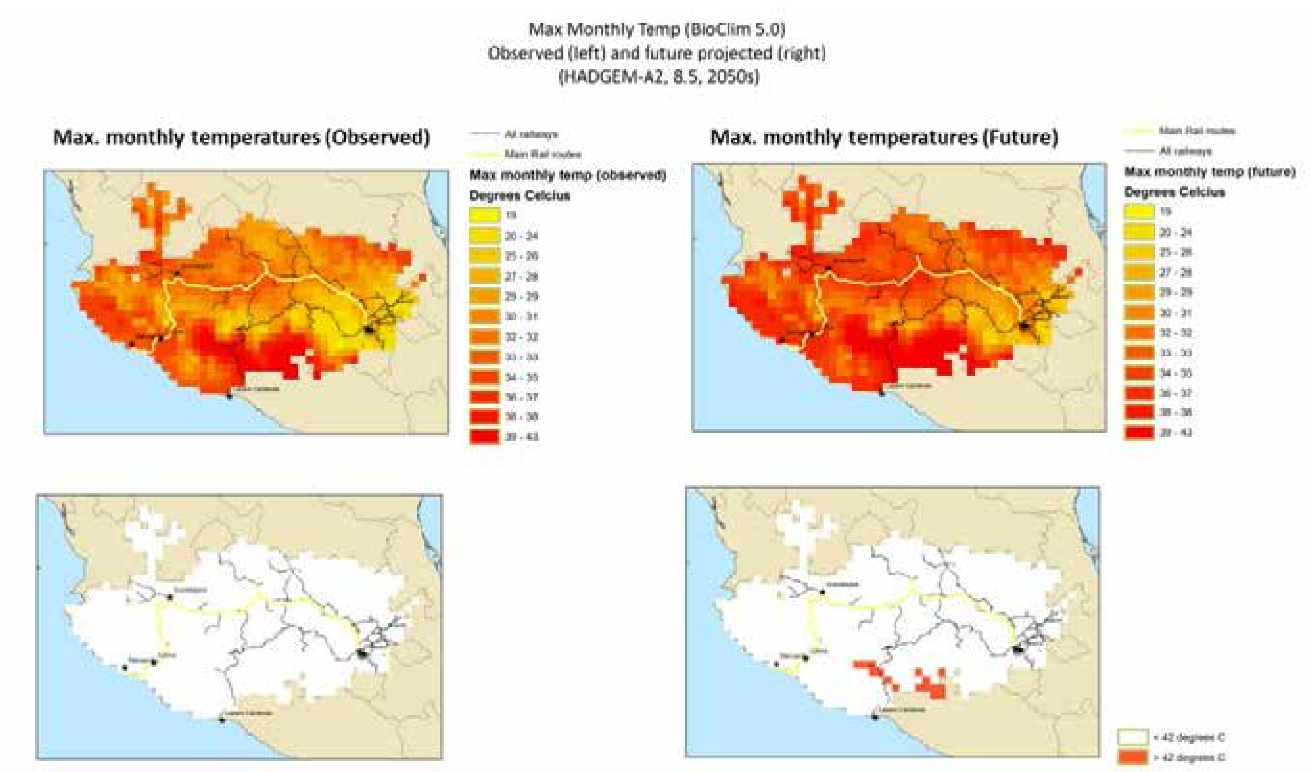
Source: Report authors

Cyclones are the main driver of flooding affecting the transport network of the port. However, as outlined in Section 2.1, there is significant uncertainty over future changes in cyclones due to climate change. For the moment it is therefore not possible to provide accurate estimates of how future changes in cyclonic activity and subsequent incidence of floods may disrupt transport networks. API should monitor scientific advances in this area until better information is available to support these assessments.

It is, nevertheless, possible to explore the implications of projected changes in temperature. During consultations with Ferromex, it was noted that the key climate parameter causing interruptions and delays on the rail network is snow in the north of Mexico, which affects transportation of products to and from the United States as trains may need to stop or slow down, in accordance with SCT operational standards.[146] The incidence of snow is strongly temperature-dependent and represents a problem in the north of the country, along the border with the United States. However, since this route is outside the main area of influence of the port's activity (see Section 3.6.2, chapter "Key characteristics of the road and rail network connecting the port to its areas of influence") an analysis of snow events in the rail network has not been undertaken. Additionally, consultees from Ferromex noted that extreme high temperatures (specifically, temperatures above 42°C) can cause delays in the rail network, as trains are forced to reduce their speeds. Taking into account future projected increases in temperature (see Section 2.1), analysis has been undertaken of maximum monthly temperatures for the key rail transport routes used by the port, to evaluate the extent to which future temperature changes may affect the incidence of delays (see Figure 3.30). The results, based on a mid-range climate model, suggest that for the Ferromex route connecting the port to Guadalajara and Mexico D.F., the likelihood of temperatures exceeding 42°C by mid-century are low: nowhere along the route are temperatures seen in excess of 42°C. In contrast, Figure 3.30 indicates that the rail network connecting Lazaro Cardenas to Guadalajara and Mexico D.F. may be more affected by extreme high temperatures in the future, as it runs through areas where temperatures in excess of this threshold are projected to occur. This may provide a reputational benefit and thus a source of competitive advantage to the Port of Manzanillo.

FIGURE 3.30

Observed and future maximum monthly temperatures (top) and maximum monthly temperatures in excess of 42°C (bottom).[147] The main rail route from the port to Mexico D.F. is shown in yellow



Source: Report authors

Adaptation actions

Since API Manzanillo is not responsible for the road and rail networks outside the port, it can do little directly to reduce its vulnerability to climatic events affecting Mexico's transport network. Changes and upgrades to the transport system will be the responsibility of local and national transport departments and Ferromex. However, if API Manzanillo has evidence from the port's customers suggesting higher levels of dissatisfaction due to disruptions experienced, it could use this information to engage with government on the importance of developing a climate resilient transport system. Currently, Mexico's National Disasters Fund only provides financial support for the reconstruction of road infrastructure by following the same parameters of construction of the original infrastructure prior to damage. A potential increase in the destructive potential of tropical cyclones, along with projected changes in other climate-related parameters, should be taken into account during reconstruction works to ensure new infrastructure is resilient to climate change. Information gathered by the port in collaboration with other key users of the transport network could help provide the evidence needed to encourage the Fund to account for future climate change and climate resilient design parameters when determining investment requirements for the reconstruction of roads and rails affected by extreme hydrometeorological events.

3.6.3.
Maritime transport

SUMMARY OF KEY POINTS

- Current and future frequency and intensity of Asian typhoons can cause increased delays in vessels reaching Manzanillo. In 2014, some 25% of vessels originated from South East Asia.
- Changes in East Pacific tropical storms can also affect regional export and import of goods from Manzanillo. The port receives 68% of its cargo from the Mexican Pacific[148].
- Tropical storms result in average 0.4% annual closure for vessels > 500 gross tonnage and 3.7% for vessels < 500 gross tonnage.
- A future increase in maximum intensity and duration of typhoons and tropical storms will potentially affect regional Pacific trade using smaller vessels more than it will affect international trade using larger vessels.
- Available adaptation includes broadening the client base to be less dependent on maritime traffic from South East Asia and exploiting routes less sensitive to tropical storms e.g. the Northern Passage. The port can also ensure it has well-developed regional contingency plans such as using road and rail networks.

The Port of Manzanillo is a key part of the Pacific basin logistics chain, connected with 77 destinations around the world[149]. It is the biggest mover of containers in Mexico, with 46% of the total Twenty Foot Equivalent Units (TEUs)[150].

It has multiple maritime import routes, including Chile, Canada, the US and Russia, and South East Asian countries of Indonesia, Malaysia, Singapore, the Philippines, Hong Kong, China, Korea and Japan. Key maritime export routes are more focused on Latin American countries, including Colombia, Guatemala, Ecuador, Peru and Chile, but also include the US, Korea and Japan (Figure 3.31).

Risk Analysis

Local maritime conditions in all export and import destinations have a direct effect on the planned movement of vessels, indirectly affecting the operability and efficiency of the Port of Manzanillo.

International

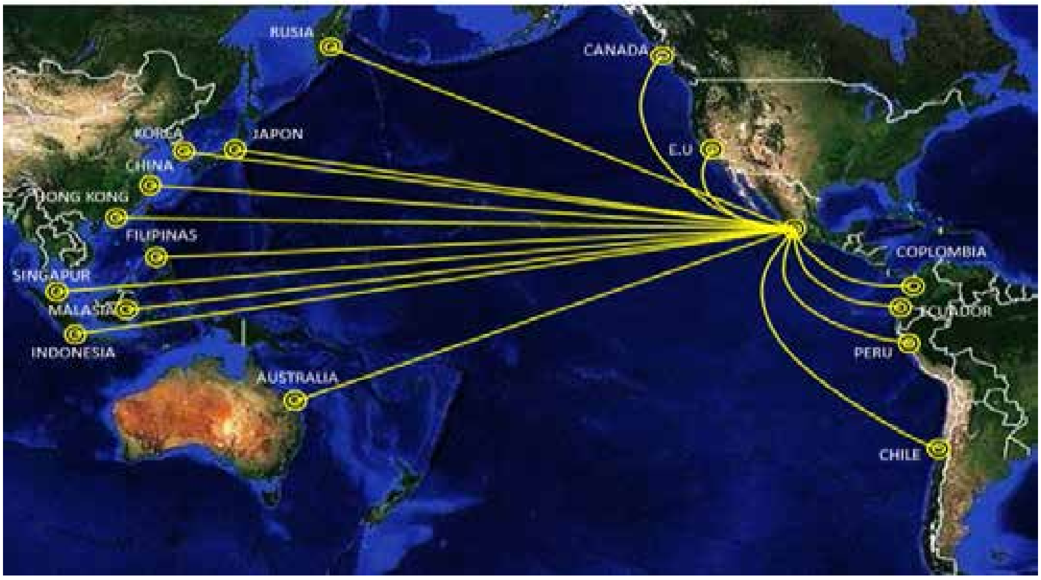
Due to the strong import relationships with South East Asia, a potential climate risk is the current and future frequency and intensity of Asian typhoons, causing delays in vessels reaching Manzanillo. Analysis of data provided by API Manzanillo shows that in 2014 approximately 25% of vessels originated from South East Asia. It takes 18 to 20 days for a vessel to arrive from Asia.

Container vessels commonly execute multiple port deliveries for a single vessel load. These multiple port deliveries are on a strictly defined schedule. If vessels are significantly delayed, the vessel could be forced to bypass Manzanillo. For example Lázaro Cárdenas is the first port on arrival from South East Asia and the last port when leaving South America.

While difficult to predict accurately, analyses indicates that the frequency of storms in the North West Pacific will decrease, but maximum intensity and duration of maximum intensity is likely to increase. Records of worldwide hurricane activity show an increase in both maximum wind speed and duration of maximum intensi-

FIGURE 3.31

Port of Manzanillo export and import routes



Source: SCT, 2013 [147]

ty over the past 30 years[151]. The average energy released has increased by approximately 70%, corresponding to a 15% increase in maximum wind speed and 60% increase in storm duration[152]. Future increases in intensity would likely result in increased delays for the maritime import of goods from key Asian markets.

If impacts from typhoons become extreme, then alternative routes could be sought, such as into the Persian Gulf, affecting overall trade between South East Asia and the Eastern Pacific. However this risk could be reduced by improved monitoring and prediction of storm activity, allowing shipping lines to plan and mitigate risks to a greater extent.

Regional

Changes in East Pacific tropical storms can also affect regional export and import of goods from Manzanillo. The port receives 68% of its cargo from the Mexican Pacific[153]. In 2014, 20% of vessels leaving the Port of Manzanillo were destined for the port of Lázaro Cárdenas, 250 km to the south.

Expert judgment of scientists (Section 2.1) indicates that fewer storms are expected in the East Northern Pacific in future, but they will likely occur with increased intensity. Manzanillo's position relative to other competitor ports on the Mexican Pacific, such as Lázaro Cárdenas and Ensenada, makes it subject to greater influence from tropical cyclones. Under this scenario, there is a risk that key export business lines will choose to export either from Lázaro Cárdenas or over land.

Data has been provided by SCT[154] on annual closures of the Port of Manzanillo. This is given for large and small vessels (greater and less than 500 UAB (Table 3.33). Vessels less than 500 UAB are shown to be subject to more frequent access closure. As already noted, an estimated 15% of vessel traffic (in terms of cargo value) through the port is comprised of vessels less than 500 UAB. The climatic reason for the port closure is not specifically given in the data. However the record indicates the majority of delays occur in the tropical storm season of June to October.

The average loss of access 2010 to 2013 for large vessels at Manzanillo is only 0.4%, but for smaller vessels it is 3.7%.

Both large and small vessels are used for both international and national\regional trade. However smaller vessels are likely to dominate the Mexican Pacific movement of goods. This could result in greater sensitivity for national\regional maritime transport, compared to international shipping routes using larger vessels.

A 25% or 50% increase in the intensity and\or proximity of tropical storms to Manzanillo would not have a significant effect on larger vessels (0.1% to 0.2% increase in closure). However smaller vessels, being more sensitive to berthing in high wind and wave conditions would be subject to a significantly greater loss of access per year (0.9 % to 1.8% increase).

Financial analysis

Financial impacts from vessel delays at origin will be borne by the shipping lines and\or terminals. This is dependent on contractual conditions. For example CEMEX stated that when a vessel from South East Asia has reserved a berthing and offloading slot at Manzanillo but then decides not to come, the terminal loses the revenue. If the vessel has departed and is transiting to Manzanillo, but is late for that berthing slot, then it does not affect the terminal financially.

Understanding the specific level of future financial impact to the Port of Manzanillo is beyond the scope of this study, due to the inability to accurately predict storm activity. Analysis of costs of port closure for vessels can be given as an indication of potential lost revenue from maritime traffic. This is discussed in Section 3.2.4.

As size of vessel is shown to be key in determining potential disruption, an assessment could be made of vessel size (<> 500 UAB) and origin and destination. This would allow an understanding of the level of potential impact for different regions, and likelihood of selection of alternative transport, e.g. road\rail.

Adaptation

The options for adaptation and mitigation of impacts can focus on broadening the client base to be less dependent on maritime traffic from South East Asia, and increasing the diversity of clients from international regions less subject to storms. New shipping routes less sensitive to tropical storms e.g. the Northern Passage could also be exploited. The attractiveness of the port to Mexican Pacific cargo can be maintained through well-developed regional contingency plans, such as the use of road and rail networks if required.

TABLE 3.33

Annual access closure of the port relative to vessel size

Year	Vessels greater than 500 UAB	Vessels less than 500 UAB
2010	0 days (0.0%)	4 days 18 hours (1.3%)
2011	1 day 16 hours (0.5%)	19 days 15 hours (5.4%)
2012	0 days 0.0%	10 days (2.7%)
2013	3 days 23 hours (1.1%)	19 days 3 hours (5.3%)

Source: Report authors

3.7. Environmental aspects

3.7.1. Summary of Climate Risks

A summary of key climate risks for the environmental performance of the port is given in Table 3.34.

3.7.2. Baseline Environment

The area in and around the Port of Manzanillo includes valuable marine ecosystems subject to potential impacts from climate change. These include protected coastal lagoons and protected mangrove habitat.

Mangroves

Mangroves are considered as a 'species of less concern' by the International Union for Conservation of Nature (IUCN) Red List, due to their wide global distribution and relative abundance. However the four most common mangrove species in Mexico (White Laguncularia racemosa, Red Rhizophora mangle, Black Avicennia germinans, and Buttonwood Conocarpus erectus) are now considered threatened under Mexican legislation (NOM-059-SEMARNAT-201011). The mangroves within and around the port area are key elements determining API Manzanillo's environmental performance.

The internal port basin (Laguna de San Pedrito) currently retains a significant amount of native mangrove habitat and ecologically important areas, including:

- A 60 m wide mangrove border on the western perimeter termed the "ecological band" including 5 hectares to the northwest acting as a seed germination bank (Figure 3.32)
- An enclosed "ecological channel" running perpendic-

SUMMARY OF KEY POINTS

- API Manzanillo is responsible for obtaining and/or maintaining the 'Certification of Clean Industry or Environmental Compliance' for the port area. The port is certified to ISO 14001.
- Climate change may impact on the environment, and result in increased risks to API Manzanillo's environmental performance.
- Potential issues will be:
  - Increased pressure on mangroves through sea level rise, high temperatures and drier conditions;
  - Increased levels of dust creation and dispersion inside and outside the port as conditions become drier and hotter;
  - Increased disposal of maintenance dredging material affecting benthic habitat;
  - Increased energy use and greenhouse gas emissions.
- API Manzanillo are insured against environmental non-compliance determined by SEMARNAT.
- Adaptation options include managing the mangroves within the port to adapt to SLR, and reducing where possible other negative stressors for mangroves outside the port.
- API Manzanillo should also review and enhance current protocols for dust management in consultation with the municipality, bearing in mind API Manzanillo's commitments under ISO 14001.
- Actions for reducing GHG emissions that can be applied to energy use for reefers and cold storage warehouses include implementation of a system using photovoltaic power generation, and a port wide review of energy efficiency and development of an energy management system taking into account rising temperatures.

TABLE 3.34

Environmental risks

Risk	Thresholds and Sensitivities	Current and future climate/ oceanographic variability and change	Risk Description
Changing climatic factors affecting API Manzanillo's environmental performance and insurance costs for mangrove habitat	• API Manzanillo is responsible for maintaining 'Certification of Clean Industry or Environmental Compliance' for the port area. Port is certified to ISO 14001. • Mangroves are the coastal habitat of key concern. • API Manzanillo is insured against non-compliance for environmental targets with respect to mangroves. • Sea facing wall protecting the Laguna de las Garzas is +1.25 m above sea level.	• Mangrove distribution, health and species affected by multiple combining climate driven factors. Sea level, rainfall, temperature are key issues. • Worst case sea level rise (RCP 8.5) to be 0.16m by 2050. • Drier conditions overall - daily ERA-I data shows modest decreasing trends in low threshold exceedances e.g. 1 to 4 mm • Hotter conditions - Warming along the coast near Manzanillo reaches 2˚C in the dry season by the 2040s for RCP 8.5 (1.2˚C for RCP 4.5) and 3˚C by the 2070s for RCP 8.5 (1.8˚C for RCP 4.5).	• Mean SLR unlikely to have significant effect on mangroves by 2050. • Worst case mean SLR scenario by 2100 combined with tidal, seasonal and El Nino maximums would result in frequent exceedance of the sea facing wall, resulting in 'drowning' of the mangroves • Drier conditions will result in a fall in productivity and diversity. • Hotter conditions can improve growth but disrupt ecosystem balance. • Insurance costs borne by API Manzanillo will likely increase if port activities\expansion disrupt additional areas and protected species.

Increased problems of dust creation and dispersion in drier conditions, both inside the port and from surrounding municipal areas	• Inside the port, dust is generated mainly from the handling of bulk minerals. • Outside the port from unpaved storage areas, construction activities and movement of traffic. • The hydrological flooding events also result in sedimentation of the main port entrance and the internal access road	• Conditions becoming hotter and drier (see above). • Will lead to increased dust creation and dispersion inside and outside the port	• Management of dust was reported as a significant issue inside and outside the port. • Dust is considered more of a social\health issue than an environmental one. • Dust management protocols are in place, developed in discussion with the local community. • These will require review and enhancement under hotter and drier conditions • Bulk mineral handling terminals affected the most. Terminals have own management protocols. • However dispersion occurs throughout the port, affecting all terminals.
Increased loss of water quality and benthic habitat due to increased runoff, maintenance dredging and disposal of dredge material	• Mangroves and associated flora and fauna are dependent on water quality within the port. • Surface water flooding can result in pollutants being washed from storage areas into the port basin. • Dredging can impact on water quality, as hydrocarbons, heavy metals, polychlorinated biphenyls (PCBs), and nutrients can bind to suspended sediment. • Disposal of dredged material also generally results in an impact on benthic communities.	• Significant increasing historical trend for Manzanillo ERA-I data (June) for higher rainfall threshold exceedances e.g. 10 mm and 20 mm. • 8% increase in 20-yr median return value for 24 hr precipitation by 2050. • Increased rainfall will required increased maintenance dredging and offshore disposal of sediment.	• Approximate doubling in frequency of surcharge of the drainage system at the port. • 8% increase in heavy rainfall by 2050, additional 8,000m^3 of dredge material to be removed per year. • However API Manzanillo only dredges in the turbid inner harbor, release of contaminants expected to be limited. Offshore shore disposal will likely receive increased scrutiny under a scenario of climate change impacts on ecosystems. • Affects whole port area and municipality surrounding the port.

Source: Report authors

FIGURE 3.32

Mangrove border, ecological and intra-lake channels

Source: API Manzanillo, 2014 [155]

ular from the mangrove border to the port's harbor to supply the water needed for survival of the mangroves; and

- The "intra-lake channel" opened to maintain hydrological connectivity between the port and the Laguna de Las Garzas to the north

Historically, evidence indicates that mangroves were not prevalent prior to development of the original port. Figure 3.33 shows a pre-1970 aerial photograph of the port area where halophytic plants are dominant. Following the widening of the ocean outlet channel after 1972, tidal marine waters were able to enter the lagoon, producing conditions more suited to mangrove development (Figure 3.34).

Protected species

API Manzanillo's financial environmental commitments are largely determined by the protected species that are found in areas that construction and operational activities affect. In addition to protected mangrove species, the recent development of the CONTECON terminal provided information on protected fauna that were present in the affected mangrove habitat (Table 3.35).

While the American crocodile is an IUCN Vulnerable Species, it is not considered likely that the Manzanillo mangroves are crucial for the survival of this species. The mangrove area removed as part of the CONTECON development was not unique in the region nor did it represent a significant proportion of the overall available mangrove habitat in Mexico.

Laguna de Las Garzas

The port harbor is connected to the Laguna de las Garzas to the north through a 700 m long channel. The lagoon has undergone recent significant reforestation and restoration through an API Manzanillo management program (Figure 3.35). A total of 9.5 hectares have been reforested using red mangrove and white mangrove seedlings. As part of the CONTECON project, the IDB and IFC have included legal requirements to ensure compliance regarding mangrove reforestation.

Laguna de Cuyutlan

The Laguna de Cuyutlan to the south of Manzanillo is the fourth largest coastal wetland in the country and is designated a Ramsar site (No. 1985). It is the only large wetland along the entire 1150 km of the Mexican Pacific coast. The large complex supports significant mangrove habitat and water birds and receives international attention. At least 25 water bird species are known to breed in the lagoon and at least 61 water bird species use the lagoon during their non-breeding season[160]. The lagoon has been subject to several structural modifications, including levees and artificial channels opening access to the sea, while terrestrial water supply has decreased[153].

Cuyutlan is currently being studied as an area for potential expansion for the port.

El Chupadero

API Manzanillo signed an agreement with SEMARNAT in 2014 for the performance of the necessary studies to declare El Chupadero Estuary as a Protected Natural Area. These studies have been prepared and are under evaluation by SEMARNAT. In discussion with API Manzanillo the estuary was included as an indicator of environmental performance for the port.

The Chupadero estuary lies approximately 60 km southeast of Manzanillo. It supports the four different species of mangrove present in Mexico. The mangroves are in constant contact with local residents and are considered under pressure. Chupadero supports a wide variety of mammals including the Neotropical otter (Lontra longicaudis), deer, coatis and peccaries. Historically the Chupadero lagoon has provided sanctuary for large populations of green iguanas (Iguana iguana).

FIGURE 3.33

Pre-1970 image of Port area

Source: CH2M Hill, 2014 [156]

FIGURE 3.34

Year 2005 image of Port area showing mangrove habitat

Source: CH2M Hill, 2014 [157]

3.7.3.
API Manzanillo's environmental responsibilities

API Manzanillo is responsible for obtaining and/or maintaining the 'Certification of Clean Industry or Environmental Compliance' for the port area. These are required to ensure that the port leaseholders and service providers within the port implement actions to maintain the local environment. API Manzanillo is also responsible for monitoring compliance with environmental legislation within the port, and compliance with agreements issued through concessions to the terminals.

API Manzanillo is certified to ISO 14001, which demonstrates a strong commitment to environmental protection[xxxiii]. ISO 14001 applies to those environmental aspects over which API Manzanillo has control and can be expected to have an influence on.

Construction works (such as development of the northern zone) and ongoing operational activities at the port have a range of environmental impacts, namely:

- Impacts on mangroves
- Impacts of dredging, water quality; and
- Dust generation, air quality

How climate change will influence these issues and the effect on API Manzanillo's environmental performance are discussed below.

3.7.4.
Summary of climate change impacts on the environment around the port

Mangroves

Four main abiotic factors limit the distribution of mangrove trees: climate (especially temperature), salinity, tidal fluctuation and wave energy[161]. Of these, changes in salinity through sea level rise are projected to be the greatest climate change-related impact[162].

TABLE 3.35

List of protected species relocated from mangrove areas during clearance for the CONTECON terminal

Protected Species	Common Name	Protection Status - Mexico[xxxii] and IUCN
Syrrhophus modestus	Blunt-toed chirping frog	Endemic with Special Protection in Mexico; Not yet assessed for IUCN Red List
Iguana	Green iguana	Non-endemic with Special Protection in Mexico; Not yet assessed for IUCN Red List
Ctenosaura pectinata	Spiny-tailed Mexican iguana	Endemic and Threatened in Mexico; Not yet assessed for IUCN Red List
Boa constrictor	Boa	Non-endemic but Threatened in Mexico; Not yet assessed for IUCN Red List
Crocodylus acutus	American crocodile	Non-endemic but Special Protection in Mexico; Considered a Vulnerable species in the IUCN Red List
Aspidoscelis lineatissimus	Colima whip-tail lizard	Endemic with Special Protection in Mexico; Not yet assessed for IUCN Red List

Source: IADB, 2014 [158]

In general, mangroves are restricted to a narrow fringe within the intertidal area. As sea level rises, the region where suitable conditions exist for mangrove can move or disappear.

In addition, there is likely to be a succession to saline-tolerant mangrove species due to greater ingress of seawater, particularly in combination with a reduction in annual mean rainfall. Succession occurs from red mangroves (saline tolerance to maximum 60 parts per thousand) to white mangroves (80 parts per thousand) as conditions become more saline.

Air quality\Dust

Management of dust was reported as a significant issue at the port and is a cause for concern within the municipality. Inside the port, dust is generated from handling of bulk minerals, and outside the port from unpaved storage areas, construction activities and movement of traffic. The hydrological flooding events also result in sedimentation of the main port entrance and the internal access road. This deposited sediment can turn to dust on drying. Major weather events such as Hurricane Jova have also resulted in substantial transport of sediment towards the port, which results in dust. By affecting air humidity, temperature and wind, climate change can favor dust creation and dispersion. As average conditions become drier and hotter at the port, increased levels of dust are likely to occur.

Water quality

Water effluents from port activities often contain pollutants. When surface or seawater flooding occurs, and drainage systems, sediment traps and oil/water separators are insufficient, pollutants are washed from storage areas into water bodies.

The frequency of intense rainfall events and maximum intensity of these events is already increasing at the port. Surface water flooding events are likely to increase in the future, resulting in greater occurrences of contaminants entering the harbor.

As already noted, increased runoff from storm events will also result in increased sedimentation and maintenance dredging at the port. Dredging can impact on water quality, as hydrocarbons, heavy metals, polychlorinated biphenyls (PCBs), and nutrients can bind to suspended sediment[163]. Disposal of dredged material also generally results in an impact on benthic communities[164].

FIGURE 3.35

Laguna de las Garzas

Source: API Manzanillo, 2014 [159]

Coastal erosion

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.

Limited research exists on the degree of coastal erosion close to the port. However discussions with API Manzanillo and Consultec indicate that a degree of erosion of Las Brisas beach, adjacent to the port, has been occurring for a number of years. This is reportedly due to the construction of buildings and apartments close to the shore affecting natural deposition processes, a lack of longshore transport, and decreased deposition of sediment from discharges into the sea.

Increased wave strength will also result in greater coastal erosion. Studies indicate that maximum and average wave height is likely to increase in the future in the tropical Eastern Pacific (Section 2.3.2, chapter "Mean sea Level")[165]. Increases in mean sea level will compound these impacts. 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 further increasing coastal erosion rates.

While not currently considered a major hazard, coastal erosion is likely increase in the future at Manzanillo, particularly if combined with the loss of 'soft' coastal defenses such as mangrove habitat.

Climate risks on API Manzanillo's environmental performance

Mangroves

In the general absence of significant coral reef and seagrass habitats around the port, mangroves are the coastal habitat of key concern. API Manzanillo's responsibility to maintain mangrove habitats is significant. Commitments are outlined in the port Environmental Impact Assessment (EIA) and Environmental Management Plan (EMP), with penalties to be paid to the government for non-compliance. API Manzanillo is insured against non-compliance, in consultation with SEMARNAT.

With respect to setting the level of insurance paid and how this will change in the future, this is determined by SEMARNAT. If a construction project affects a protected species (NOM-059-SEMARNAT-201), SEMARNAT will review the project and set costs for the policy to ensure prevention, mitigation and compensation of impacts. For API Manzanillo, insurance costs could not increase in the future unless a new construction project e.g. expansion of the Cuyutlan Lagoon goes forward. However the level of potential increase is not readily quantifiable at this stage.

Climate change has a number of potential impacts on mangroves. The following issues are considered of note for their future management in and around the port:

Sea level rise

Tidal wetlands are extremely sensitive to sea level rise. If flooding is excessive mangroves will "drown"; if the receive too little sea water their productivity will be reduced and they will be replaced with salt marsh or cyanobacterial communities[166].

The sea facing wall protecting the Laguna de las Garzas is currently +1.25 m above mean sea level. Under the 'moderate' SLR scenario developed for this study (IPCC RCP 2.6), mean sea level would increase by +0.13 m by 2050 (relative to 2015). If combined with tidal, seasonal and ENSO maximum contributions to sea level this would result in a height of +0.83 m by 2050 (see Table 2.17). Seawater flooding of the lagoon would only occur in combination with a storm surge, such as the 1 in 50 year event. For example +0.83 m from mean SLR plus tidal, seasonal and ENSO maxima + 0.91 m from the 1 in 50 year storm surge = +1.74 m.

By 2100, the 'worst-case IPCC SLR scenario (RCP 8.5) shows a mean sea level increase by +0.66 m (relative to 2015). This would result in a rise of +1.36 m when combined with tidal, seasonal and decadal maximum contributions, resulting in frequent flooding. In this case, additional protection would have to be implemented by API Manzanillo.

Whilst species succession due to changing salinity is already visible at the port, the responsibility of API Manzanillo to manage this as part of the overall conservation program is not currently defined.

Rainfall

Meteorological data for Manzanillo shows a significant observed dry season decrease in rainfall of 2.7 mm per year (Section 2.1). Extrapolation of ERA-I data indicates a 23% decrease in rainfall events at Manzanillo by 2040.

A number of issues occur with mangroves when mean rainfall is reduced. Sedimentation decreases, combined with a fall in productivity and diversity. Both of these factors reduce wetland surface elevation, increasing susceptibility to sea level rise. Areas with low tidal ranges, low rainfall and limited sediment supply such as Manzanillo are more likely to experience a landward retreat of tidal wetlands[167]. Drier conditions are expected to result in significant pressures on the mangroves in and around the port. This will result in increased management and potentially higher insurance costs for API Manzanillo.

Temperature

Rising air and sediment temperatures can have a number of impacts on the reproductive capacity of mangroves. Higher temperatures can increase rates of root respiration and growth, leading to increased rates of nutrient recycling and regeneration. However photosynthetic canopy respiration can be reduced at higher temperatures e.g. 38 to 40°C[168].

Mean temperatures are shown to potentially increase by 3.4°C by the 2070s under the mid-range RCP 8.5 scenario. Estimating the impact of this change on the mangroves is challenging, as multiple factors will determine the outcome. However Manzanillo is likely to experience an increase in mangrove growth rates over time, but with potential negative effects on carbon balance that is not matched by increases in production[159]. The balance between mangroves and other species within the wetland is likely to be altered.

Air Quality\Dust

Increased levels of dust creation and dispersion inside and outside the port are likely to occur as conditions become drier and hotter. Dust is considered a social\ health issue rather than an environmental one and is discussed further in Section 3.8.

A number of environmental management standards exist for implementation and control of dust, including ISO14001 to which API Manzanillo is certified. During discussions, API Manzanillo stated that specific dust management protocols are in place, developed in discussion with the local community.

These current protocols will likely require future enhancement and increased investment from API Manzanillo. As issues with dust are frequently outside of API Manzanillo's control, stakeholder engagement and management will need to be maintained and\or improved. This includes working with the municipality, terminals and vessel operators.

Water quality

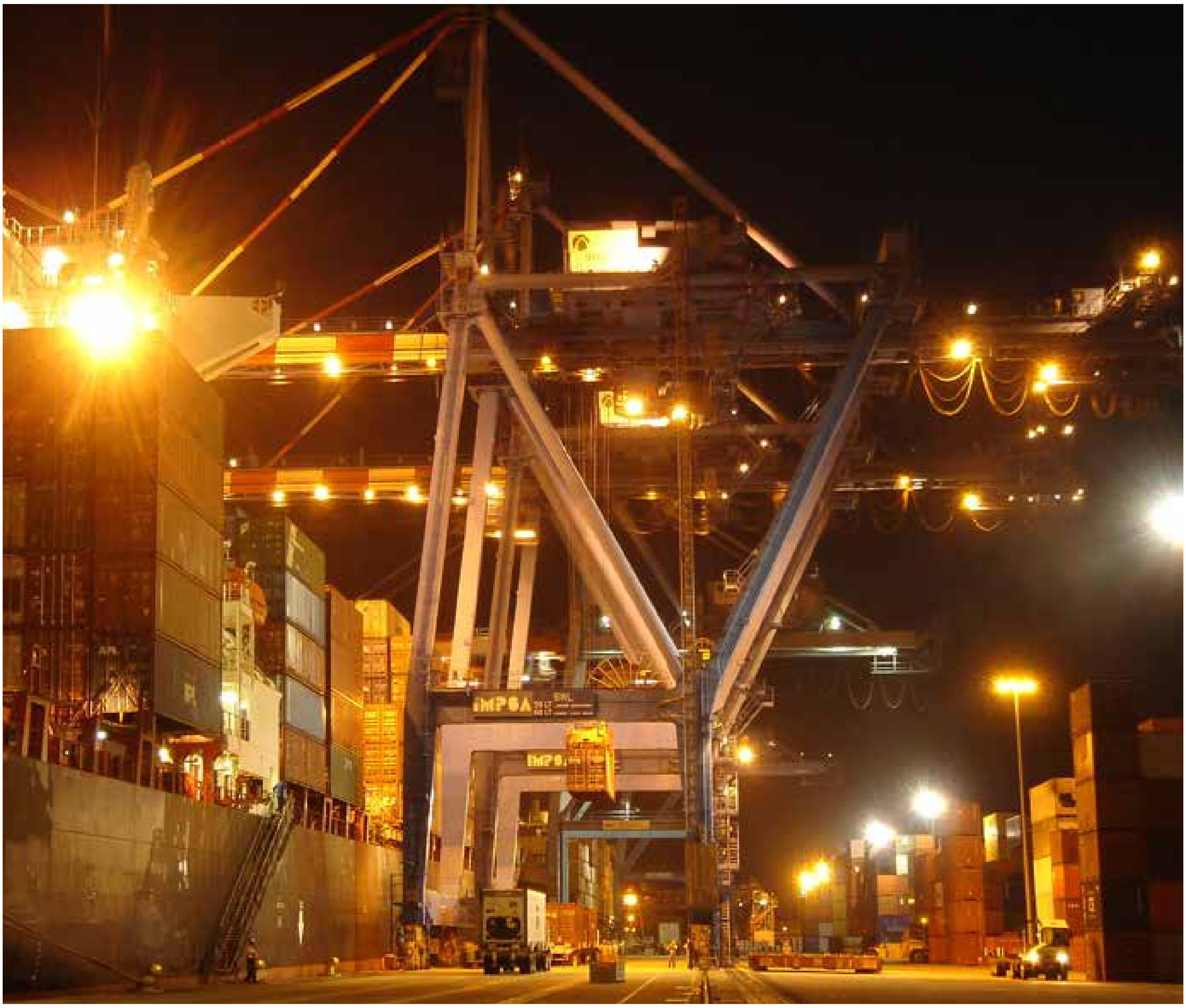
The effect of climate change on API Manzanillo's responsibility to maintain water quality is expected to be limited.

With regards to greater impacts on water quality from increased maintenance dredging, API Manzanillo only dredges in the inner harbor. This is not considered a pristine environment, and turbidity is already high compared to offshore. Any increase in maintenance dredging will therefore not significantly affect the port's environmental performance through release of contaminants.

Regarding offshore disposal, the quality of maintenance dredge material is regularly tested, and disposal occurs under license. However the future disposal of dredged material is crucial. Disposal sites must be selected carefully to reduce the impact on benthos and reduce the risk of sedimentation affecting sensitive marine habitats. This is within a scenario of climate change impacts on sensitive ecosystems leading to increased scrutiny on nearby dredging activities.

Increased energy use and associated greenhouse gas emissions

As discussed in Section 3.1, rising temperatures are likely to result in increased energy use at the port and hence a rise in associated GHG emissions. The 2015 carbon footprint study[169] undertook an energy audit to assess



the primary sources of energy used and where energy could be saved. Two of the primary factors listed are office buildings and warehouses, and air conditioning equipment, both sensitive to increases in temperature. Other primary usage is from cranes, conveyors, lighting systems and recharge of electrical machinery such as forklifts and trucks.

3.7.5. Adaptation

The following actions can further benefit the port's environmental performance, and help to maintain required standards under climate change:

Mangroves

The remaining mangrove habitat on the western perimeter of the port, and to the north and south in the Laguna de las Garzas and Laguna de la Cuyutlan, can act as an important coastal protection from coastal flooding.

API Manzanillo can consider adaptation measures which could help the mangrove within the port harbor to adapt to SLR. Due to its location in a restricted channel to the west of the CONTECON terminal, it is not possible for the mangrove to retreat as sea level rises. Therefore it must move upward out of the water in response.

To do this the sediment substrate must increase in height and API Manzanillo can assist this process, for example through the use of dredge material[170]. 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 e.g. how species succession can affect the protection offered by mangroves and how this can be managed within the port.

In addition, where possible, port expansion should be designed to avoid disturbance of protected species and avoid increased insurance costs to SEMARNAT.

Reduction of greenhouse gas (GHG) emissions

Adaptation associated with improving the energy efficiency of cooling equipment (as described in Section 3.1.3, chapter "Increase the efficiency of cooling equipment") will have a positive impact on the environment through reduced GHG emissions associated with the consumption of thermal electricity. The 2015 carbon footprint study[171] reviewed the primary sources of GHG emissions and made recommendations for reducing energy use. Two priority actions from that study can be applied to energy use for reefers and cold storage warehouses:

- Implementation of a system using photovoltaic power generation; and
- A port wide review of energy efficiency and development of an energy management system. In line with the findings of this adaptation study, this should be conducted taking account of the impacts of rising temperatures

Further detail on overall recommendations for reducing GHG emissions e.g. electrification of cranes and reduction of ship speed in the harbor can be found in the carbon footprint study.

Reduction of flooding events

An improvement in the capacity of the drainage system and upgrade of sediment traps and frequency of drain clearance (as recommended in Section 3.3.2) will reduce incidents of surcharge of the drainage system. Runoff of pollutants into the port harbor will therefore decrease, lowering impacts on water quality.

In addition the reduction of flooding events will result in less residual sedimentation on the access road and other areas, which turns to dust on drying.

3.8. Social aspects

3.8.1. Summary of Climate Risks

The climate-related issues for the port's social performance can be considered under two main headings:

- Health and safety risks to workers at the port related to climatic factors
- The interactions between the port and the municipality of Manzanillo, and how these could be affected by climate change

A summary of climate risks to the port's social performance is provided in Table 3.36.

3.8.2. Analysis of climate risks to health and safety of port workers

According to API Manzanillo, there are around 4,000 to 5,000 port workers, working in three shifts per day (i.e. approximately 1,500 workers per shift). The follow-

SUMMARY OF KEY POINTS

- The number of people in Mexico affected by dengue has grown from less than 1,000 per year in the late 20th Century to more than 100,000 per year in recent years, mainly due to the appearance of the disease in large cities. Mexico's Fifth National Communication predicts a large increase in the risk of dengue epidemics due to climate change. Other studies however suggest that the distribution of the mosquitoes carrying the disease will likely be relatively stable in coming decades.
- High temperatures can lead to dehydration and, in extreme cases, heat stress. Recorded cases at the port are generally low and future increases in maximum temperatures do not suggest a large increase in risk is likely to occur.
- Dust can lead to increased incidence of conjunctivitis. Airborne dust levels at the port can be expected to increase in future. This could potentially lead to increased cases of conjunctivitis and other health concerns, though actions to manage dust impacts on workers can reduce the risk potential.
- High winds and rainfall can lead to hazards for port workers. Reduced annual and seasonal mean rainfall is expected in future, with more rain falling in heavy events. This implies that the number of days with rain throughout the year is likely to reduce and that the risk of rain related worker accidents is unlikely to increase. It is expected that tropical storms, and hence extreme wind speeds, will become more intense in the future.
- Climate change has the potential to exacerbate existing challenges in the relationship between the port and the local community. Hotter and drier conditions expected under climate change will increase dust generation. Also, increased flood risk on the port access road could worsen traffic congestion problems.
- API Manzanillo should monitor dengue cases and keep in touch with health authorities on future forecast of potential epidemics.
- API Manzanillo should provide warnings of extreme high temperatures to minimize heat stress risks for workers.
- API Manzanillo should engage with the Municipality on areas where coordination of adaptation actions will be beneficial. This includes management of dust on roads outside the port and ensuring traffic movements avoid congestion during extreme weather events.

TABLE 3.36

Social risks

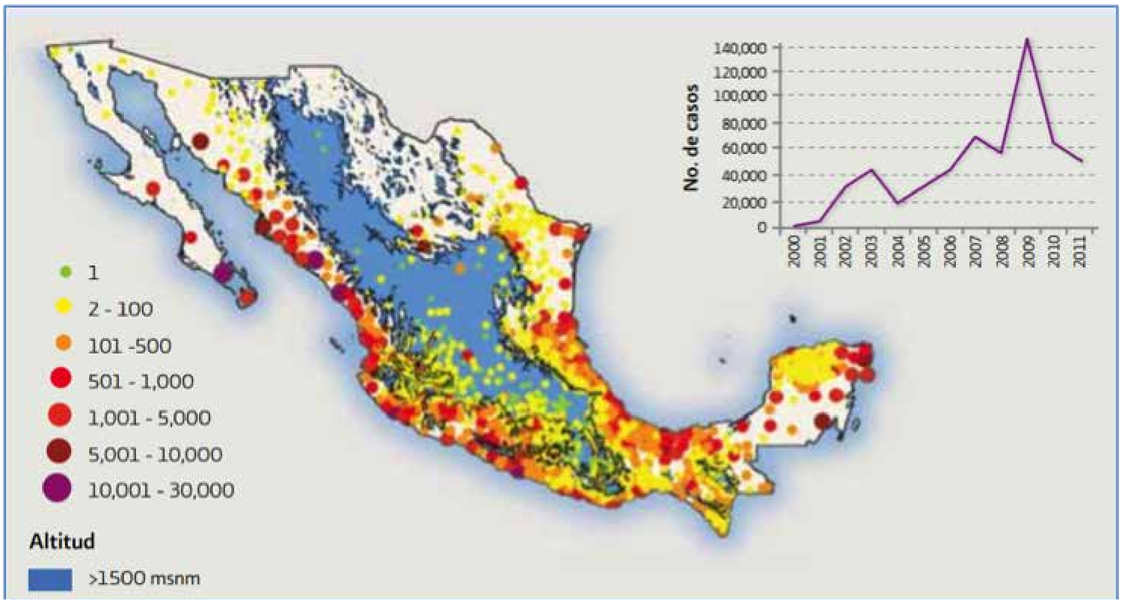
Risk	Thresholds and Sensitivities	Current and future climate/ oceanographic variability and change	Risk Description
Changes in temperature and relative humidity lead to more favorable conditions for mosquitoes carrying dengue and chikungunya and hence more cases of these diseases	• Cases of dengue fever across Mexico have increased significantly, from less than 1,000 per year in the late twentieth century to more than 100,000 per year in recent years • The mosquitoes carrying the viruses are widespread in Mexico at altitudes below 1500m	• Monthly mean temperatures range from 24˚C (January to March) to 27˚C June to August. • Observed data shows significant trend of 0.4 to 0.5˚C increase per decade. • Warming along the coast near Manzanillo reaches 2˚C in the dry season by the 2040s for RCP 8.5 (1.2˚C for RCP 4.5) and 3˚C by the 2070s for RCP 8.5 (1.8˚C for RCP 4.5). • Wet season temperature increases are similar to dry season but slightly lower for each respective RCP pathway.	• Numbers of dengue cases affecting workers at the port are unknown • Studies provide conflicting views of whether or not climate change will increase incidence of dengue in Mexico.
Increased maximum temperatures cause increased risks of heat stress and dehydration for port workers	• API Centro de Emergencias dealt with 5 cases of heat stress over the period 2011-2014 • 'Apparent temperature' thresholds for heat stress in Mexico's Fifth National Communication to the UNFCCC are: • 28 to 32˚C: Precaution • 32 to 41.5˚C: Extreme precaution • 41.5 to 49˚C: Danger • Above 49˚C: Extreme danger		• Currently, only low numbers of cases of heat stress are being reported • Higher temperatures due to climate change will increase risks of heat stress, but, with proper precautions, and given the low number of cases at present, this is unlikely to be a major issue

Increased temperatures coupled with lower precipitation leads to increased dust generation and more cases of conjunctivitis	• Incidence of conjunctivitis for port workers is in part related to airborne dust levels	• Warming along the coast near Manzanillo reaches 2˚C in the dry season by the 2040s for RCP 8.5 (1.2˚C for RCP 4.5) and 3˚C by the 2070s for RCP 8.5 (1.8˚C for RCP 4.5). • Mean rainfall to decrease by up to 0.5 mm/day by the dry season 2040s and 0.7 mm/day by dry season 2070s (RCP 8.5). • RCP 4.5 equivalent is 0.2 mm/day (2040s), 0.3 mm/day 2070's mean rainfall decrease. • Mean wind speeds are not projected to increase significantly	• Numbers of conjunctivitis cases affecting workers at the port are unknown • Higher temperatures, lower precipitation will increase risks of dust generation inside the port, but the risks to the port associated with more cases of conjunctivitis are unlikely to be significant overall
Increased temperatures coupled with lower precipitation leads to increased dust generation and adversely affect the port's relationship with the local community	• Dust generated by traffic movements along roads into the port, and from unpaved storage areas outside the port is a source of complaints		• Higher temperatures and lower precipitation will increase risks of dust generation outside the port, and could create further stress on the relationship between the port and the local community.

Source: Report authors

FIGURE 3.36

Number of cumulative cases of dengue in Mexico between 2000 and 2011 (circles); Graph: Annual total number of cases recorded nationally over the same period



Source: Cofepris, 2012[176]

ing climate-related health and safety issues have been identified through discussions with API Manzanillo, the terminals and API Centro de Emergencias:

- Diseases carried by mosquitoes, including dengue and chikungunya
- High temperatures, which can lead to dehydration and, in extreme cases, heat stress
- Dust, which can lead to increased incidence of conjunctivitis
- High winds and rainfall, which can lead to safety hazards

Each of these issues is discussed briefly in turn below.

Dengue and chikungunya

Dengue is typically a mild, non-specific febrile illness, with over half of infected people showing no symptoms. Dengue fever is characterized by acute onset of a high fever 3 to 14 days after the bite of an infected mosquito. Symptoms often include severe headache, pain behind the eyes, muscle pain, joint pain, rash, and in severe cases bleeding manifestations.

Chikungunya is characterized by acute onset of fever and severe, debilitating joint pain. Chikungunya fever occurs 3-7 days after the bite of an infected mosquito. Other symptoms may include headache, muscle pain, fatigue, and rash.

Dengue and chikungunya viruses are transmitted by two mosquito vectors, Aedes aegypti and Aedes albopictus. While Ae. aegypti is responsible for most or all massive outbreaks of dengue[172], chikungunya is readily transmitted by Ae. albopictus. In recent decades, these species have spread worldwide at lower and middle latitudes, particularly in periurban settings[173].

Studies in Mexico show that the number of people affected by dengue has grown from less than 1,000 per year in the late twentieth century to more than 100,000 per year in recent years, mainly due to the appearance of the disease in large cities including Cuernavaca, Morelos and Guadalajara, Jalisco. The increases have been greatest at altitudes below 1500 m and near the sea[174] (see Figure 3.36).

Cases of chikungunya in Mexico are much rarer. The first ever locally-transmitted case in Mexico was reported in October 2014, in the state of Chiapas. As of December 31, 2014 a total of 155 chikungunya cases had been reported in Mexico across five states: Chiapas (135), Guerrero (11), Oaxaca (7), Sonora (1), and Sinaloa (1)[175].

According to Mexico's Fifth National Communication to the UN Framework Convention on Climate Change (UNFCCC), increases in temperature and humidity due to climate change increase the risk of epidemics of dengue in the country, and the upward trend in temperature and humidity observed over the last ten years seems related to the growth in the recorded cases of dengue.

Modeling studies have aimed to evaluate changes in distributions of the two mosquito vector species, Ae. aegypti and Ae. albopictus, responsible for dengue and chikungunya, due to climate change. One major global study[177] finds that, with the exception of small regional shifts, the distributions of the two vector species globally will likely be relatively stable in coming decades[xxxiv] (see Figure 3.37). This is a consequence of broad tolerances in both species to climatic factors (temperature and rainfall), such that climate changes may not translate into major distributional shifts. This finding is somewhat at odds with the observation in Mexico's Fifth National Communication, that the upward trend in temperature and humidity in recent years seems related increased cases of dengue. These differences point to uncertainties in how future climate change will affect dengue outbreaks.

Dehydration and heat stress

High temperatures combined with high relative humidity reduce the body's ability to cool itself, increasing the risk of heat exhaustion, heat stroke, and other heat-related health problems. Mexico's Fifth National Communication to the UNFCCC[179] identifies a Heat Index based on 'apparent temperature' (the perceived temperature derived from a combination of air temperature and relative humidity[180]) as summarized in Table 3.37.

TABLE 3.37

Heat index and associated threat to health in Mexico

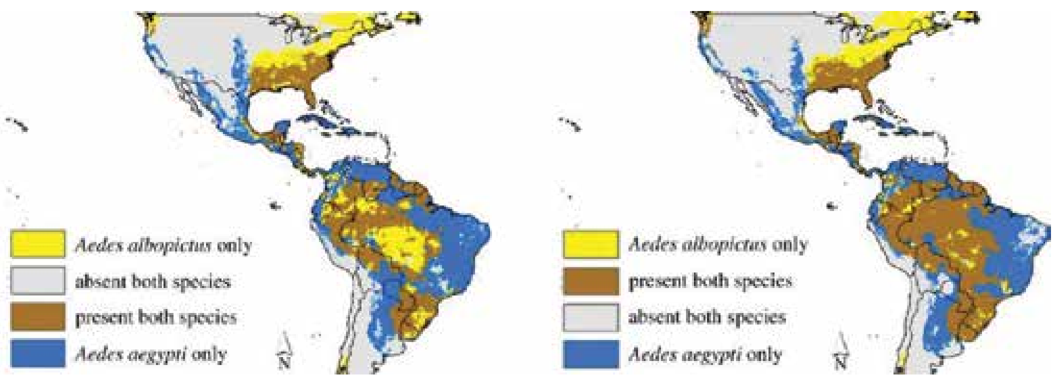
Heat index (apparent temperature, °C)	Level of threat to human health
28 to 32	Precaution
32 to 41.5	Extreme precaution
41.5 to 49	Danger
Above 49	Extreme danger

Source: Government of Mexico, 2012[181]

In extreme cases, very high temperatures can lead to increased mortality. While the relationship between hot days[xxxv] and an increase in mortality is very robust[182], many factors can influence it. Age, health and socio-economic conditions all affect a person's vulnerability to heat. The degree of acclimatization (be it physiological, social, or technological) to increasing heat over long time periods also come into play. Furthermore, 'heat waves' (whereby high temperatures occur over several consecutive days) appear to bring higher mortality than would be expected solely on the basis of short-term temperature-mortality relationships[183]. Finally, both

FIGURE 3.37

Summary of potential distributions derived from ecological niche models of Ae. aegypti and Ae. albopictus, under current climate conditions (left panel) and modeled future climate conditions (right panel) (2050, A1B scenario).



Source: Campbell et al, 2015 [178]

average temperatures and variability in temperature affect mortality, with studies finding that temperature variability had an effect (in terms of increased mortality) over and above a rise in average temperatures[184].

API Centro de Emergencias report that they have dealt with around five cases of heat stress over the period 2011-2014[185]. During meetings, some of the terminals also identified dehydration and heat stress as potential health risks associated with extreme high temperatures. Health risks during heat extremes are greater in people who are physically active, so workers at the port who are involved in manual labor are more susceptible. However, on the basis of the small number of cases dealt with by the Centro de Emergencias over the last four years, it would appear that heat stress is not a major issue at present.

Table 3.38 summarizes data on the highest temperatures recorded at Manzanillo meteorological station from 1984 to 2013. There is some doubt about the validity of the three measurements in excess of 50˚C, given that the highest temperature ever reported in Mexico was 52˚C, recorded in July 1966 in Sonora. Nevertheless, the data indicate ten records of temperatures of 35˚C or above at Manzanillo, out of a total of more than 42,126 measurements in the station record, i.e. for 0.02% of measurements.

As noted in Section 2.1, projected average monthly temperature increases for Manzanillo by the 2020s are typically 1.0˚C for RCP 8.5, and by the 2040s, around 1.7˚C. Changes in relative humidity will also affect the 'apparent temperature' and hence the significance of climate change in terms of increased risk of heat-related illnesses at the port.

Incidence of conjunctivitis related to dust

Conjunctivitis is a common eye condition worldwide. It causes inflammation (swelling) of the conjunctiva, the thin layer that lines the inside of the eyelid and covers the white part of the eye. The most common causes of conjunctivitis are viruses, bacteria, and allergens, though there are other causes, including chemicals, fungi, certain diseases and wearing contact lenses. The conjunctiva can also become irritated by foreign bodies in the eye and by air pollution caused by, for example, dust, chemical vapors, fumes or smoke[186].

API Manzanillo noted that the incidence of conjunctivitis for port workers was in part related to airborne dust levels. Port workers will potentially be exposed to dust during their working hours; many will also be resident in the city of Manzanillo, and therefore exposed to dust on their journeys to/from work, and at their place of residence (as outlined in Section 3.8.3).

Inside the port, dust is generated mainly by handling of bulk minerals at the APASCO and USG terminals. Management actions for dust emissions are already in place at these terminals. Climate change is projected to lead to higher temperatures, reduced annual and seasonal

TABLE 3.38

Occurrence of high temperatures at Manzanillo over the period March 1984 to May 2013

Temperature threshold (˚C)	No. of occurrences (a)
>50	3
45 to 49.9	0
40 to 44.9	1
35 to 39.9	6
Note: (a) Three measurements were recorded per day at 00:00h, 12:00h and 18:00h. An 'occurrence' refers to a single measurement.	

Source: Report authors

mean rainfall, and minor increases in wind speeds. Furthermore, levels of sediment carried onto the port access road may increase, as intense rainfall events become more severe. These factors would indicate that airborne dust levels at the port can be expected to increase in the future, with potential to lead to increased cases of conjunctivitis and other health concerns, unless actions to manage dust are strengthened.

High winds and rainfall

Several terminals reported the potential for high winds to affect worker safety. However, the decision to close the port, taken by the Harbor Master, is designed to avoid these impacts.

GRANELERA, a terminal which handles bulk agricultural products, noted during consultation meetings that rainfall can create dangerous slippery conditions for its workers. This occurs when loading products from silos into trains, as workers have to stand on top of train carriages to perform this activity. This can lead to interruptions to loading activities. However, as noted in Section 2.1, rain can also halt loading operations onto trains due to the carriages losing traction and being unable to move. It would therefore be difficult to disentangle these issues. Climate change is projected to lead to reduced annual and seasonal mean rainfall in the future, with more rain falling in heavy events. This implies that the number of days with rain will likely reduce, and that the risk of worker slippages will not increase.

3.8.3. Port-city relationship

For historical reasons, and since their foundations, ports and cities have co-evolved. In many ports across Latin America it is common to refer to joint development of a port-city or city-port, even though each has its own administrative bodies, roles and objectives. Despite a common interest in the socio-economic progress and development of their area, ports and cities may sometimes have diverging approaches to development. These need to be negotiated and require coordinated action between both port and urban communities for their successful and harmonious achievement.

In the case of Manzanillo, it is acknowledged that the development of the port can both positively and negatively affect urban development. While the development of the port has brought economic prosperity to the city, construction and expansion works have also modified and sometimes constrained the urban space in ways that are not always beneficial.

The port exerts a positive economic influence in the city and more widely. It is the key engine of economic development in the municipality of Manzanillo and the State of Colima, generating the highest rates of employment and investment in the State.[187] It also provides support to the city during natural disasters. For examples in several instances the Centro de Emergencias has offered its services to the city to control vegetation fires and assist in risk management operations.

However, there is an acknowledged imbalance between urban and port developments, generally attributed to a lack of clear integrated land use planning.[188, 189] Some of the existing urban structures, especially the road network, are below current and future population needs, causing direct conflict in the use of public infrastructure between city and port users.[190] A common complaint from city residents is high volumes of traffic on the roads due to cargo movements, which cause continued traffic jams, pollution and airborne dust.[191] On the other hand, API Manzanillo and some of the terminals cited urban developments in the upper catchments and associated deforestation activities as important potential causes of flooding inside the port.[192] Similarly, high levels of solid waste found in the drainage system at port resulting in higher costs to API Manzanillo for drain cleaning are attributed to a lack of proper waste management systems in the city.

According to meetings with the Municipality, dust outside the port leads to recurrent complaints from city inhabitants. The communities that are believed to be most affected by high concentrations of airborne dust are Jalipa and Francisco Villa.[193] Dust may be generated by daily movement of trucks in and out of the port, by construction works associated with port extensions and by unplanned development of unpaved storage areas outside of port premises. As part of the Permanent Program for the Maintenance and Cleaning of the Port Precinct, API Manzanillo carries out cleaning works between the areas of Puerto Interior, Glorieta del Pez and Patio Regulador de Contenedores[194]. However, dust generated by trucks can be carried further away from the port and is combined with dust generated by road improvement works, such as the recent construction works for the Jalipa road and the construction of the bridge outside the port's main entrance. Dust may also be generated by the clearing of areas that are subsequently let for container storage. Many companies have started to develop these types of uncovered patio areas outside the port to provide an alternative and cheaper option to companies willing to store cargo for longer periods[195]. These are established in the absence of clear standards or planning requirements that may prevent the generation and dispersion of airborne dust. In many cases, although dust problems are attributed to API Manzanillo, they are outside of API Manzanillo's control or jurisdiction and require the development of monitoring and control tools from the Municipality.

Climate change has the potential to exacerbate these existing challenges and adversely affect the relationship between the port and the local community. Hotter and drier conditions expected under climate change will increase dust generation. Further, increased flood risk on the port access road could worsen congestion problems.

3.8.4. Adaptation actions

In light of the risks identified above, the following adaptation actions are recommended:

Dengue:

- Given the uncertainties noted above about how climate change will affect the number of cases dengue in future, API Manzanillo is recommended to monitor cases, and ensure it is notified by public health authorities when the risk of dengue outbreaks is high. API Manzanillo should ensure the port community is kept informed of the risks.
  - Efforts by the Federal Commission for the Protection against Sanitary Risk (Cofepris) to control the spread of dengue include preventive monitoring by ovitraps (which can detect Aedes mosquito populations, thus acting as an early warning signal of an impending dengue outbreak) and developing climate-health relationships that establish threshold values of the environmental conditions favoring outbreaks. Cofepris' goal is to develop an Early Warning System for dengue, and to ensure the population is informed of the risks[196].

Heat-stress

- API Manzanillo could monitor weather forecasts and issue heat health warnings to terminals when apparent temperatures are forecast to exceed the thresholds shown in Table 3.37
- The warnings could be graded according to the severity of the forecast (precaution; extreme precaution; danger and extreme danger), providing advisory notes to the terminals on recommended actions. Such heat health warnings are in place in other countries, and could be co-developed with Cofepris.

Dust within the port

- Given that airborne dust levels within the port are likely to increase with climate change, the current dust suppression measures in place at the terminals and by API Manzanillo will need to be reviewed to see if they need to be strengthened.

Port-city

To ensure the harmonious development of the city-port, future developments will benefit from closer collaboration between port and city authorities and integrated initiatives that seek co-benefits.[197] The port and city authorities can develop complimentary objectives and activities and take advantage of synergies that can emerge from joint efforts for risk prevention and risk management. As noted in Strategic Objectives 6 and 7 of the Municipal Development Plan of Manzanillo[198], the city and the port must co-exist in a harmonious, efficient and balanced way. To achieve this, the Municipality of Manzanillo acknowledges the importance of close collaboration between the port community, local organizations and the Navy[xxxvi] to further promote development in Manzanillo and provide coordinated support to communities where needed.[199] The management of dust on the roads outside the port and traffic movements to avoid congestion during extreme weather events will be important aspects to consider. In terms of how such collaboration could be relevant to coordinated action on adaptation, the Municipality of Manzanillo is currently preparing a strategy to incorporate climate change criteria into its guidelines for territorial planning. It will important for the port to take the elements of this strategy in consideration when framing and implementing adaptation actions and, accordingly, to communicate to the Municipality adaptation needs that may require coordinated action with other stakeholders at the city and catchment levels.

3.9. Demand and consumption patterns

3.9.1. Approach to this section

This section explores how climate change may affect the import and export of goods traded through the port. It begins with a review of general trends in global trade and of recent and projected trade through the port. It then provides an analysis of the existing relationships between global GDP, the GDP of the port's key trading partner countries and the port´s business performance, to evaluate the correlation between these factors. This leads on to an analysis of the impacts of climate change on trade and its resulting estimated effects on the port´s revenue and key business lines.

A summary of key climate risks and opportunities related to demand and consumption for the port is provided in Table 3.39.

Assessing the economic impacts of climate change on demand and trade patterns is a challenging task, and impacts are difficult to quantify due to the various other factors that affect trade dynamics. The analysis presented here offers high-level estimates founded on the best available literature, world databases on GDP and information on the port provided by API Manzanillo.

It should also be noted that this section does not include information on the impacts of greenhouse gas emissions reduction targets and climate change legislation on global trade, (these are briefly discussed in Section 3.11) nor does it review the literature on existing trade agreements. Its primary objective is to provide a point of reference on potential climate change impacts that may support high-level strategic thinking for the future development of the port.

3.9.2. Trends in global trade

In the last half-century, global exports have risen substantially, leading to a large increase in international trade flows (see Figure 3.38), outstripping global economic growth (Figure 3.39). Since 1950, world trade volumes have risen nearly 32-fold[201], four times the growth of the world economy, which has increased by around a factor of eight over the same time period.[202]

SUMMARY OF KEY POINTS

- Global GDP and revenue flows at the port are strongly correlated. For every 1% fall in global GDP, revenue at the port falls by 1.5%.
- Hence the port´s economic output could be negatively affected by the impacts of climate change on the world´s economy.
- Based on the findings of the Stern Review, revenue losses due to climate change could range from -0.30% to -0.95% by the 2020s and -0.38% to -1.88% by the 2050s.
- By the mid-2030s, the port could see annual revenue losses of 4 million to 10 million MXN, and 6 million to 15 million MXN by the mid-2040s.
- As the port is strongly dependent on trade flows with key trading partners such as China, Japan, and South Korea, climate change impacts on the economies of these countries can affect the port.
- Within Mexico, climate change may negatively affect economic production in the States of Jalisco, Estado de México, Colima and Distrito Federal. These states account for 65% of the port's import market and 83% of the source of goods for export.
- Adaptation options include diversification of trading partner countries and growing a broader range of business lines.
- Diversifying trading partners can help with managing the potential for reduced trade flows from countries that are more negatively affected by climate change impacts.
- The port can explore opportunities to increase import of agricultural commodities where there is high demand in Mexico and where domestic production can be adversely affected by climate change, in particular the trade of corn.

TABLE 3.39

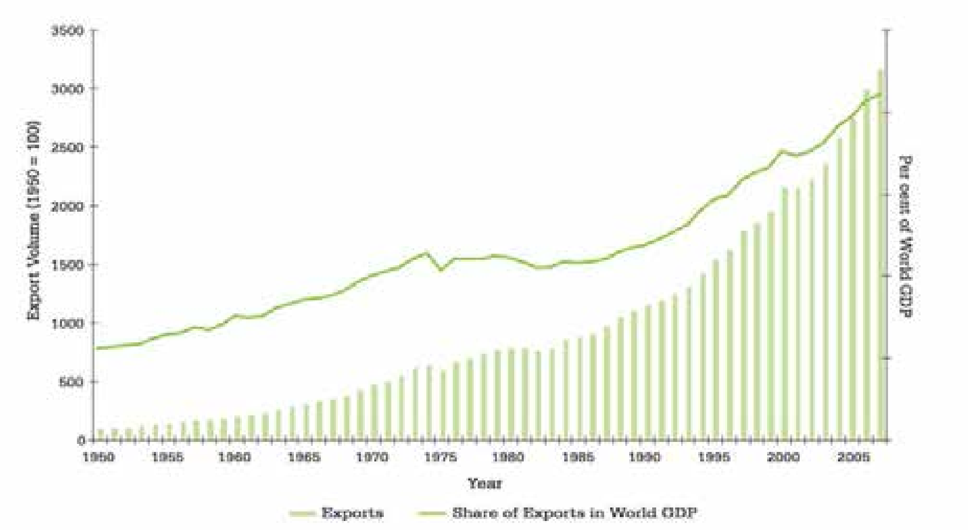
Demand and consumption risks

Risk/ Opportunity	Thresholds and Sensitivities	Current and future climate/ oceanographic variability and change	Risk Description
Impacts of climate change on the global economy affecting trade flows at the port	• Impact of climate change on global GDP and associated effects on levels of global trade. • Mean economic cost of climate change between 2020 and 2080 may range from 0.2% to 1.88% of global per capita consumption per annum.	• Impacts of climate change affecting economic activities worldwide. • Increased global expenditure to deal with climate risks.	• Impacts on global GDP can affect seaborne trade flows and revenue at the port, with projected revenue losses for the port ranging from -0.30% to -0.95% by the 2020s, between -0.38% and -1.88% by the 2050s and between -0.75% and -2.82% by the 2080s.
Impacts of climate change on the economies of the port's main trading countries affecting trade flows at the port	• Impacts of climate change on the economic activities of trading partners affecting their productivity, GDP and trade flows.	• Reduction in agricultural productivity of key partners such as U.S.A due to drought and flood events, expected to intensify in some parts of the U.S.A. due to climate change.	• Effects on the demand of port services and facilities can have significant effects on the port's revenue and may lead to the development / strengthening of commercial routes
Impacts of climate change to the economy of Mexico affecting trade flows at the port	• Impacts of climate change on the economic activities of Mexico that influence import and export of goods traded through the port.	• Agricultural productivity of key crops such as corn have already been affected by droughts and floods and may be adversely affected by climate change.	• Reduced local production of key agricultural commodities such as corn may increase Mexico's dependence on food imports, affecting the country's food security. The port could benefit from expanding imports of corn to meet demand.
Changes in distribution of global production of climate-sensitive products (e.g. agricultural commodities).	• Between 2005 and 2007 world prices of maize, wheat and oilseed crops nearly doubled in nominal terms.[200] • Recent years have seen reductions in global agricultural trade, particularly for grains. This may be due in part to adverse climate conditions in producing countries, including the effects of climate change-induced extreme weather events.	• Climate change is expected significantly to affect the total agricultural output of countries across the globe. • Yield, quality and prices of agricultural products are climate-sensitive • It is considered very likely that changes in temperature and precipitation, may lead to increased food prices, with estimated increases ranging from 3 to 84% by 2050.	• Changes in distribution of agricultural production may offer opportunities to develop / strengthen trading routes with new / existing country partners.

Source: Report authors

FIGURE 3.38

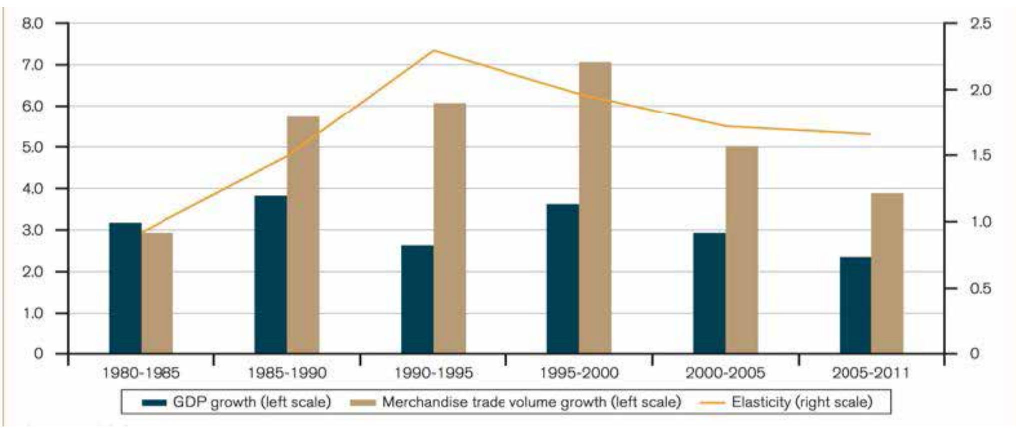
Rising contribution of trade to global output, 1950-2007



Source: WTO UNEP, 2009 [205]

FIGURE 3.39

Real GDP growth and world merchandise trade volume growth, 1980-2011 (annual percentage change) together with implied elasticities of trade with respect to global GDP



Source: WTO, 2013 [206]

Similarly the contribution of world trade to global GDP has increased from 5.5% in 1950 to 21% in 2007[203]. Drivers explaining this expansion in trading activities include: technological changes that have reduced the costs of transportation and communication; the development of more open trade and investment policies; the development of multilateral trade negotiations and the reduction of trade barriers; and the spread of business models that encourage outsourcing, offshoring and lean sourcing. Additionally, world demand patterns are strongly linked to the growth of emerging economies such as India, Brazil and China.

Maritime transport plays an important role in global trade, handling over 80% of the volume of all traded goods and accounting for over 70% of total global trade value[204]. Over time, ocean vessels have become larger and heavier, requiring ports to be more efficient and reliable. Additionally, with increases in world population, consumption of globalized goods and South-to-South trading activities, the need for shipping services and demand for port facilities that can accommodate growing consumption looks set to continue to increase in coming decades.

The financial crisis of 2009 had a significant impact on trade worldwide, and seaborne trade was also affected. The maritime sector has nonetheless shown signs of recovery. Despite the crisis, the sector has seen a substantial expansion in world fleet, of 37% between 2008 and 2012[207]. Container transport has now become the prime means of maritime transport, carrying around 90% of total global trade in monetary value.

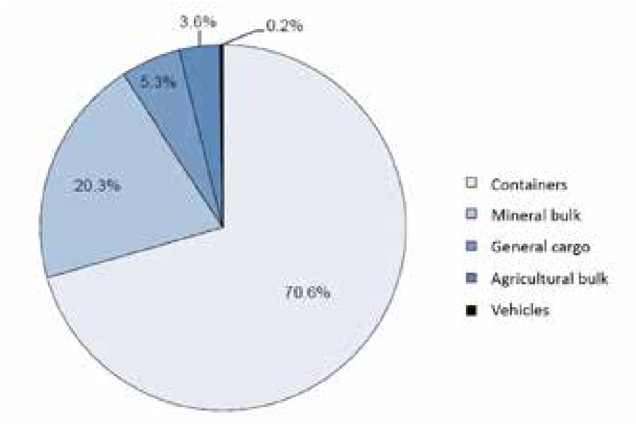
3.9.3. Recent and projected future trade through the Port of Manzanillo, without the effects of climate change

The geographic location of the Port of Manzanillo and its location in relation to maritime shipping routes have helped to develop the port into an important regional traffic hub. Additionally, the port has been developing its quality guarantees ("Marca de Calidad") as a mechanism to differentiate itself from other ports in the region and attract new customers, which is also expected to increase its traffic flows in the upcoming years. These factors together with global trade patterns offer opportunities for the port's expansion and act as an incentive for the further development of its key business lines.

The port handles most of the containerized cargo crossing Mexico (46% of total cargo trade in Mexico). Over the next decade, trading by containerized cargo at the port is projected to increase at an annual growth rate of 5.6%.[xxxvii] Improvements to the rail and road network, increases in operational capacity and the development of quality guarantees for port users[xxxviii] generate a positive environment for its future competitiveness. As of 2011, containerized cargo represented over 70% of total goods traded through the port (see Figure 3.40), with 1,860,601 TEUs being traded. This is projected to increase up to around 3,200,000 by 2022 (see Table 3.40) almost doubling the volume of containerized cargo in 10 years. In the same period (2011-2022) all other key lines of business are also expected to expand (see Figure 3.41).

FIGURE 3.40

Commercial trade at the port (in % of tons for 2011)



Source: API Manzanillo, 2014 [208]

China, Japan and South Korea are the three key trading partner countries for the Port of Manzanillo. Between them, they account for 59% of all goods exported and 57% of all goods imported. Regional partners that are also of influence include Chile (origin of 12% of all imports) and Colombia (destination for 6% of total exports) (see Table 3.41).

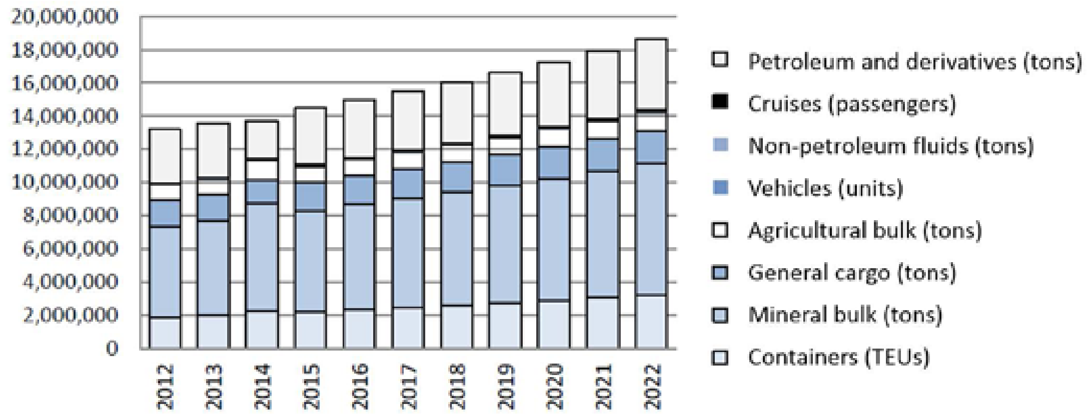
In terms of the area of influence of the port within Mexico, the key origins for exports include Distrito Federal, the Estado de Mexico and Colima, together accounting for 83% of all production for exports. Key states receiving goods imported through the port include the neighboring state of Jalisco, Distrito Federal, Colima and Aguascalientes, together accounting for 71% of all imports (see Table 3.42).

3.9.4. Relationship between the port´s trade revenue, world GDP, the GDP of key trading partner countries and Mexico's GDP

As noted by the United Nations Conference on Trade and Development (UNCTAD) and the Organization for Economic Cooperation and Development (OECD), there is a strong correlation between global industrial production, world economic growth and global and maritime trade (see Figure 3.42)[213]. Studies show that shipping

FIGURE 3.41

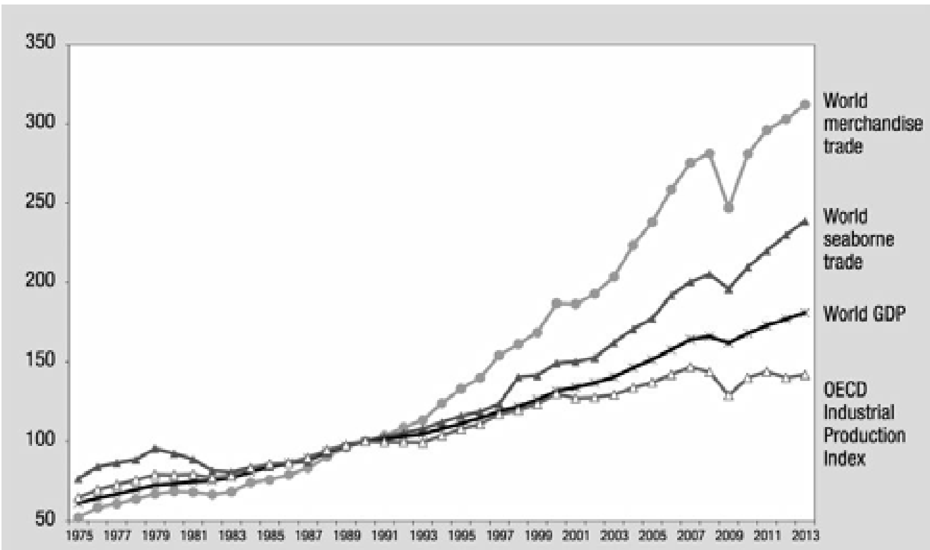
Future projections of goods traded through the port. Data are available in volume units and not in revenue values



Source: API Manzanillo, 2012 [210]

FIGURE 3.42

Organization for Economic Cooperation and Development (OECD) Industrial Production Index and indices for world GDP, merchandise trade and seaborne trade (1975–2012) (1990 = 100).



Source: UNCTAD, 2013 [215]

trade and countries' Gross National Product (GNP) are closely correlated, with wealthier and larger countries having the highest levels of exports and imports.[214]

Economic activities are a key determinant of seaborne trading activities and hence a port´s revenue. It can therefore be argued that changes in global GDP and in the GDP of key trading partner countries will affect the total revenue of ports. To investigate if this is the case at the Port of Manzanillo, the relationship between the port´s historic annual cargo movements[xxxix] is compared to global GDP, the GDP of Mexico and that of some of the port's key trading partner countries. Additionally, historic trends for each key business line at the port are compared to global GDP trends.

The analysis indicates that global GDP and the total revenue of the port have followed a similar trend, demonstrating a correlation between global economic activity and port revenue (see Figure 3.43). This correlation is further explored in Section 3.9.10, in the context of the implications of climate change for global trade at the port. There are also strong correlations between global GDP and the GDPs of Mexico, South Korea and China (see Figure 3.44 and Figure 3.45), with correlation coefficients of 0.91, 0.95 and 0.91 respectively. The correlation is not as evident when looking at the relationship between global GDP and the GDP of Japan (correlation coefficient of 0.29, Figure 3.45).

3.9.5. Relationship between world GDP and the port's key business lines

Historic trends for each key business line at the port have been compared to global GDP trends. It is evident that total cargo volumes for four of the key business lines (namely containers, mineral bulk, general cargo and agricultural bulk) follow similar trends to global GDP, and to each other (see Figure 3.46 and Figure 3.47).

The same cannot be said for vehicles and petroleum products, which do not appear to follow global GDP trends closely, except in 2009 where traffic decreased in both business lines, along with the global economic crisis (see Figure 3.48).

3.9.6. Relationship between trends in global crude oil prices and petroleum products

Analysis of the relationship between global crude oil prices and petroleum trade through the port does not appear to demonstrate a strong association between the two factors (correlation coefficient = -0.33, see Figure 3.49). Based on the lack of correlation between global GDP and petroleum products noted above, and a similar weak relationship with crude oil prices, it appears

TABLE 3.40

Projected increase between 2011 and 2022 for the port's lines of business

Line of business	2011	2022	% increase
Containers (TEUs)	1,762,508	3,198,014	81%
Mineral bulk(tons)	5,274,198	7,946,658	51%
General cargo(tons)	1,384,709	1,958,366	41%
Agricultural bulk (tons)	932,534	1,124,069	21%
Vehicles(units)	43,552	68,654	58%
Petroleum and its derivatives (tons)	3,241,155	4,262,174	32%

Source: API Manzanillo, 2012 [209]

TABLE 3.41

International destination of exports and origin of imports (by share in total trade).

Destination of exports	(% of total)	Origin of imports	(% of total)
China	39	China	26
Japan	14	South Korea	19
South Korea	6	Japan	12
Colombia	6	Chile	12
Chile	5	U.S.	10
Taiwan	4	Canada	7
Peru	4	Taiwan	2
Panama	4	Panama	2
Costa Rica	3	Others	12
El Salvador	3		
U.S.	3		
Other	11		

Source: API Manzanillo, 2012 [211]

TABLE 3.42

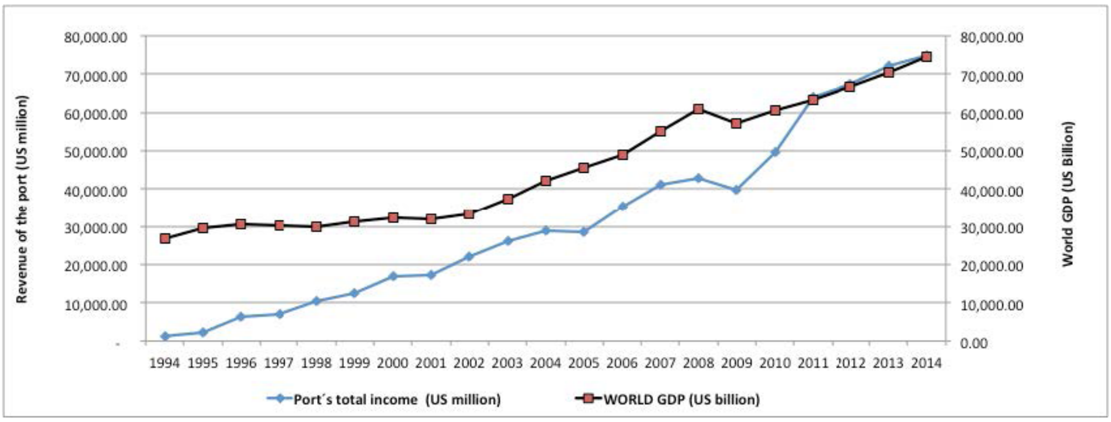
Destination of imports and origin of exports within Mexico

Destination of imports	(% of total)	Origin of exports	(% of total)
Jalisco	47	Distrito Federal	45
Distrito Federal	11	Estado de México	26
Colima	7	Colima	12
Aguascalientes	6	Coahuila	6
Estados de México	4	Sinaloa	6
Other	13	Nuevo León	2
		Other	3

Source: API Manzanillo, 2012 [212]

FIGURE 3.43

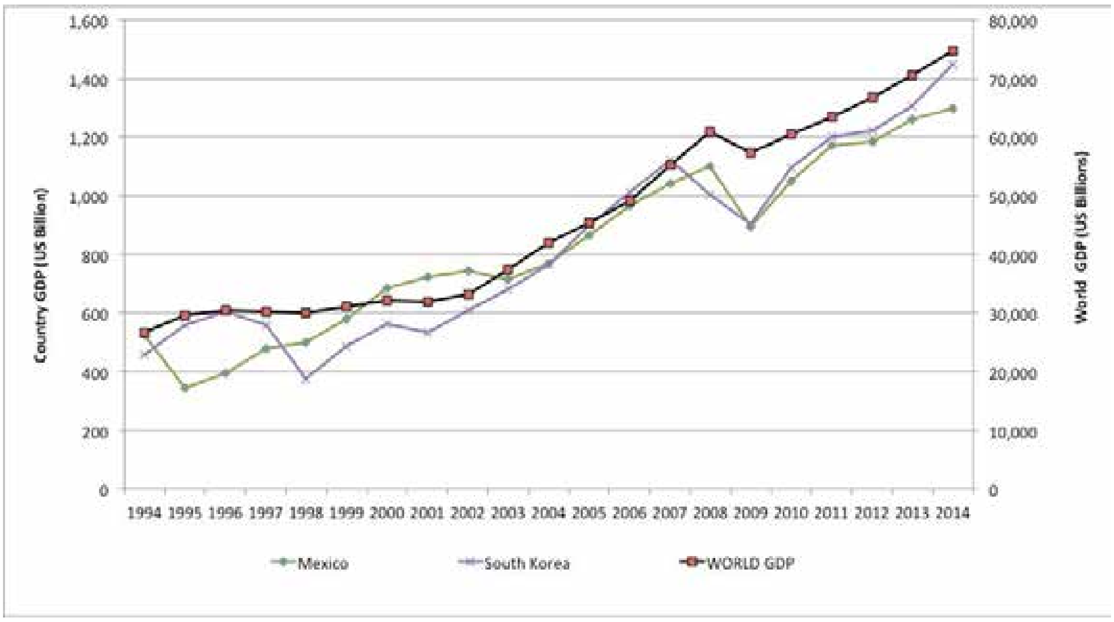
Comparison between World GDP and the Port of Manzanillo revenue from 1994 to 2014



Source: Report authors

FIGURE 3.44

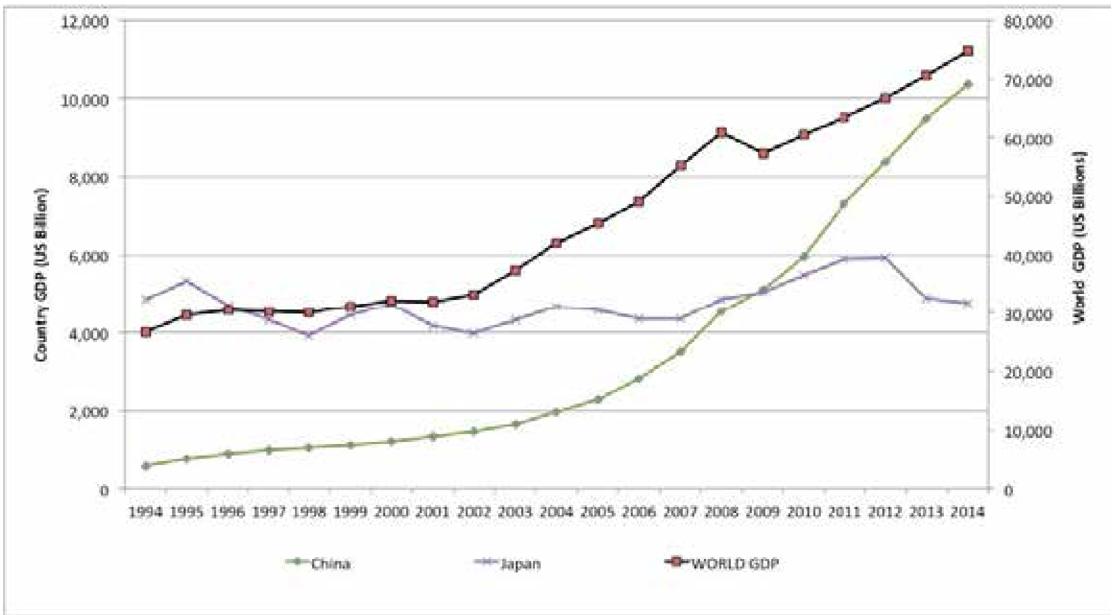
Comparison between World GDP, Mexico GDP and South Korea GDP trends from 1994 to 2014



Source: Report authors

FIGURE 3.45

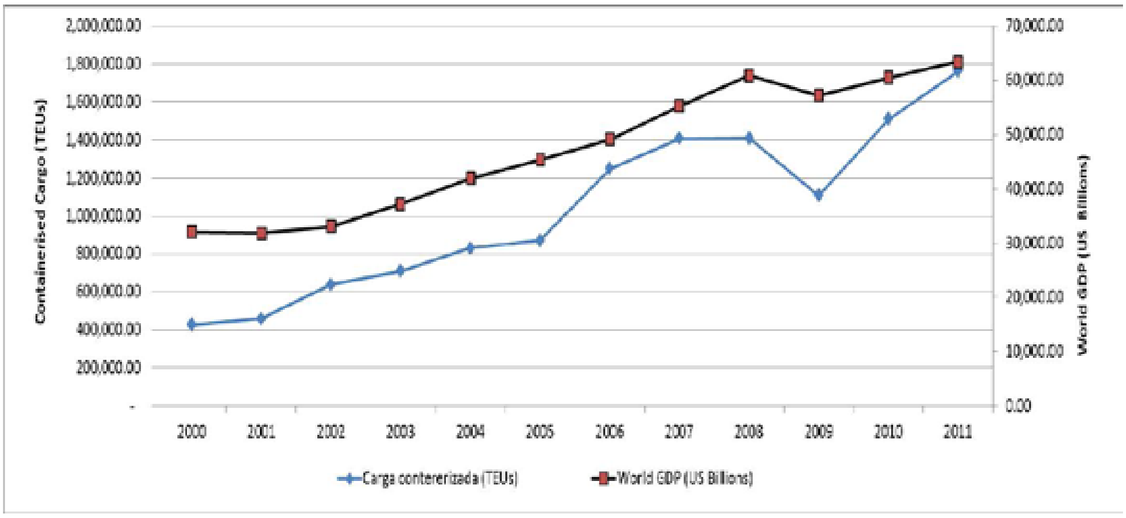
Comparison between World GDP, China GDP and Japan GDP trends from 1994 to 2014



Source: Report authors

FIGURE 3.46

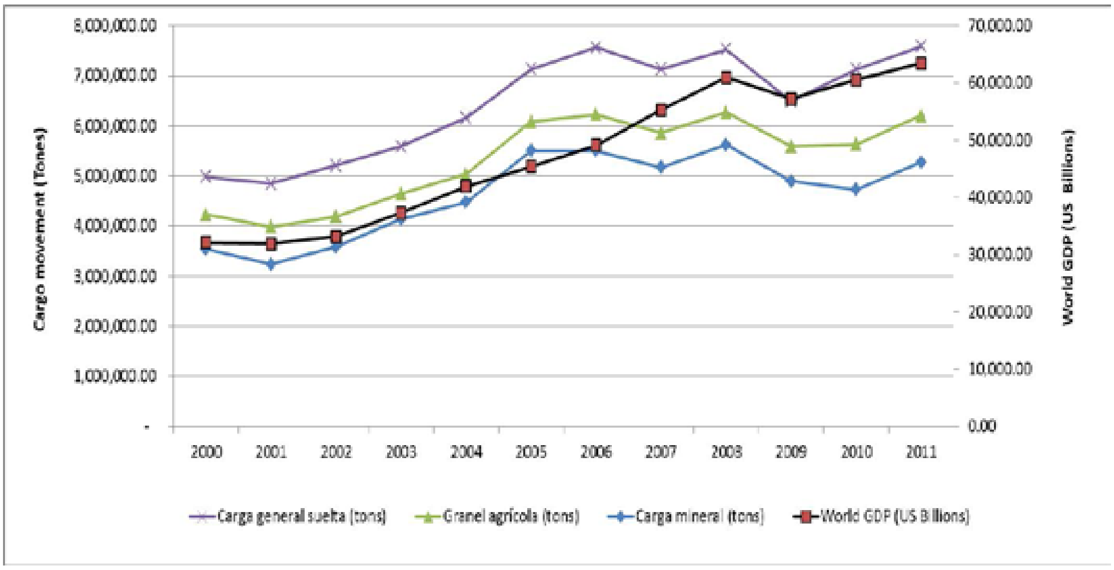
Comparison between world GDP and movement of containerized cargo at the port from 2000 to 2011



Source: Report authors

FIGURE 3.47

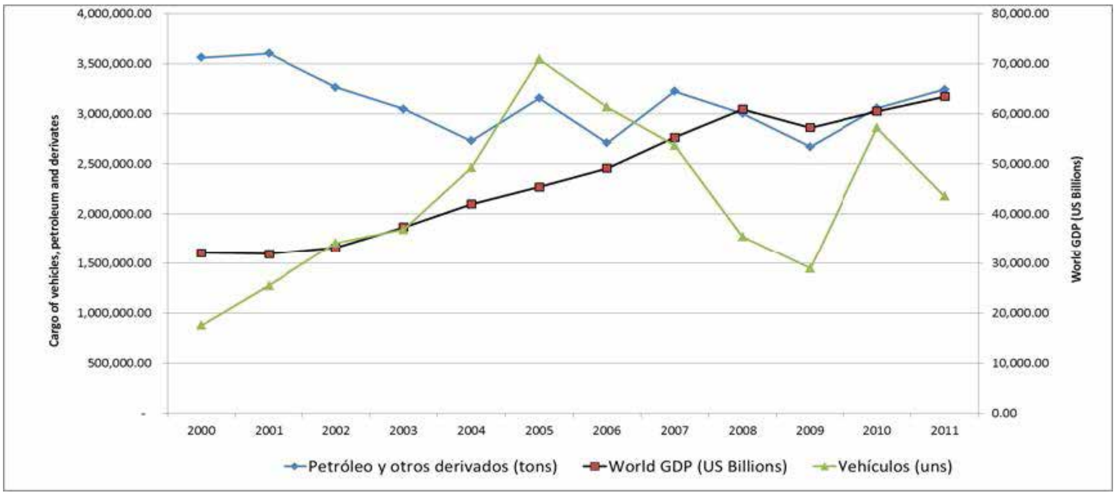
Comparison between world GDP, mineral bulk, general cargo and agricultural bulk movements through the port from 2000 to 2011



Source: Report authors

FIGURE 3.48

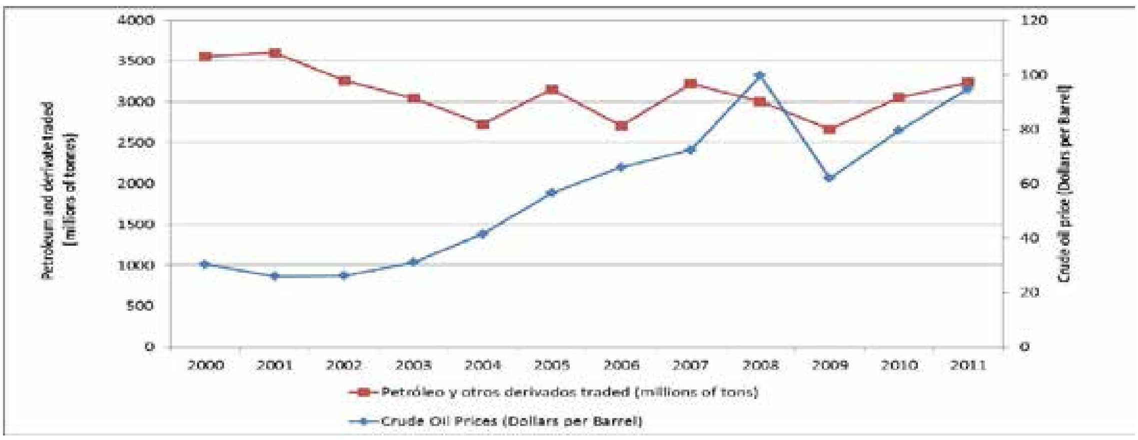
Comparison between World GDP and movements of vehicles and petroleum products at the port from 2000 to 2011



Source: Report authors

FIGURE 3.49

Relationship between global crude oil prices and petroleum products traded through the port from 2000 to 2011



Source: Report authors

difficult to predict trade flows of petroleum products on the basis of macroeconomic trends. This indicates that other factors may be driving petroleum trade through the port.

3.9.7. Impacts of climate change on the global economy

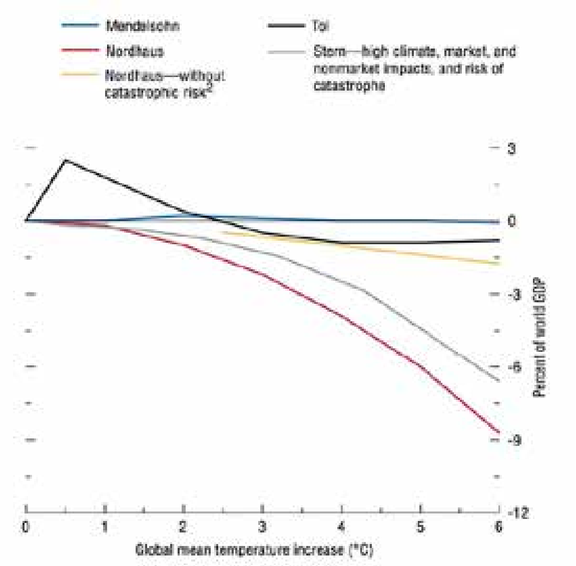
According to studies, climate change is expected to have a strong effect on the global economy. Given the relationships described above, these impacts will be reflected in levels of global seaborne trade, affecting revenue at ports.

Most studies which attempt to determine climate change costs to the world's economy base their analysis on damage functions that typically relate increases in temperature to potential GDP losses. Key benchmark studies project GDP losses on the range of 0% and 3% for a 3°C warming (based on 1990-2000 baseline levels, see Figure 3.50). The Stern Review on the Economics of Climate Change ('Stern Review 2007')[216] remains the most comprehensive examination of the economic impacts of climate change under business-as-usual conditions (i.e. with no action to address climate change), and of the costs and benefits stemming from climate change adaptation and mitigation action. Stern's analysis estimates that under a "future with climate change per year with no action taken" the mean cost of climate change between 2020 and 2080 may range from 0.2% to 1.88% of global per capita consumption per annum. The estimated impact on global GDP decreases as mitigation and adaptation actions are incorporated in the analysis, as shown in Table 3.43. In the "with mitigation and adaptation" scenario, impacts on global GDP are less significant, in the range 0.05% to 1.00% of global GDP. This scenario assumes that the effects of climate change are counteracted by adaptation and mitigation so that economic costs are entirely avoided from 2055 onwards as a result of the stabilization of carbon emissions at 500-550ppm CO_2e (parts per million carbon dioxide equivalent). As noted by the IMF[217] and others, these estimates are often incomplete and may be underestimating total economic damages from climate change and disregarding the worst-case scenario outcomes.

Table 3.56 Stern Review (2007) projections of the economic impacts of climate change for the years 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). (Source: Report authors).

FIGURE 3.50

Mean global GDP losses from climate change for a range of global mean temperature increases. Mean losses vary depending on the methodology and coverage of climate change impacts and risks. In all studies GDP losses increase with temperature



Source: Stern, 2007 [218]

3.9.8. Impacts of climate change on the economies of the port's main trading countries

Countries will be affected to different degrees by climate change according to a number of factors including:

- Size and location
- Underlying vulnerabilities (for example, countries with existing adaptation deficits such as low income countries may be more vulnerable than wealthier countries)
- Adaptation capital potential
- Reliance of the economy on specific industries (for example countries relying heavily on climate-sensitive sectors such as agriculture will be more significantly affected)

Since the revenue of the Port of Manzanillo is also strongly dependent on the economic activity of its key trading partner countries, climate change impacts on the economies of these countries can also be expected to affect the port's revenue.

TABLE 3.43

Stern Review (2007) projections of the economic impacts of climate change for the years 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 (%)	5th percentile (%)	95th 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
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	-1.0	-0.25	-1.75
		2085	-1.5	-0.75	-4
	Market impacts + risk of catastrophe + non-market impacts + value judgments for regional distribution	2025	-0.63	NA	NA
		2055	-1.25	NA	NA
		2085	-1.88%	NA	NA
Mixed scenarios	Mitigation and adapta-tion(b)	2025	-0.055 (c)	NA	NA
		2055	-1 (d)	NA	NA
		2085	-1 (e)	NA	NA

Notes

(a) NA = not available.

(b) 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).

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

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

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

Source: Report authors

TABLE 3.44

Regional cost benefit analysis of the economic impacts of climate change

		Climate + Carbon Costs			Highest action	
Region	No action	Highest action (400ppm)	High action (450 ppm)	Moder-ate action (550ppm)	Avoided costs	Mitigation costs
USA	3.0	1.0	1.00	1.5	2.0	1.5
Japan	0.5	0.5	0.5	0.5	0.5	0.5
Russia	4.5	1.5	2.0	2.0	3.0	2.0
China	4.5	2.0	2.5	2.5	2.5	2.0
India	11.0	5.0	6.5	6.5	6.0	3.0
EU27	1.0	0.5	0.5	0.5	0.5	1.0
ROW	8.5	3.5	4.5	4.5	5.5	2.0
World	4.0	1.5	2.0	2.0	2.5	1.5

Source: Fundación DARA Internacional, 2012 [221]

High action		Moderate action		Net benefit		
Avoided costs	Mitigation costs	Avoided costs	Mitigation costs	Highest action	High action	Moderate action %
2.0	1.0	1.5	0.5	0.5	1.0	1.0
0.5	0.5	0.5	0.5	0.0	0.0	0.0
3.0	2.0	2.5	2.5	1.0	1.0	0.0
2.5	1.5	2.0	1.0	0.5	1.0	1.0
5.5	2.0	4.5	0.5	3.0	3.5	4.0
0.5	0.5	0.5	0.5	0.0	0.0	0.0
5.0	1.0	4.5	0.5	3.5	4.0	3.5
2.0	1.0	2.0	0.5	1.0	1.0	1.0

China (here referred also as the People's Republic of China – PRC[xl]), Japan and South Korea are the three key trading partners of the Port of Manzanillo. Countries in East Asia are exposed to a variety of climate-related challenges due to both their size and their location. Of particular concern are risks associated with sea level rise, cyclones and flooding. A brief review of the available information on the potential economic costs associated with these risks is provided below.

According to a report published by the Asian Development Bank (ADB) on the economics of climate change in East Asia, amongst these three countries, Japan and China are more vulnerable to the impacts of sea level rise. Without adaptation, sea level rise could result in the forced migration of 1 million people from 2010 to 2050 in the PRC, with associated costs of USD150 billion. Under a medium sea level rise scenario, the impacts are still significant: 500,000 people displaced and associated costs of around USD86 billion. Economic impacts due to cyclonic activity are estimated to be higher in Japan and South Korea than in the PRC. On average, the study estimated that around 9% of the population in Japan and 18% of its rural population, as well as 4% of the population in South Korea could live in areas where increases in economic losses due to cyclones will be more than 1% of local GDP[219]. Japan, South Korea and coastal areas of the PRC will also be affected by short-term flooding. On average, between 18% and 22% of the populations of these regions will suffer an increase in the expected annual loss due to flooding of at least 1% of local GDP[xli] by 2050.

A recent study by Fundación DARA Internacional[220] provides estimates of the potential costs of climate change for China and Japan. The study notes that, with no action on either adaptation or mitigation, the cost to the national economy of China is equivalent to 4.5% of its GDP per year over the period 2010-2100, which is slightly higher than the world average GDP loss quoted by the same study (4.0%). The case for Japan appears quite different, with the study suggesting a loss of GDP much below the global average, at 0.5% under the "no action" scenario (see Table 3.44).

3.9.9. Impacts of climate change on Mexico´s economy

Mexico is considered highly vulnerable to climate variability and climate change due both to its physical characteristics (geography, topography and climate) and its socio-economic context (e.g. territorial planning, urban development, social inequality and poverty). Additionally many of Mexico's productive and industrial clusters are located in the north of the country, which suffers from the highest levels of water stress.

Droughts, floods and tropical cyclones in particular, have been the most detrimental weather-related events affecting the country´s economy. The combined impacts of floods, storms and hurricanes for the year 2010 were estimated at over 69,000 million pesos (USD5.3 million)[222]. In the same year, water deficits in productive regions of the country resulted in losses of over 15,000 million pesos, due primarily to losses in bean and maize crops and losses in livestock.[223] In 2011, abnormal frost conditions resulted in over 30,000 million pesos in losses in the agricultural sector.[224] The drought that affected the country between 2011 and 2012 and that has been the hardest on record for the past 70 years resulted in economic losses of 16,000 million pesos.[225]

With climate change, temperatures are projected to increase across the country. Decreases in total annual rainfall are expected, but intense meteorological events (droughts and heavy rainfall events) may worsen. Additionally there is a high risk of coastal inundation in some areas, due to rising sea levels and storm surges as well as potentially a higher incidence of vector-borne diseases due to changed rainfall patterns and increased temperatures.[226] Without adaptation, these impacts would likely cause significant losses to the country´s economy. The World Bank estimates that up to 71% of the country´s GDP is at high risk of adverse climate change impacts.[227] Results from SEMARNAT (2009) suggest that climate change costs to the Mexican economy could be around 3.2% of GDP by the 2050s and up to 6.2% of GDP by the end of the century.[xlii]

3.9.10. Impacts of climate change on trade at the port

This section aims to provide high-level estimates of climate change impacts on future trade at the port. It uses port trade projections provided by API Manzanillo and applies changes to these, based on the observed relationship between global GDP and port revenue, and using Stern's estimates of climate change impacts on global GDP.

The studies cited in Sections 3.9.8 and 3.9.9 provide useful insights into the potential economic impacts of climate change on the port's key trading partner countries and on Mexico. However, this analysis utilizes Stern's global estimates because his study provides data for the 2020s, 2050s and 2080s, whereas the Fundación DARA Internacional study provides estimated GDP losses averaged over the period 2010 to 2100 and the ADB study estimates averaged from 2010 to 2050. Furthermore, the ADB study provides information on three of the port's main trading partner countries (China, Japan and South Korea) which together account for 59% of goods exported and 57% of goods imported, whilst the Fundación DARA Internacional study only provides information on two (Japan and China), accounting for 53% of exports and 38% of imports. An analysis of climate change impacts on the port's future trade flows based entirely on these three countries would therefore provide an incomplete picture of the economic context that drives revenue at the port. Finally, it is worth noting that the range of estimates of GDP loss provided in the Stern Review are within the range of GDP losses estimated in the Fundación DARA Internacional study for Japan and China.

3.9.11. Impacts of climate change on total trade

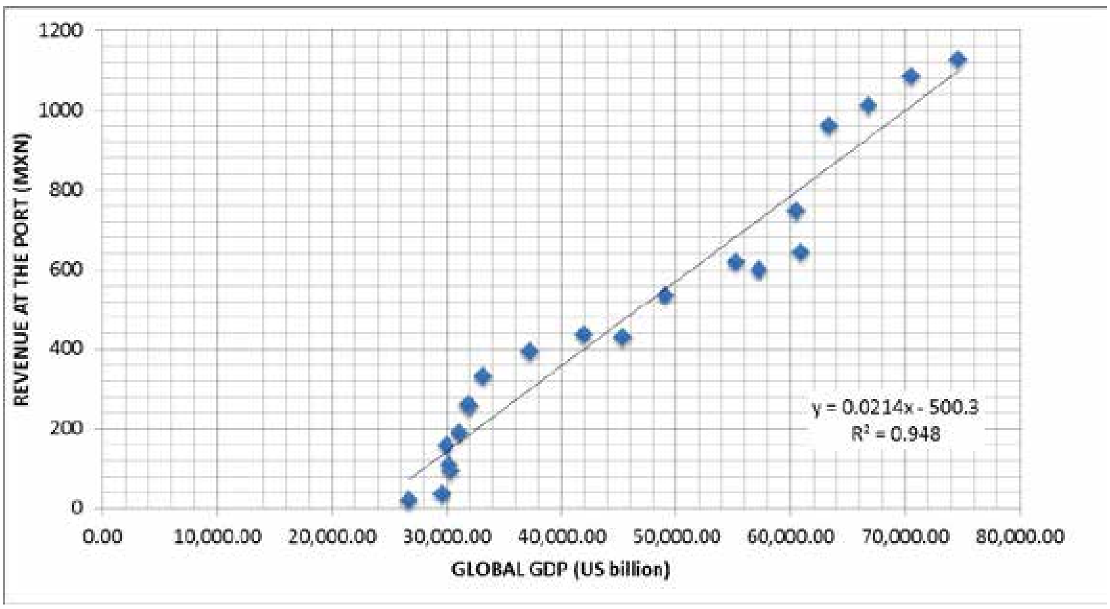
Taking into account the strong correlation between global GDP and the revenue flows at the port (correlation coefficient = 0.948, see Figure 3.51) is it concluded that climate change impacts on the world´s economy can directly affect trade at the port. The elasticity[xliii] of the port's revenue is near to 3, i.e. a 1% increase in world GDP leads to a 3% increase in the port's revenue. Accordingly, a 1% reduction in global GDP leads to a 1.5% reduction in the revenue of the port.

Clearly, there are other factors affecting fluctuations in cargo movements and associated revenue at the port. As noted before, not all business lines correlate closely with world GDP and factors such as competition with other ports, relationships with clients and socio-economic circumstances in key trading partner countries also affect the port's revenue. It is therefore challenging to infer changes in port revenue from changes in world GDP due to climate change impacts. Additionally, there is considerable uncertainty regarding the economic impacts of climate change.

Nonetheless, applying Stern's estimates (Table 3.43) to the observed relationship between global GDP and the port's revenue provides mean projected revenue losses at the port ranging between -0.30% to -0.95% by the 2020s, between -0.38% and -1.88% by the 2050s and between -0.75% and -2.82% by the 2080s (see Table 3.45). These estimates have been applied to revenue projections for the port and the resultant impacts are summarized in Figure 3.52 and Figure 3.53. They indicate that, by the mid-2030s, the port could see annual revenue losses of 4,000,000 to 10,000,000 MXN, and 6,000,000 to 15,000,000 MXN by the mid-2040s.

FIGURE 3.51

Analysis of the correlation between global GDP and revenue at the Port of Manzanillo over the period 1994-2014



Source: Report authors

TABLE 3.45

Estimated effects of world GDP losses due to climate change (from Stern) on the port´s revenue (% change) for the 2020s, 2050s and 2080s

Climate	Economic	Year	Mean (%)	5th percentile (%)	95th percentile (%)
Baseline climate	Market impacts + risk of catastrophe	2025	-0.30	NA	NA
		2055	-0.30	NA	NA
		2085	-0.75	NA	-1%
High climate	Market impacts + risk of catastrophe	2025	-0.38	NA	NA
		2055	-0.75	NA	NA
		2085	1.1	-0.01	-1.75
	Market impacts + risk of catastrophe + non-market impacts	2025	-0.75	NA	NA
		2055	-1.5	-0.25	-1.75
		2085	-2.3	-0.75	-4%
Mixed scenarios	Market impacts + risk of catastrophe + non-market impacts + value judgments for regional distribution	2025	-0.95	NA	NA
		2055	-1.9	NA	NA
		2085	-2.82%	NA	NA
	Mitigation and adaptation	2025	-0.08%	NA	NA
			-0.75%	NA	NA
		2055	-1.50%	NA	NA
		2085	-1.50%	NA	NA
Notes: NA = Not Available					

Source: Report authors

3.9.12.
Impacts of climate change on containerized cargo and general cargo

International seaborne trade of containerized cargo has been expanding over the past decades, closely following trends in world economic growth. The Federal APIs in Mexico emphasize the importance of this type of cargo, which holds the highest aggregate value and greatest market demand globally. This has led to increased investments in Mexico that aid the expansion of this business line. Future forecasts of containerized cargo movements through the Port of Manzanillo project annual growth of 5.6% over the next decade.

In contrast, general cargo has seen a decrease in total volumes through the port. Future annual growth of this business line is forecast at 1.9% per annum over the next decade.

As shown in Section 3.9.5, containerized cargo and general cargo follow global GDP fluctuations (see Figure 3.47 and Figure 3.48). It is therefore reasonable to apply the percentage changes due to climate change shown in Table 3.45 to these two business lines. The results of this analysis for the year 2025 are shown in Table 3.46. The analysis uses the 'medium scenario' of projected cargo movements for 2025 provided by API Manzanillo[228] and applies the higher-end climate change impact scenario of Stern ('Market impacts + risk of catastrophe + non-market impacts + value judgments for regional distribution').

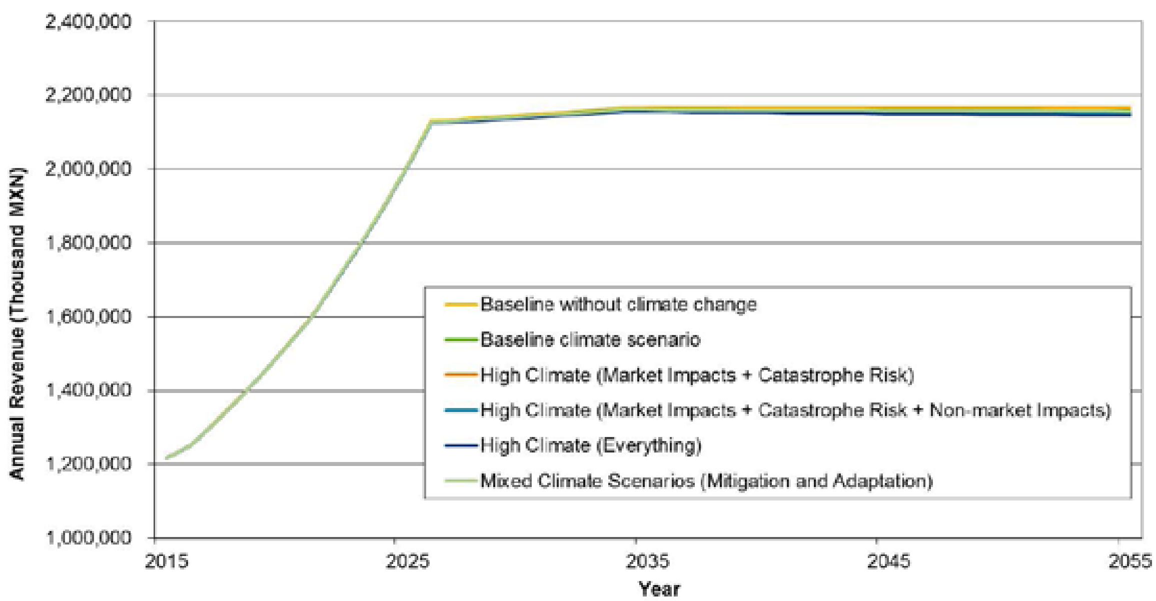
It is also possible that the production and demand for specific types of containerized cargo and general cargo may be particularly climate-sensitive, over and above Stern's estimates. This could apply, for instance, to food products. Owing to the wide range of possible cargo types, this issue is not considered further.

3.9.13.
Impacts of climate change on mineral bulk

World trade for minerals and metal products has seen a significant increase, particularly with the growth of manufacturing activities in emerging economies such as India and China. In Mexico, around 15 companies manage over 90% of mineral bulk traded through the

FIGURE 3.52

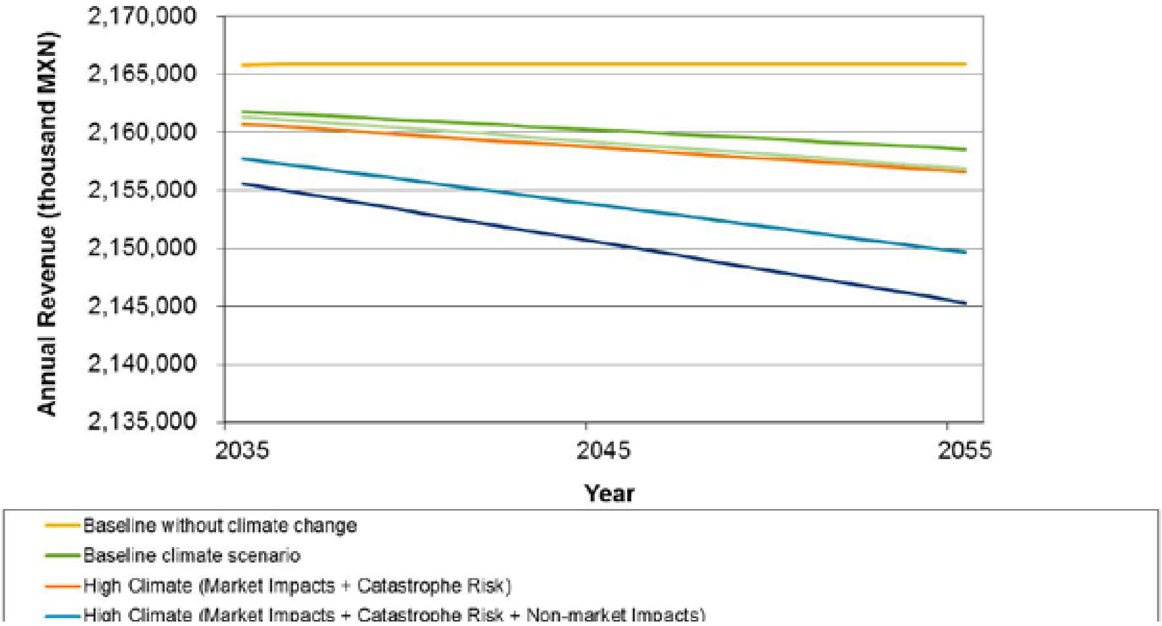
Estimated effects of world GDP losses due to climate change (from Stern) on the port´s revenue (thousand MXN) from 2015 to 2055



Source: Report authors

FIGURE 3.53

As Figure 3 52 but showing the period 2035 to 2055 only



Source: Report authors

TABLE 3.46

Estimated climate change impacts on movements of containerized and general cargo in 2025 under Stern's worst case scenario

Type of cargo	Forecast cargo movements without climate change (2025, medium scenario) (tons) (a)	Change due to climate change		Forecast cargo movements (2025, with climate change) (tons)
		% (b)	tons (b)	
Containerized cargo	43,102	-1.5	-647	42,455
General cargo	2,297	-1.5	-34	2,263

Notes:

Provided by API Manzanillo

Using Stern's scenario "Market impacts + risk of catastrophe + non-market impacts + value judgments for regional distribution"

Source: Report authors

TABLE 3.47

Estimated climate change impacts on movements of mineral bulk in 2025 under Stern's worst case scenario.

Type of cargo	Forecast cargo movements without climate change (2025, medium scenario) (tons) (a)	Change due to climate change		Forecast cargo movements (2025, with climate change) (tons)
		% (b)	tons (b)	
Mineral bulk	12,846	-1.5	-193	12,653

Notes:

Provided by API Manzanillo

Using Stern's scenario "Market impacts + risk of catastrophe + non-market impacts + value judgments for regional distribution"

Source: Report authors

Federal APIs and while mineral trading is related to national industry in general, it is also strongly determined by the behavior of these companies.

The port trades approximately 20% of mineral bulk transported through the Pacific (nearly 5.3 billion tons in 2011), mostly iron from Peña Colorada mine, north of the port, in Colima State. According to the Economy Secretariat, Colima and Jalisco produced around 3 million tons and 400,000 tons of iron ore respectively in 2010. The consolidation of production in this sector and future projections of sustained exploitation of Mexico's mineral resources are important pillars for the growth of the port. Annual average growth rates in mineral bulk trade at the port between 2000 and 2011 were 3.7%. API Manzanillo forecasts an increase in mineral bulk trade of 4.9% per annum over the next decade.[229]

Climate change has the potential to affect all aspects of mineral production and trade, from exploration, extraction, production, and shipping in the mining and quarrying industry. The mining industry is beginning to acknowledge these impacts and their potential to increase costs for infrastructure, operations and transport.[230; 231]

The fact that over 90% of mineral traffic in Mexico is handled by only 15 companies raises the questions as to how operational disruptions to one or more of these companies may affect movements of minerals through the port.

Nonetheless, global GDP will remain a key determinant for mineral bulk trade, particularly in relation to demand for construction materials and for metallurgic and industrial activities in importing countries. It can thus be inferred that climate change impacts on world GDP may affect mineral bulk trade in a similar fashion as for containerized cargo and generalized cargo (per Section 3.9.12 above). Following the same approach, high-level estimates of the potential impacts of climate change on mineral bulk cargo in 2025 under Stern's high-end scenario are provided in Table 3.47.

3.9.14. Impact of climate change on agricultural trade

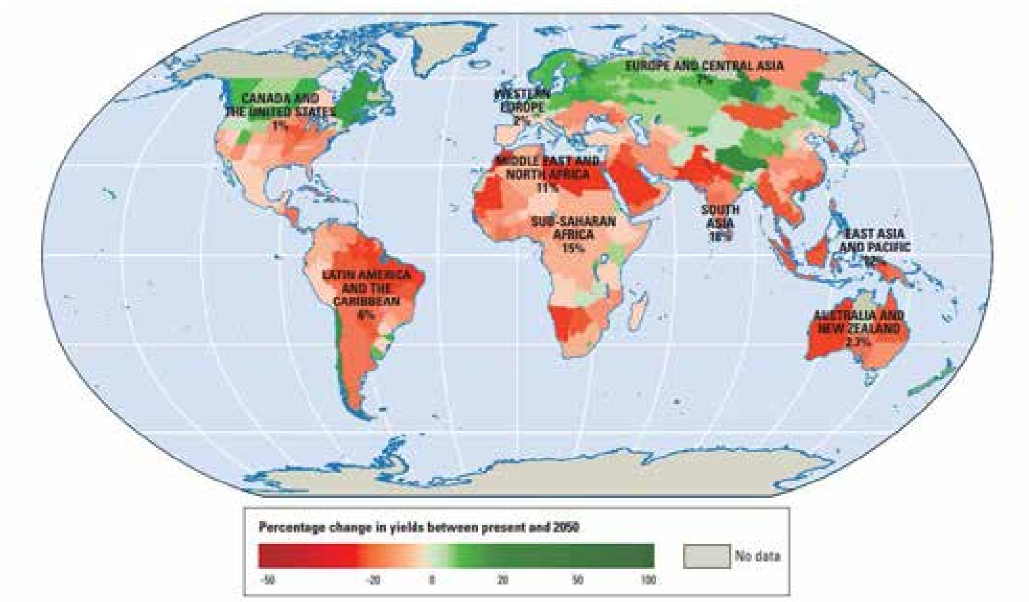
Agricultural trade flows are influenced by several supply and demand factors, including: land productivity; costs of agricultural inputs (fuel and fertilizers); population and income growth; trends in diets in emerging economies; and the price of crude oil (due to its effect on biofuel demand).[232]

Mexico is the eighth largest importer of agri-food products worldwide[233] and the second largest importer of wheat in the Latin American region.[234] As of 2010, imports of agricultural commodities represented 43% of the total percentage of domestic supply.[235]

Between 2005 and 2007 world prices of maize, wheat and oilseed crops nearly doubled in nominal terms.[236] Recent years have seen reductions in global agricultural trade, particularly for grains. This may be due in part to adverse climate conditions in producing countries, including the effects of climate change-induced extreme weather events. The year 2012 was a particularly poor

FIGURE 3.54

Projected percentage change in yields of eleven crops (rice, wheat, maize, millet, field pea, sugar beet, sweet potato, soybean, sunflower, groundnut and canola) from 2046 to 2055 compared to 1996-2005



Source: Müller, 2009 [241]

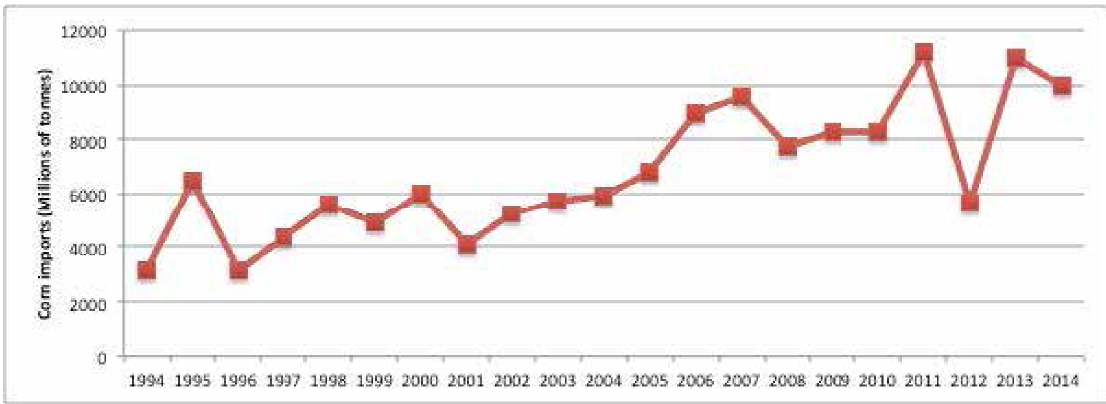
year for grain trade due to severe droughts affecting crops in major producing and exporting countries, (the United States, the Russian Federation, Kazakhstan, Ukraine and Australia) and resulting in a significant contraction in agricultural output.[237]

Climate change is expected significantly to affect the total agricultural output of countries across the globe (see Figure 3.54).[238] Yield, quality and prices of agricultural products are climate-sensitive and it considered very likely that changes in temperature and precipitation, may lead to increased food prices, with estimated increases ranging from 3 to 84% by 2050.[239]

Transport costs can vary widely between different agricultural commodities and countries of origin and destinations and can have a significant impact on commodity prices.[240] Accordingly, changes in the geographical distribution of importing vs. exporting countries may affect transport costs of agricultural commodities and, in turn, commodity prices.

FIGURE 3.55

Mexico corn imports by year (1994-2014)



Source: Index Mundi, 2014 [253]

Agricultural bulk accounts for about 6% of total cargo movement of the APIs in Mexico, but the total volume traded by sea depends also on the cost of shipping. At higher costs, transport shifts to other modes such as rail. Grains are the main agricultural commodity traded through the Port of Manzanillo. These are mostly imported from the USA and Canada, and are destined for Jalisco and Mexico State, where goods are processed and distributed across the country. Of all agricultural bulk traded through the port, 75% is canola imported from Canada, while other goods include soya, oats, sugar, wheat and muscovado sugar. The port also exports refined sugar and muscovado sugar, although this does not occur every year, and depends on the relative costs of maritime and terrestrial transport routes and the price of sugar. The increase trade of agricultural products through the port is projected to be 2% per year over the next decade[242], so current facilities at the port for handling these are enough to guarantee operations in the short and medium term.

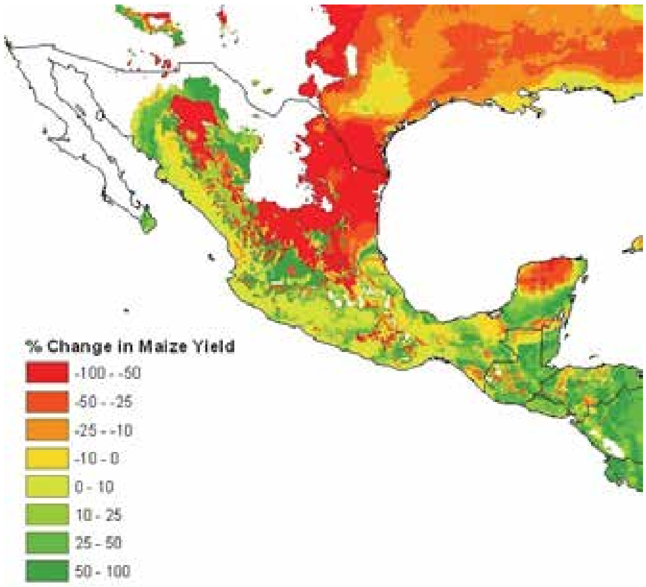
The volume of canola imported depends on the "apparent consumption" of canola in the country.[xliv] However, there are other important factors such as: the dollar-peso exchange rate, GDP of foreland countries and inland regions involved in the trade, agricultural production in the USA and Canada; and relative prices for transportation of agricultural dry bulk by sea vs. land.[243] The effects of climate change on future canola yields in Canada are still contested. The majority of studies point to potential increases in yield in the Prairie Provinces (Manitoba, Saskatchewan, and Alberta)[xlv] and the potential development of new suitable areas for production (such as British Columbia).[244] Some studies project increases in yield crops in the Saskatchewan region as a result of warmer temperatures and earlier springs[245] though higher than average temperatures during the summer may also lead to lower yields due to heat stress.[246] While some studies estimate critical maximum temperatures above which yields would decrease to be around 29°C[247], others suggest that increases in temperatures will have negligible effects on canola yields and may only affect yield variability.[248] In terms of the potential effects associated with rainfall trends, studies suggest that higher future precipitation may result in increases in canola production in the Prairie Provinces.

For Mexico as a whole, corn (maize) is the most important agricultural crop, occupying 50% of total cultivated land. Over recent decades, and despite structural changes to increase domestic production of corn, there has been an increase in total imports (see Figure 3.55). Following Japan, Mexico is now second in terms of total maize imports.[249] The U.S.A. is currently the main origin of corn imports, and, as temperatures are rising due to climate change, corn is replacing wheat in some parts of the northern U.S.A. and Canada where it could not previously be grown [250;251]. Furthermore, studies suggest there will be a diversification of import sources to Mexico, involving countries such as Brazil and South Africa,[252] and new markets may develop for the import of yellow corn (a variety already commonly imported for feeding livestock).

Corn is highly susceptible to climate variability and climate change, in particular to droughts. Climate change scenarios suggest reductions of up to 4% by 2020 in the

FIGURE 3.56

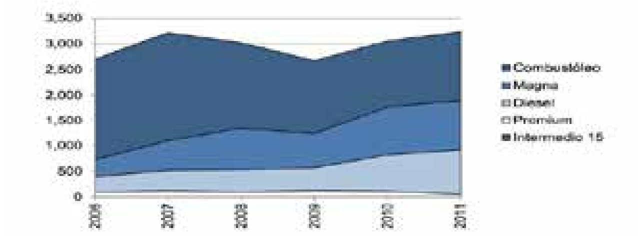
Crop suitability index for maize, expressed as percent change in maize yield by 2055 compared to 1961 – 1990 baseline. Based on results from IIASA MAIZE model simulation



Source: World Bank, 2009 [255]

FIGURE 3.57

Historic trend of petroleum and derivatives traded through the port



Source: API Manzanillo 2012 [259]

arable land suitable for seasonal corn crops in Mexico, with the greatest reductions expected in the state of Sonora, located in the North West of Mexico (see Figure 3.56). Considering the high dependence on corn imports and future decreases in national production due to climate change, it is possible to infer that, without domestic adaptation action to preserve yields, Mexico may increase corn imports into the country. Due to the significant importance of corn in the national diet, import volumes may be somewhat inelastic to increases in price due to climate change or other factors.

The FODA (SWOT) of the PMDP for 2012-2017 recommends that the port should explore opportunities to increase trade of agricultural products other than canola.[254] Exploring the potential development of corn trade through the port could therefore be in accordance with the FODA. Further analysis of this possibility is thus recommended.

3.9.15. Impacts of climate change on vehicles and on petroleum products

As noted in Section 3.9.5, cargo movements for vehicles and petroleum do not follow world GDP trends.

Historically, the movement of vehicles through the port has had an average annual growth rate of 8.6% (2000-2011). However, trade in vehicles at Manzanillo is minor compared to other ports.[256] Other ports have specialized facilities for handling vehicles and are closer to the key centers for distribution and production of cars and car parts[xlvi]. For these reasons, the future growth in vehicle trade at the port is projected by API Manzanillo to be rather small, at around 2.6% per annum for the next decade.

In terms of trade movements for petroleum products, the Energy Secretariat estimates annual increases in Mexico of 4% by 2020 for Premium and Magna gasoline, and of 3% for diesel. Annual demand for heavy fuel oils is projected to decrease by 7% by 2020.[257]

Trade trends for this business line at the port show an increase in the relative contribution of gasoline (diesel, Magna and Premium) from 27% in 2006 to 58% of all petroleum products traded (see Figure 3.57). Following future national trends, projected growth of petroleum and derivatives at the port is projected to be 2.8% per annum by 2022, a result in the combined growth of Premium (+3.7%), Diesel (+ 7.9%) and Magna (5.0%). Trading at the port of heavy fuel oils is expected to decrease by 8.2% per annum over the same time period.[258]

As trade in vehicles and petroleum products do not seem to follow general trends in world GDP (see Section 3.9.5), it is not possible to provide estimates of the impacts of climate change on these two business lines.

3.9.16. Implications for adaptation

Climate change impacts on the world's economy will affect trade at the port, although the scale of the impacts remains uncertain, and the figures suggested by the Stern Review may be a significant underestimate. Furthermore, some of the port's key trading partner countries may be more seriously affected than global average figures would suggest. There may be limited scope for action by the port to counter the negative impacts of climate change on the global economy and on the economies of trading partners.

In the face of these uncertainties, diversification of trading partner countries over the longer term would appear to be a useful risk management action as it can help with managing reduced trading flows from countries that are more affected by climate change impacts (as discussed in Section 3.9.8). Similarly, developing additional business lines can help to spread risk and to profit from expanding import markets in light of climate change impacts, such as corn imports. Such a supply chain risk management approach would require API Manzanillo and the terminals to liaise with shipping companies and customers. These opportunities can be further investigated as part of strategic analysis carried in the development of future Master Plans for Port Development.

The port may also develop strategies to monitor national and international climate change mitigation policies that can affect supply and demand of traded products (see Section 3.11 and Appendix 8). It can also monitor customer expectations in terms of reliability of port services and develop a communication plan on how negative effects of climate-driven disruptions are being addressed.

There may be some opportunities for the port to develop trade in imports of climate-sensitive products, such as corn, where there is high demand in Mexico and where domestic production may be adversely affected by climate change. SEMARNAT and INECC would be well-placed to keep the port updated on the findings of the latest research in this area. This would be in accordance with opportunity needs identified in the FODA (SWOT) analysis provided by the PMDP[260] for 2012-2017.

3.10. Competition with other ports

A comparative assessment has been undertaken to evaluate whether the main climate change hazards for the Port of Manzanillo could be more or less severe than those facing its main Mexican competitor ports. The three main climate change parameters examined were sea level rise, tropical cyclones and temperature.

SUMMARY OF KEY POINTS

- Key Pacific competitor ports for Manzanillo are considered to be Lázaro Cárdenas, and Ensenada. Atlantic competitor ports are Veracruz, Tampico and Altamira.
- Due to reduced storm activity, the Pacific ports experience a significantly reduced annual closure to large and small vessels compared to the Atlantic ports.
- Annual closures for Pacific ports occur on average 0.5% of the time for vessels >500 UAB, and 5.5% of the time for vessels < 500 UAB. At Manzanillo, annual closures are 0.4 % and 6.6 % respectively.
- Annual closures for Atlantic ports average 5.4% of the time for vessels >500 UAB, and 21% of the time for vessels <500 UAB.
- For the Pacific ports, poleward extension of the storms tracks[261] is not sufficient to bring Ensenada under the influence of storms to the degree that Manzanillo currently experiences or is likely to experience in the future. Ensenada maintains its competitive edge therefore in this respect. The same is true, but with slightly lower confidence, for Lázaro Cárdenas.
- No significant variations in mean sea level rise will give any port a competitive advantage.
- Variations in changes of temperature are too small to conclude that the vulnerability of competitor ports will be significantly different from Manzanillo.

3.10.1. Overview of the main ports in Mexico

As noted in Section 1.3, there are six major ports in Mexico: Ensenada, Manzanillo, and Lázaro Cárdenas from north to south on the Pacific coast, and Altamira, Tampico and Veracruz on the Atlantic coast (Figure 3.58).

Before discussing Manzanillo's competitor ports in Mexico, it is useful to outline some of the issues facing Manzanillo, for comparison. Manzanillo is the major port on Mexico's Pacific coast. It has historically handled a variety of bulk material products and agricultural products, expanding in recent years into containers and shipping of vehicles. However, it has some disadvantages compared to its competitors. It is located in the center of a busy Mexican city and thus suffers from difficult access and traffic congestion on its major trucking routes into and out of the terminal. It also is located in some of Mexico's most environmentally sensitive areas, including the mangroves along the south and western fringes of the port basins and the Laguna de Las Garzas.

It also is approaching the limit of the area available to it for expansion. With the development of the Zona Norte including the new CONTECON terminal, there is little land remaining in the central port area suitable for future terminal development. Future port development, if it is to take place, would likely need to be located in and around the Cuyutlan Lagoon. This area would require a substantial investment to improve road and rail access and in dredging of navigation and berthing channels.

3.10.2. Lázaro Cárdenas

The Port of Lázaro Cárdenas was developed in the 1970s as part of the Mexican government's program for constructing a large integrated steel mill on the Pacific coast. With the signing of the North American Free Trade Agreement (NAFTA), increasing globalization and a growing trade between Mexico and Asia, expansion of the container handling facilities at the port has accelerated. The port has become a direct competitor to Manzanillo, particularly in the area of container terminals and automobile shipping. Recently, the Hutchison Port

FIGURE 3.58

Main ports in Mexico

Source: Report authors

Holdings Group completed the second phase of a major expansion of their container terminal facilities at the port, commissioning a green field terminal to be constructed in four phases with an ultimate capacity of 2.6 million TEUs and the ability to handle Super Post-Panamax vessels. Plans are underway to construct a second major container terminal and an adjacent automobile terminal north of the Hutchison terminal (Figure 3.59). Lázaro Cárdenas likely constitutes the greatest competitor to Manzanillo. It has several advantages in that:

- It is located outside the town of Lázaro Cárdenas and has excellent road and rail links to the interior of Mexico and through to the US
- It has plenty of land for future terminal expansion; and
- It is not in an environmentally sensitive area and does not experience significant levels of siltation requiring frequent maintenance dredging

FIGURE 3.59

Aerial view of the Port of Lázaro Cárdenas with the location of the new container terminal shown

Source: Worley Parsons Engineering [262]

3.10.3. Ensenada

The Port of Ensenada is a marine freight and cruise terminal in Ensenada, Baja California. This deep water port lies in Bahia de Todos Santos. Ships arrive to the port from major ports in Asia, North America and South America. The port accommodates cargo and cruise terminals as well as serving as an unloading dock for containers. Activities based from within the port extend to commercial and sport fishing, pleasure craft, and marina areas. The Port of Ensenada maintains specialized shipyards and handles mineral bulk. The Port of Ensenada is also Mexico's second busiest port, as well as the second most visited port-of-call for major cruise lines and pleasure boats in Mexico.

3.10.4. Veracruz

The Port of Veracruz is Mexico's oldest Port, having been established in the 16th century under Spanish colonial rule. In 1991, the Federal Government took over the control and administration of the Port of Veracruz and brought in private stevedoring companies to improve cargo handling operations. The Administración Portuaria Integral de Veracruz (APIVER) was established in 1994.

The Port of Veracruz boasts state-of-the-art infrastructure and technology and the ability to load and discharge cargo in an efficient and timely manner. It has excellent connections to Mexico's important population centers by both road and rail. The major exports from the port include containers, vehicles, steel and agricultural products. With over 3,000 meters of piers, the Port of Veracruz contains 11 berths ranging in length from 178 to 507 meters. The Container Pier is over 507 meters long with an alongside depth of 12.8 meters. The Cement Pier is 178 meters long with an alongside depth of 10.7 meters.

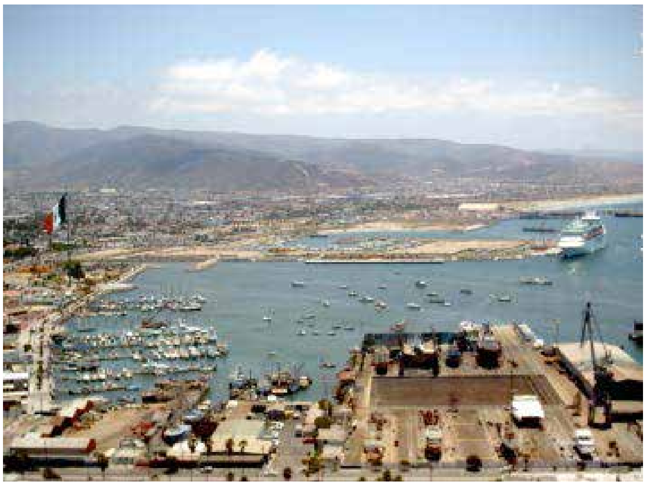
3.10.5. Tampico

The Administración Portuaria Integral (API) de Tampico S.A. de C.V. was created in 1999. As one of Mexico's busiest and most important east coast seaports, Tampico is an important gateway for petrochemical and mining products, steel, wood, and many industrial goods.

The Port of Tampico has modern infrastructure and facilities, with large, open warehouses and good rail connections. The port has six private terminals, two public terminals, and ten fields dedicated to constructing marine oil rigs. It is connected with over 100 countries through 20 shipping lines. Its major trade and shipping

FIGURE 3.60

View of the Port of Ensenada



Source: Ferreira, 2004 [263]

FIGURE 3.61

View of the Port of Veracruz

Source: International Transport Workers Federation, 2015 [264] partners include the United States, Canada, Europe, Cuba, Brazil, the Dominican Republic, Brazil, Singapore and Australia.

The port has three public terminals with specialized equipment to handle general cargo, containers, oversized cargo, and bulk mining and agricultural products. It has a total of 2,141 meters of piers in 11 dock positions with alongside depths ranging from 10.7 to 11.3 meters. The public terminals at the port are served by a double-railway allowing for direct loading and unloading and direct access to Mexico's highway network. The terminals include over 60,000 square meters of roofed storage space.

3.10.6. Altamira

The Port of Altamira handles multiple cargo types. The port is home to a large liquid natural gas (LNG) facility, and expansion plans include the construction of a new patio to build deep water oil platforms, the construction of a new coke, coal, and graphite plant, and the construction of an industrial plant to produce galvanized steel for the automotive industry. The expansion of Altamira is being driven by API Altamira and several private terminal investors. Each of the expansions will be funded by private investment, with API Altamira providing public funds for investment in general port infrastructure. Altamira does not face significant land constraints as the port is located outside the town's urban area and has plenty of surrounding land.

FIGURE 3.62

View of the Port of Tampico

Source: tomzap.com, 2015 [265]

FIGURE 3.63

View of the Port of Altamira

Source: Puerto Altamira, 2015 [266]

3.10.7. Comparison of climate risks

Tropical Cyclones

Current

To compare current operational sensitivity to storms, data has been provided by SCT[267] on annual closures at each of the ports above. This is given for large and small vessels (greater and less than 500 UAB (Table 3.48 and Table 3.49). The climatic reason for the port closures is not specifically given in the data. However the records indicate that the majority of delays occur in the tropical storm season of June to October.

It can be seen that the Pacific ports of Manzanillo, Lazaro Cardenas and Ensenada are subject to significantly less downtime than the Atlantic ports of Vera Cruz, Tampico and Altamira. This can be attributed to the greater frequency with which storms impact coastal regions in the Atlantic compared to the East Pacific. Tropical cyclones typically form in the tropical latitudes of the Northern Hemisphere, where prevailing winds blow from east to west. In the Atlantic, storms generally move towards coastal ports while in the Pacific more frequently they move away.

Future

A comparative assessment for each port was conducted regards projections for future changes in the location of tropical cyclones. It should be emphasized that methods for predicting sub-basin scale future tropical cyclone tracks are in their infancy. Manzanillo is shown to have

TABLE 3.48

Percentage annual closure to vessels > 500 UAB for all ports

Year	MANZANIL-LO	LAZARO CARDENAS	ENSENADA	VERACRUZ	TAMPICO	ALTAMIRA
2010	0.00%	0.45%	0.00%	5.27%	5.54%	4.78%
2011	0.50%	1.34%	0.00%	3.87%	5.27%	5.32%
2012	0.00%	0.00%	0.23%	3.24%	4.20%	4.91%
2013	1.10%	2.23%	0.00%	8.39%	6.71%	8.06%
Average % Downtime	0.40%	1.01%	0.06%	5.19%	5.43%	5.77%

Source: Report authors

TABLA 3.49

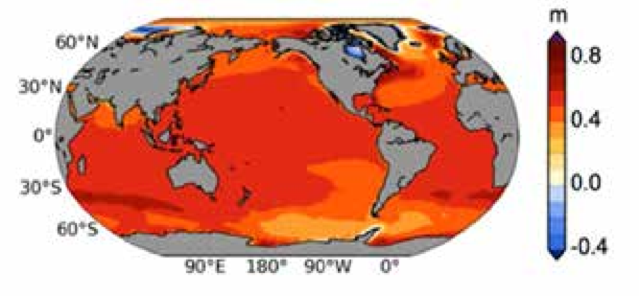
Percentage annual closure to vessels < 500 UAB for all ports

Year	MANZANIL-LO	LAZARO CARDENAS	ENSENADA	VERACRUZ	TAMPICO	ALTAMIRA
2010	13.00%	3.33%	7.30%	20.39%	16.43%	16.43%
2011	5.40%	3.98%	6.30%	24.15%	21.92%	23.32%
2012	2.70%	7.25%	2.27%	23.60%	17.06%	14.76%
2013	5.30%	7.73%	1.16%	32.47%	20.87%	22.86%
Average % Downtime	6.60%	5.57%	4.26%	25.15%	19.07%	19.34%

Source: Report authors

FIGURE 3.65

IPCC projections of regional sea level rise by the end of the 21st century



Source: PICC, 2013 [272]

potential greater impact to tropical cyclones compared to other competitor ports on the Pacific coast, but less than the Atlantic ports.

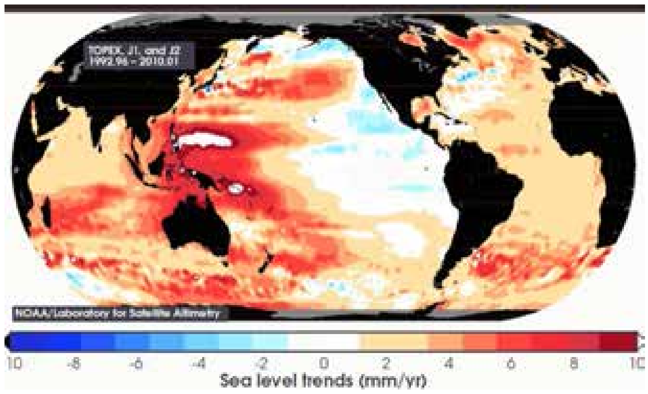
Over the period of the satellite era historical record (1980 to 2014), Ensenada lies effectively beyond the climatology of tropical cyclone tracks. Poleward extension of the storms tracks[268], which is currently occurring, is not sufficient to bring Ensenada under the influence of storms to the degree that Manzanillo currently experiences or is likely to experience in the future. Ensenada maintains its competitive edge therefore in this regard. The same is true but with slightly lower confidence in the case of Lázaro Cárdenas. This port does lie closer to the northern limit of the storm tracks but it would require a substantial poleward shift and attendant tropical cyclone tracks to bring the port under the same degree of influence as Manzanillo currently experiences, or is likely to experience in the future.

Relative to the Atlantic ports of Veracruz, Tampico and Altamira, the Port of Manzanillo has a competitive advantage owing to the relatively more frequent large storms making landfall at the latitude of the Atlantic ports.

Importantly, expert judgement on the future of tropical cyclones shows a consensus of a 50% increase in the annual frequency of category 4 and 5 storms along the coastline of the Atlantic ports. In contrast, it is held that there is insufficient data to be able to assess this metric for the case of coastline of the Pacific ports. Estimates of the increase in the lifetime of the storms and the extreme precipitation from the storms are similar between the Pacific and Atlantic coasts.

FIGURE 3.64

Changes in sea level in the period 1992 to 2010 based on satellite altimetry



Source: NOAA, 2015 [270]

Sea level

Figure 3.64 shows observed global changes in sea level between 1992 and 2010 based on the NOAA Jason 1 and Jason 2 satellite altimetry program[269]. These data indicate that the average sea level for the Port of Manzanillo remained unchanged over this period, and declined by 2 mm per year at Lázaro Cárdenas. On the Caribbean coast, the satellite data indicate that the Port of Veracruz saw an increase in mean sea level of 2 mm/year and the Ports of Tampico and Altamira saw increases of 4 to 6 mm/year. One cause of this variation is the changes in land levels due to the action of the major tectonic fault line running offshore along Mexico's Pacific coast. This is due to up-thrusting of the Pacific coastal and Sierra Madre area of Mexico and some subsidence around the Gulf of Mexico.

In the longer term, under the rate of sea level rise based on IPCC Scenario RCP 8.5 it is anticipated that sea level changes around Mexican coastal areas will be positive (higher) for both the Pacific and the Gulf of Mexico. Figure 3.65 shows the projections from for regional sea level rises by the end of the 21st century[271].

These data indicate that by the end of the century, sea level will be rising by 5 to 6 mm/year for the Port of Manzanillo and its major competitors. The rate of rise for the Port of Ensenada might be up to 1 mm/year less than Manzanillo. Effectively, it can be concluded that the effects of sea level rise due to climate change will be broadly comparable for all the Mexican ports reviewed in this report.

Temperature

The analysis conducted for this report (Section 2.1) provided projections of future temperature changes for Manzanillo and its major competitor ports. For comparison the results are provided in Table 3.50.

The results show that variations in mean near-surface temperature changes are small among the selected ports. In the 2040s, the temperature change is in the range of 1.8 to 2.0˚C, except for Ensenada which is slightly higher at 2.0 to 2.2˚C in June to November. In the 2070s the variations are slightly greater. Manzanillo's predicted temperature rise is equal to or less than its competitors by up to 0.2˚C, except for Tampico/Altamira which is estimated to be 0.2˚C less than Manzanillo in June to November.

Variations in changes of these magnitudes are too small to conclude that the vulnerability of Manzanillo to climate change induced temperature increases will be significantly different to that of its competitors.

TABLE 3.50

Projected mean near-surface temperature changes for Manzanillo and its competitor ports

PORT	2040s Temperature Change ˚C		2070s Temperature Change ˚C	
	Dec-May	Jun-Nov	Dec-May	Jun-Nov
Manzanillo	1.8 - 2.0	1.8 - 2.0	3.0 - 3.2	3.2 - 3.4
Ensenada	1.8 - 2.0	2.0 - 2.2	3.2 - 3.4	3.4 - 3.6
Lázaro Cárdenas	1.8 - 2.0	1.8 - 2.0	3.0 - 3.2	3.2 - 3.4
Veracruz	1.8 - 2.0	1.8 - 2.0	3.2 - 3.4	3.2 - 3.4
Tampico/Altamira	1.8 - 2.0	1.8 - 2.0	3.0 - 3.2	3.0 - 3.2

Source: Report authors

3.11. Implications of international and national agreements or commitments to reduce greenhouse gas (GHG) emissions

A summary of the risks to the port associated with international and national agreements to reduce emissions of greenhouse gases is provided in Table 3.51. Further details are provided in Appendix 8.

SUMMARY OF KEY POINTS

- Changes in regulations, standards and investors' expectations in Mexico due to international and national commitments to reduce greenhouse gas emissions can have implications for the port's business lines.
- The Conference of the Parties (COP) in Paris in late 2015 is seeking to achieve a legally binding and global agreement on climate. However, there is considerable speculation about the outcome of the COP.
- According to Mexico's Intended Nationally Determined Contributions (INDC), the country is committed to reduce unconditionally its emissions of GHG and short-lived climate pollutants by 25% below Business As Usual (BAU) by the year 2030. This commitment could increase up to 40% conditional on the Paris COP reaching a global agreement.
- Climate change mitigation commitments could affect the price of petroleum products and the demand for different fuel types traded through the port.
- Other cargoes where demand could be affected by mitigation commitments may include vehicles and minerals.

TABLE 3.51

Risks associated with international and national agreements to reduce emissions of greenhouse gases

Risk	Thresholds and Sensitivities	Current and future policy on climate change	Risk Description
Increase import price of fossil fuels can affect volume flows of petroleum and its derivatives	The introduction of emission reductions caps and/or policies and legislation aimed at the promotion of renewable energies and fuels, energy efficiency measures and cleaner transport may increase the price of those fuels	Mexico's submitted INDC indicates an unconditional mitigation effort by Mexico equivalent to a reduction of GHG and short lived climate pollutants emissions of 25% by 2030 below Business As Usual (BAU). This commitment is in line with the General Climate Change Law and equivalent to a reduction of 22% of GHG emissions and 51% of black carbon emissions. If the Conference of the Parties in Paris reaches a global agreement, this commitment could increase up to 40%.	International commitments to be agreed at the next Conference of the Parties in Paris are uncertain at present. Together with Mexico's commitments in its INDC, this has the potential to affect the production and trade of commodities traded through the port.
Effects of mitigation policy on GHG intensive cargoes (e.g. minerals and vehicles) may affect cargo flows of these commodities. For example changes in regulations, standards and investors' expectations may have implications for port business activities	Volumes of exports and imports of various materials through the Port of Manzanillo have not been affected directly or indirectly by international negotiations and climate change legislation to date. However, this could change in light of Mexico's submitted INDC and depending on the outcome of the Paris COP.		

Source: Report authors

3.12. Implications of future evolution of the insurance market

SUMMARY OF KEY POINTS

- API Manzanillo has a comprehensive insurance package which covers it against asset damage, costs relating to temporary relocation of port services in case of operational disruptions, public liability, vessels and vehicles. It is not apparent from API Manzanillo's policy documents that business interruption is included.
- From 2010 to 2014 two weather-related insurance claims were made by API Manzanillo, for damage to electrical equipment affected by electrical storms.
- Terminals that provided insurance details were shown to hold commercial insurance policies which typically covers asset damage and third-party (civil) liability. Some also have business interruption cover.
- None of the insurance claims made by the terminals in recent years were weather-related.
- Globally, an increase in the frequency and intensity of weather and climate related events combined with development and increased asset value has led to an increase in the number and value of insurance loss claims.
- Future increases in the frequency of weather-related events and associated insurance claims may result in increases in premium costs for API Manzanillo and the terminals.
- Adaptation options include risk prevention and reduction measures for assets.
- API Manzanillo and the terminals should monitor changes in premium costs for policies covering assets against natural disasters.
- With its adaptation plan in place, API Manzanillo and the terminals could request that insurers provide more favorable insurance terms.

3.12.1. Insurance policies held by API Manzanillo

API Manzanillo has a comprehensive insurance package with AXA Seguros S.A. de C.V. The same package covers all major commercial ports of Mexico[xlvii] and protects them against climate-related hazards and other perils. API Manzanillo have provided the technical details of their AXA TRiesgo insurance policy package (2014-2015) which covers the APIs against fire, commercial and industrial risks.

Within the TRiesgo package help by API Manzanillo there are five main sub-policies, namely:

1. Policy for major risks: for buildings, port constructions and maritime signage equipment
2. Business insurance
3. Public liability insurance
4. Insurance for lower vessels (operational vessels)
5. Insurance for vehicles (cars, trucks, buses and motorcycles)

Insurance sub-policy 1 for major risks incorporates insurance for physical assets that are the property or responsibility of API Manzanillo, including: piers, mooring, dolphins, breakwaters, groynes, seawalls, patios and roads, defense barriers, perimeter fences, railroad spurs, maritime signage (e.g. buoys, lighthouses), baffles, moorings and marginal protection[xlviii]. The policy also covers remediation and cleaning due to sudden or unexpected pollution. Risks insured under policy 1 therefore refer to all property owned or under the responsibility of API Manzanillo that has been damaged or lost (as long as damage or loss is accidental, sudden or unexpected) and resulting in costs incurred by API Manzanillo including:

- Costs of reconstruction

TABLE 3.52

Value of insured elements for API Manzanillo

Elements covered	Total value insured (MXN)
Buildings and complete works	344,862,462.54
Berthing, piers and docks	1,751,983,595.45
Protection jetties, breakwaters and marginal protection, breakwaters, deflectors	682,687,183.49
Patios, roads and railway infrastructure	558,863,190.17
Maritime signage	14,473,466.40
Total	3,382,869,898.04

Source: API Manzanillo [274]

TABLE 3.53

Deductibles per asset type for claims triggered by 'natural phenomena'

Type of asset	Excess/deductible
Port works	1% of the loss with a minimum of USD 3,000 and a maximum of USD 50,000 per event
Buildings	1% of the loss with a minimum of USD 3,000 and a maximum of USD 10,000 per event
Channel and inner harbor dredging	USD 500,000
Civil engineering works under construction	USD 5,000

Source: API Manzanillo [275]

- Dredging in the navigation channel and inner harbor due to sedimentation
- Solid waste removal (including costs for demolition and cleaning of materials)
- Additional costs (e.g. rental of temporary location for carrying on port activities, moving costs, light and heating at temporary location, temporary adaptation of areas for loading and unloading)

Importantly, costs incurred for dredging of the channel and eligible under Insurance sub-policy 1 are repaid on the basis of the difference between sedimentation levels recorded at the last existing official bathymetric study and the bathymetry encountered after the event that triggers the insurance claim. In this respect, AXA Seguros only accepts bathymetric studies that are less than 6 months old as baseline for contrasting sedimentation levels prior to and after a natural disaster. Dredging activities for material deposited in the bay at natural rates of deposition and within the natural oceanographic conditions of the area are not covered.

The insurance policy package does not cover the goods and merchandise that are part of the cargo of the terminals. Accordingly, the insurance policy for the APIs does not cover direct/indirect losses or damages to goods due to fungal growth, mold or growth of other microorganisms in the goods traded.

For the current coverage period (2014-15), the total value of repayment coverage for buildings, port works and maritime signage equipment for the Port of Manzanillo was close to 3.4 billion MXN (Table 3.52). According to this, Manzanillo has the second largest value of insured assets under the AXA policy insurance 1 of all the APIs.[xlix] The total insurance premium paid by API Manzanillo for 2014-15 amounted to USD 1,856,017.91 (0.8% of insured asset value).[273]

Insurance sub-policy 1 against major risks, provides cover for:

1. fires, lightning or explosions (with no excess value);
2. 'natural phenomena' which would include meteorological and hydrometeorological events;
3. earthquake and volcanic eruptions;
4. other risks; and
5. in the case of port operations, theft and loss of maritime signage

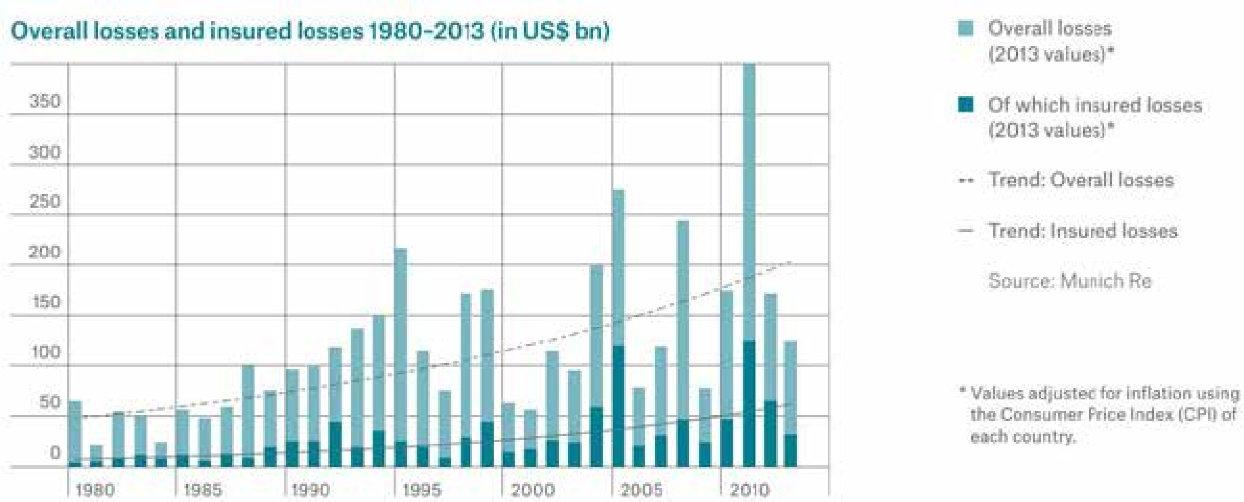
Table 3.53 provides information on excess values (deductibles) for insurance claims triggered by natural phenomena. It is worth noting that dredging has a deductible of USD 500,000.

The summary documents which were examined explicitly indicate that when referring to natural phenomena, losses incurred due to earthquake, volcanic eruption or natural phenomena are presented as a single loss when:

1. There is more than one of these events occurring in a period under 72 hours during the period of insurance coverage
2. If a flood event occurs in a period of continued

FIGURE 3.66

Losses (overall losses and insured losses) worldwide due to major natural catastrophes from 1980 to 2013



Source: Münich Re 2014 [278]

TABLE 3.54

Insurance claims made by API Manzanillo over the period 2010-2014 which have relevance to climate factors

Insurance claim by API Manzanillo	Date	Description	Value of claim	Climate relevance
Extraordinary work carried out by tugs	April 22nd, 2012	An earthquake led to sedimentation at pier 7 track 8 Band C affecting draft and the ability of vessel B/M Moonray to berth. This forced the vessel to berth 50 cm from the pier and required extra support from tugs for berthing.	2,500,000.00 MXN (estimated costs of operation for API)	While this event was an earthquake, extreme climate events could potentially cause similar impacts.
Replacement of NEPSY 4000 equipment	October 8th, 2013	Electrical storm	208,307.51 MXN compensable for loss	Potential increases in future storm intensity may lead to higher frequency of electrical storms
Dredging operations	April 11th, 2014	Additional dredging required to remove volumes of material accumulated due to tropical storms Hector (Aug. 2012) and Manuel (Sept. 2013)	39,999,999.33 MXN (a)	Potential increase in mean lifetime of storm maximum intensity and precipitation rate within 200 km may lead to higher sedimentation rates and increased dredging requirements and costs
Fixing CCTM (Centro de Control de Tráfico Marítimo) equipment	June 30th, 2014	Electrical storm	251,895.25 MXN	Potential increases in future storm intensity may also lead to higher frequency of electrical storms

Notes:

Value provided based on two insurance claims for dredging costs:

MXN 28,499,999.59 (period Nov 14th to Dec 14th 2013)

MXN 11,499,999.74 (period Dec 15th 2013 to Jan 5th 2014)

MXN 39,999,999.33 Total

Source: APII Manzanillo [277]

overflow or river(s) or current(s) and “if the water lowers among the banks of the river(s) or current(s)”.
3. If a flood results from one or several surges caused by the same ‘commotion’

The policy documents for sub-policy 2 Business insurance) specify conditions under which, in cases of business disruption, the policy will cover API Manzanillo against costs to support business continuity, such as the costs of temporal relocation of business activities. However, it is not apparent from these policy documents that this policy covers API Manzanillo for loss of revenue due to business interruption.

It also appears that insurance sub-policies 1 and 2 do not include either Contingent Business Interruption or Ingress/Egress coverage. In general terms, physical loss or damage to an insured asset can trigger a business interruption loss. A Contingent Business Interruption or Ingress/Egress policy could cover API’s loss of revenue, regardless of the existence of a loss or damage to an insured asset.[276] It would therefore cover API against business interruption from:

- Climate-related hazards affecting API Manzanillo’s customers, and
- Flooding, strong winds or heavy rainfall affecting the access to and from the port or vehicle movements at the port, and causing business interruptions or downtime.

3.12.2. Historic insurance claims by API Manzanillo

The historic insurance claims made by API Manzanillo which have relevance in the context of climate variability and change are summarized in Table 3.54. It can be seen that of the claims made, three were directly caused by poor weather conditions, specifically equipment damage caused by electrical storms and dredging following tropical storms Hector and Manuel.

3.12.3. Insurance policies held by terminals

Some of the terminals have provided details of the types of insurance policies they hold, the assets or elements covered, and the perils covered (see Table 3.68).

All the terminals that provided insurance details (six in total) hold a commercial insurance policy, which typically covers asset damage and third-party (civil) liability. According to the terminals, the policies usually cover ‘weather-related’ events, ‘hydrometeorological events’ or ‘waves and tides.’ In some cases, terminals hold a stand-alone maritime civil liability policy. Some of the terminals reported having business interruption cover, which should cover loss of revenue due to extreme weather events.

Only one terminal out of the six reported having made a claim in the period 2009-2014. This was for materials damage, and was not caused by weather-related events. Interestingly, none of the terminals reported insurance claims resulting from business interruption due to events described during consultation meetings, (and referred to elsewhere in this report), namely:

- Blockage of port entry access road due to flooding and sediment accumulation caused by heavy rainfall in 2011, 2012 and 2014 (see Section 3.6.1, chapter “Surface flooding”).
- Interruption of Ferromex rail services during a 17 day period due to reconstruction works of the bridge to cross the Armería river, which was destroyed by high river flows following Hurricane Jova in 2011.
- Closures in the port by the Harbor Master in preparation for heavy tropical storms and hurricanes.

3.12.4. Response of the insurance industry to climate change

The insurance industry globally is recording increasing insured losses due to weather-related catastrophes (Figure 3.55). Several factors explain this upward trend, including increased property values and greater insurance cover, along with rising numbers of weather- and climate-related loss events. While the number of geophysical events (earthquake, tsunami and volcanic eruption) has remained fairly constant over the period 1980 to 2013, it is clear from Figure 3.67 that meteorological events, hydrological events and so-called climatological events have become more frequent. Since the 1980s, the number of loss-relevant weather-related catastrophes has almost tripled.

Figure 3.68 shows the countries most affected by natural catastrophes in 2013. Mexico was the seventh most affected country worldwide in terms of number of events and the sixth most affected in terms of overall losses. Meteorological events were the most common events

TABLE 3.55

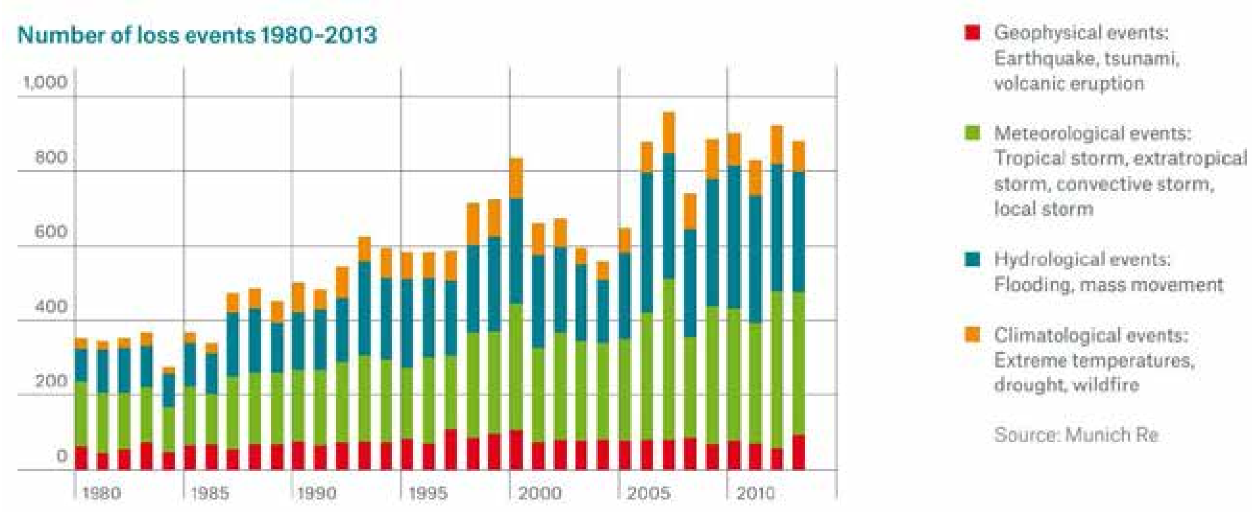
Summary of insurance held by terminals

Policy type	Assets/ elements covered	Perils covered
Commercial (including asset damage, business interruption, professional misconduct and third-party (civil) liability)	Permanent buildings, cargo handling equipment, wharves, docks, moorings, bulkheads, structures within the port area, contamination and leaks, liability to cargo	Earthquake, volcanic eruption, waves, tides, tsunami
Commercial (including asset damage and civil liability)	Materials damage, damage to contents, consequent losses, theft of goods	Earthquake, fire, lightning, explosion, strikes, weather events
Commercial (including asset damage and civil liability)	Buildings and activities, debris removal, theft, accidental damage, general liability	Earthquake, volcanic eruption, fire, hydrometeorological events
Commercial	Not described	Earthquake, volcanic eruption, fire, lightning, explosion, strikes, riots, civil unrest, vandalism hydrometeorological events
Maritime civil liability (a)	Damage to third parties (ships, cargo and other) including damages for delay, third party liability, debris removal, sudden and accidental pollution, legal liability	Fire, war, strikes, terrorism

Source: Report authors

FIGURE 3.67

Number of loss events worldwide by type of natural catastrophe from 1980 to 2013



Source: Munich Re 2014 [279]

in Mexico in that year (Figure 3.68, top panel), and the dominant sources of the country's losses (Figure 3.68, lower panel).

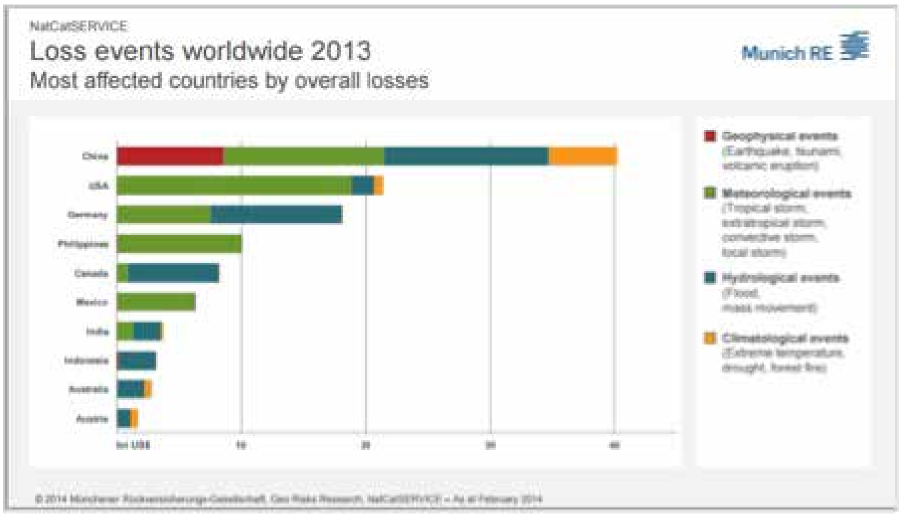
The insurance industry has been vocal about climate change for more than a decade, expressing its concerns that, without strong action to reduce global greenhouse gas emissions, there will be major shifts in risk landscapes worldwide and threats to human and economic wellbeing. In November 2013, three insurance initiatives[li] with a combined membership of more than 100 of the world's leading insurers published a Global Insurance Industry Statement, "Building climate and disaster-resilient communities and economies: How the insurance industry and governments can work together more effectively"[281]. It explains that the industry sees the need for both public and private actors to engage in a "broader societal discussion about the use of insurance in the context of climate- and disaster-resilient development". It sets out a number of key areas of action that insurers have agreed to take forward, namely:

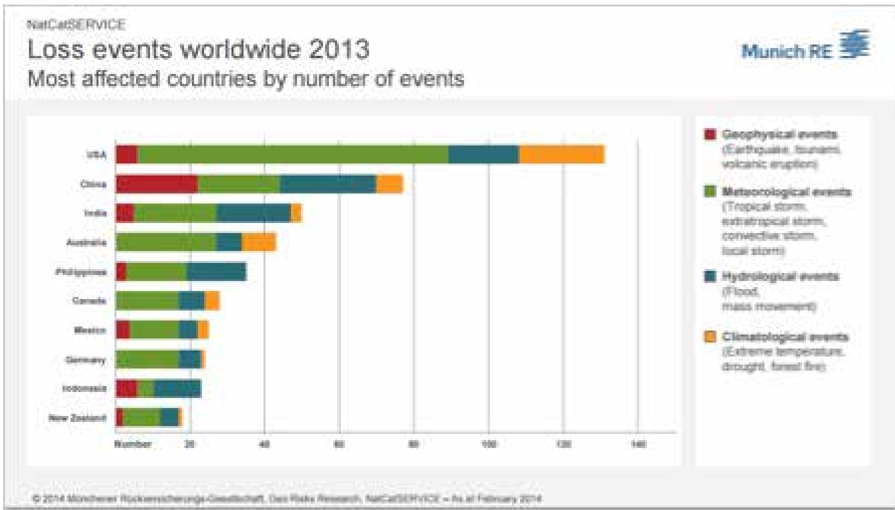
- Demonstrating leadership to decarbonize economic activity at the scale and pace demanded by scientific consensus and supporting corresponding public sector decision-making
- Identifying and developing incentives to reduce climate risk by promoting risk awareness, risk prevention and risk reduction solutions that contribute to building adaptation to the effects of climate change including disaster resilience
- Where risks cannot be effectively reduced or retained, supporting the transfer and sharing of such risks through insurance mechanisms including risk pooling mechanisms
- Considering how insurance industry responses to climate-related events can shape the behaviors and decisions of governments, communities and businesses in managing climate risks

In practice, these actions imply that ports (along with others) may face higher premiums and higher deductibles if they make more claims for weather-related losses, as events become more frequent due to climate change. Insurance companies can also be expected to take a more active role in engaging with clients on climate resilience. Ports with climate change adaptation plans in place could request that their insurers provide more favorable insurance conditions.

FIGURE 3.68

Loss events worldwide in 2013 by number of events (top panel) and overall losses (lower panel).





Source: Munich Re 2014 [280]

3.13. Risk assessment summary

Based on the risk prioritization approach described in Section 1.5 and Appendix 1, risk scores were assigned to each of the risks described in Sections 3.1 to 3.12 of this report. The risks rated as 'high priority' are summarized in Table 3.56, while those rated as medium to low priority are shown in Table 3.57. The scores reflect risk levels for the port as a whole but, where relevant, Table 3.56 and Table 3.57 identify specific terminals facing higher risks than the average across the port.

Adaptation measures to address these risks have been identified in Sections 3.1 to 3.12. The measures are assessed further in Sections 4.2 and 5 below.

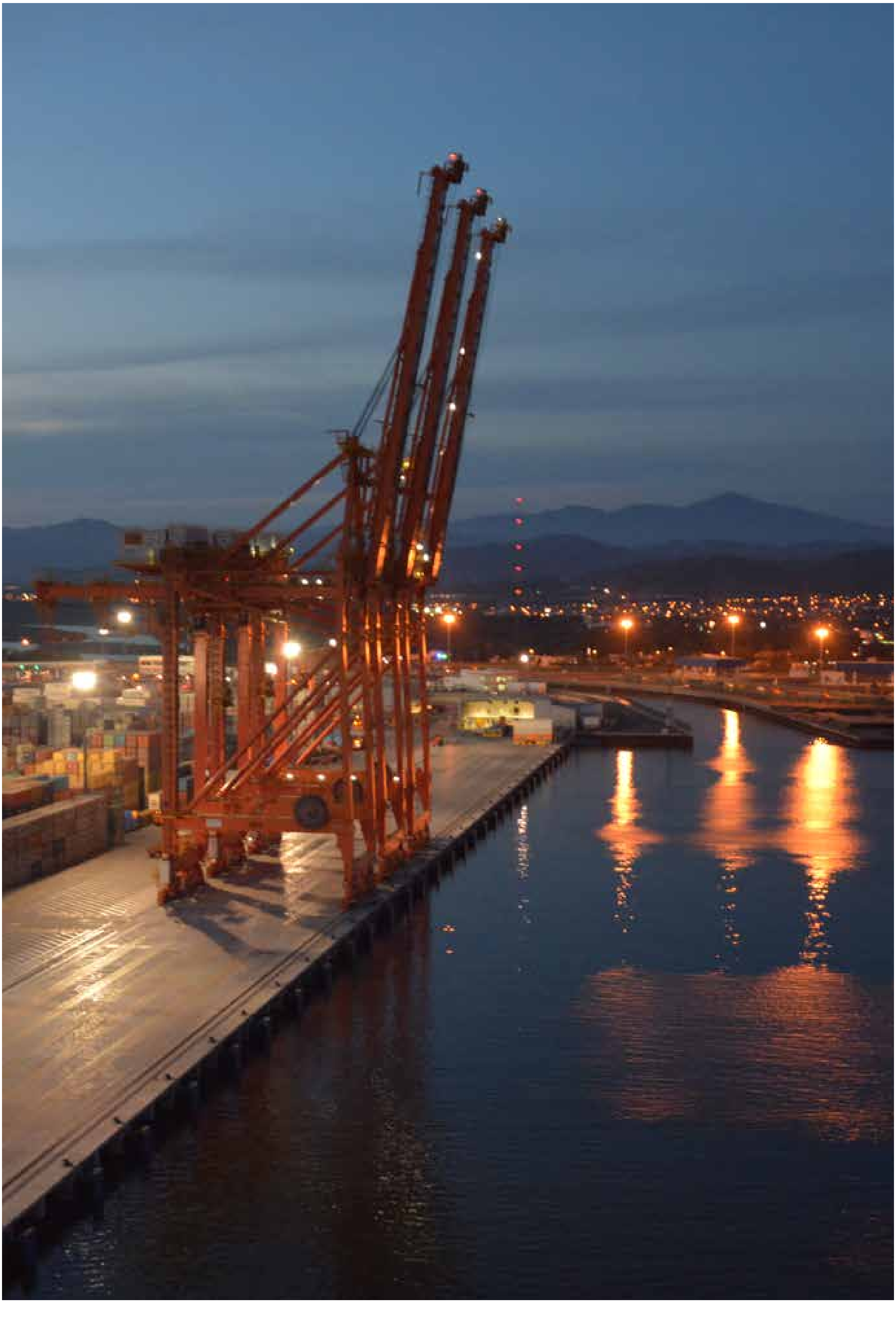


TABLE 3.56

Summary of high priority risks identified for the Port of Manzanillo

Risk area for the port		Climate risk	Current vulnera-bility is high
HIGH PRIORITY RISKS			
DAMAGE TO INFRASTRUCTURE, BUILDING AND EQUIPMENT		Increased frequency of intense rainfall events causes damage to infrastructure and equip-ment through surface water flooding	H
PORT SERVICES		Increase in intensity of rainfall causing increased sedimentation of the port basin, reducing draft clearance for vessels and ter-minal access	H
TRADE ROUTES	Loss of Port connectivity with land transport routes	Increased intensity of rainfall causes surface water flooding of internal access road and en-trance, causing disruptions to port operations	H
		Increased intensity of rainfall causes surface water flooding of internal port rail tracks, causing disruptions to port operations	H

Source: Report authors

Projected impacts of climate change are large	Decisions have long lead times or long-term effects	Scale of future risk is uncertain (but could be large)	Comments (including terminals facing higher vulnerabilities / risks)
H	M	M	Current reputational risk high through international clients. Projected reputational high. All terminals affected
H	M	M	Current reputational risk high through international clients. Projected reputational high. All terminals affected
H	M	M	Current reputational risk high. Projected reputational risk high. All terminals affected
H	M	M	Current reputational risk high. Projected reputational risk high. All terminals affected

TABLE 3.57

Summary of medium and low priority risks identified for the Port of Manzanillo

Risk area for the port	Climate risk	Current vulnera-bility is high
MEDIUM AND LOW PRIORITY RISKS		
GOODS STORAGE	Increased average and peak temperatures cause increased refrigeration and freezing costs	L
GOODS HANDLING	Increased intensity of rainfall events causes increased stoppages to handling equipment e.g. Crane and forklift operator visibility	L
	Decreased number of rain days reduces delays from rain to vessels loading\unloading	L
	Sea level rise combined with storm surge causes flooding of the port resulting in goods handling stoppages	L
	Increased maximum intensity and duration of maximum intensity of tropical cyclones causes increased handling downtime	L
DAMAGE TO INFRASTRUCTURE, BUILDING AND EQUIPMENT	Extreme storm event wind speeds damaging handling equipment	L
	Sea level rise combined with storm surge causes flooding of the port resulting in damage to port equipment and infrastructure	L
PORT SERVICES	Increase in intensity of rainfall requiring in-creased maintenance of the port drainage system	M
	Increased maximum intensity and duration of tropical cyclones and associated wind and wave activity leading to port closures, berthing prob-lems, operational downtime	L
	Increases in mean sea level reduced berthing availability by exceeding minimum threshold dock height for vessels	L

Source: Report authors

Projected impacts of climate change are large	Decisions have long lead times or long-term effects	Scale of future risk is uncertain (but could be large)	Comments (including terminals facing higher vulnerabilities / risks)
L	L	L	
M	M	M	
L (+ve)	L	M	Higher risk for mineral, grain and container consolidation terminals: OCUPA, CEMEX, APASCO, FRIMAN, MULTIMODAL, TIMSA, GRAN, USG, LA JUNTA
M	L	H	
M	L	H	PEMEX at increased risk compared to other terminals due to increased exposure to wind and wave activity
L	L	H	Container terminals with cranes at increased risk
L	L	H	All terminals face similar risk of flooding from sea level rise combined with storm surge
M	M	M	
M	L	H	PEMEX at increased risk compared to other terminals due to increased exposure to wind and wave activity
M	L	M	

TABLE 3.57

Summary of medium and low priority risks identified for the Port of Manzanillo

Risk area for the port		Climate risk	Current vulnerability is high
MEDIUM AND LOW PRIORITY RISKS			
TRADE ROUTES	Land transport on wider network	Tropical storms, flooding and snow affect the broader road and rail networks in Mexico used by port clients, causing interruption and delays in movement of goods to and from the port	L
	Maritime transport	Increased disruption to regional and international maritime transport from tropical storms	M
ENVIRONMENTAL		Increased problems of dust creation and dispersion in drier conditions, both inside the port and from surrounding municipal areas.	M
		Changing climatic factors and port expansion affecting API Manzanillo environmental performance and insurance costs for mangrove habitat	L
		Increased loss of water quality and benthic habitat due to increased maintenance dredging and disposal of dredge material	L
SOCIAL		Changes in temperature and relative humidity lead to more favorable conditions for mosquitoes carrying dengue and chikungunya and hence more cases of these diseases	L
		Increased maximum temperatures cause increased risks of heat stress and dehydration for port workers	L
		Increased temperatures coupled with lower precipitation leads to increased dust generation and more cases of conjunctivitis	L
		Increased temperatures coupled with lower precipitation leads to increased dust generation and adversely affect the port's relationship with the local community	M

Source: Report authors

Projected impacts of climate change are large	Decisions have long lead times or long-term effects	Scale of future risk is uncertain (but could be large)	Comments (including terminals facing higher vulnerabilities / risks)
M	H	M	
M	L	M	
M	M	M	Higher risk inside the port for bulk mineral and cement terminals APASCO, CEMEX, USG, HAZESA.
M	L	H	
M	L	L	
L	L	M	
M	L	L	
M	M	M	
M	M	L	

TABLE 3.57

Summary of medium and low priority risks identified for the Port of Manzanillo

Risk area for the port	Climate risk	Current vulnerability is high
MEDIUM AND LOW PRIORITY RISKS		
DEMAND AND CONSUMPTION PATTERNS	Impacts of climate change on the global economy affecting trade flows at the port	L
	Impacts of climate change on the economies of the port's main trading countries affecting trade flows at the port	L
	Impacts of climate change to the economy of Mexico affecting trade flows at the port	L
	Changes in the production and price of climate-sensitive commodities affect demand for port's services and/or offer opportunities to develop / strengthen trade with new / existing clients	L
COMPETITION WITH OTHER PORTS	Changes in tropical cyclones affect the attractiveness of Manzanillo relative to other ports	M
IMPLICATIONS OF POSSIBLE AGREEMENTS ON GHG EMISSIONS	Increase import price of fossil fuels affecting volume flows of petroleum and its derivatives	L
	Effects of mitigation policy on GHG intensive cargoes (e.g. minerals and vehicles) affect cargo flows of these commodities.	L
IMPLICATIONS OF THE EVOLUTION OF THE INSURANCE MARKET	Increased damage and disruption due to extreme events leads to increased claims and higher insurance premiums and deductibles for APIMAN and/or terminals	L
	Insurers provide more favorable terms to the port due to the implementation of risk-reducing measures in the Adaptation Plan	L

Source: Report authors

Projected impacts of climate change are large	Decisions have long lead times or long-term effects	Scale of future risk is uncertain (but could be large)	Comments (including terminals facing higher vulnerabilities / risks)
M	M	H	
M	M	H	
M	M	H	
M	M	H	
M	L	H	
M	M	M	
L	M	M	
M	M	H	
L (+ve)	M	M	

4. Financial and economic summary

4.1. Costs of climate change impacts

In the previous chapter, the possible financial implications of climate change risks and adaptation actions have been examined separately for each element of the port's value chain.

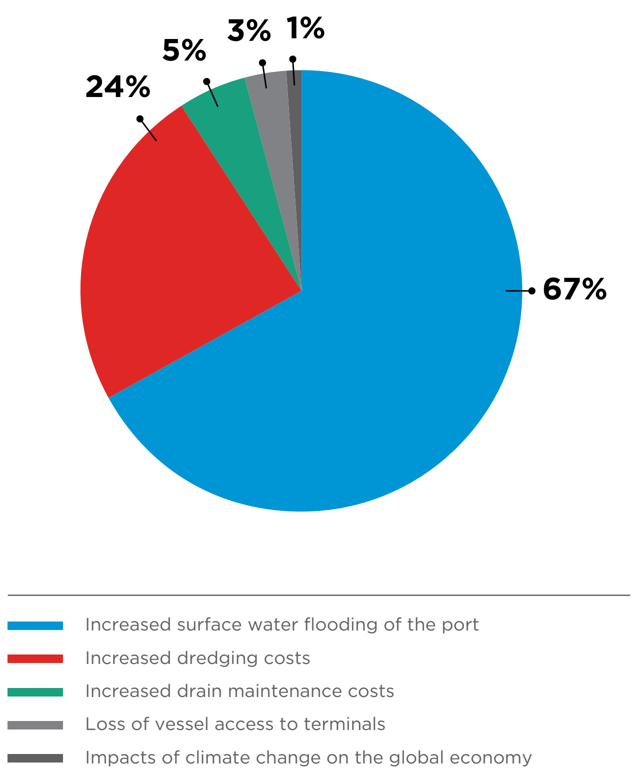
The assessment demonstrated that the climate change risks with the most significant financial impacts for the port as a whole are:

- Increased surface water flooding of the port and the associated increased disruption to vehicle and rail movements (Section 3.6.1, chapter "Surface flooding") affecting the terminals, and increased maintenance costs, affecting API Manzanillo (Section 3.4.2, chapter "Drainage maintenance").
- Increased intensity of rainfall causing greater sedimentation of the port basin. This reduces draft clearance for vessels, affects terminal access, and increases maintenance dredging which also disrupts terminal operations (Section 3.4.2, chapter "Increased maintenance dredging")
- Impacts of climate change on the global economy, which in turn, could affect trade through the port (Section 3.9)

The findings indicate that, if no action is taken, significant financial impacts will be borne by both API Manzanillo and the terminals for these key issues. These costs are summarised below. However, the impacts are not severe enough to pose risks to the continuity of business at the

FIGURE 4.1

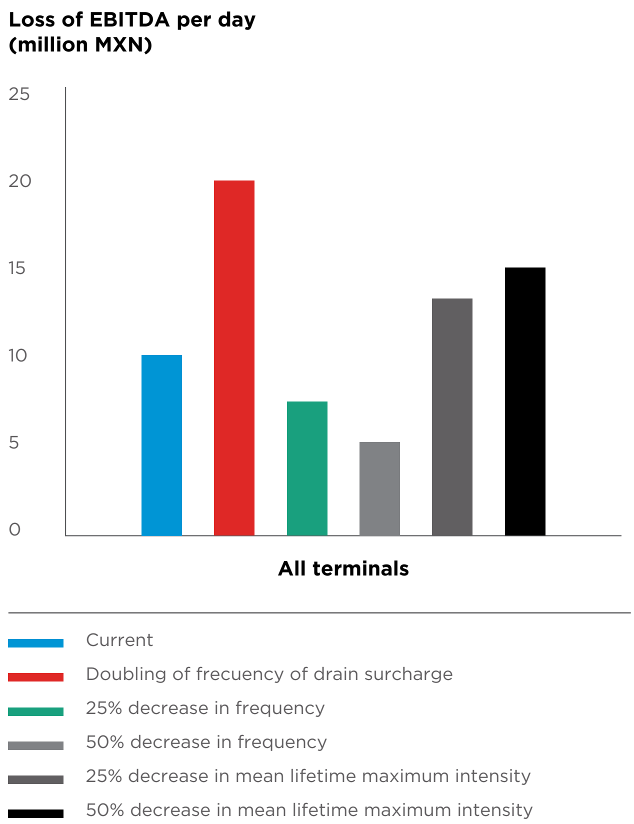
Increase in annual costs or annual loss of revenue by 2050 for climate change risks with significant financial impacts



Source: Report authors

FIGURE 4.2

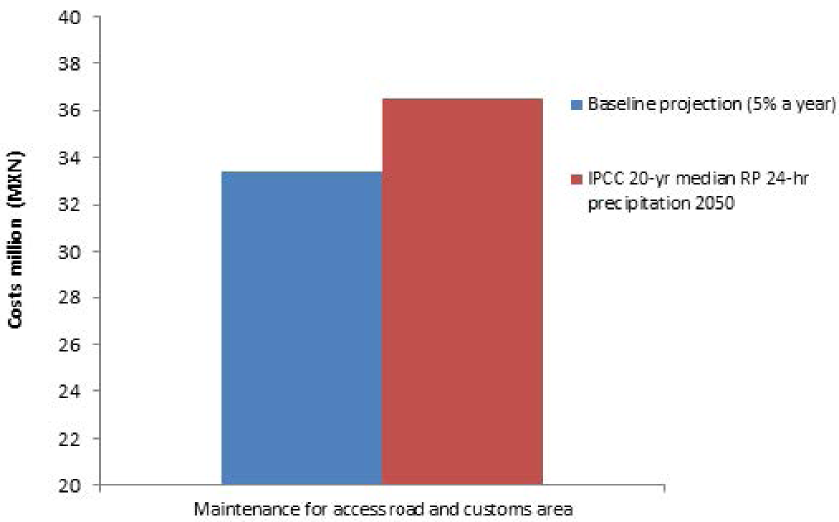
Average annual total loss of EBITDA per day for operational downtime due to surface flooding for all terminals, under increased frequency of drain surcharge and changing storm scenarios



Source: Report authors

FIGURE 4.3

Increase in API Manzanillo annual maintenance costs for road and customs area due to increased rainfall intensity in 2050



Source: Report authors

port over the medium or long term (2050s to 2080s). A comparative summary of the increase in costs due to climate change by 2050 is given in Figure 4.1.

As increases in energy costs due to rising temperatures are quantifiable and are significant for specific terminals, they are also summarized here.

With respect to other risks, the estimated financial impacts are relatively small, or cannot be readily quantified, and are therefore not discussed below.

4.1.1. Increased surface water flooding

The study shows that surface water flooding at the port is already a problem, primarily caused by heavy rainfall during tropical storms. Furthermore, port clients and the port community have identified congestion of the port access road, together with the poor rail service as two of the main weaknesses of the port. These weaknesses are thus a reputational risk.

Figure 4.2 provides a range of total estimated losses (EBITDA per day) for all terminals, associated with operational downtime due to surface water flooding. These sensitivity analyses reflect the approximate doubling of frequency of drain surcharge by 2050 shown by the hydrological analysis (Section 2.2.2, chapter “Discharges”), and various changing storm scenarios contributing to the degree of flooding.

If assumed that surface water flooding incidents and closure of the access road\rail connections can be treated as a port closure issue for API Manzanillo then revenue lost by API Manzanillo can be quantified. The financial impacts for port closure were discussed in 3.2.4. The analysis showed average annual costs of port closure to API Manzanillo to be 0.12% of annual income per 24 hours. Sensitivity analysis can then be applied to illustrate the effect on revenue under changing storm scenarios (Figure 4.4).

4.1.2. Increased sedimentation of the port

Increased sedimentation of the port basin and drainage system due to increased intensity of rainfall has multiple financial risks:

- An increased requirement for maintenance dredging
- Impacts of dredging activities on vessel access to terminals; and
- Increased drain maintenance e.g. clearing of sediment traps

Maintenance dredging

The potential increase in sediment load to the port basin under climate change is related in this study to the 8% increase in IPCC 20-yr median return value for 24-hr precipitation for the 2050s (10% by 2080s). API Manzanillo engineering stated that 0.1 million m^3 per year of sediment will be dredged under the maintenance program by 2017. Figure 4.5 shows the potential increase in costs to API Manzanillo for maintenance dredging by 2050 taking account of climate change. This equates to a 1% increase in overall OPEX for API Manzanillo.

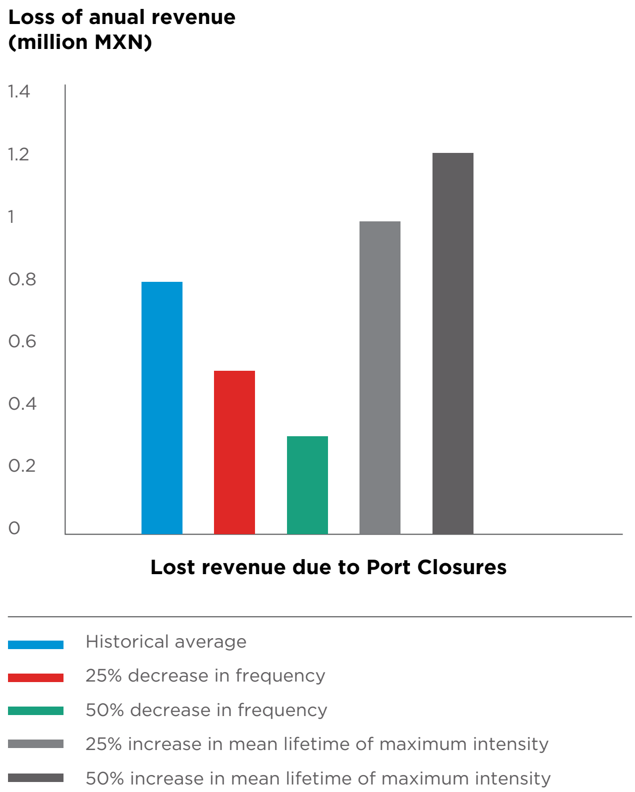
Along with regular maintenance dredging as described above, storm events can lead to significant amounts of sediment deposited in the port, requiring an immediate response from API Manzanillo outside the standard maintenance schedule. A figure of 10,000 m^3 of material (10% of annual program) is used as representative of an immediate dredging volume requirement following a storm at present. Figure 4.6 illustrates a sensitivity analysis of potential changes in annual dredging costs from emergency storm-related sedimentation, related to changes in storminess under climate change.

Impacts of dredging activities on vessel access to terminals

In addition to a reduction in draft clearance associated with dredging, movements of the maintenance dredging vessels can also prevent vessel access to all terminals, effectively stopping operations for the whole port. For

FIGURE 4.4

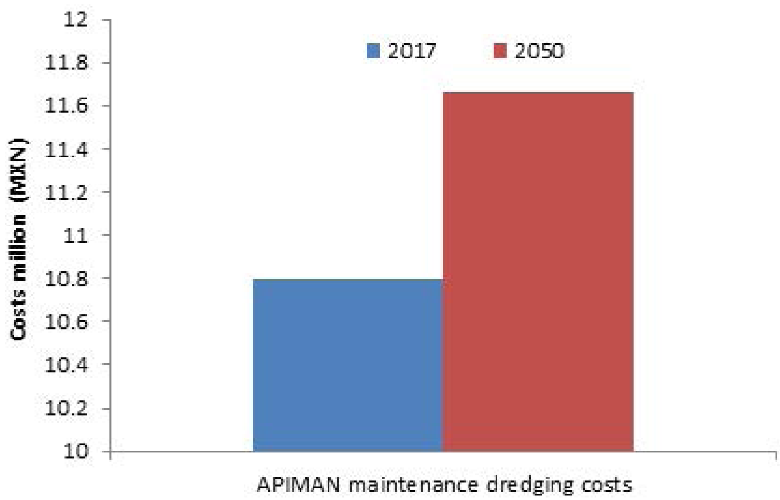
API Manzanillo loss of revenue due to port closure from surface water flooding under changing storm scenarios



Source: Report authors

FIGURE 4.5

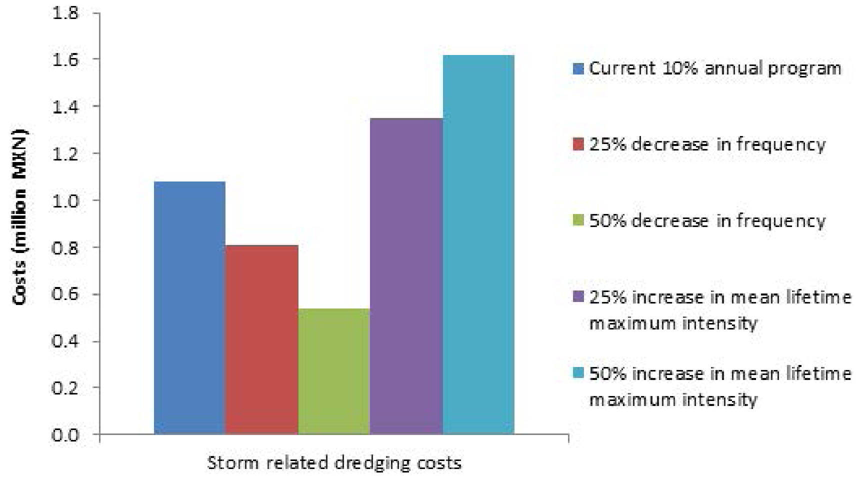
API Manzanillo annual maintenance dredging costs 2017 (without climate change) and 2050 (with climate change)



Source: Report authors

FIGURE 4.6

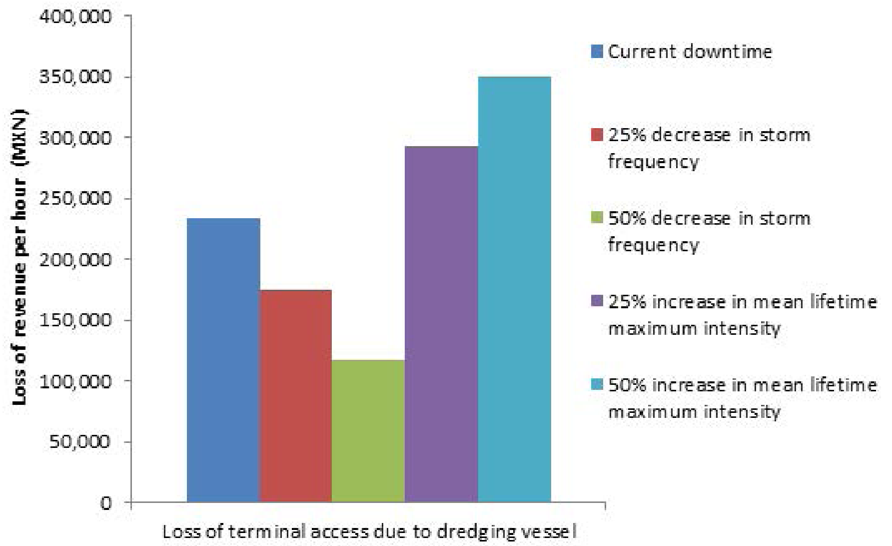
API Manzanillo storm related annual dredging costs under changing storm scenarios



Source: Report authors

FIGURE 4.7

Loss of revenue per hour due to presence of the dredging vessel stopping terminal access, affecting all terminals



Source: Report authors

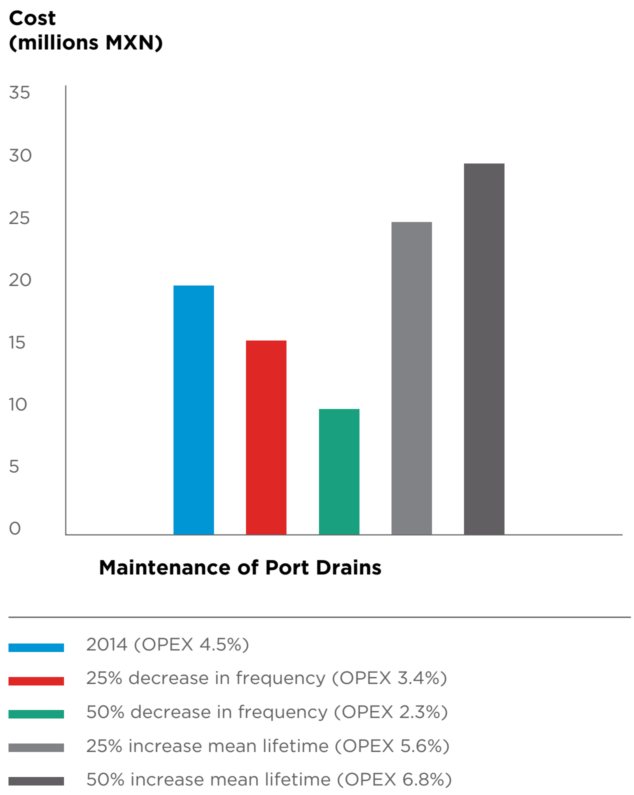
example one terminal reported an increase in handling times of 50% to unload a vessel cargo (10 hours to 15 hours).

Although reported by multiple terminals as an operational issue, financial information was available from only a single terminal on downtime due to dredging, stating that in 2011, 168 hours of operational time was lost due to dredging operations at a cost of 16,706 MXN per hour. No downtime was reported for other years, which suggests this single record represents a notable sedimentation event related to a tropical storm.

If 16,706 MXN per hour is taken as an average representative figure for a terminal at the port, then total costs for all terminals (16,706 x 14) is 233,884 MXN per hour. A proportional 8% increase in sediment deposition would therefore result in additional costs per hour for all terminals of 18,710 MXN. Figure 4.7 illustrates a sensitivity analysis of the potential effect of changing storm scenarios and resulting sedimentation on dredging requirements and terminal downtime due to vessel movements.

FIGURE 4.8

API Manzanillo annual drain maintenance costs under changing storm scenarios



Source: Report authors

As with surface water flooding, operation of the dredging vessel can effectively stop vessels entering the port. In addition to the costs to API Manzanillo for operating the vessel, API Manzanillo's revenue is estimated to be reduced by approximately 0.005% per hour that vessel movements cease (67,000 MXN in 2015).

Increased drain maintenance

As with maintenance dredging, the level of costs associated with clearance of sediment, waste and other materials washed into the drainage system can be related to increases in the frequency of intense hydrological events and changes in storm activity. Sensitivity analysis has been applied to illustrate the potential effects of changing storm scenarios on annual drain maintenance costs, expressed in million MXN and as a percentage of API Manzanillo's total OPEX (Figure 4.8).

4.1.3. Increased energy costs due to higher temperatures

The study assessed the financial impacts of increased energy costs due to higher temperatures under climate change. This is a risk borne primarily by the terminals.

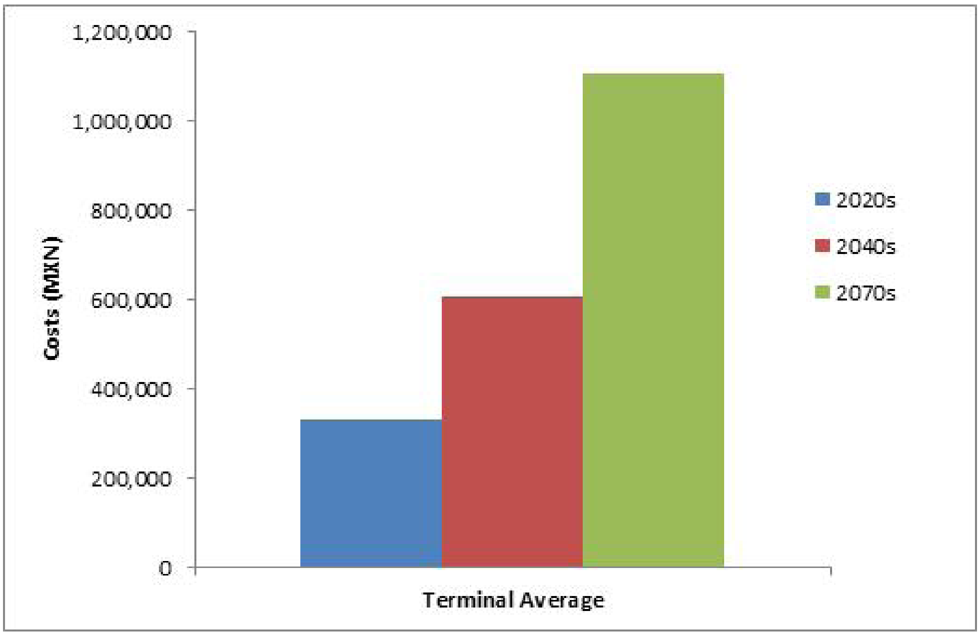
A significant positive relationship was shown between monthly mean temperatures and monthly energy costs for freezing at a representative terminal. This equated to an approximate 5% increase in annual mean energy costs for each 1oC increase in mean temperature.

Based on projected mean temperature increases due to climate change, associated increases in energy costs for cooling have been estimated for the terminals with refrigerated / frozen warehouses, and those with reefers. (Note that not all terminals with reefers provided energy cost data. A summary of the results averaged across three terminals is provided in Figure 4 9.

The data provided by the individual terminals showed that for some, the overall energy costs for cooling are small, so increased temperatures are not a significant hazard across the port as a whole. However for specialist terminals with refrigerated/frozen warehouses, the financial impact is more significant and could warrant investment to mitigate the effects.

FIGURE 4.9

Potential increases in average annual energy costs due to rising temperatures for three representative terminals



Source: Report authors

4.1.4. Impacts of climate change on total trade

The study assessed how impacts of climate change on the global economy could affect total trade through the port. A strong correlation was identified between global GDP and revenue at the port (see Section 3.9). It is therefore concluded that climate change impacts on the world´s economy can directly affect trade at the port. The elasticity of the port's revenue to global GDP is near to 3 (i.e. a 1% increase in global GDP leads to a 3% increase in the port's revenue). Accordingly, a 1% reduction in world GDP leads to a 1.5% reduction in the revenue of the port.

Clearly, several key factors affect fluctuations in cargo movements and associated revenue at the port, such as competition with other ports, relationships with clients and socio-economic circumstances in key trading partner countries. It is therefore challenging to infer changes in port revenue from changes in world GDP due to climate change impacts. Furthermore, there are considerable uncertainties regarding the global economic impacts of climate change.

Nevertheless, the study applied estimates of climate change impacts from the Stern Review on the Economics of Climate Change ('Stern Review 2007')[282]. These lead to estimates of projected revenue losses at the port ranging between -0.30% to -0.95% by the 2020s and between -0.38% and -1.88% by the 2050s. The estimates are presented in Figure 4.10 for the years 2035 and 2045, for Stern's low and high climate impact scenarios[lii]. They indicate approximate revenue losses of 4,000,000 to 10,000,000 MXN by 2035, and 6,000,000 to 15,000,000 MXN by 2045 (undiscounted).

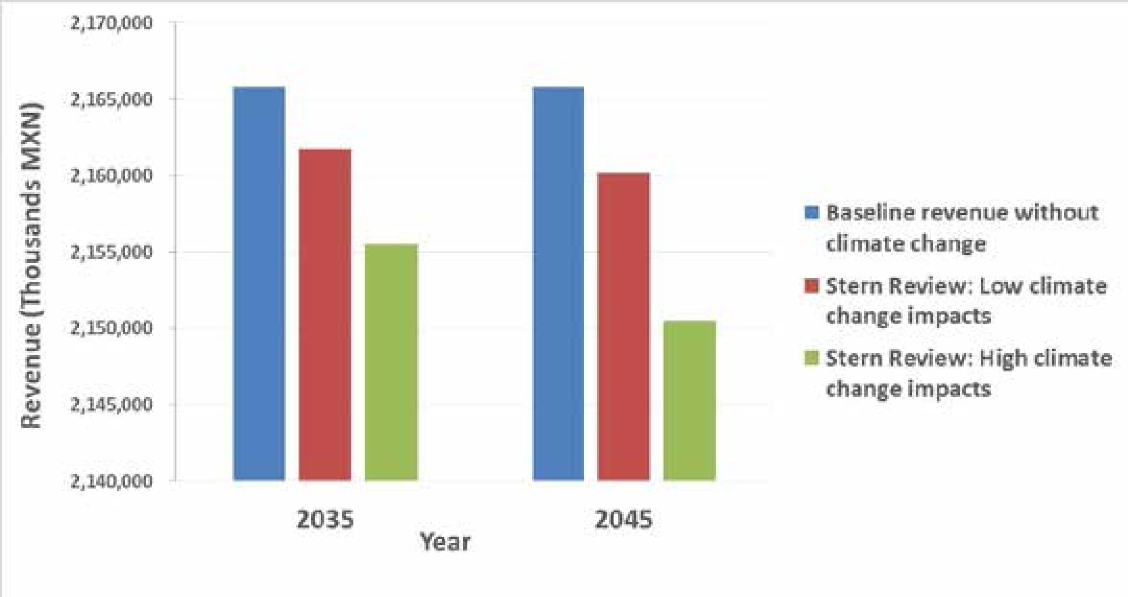
4.1.5. Other risks

Other climate change risks that can typically affect ports have been found unlikely to occur or not to result in significant financial costs to API Manzanillo and\or the terminals, though potential impacts cannot be totally excluded. These include:

- Goods handling, which is not expected to be significantly affected by increases in intense rainfall and changes in wind speeds;

FIGURE 4.10

Estimated effects on the port´s revenue in 2025 and 2035 due to global GDP losses from climate change (based on the Stern Review).



Source: Report authors

- Damage to port infrastructure and equipment, which can occur due to increases in extreme tropical cyclones (Category 4 and 5) and extreme storm surge causing coastal flooding. The likelihood of these events is low at Manzanillo
- Issues with navigation and berthing availability due to weather extremes are not port-wide, though they are significant for the PEMEX terminal. Increases in sea level are found to be within threshold limits for berthing;
- Maintenance of mangroves habitats around the port is undertaken in consultation with SEMARNAT, and covered under insurance paid by API Manzanillo. Factors such as sea level rise are not anticipated to have a significant effect on mangroves at Manzanillo, however there is high uncertainty around the level of impacts; and
- Effects of extreme weather events on maritime transport.

4.1.6. Beneficial impacts of climate change

The assessment also reveals that climate change could potentially bring some positive financial impacts for the terminals through decreased rainfall. If observed trends continue, the port will experience a 6% reduction in wet season daily rainfall events (<1mm) by 2020 and a 23% decrease by 2040.

This will result in decreased unloading\loading downtime due to rain for specific terminals that handle products sensitive to rain e.g. agricultural and bulk mineral terminals and terminal involved in the consolidation and handling of container products.

4.2. Cost effectiveness analysis of measures which deliver adaptation action

Adaptation measures to address all the risks identified in this study were discussed in sub-sections of Section 3. They include measures which:

- Build adaptive capacity – these are discussed further in the Adaptation Plan (Section 5).
- Deliver adaptation action by reducing climate change risks or taking advantage of opportunities. These fall into four sub-categories:
  - Operational: changes in processes and procedures
  - Engineered/hard structural solutions, known as 'gray measures'
  - Ecosystem-based adaptation, termed 'green measures'
  - Hybrid: a combination of green and gray measures

A high level analysis of the cost effectiveness of the measures which deliver adaptation action for the priority risks identified in the study is provided below. The approach used is aligned with recent literature on cost effectiveness analysis of climate resilience measures[283].

The priority risks considered are:

- Increased intensity of rainfall causing surface water flooding of the internal access road and rail connections and port entrance, causing disruptions to port operations
- Increased frequency of intense rainfall events causing damage to infrastructure and equipment through surface water flooding; and
- Increase in intensity of rainfall causing increased sedimentation of the port basin, reducing draft clearance for vessels and terminal access

The comparative high-level cost effectiveness analysis of all operational, gray, green and hybrid adaptation measures proposed for these risks is presented in Figure 4 11 to Figure 4 13. The comparative high, medium and low scores stated in Table 4 1 are primarily a relative comparison of the costs and effectiveness of each option, based on expert judgement, the transfer of values from literature where available and application of study-specific criteria.

It should be noted that high cost does not necessarily result in more effective adaptation. There can be low cost measures with high effectiveness.

The findings are discussed further in the Adaptation Plan (Section 5).

TABLE 4.1

Cost effectiveness criteria

COST	
H	Significant investment in operational, gray, green or hybrid adaptation measures
M	Moderate investment in operational gray, green or hybrid adaptation measures
L	Minor investment, mainly operational measures
EFFECTIVENESS	
H	Measure has guaranteed effect against 100 % of the risk\impact
M	Measure has a minimum guaranteed reduction of 50-99% of the risk\impact
L	Measure has a minimum guaranteed reduction of <50 % of the risk\impact

Source: Report authors

The following key describes the type of adaptation measure and its additional consequences.

Option Category

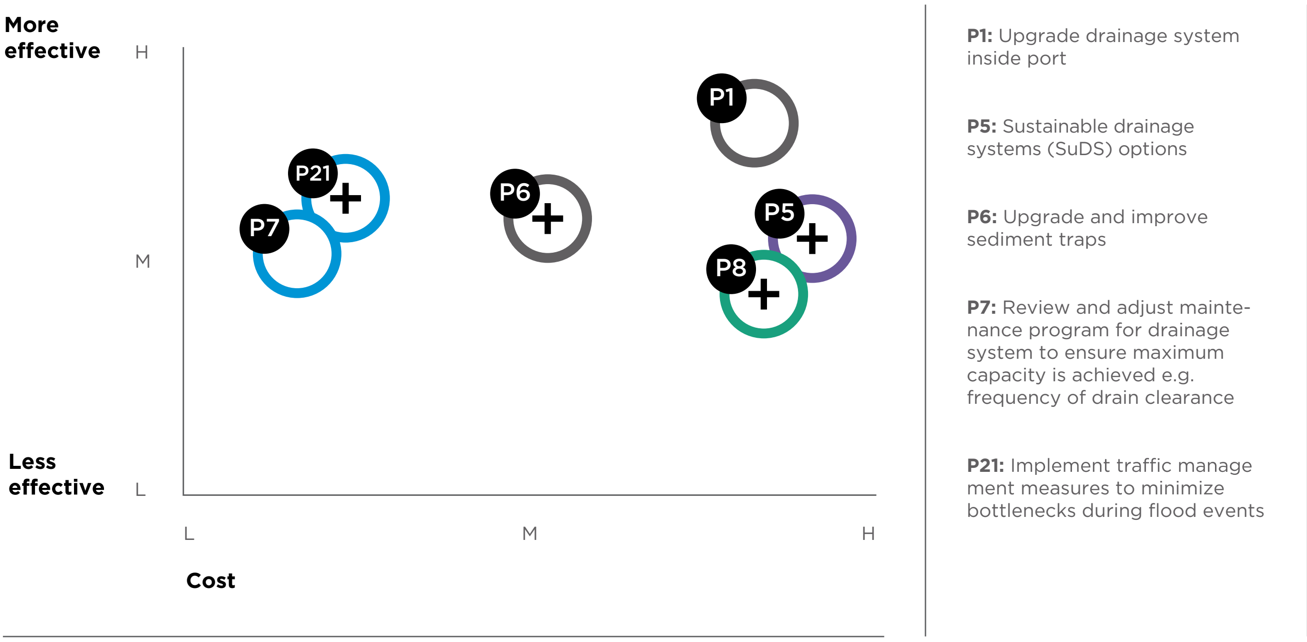
Ecosystem Based
Hybrid
Engineering
Operational

Consequences

+ Overall positive
Approximately neutral
− Overall negative

FIGURE 4.11

Loss of port connectivity through surface water flooding



Source: Report authors

'Additional consequences' refers to the adaptation measure having wider effects, beyond reducing the risk being considered. These factors can include reducing climate-related risks outside the port and providing benefits to biodiversity.

The following high-level conclusions can be made based on the findings of the cost effectiveness analysis:

- Operational measures (shown in blue) tend to be low cost and to have a medium effectiveness at reducing risk.
- Engineered (gray) measures are often the most effective at reducing risk. However, they are generally more costly and have few positive (beneficial) additional consequences.
- Ecosystem-based (green) and hybrid (purple) options have more positive additional consequences, but they are typically not as effective as engineered options at reducing risk. They tend to be more complex to implement, and the evidence base on them is weaker, so there is uncertainty regarding their effectiveness.

4.2.1. Cost effectiveness - upgrade of the drainage system and installing an additional sediment trap

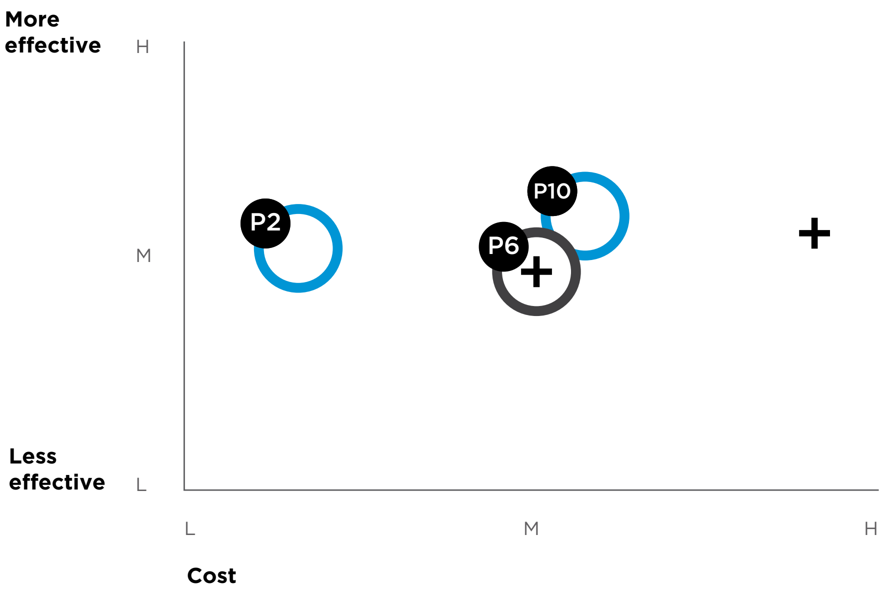
A detailed analysis of the cost and financial performance of upgrading the drainage system was presented in Section 3.4.2, including increasing the maximum capacity of the drain and the installation of additional sediment traps.

The estimated cost for upgrading the capacity of Drain 3 was found to be 92,636,245 MXN. Costs for installation of an additional sediment trap in all drains were estimated at 7,380,745 MXN.

These two engineering adaptation measures combined can provide a high level of effectiveness against both surface water flooding and sedimentation of the port basin. The savings for API Manzanillo that would result from these projects were compared to total costs for surface water flooding (port closure), maintenance dredging and drains maintenance combined. Quantifying the exact changes in drainage flow patterns for these measures is beyond the scope of this study, so it is assumed the upgrades could offset 75% of these cost

FIGURE 4.12

Increased intensity of rainfall causing increased sedimentation of the port basin



P6: Upgrade and improve sediment traps

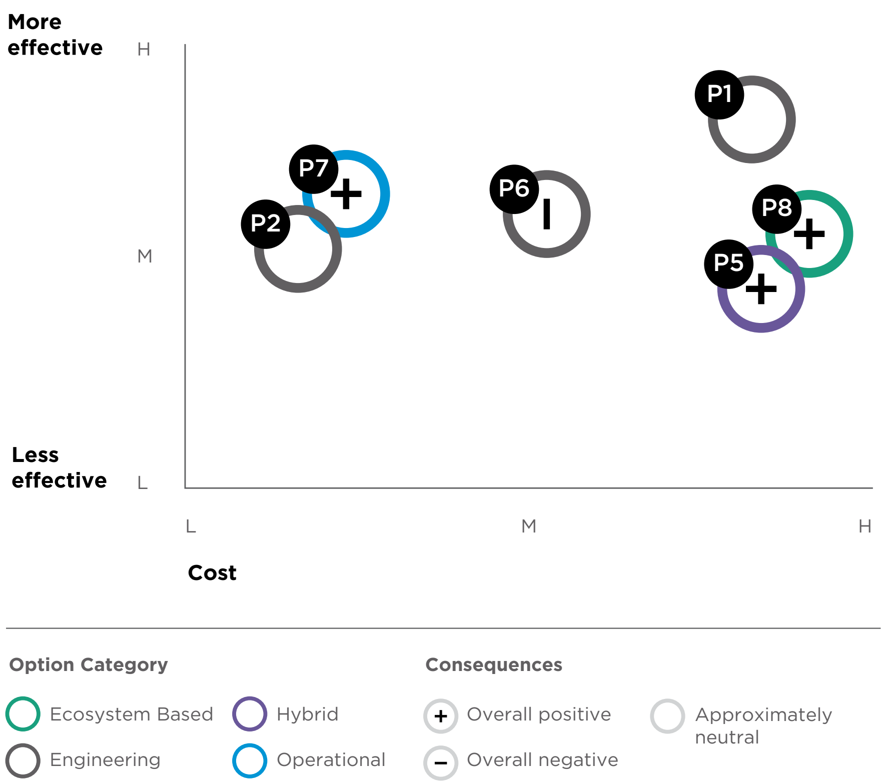
P10: Update dredging programs and schedules to reduce loss of draft clearance

P12: Review and adjust frequency of sediment trap clearance to maintain efficiency

Source: Report authors

FIGURE 4.13

Damage to port equipment and infrastructure following surface water flooding



P1: Upgrade drainage system inside port

P2: Retrofit critical infrastructu-re or assets vulnerable to flooding

P5: Sustainable drainage systems (SuDS) options

P6: Upgrade and improve sediment traps

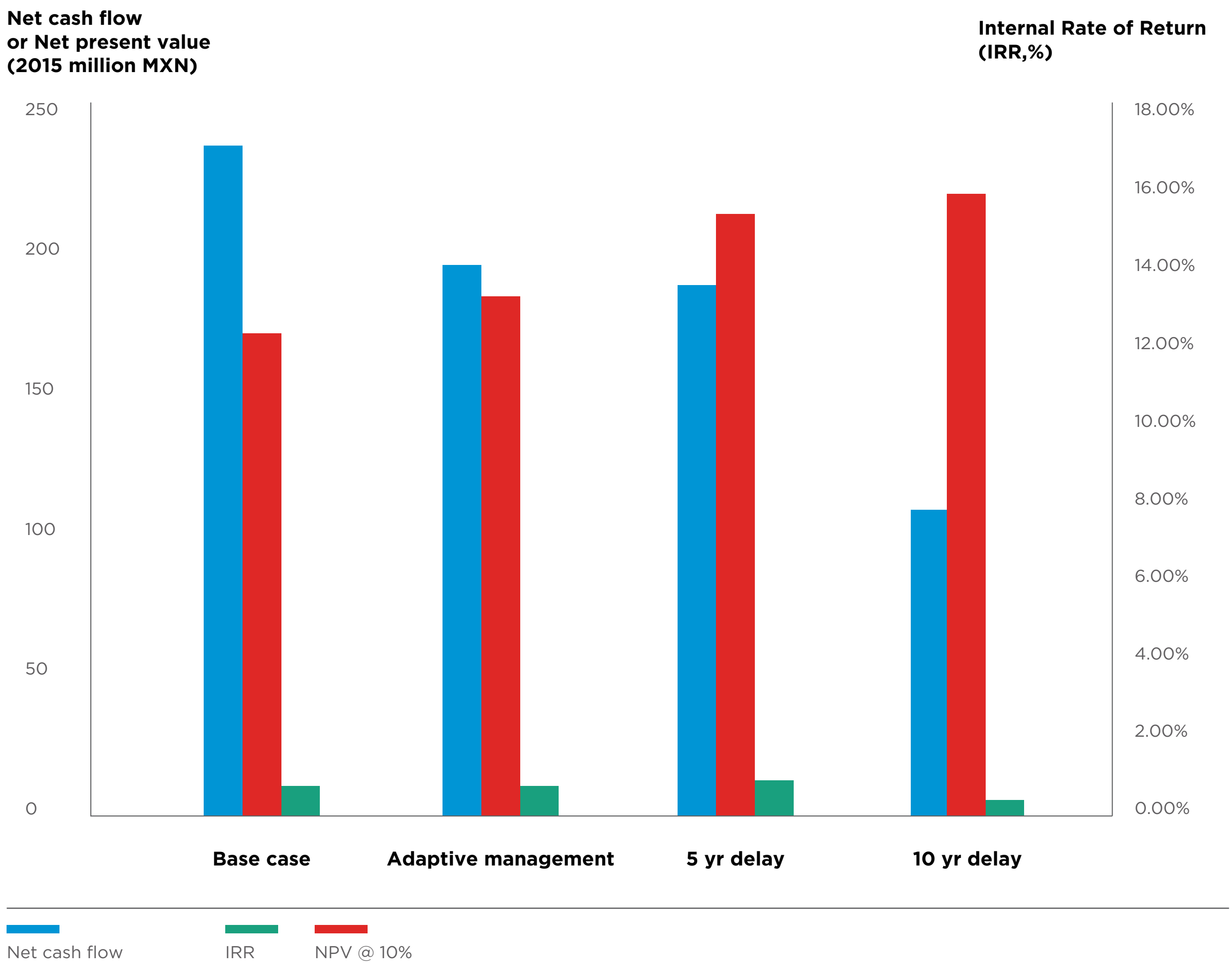
P7: Review and adjust mainte-nance program for drainage system to ensure maximum capacity is achieved e.g. frequency of drain clearance

P8: Catchment level landscape planning and ecosystem based adaptation options

Source: Report authors

FIGURE 4.14

Comparison of financial performance of adaptation implementation scenarios



Source: Report authors

increases. Four different scenarios for implementation of these adaptation measures were studied to explore how the economics are affected by completing the projects in phases or delaying the projects (Figure 4.14).

Delaying the projects, either through waiting to implement them or implementing them in phases (adaptive management) lowers the net cash flow (because it leaves the port exposed to climate change impacts for longer) but improves the rate of return on the investment (as evaluated by "internal rate of return" [IRR], the discount rate for which NPV = 0).

The results show that the projects are financially worthwhile based on the assumptions made to undertake the analysis. The costs of implementation are not large compared to API Manzanillo's overall annual operating expenditure (approximately 100 million MXN, compared to 450 million MXN), particularly if the projects are implemented in phases over several years, as proposed in the financial model. It should be noted that these results are preliminary, and significant engineering and design work will need to be undertaken to fully determine if these projects are viable. Furthermore, the analysis conducted for this study assumes that construction will not disrupt port activities. Future studies should determine whether these projects will cause any disruptions and include estimates the resulting costs, if any.

5. Adaptation Plan for the Port of Manzanillo

This section presents the Adaptation Plan for the Port of Manzanillo under five main headings:

- Introduction of principles that informed the development of adaptation measures for the port
- Presentation of recommended adaptation measures for the port addressing high, medium and low priority risks, highlighting the entities that should lead their implementation and (for high priority measures) proposing a set of adaptation indicators to monitor implementation
- Explanation of how the Adaptation Plan for the Port of Manzanillo relates to Mexico's climate change adaptation regulatory framework at the federal, state and municipal levels
- Explanation of how the adaptation measures can be integrated into strategic plans and operational activities undertaken by API Manzanillo and the terminals.
- Presentation of a Stakeholder Engagement Plan to support API Manzanillo in the implementation of this Adaptation Plan.

5.1. Principles taken into account when formulating the Adaptation Plan

This Adaptation Plan sets out actions that respond to the specific needs of the Port of Manzanillo and the port community whilst being in alignment with key policy instruments established at the Federal, State and Municipal levels. The objective of adaptation, as noted by the CICC is to "reduce, prevent and control potential disasters that may affect communities, sectors or regions in a prioritized manner, fighting the structural causes of the problems, strengthening social resilience and building a model to ensure the viability of its development under a different climate".[284]

Adaptation plans are context-specific, and thus the port's Adaptation Plan needs to be integrated into its future development plans ('Master Plans') and its operational plans and procedures. Moreover, adaptation measures set out in the plan are adequately framed only when they specify the roles and responsibilities of different actors operating in the socio-economic and political landscape where they will be operationalized.

Taking these aspects into account, a set of principles has been applied in formulating adaptation measures for the port, and in the design of this Adaptation Plan. These principles are summarized in Box 51.

BOX 5.1

Principles underpinning the development of the adaptation measures and the Adaptation Plan for the Port of Manzanillo

- **Address priority actions first.** Adaptation actions are considered a priority where:
  - Current climate-related vulnerability is high;

- And/or risks are rated as 'high' against one or more of the following criteria:
  - Projected impacts of climate change are large*, in that they could significantly affect one or more aspects of port performance (operational, financial, environmental, social or reputational, see Appendix 1);
  - Adaptation decisions have long lead times or long-term effects;
  - There are large uncertainties on the magnitude of future risk, i.e. the scale of future risk is uncertain (but could be large, as per the definition of 'large' above*).

- **Avoid maladaptation.** Actions taken to avoid or reduce vulnerability to climate change can negatively affect other systems, sectors or social groups or may inadvertently make climate change more difficult to manage in the future. Examples of maladaptive responses include those that:
  - Increase risks in another areas or for other stakeholders;
  - Impose higher costs than alternative responses which manage the risk;
  - Reduce flexibility to respond to unforeseen climatic conditions;
  - Conflict with greenhouse gas emission reduction targets.

- **Take into account environmental services** that help in responding to climate change challenges. Where possible, opportunities for ecosystem based adaptation solutions should be considered (see Box 5.2).

- **Emphasize measures that perform well** under conditions of uncertainty, namely:
  - **No regret adaptation measures:** These are measures that are worthwhile now, delivering net socio-economic benefits which exceed their costs, and that continue to be worthwhile irrespective of the nature of future climate. A sub-set of no-regret measures are so-called 'soft' measures that support understanding, capacity building and improved governance on adaptation.
  - **Low regret adaptation measures:** Measures for which the associated costs are relatively low and for which, bearing in mind the uncertainties in future climate change, the benefits under future climate change may potentially be large.
  - **'Win-win' adaptation measures:** These are actions which have other environmental, social or economic benefits as well as treating climate change.
  - **Flexible or adaptive management options:** These are measures that can be implemented incrementally, rather than through the adoption of 'one-off' costly adaptation solutions. For example, delaying measures while exploring options and working with other stakeholders to find the most appropriate solutions may be a viable approach to ensure that the appropriate level of climate resilience is reached when needed. Keeping options flexible and open-ended allows them to be adjusted, following monitoring and evaluation and systematic appraisal of their performance.
  - **Ensure adaptation measures for the port are aligned with federal, state and municipal climate change policy frameworks.**
  - **Where relevant, work in partnership with other stakeholders to develop and implement adaptation measures.** Partnership working can help to identify synergies in adaptation objectives and to avoid conflicts. This is discussed in the Stakeholder Engagement Plan (Section 5.5).

5.2. Adaptation measures to improve the climate resilience of the Port of Manzanillo

This section introduces and discusses the adaptation measures proposed by the study team for the Port of Manzanillo. Adaptation measures contribute either to:

- Building adaptive capacity: helping to understand and respond to climate change challenges. This include measures to create new information (e.g. data collection, research, monitoring and awareness raising) and measures to support governance or organizational structures. These are low cost, no/low regret adaptation measures and it is recommended that they should start to be implemented as soon as possible as in many cases they can help in delivering adaptation actions
- Delivering adaptation actions: implementing actions that help reduce climate change risks or take advantage of opportunities. As noted in Section 4.2, these are further divided into four sub-categories:
  - Operational: changes in processes and procedures
  - Gray measures: engineered/hard structural solutions;
  - Green measures: ecosystem based adaptation (see Box 52)
  - Hybrid: a combination of green and gray measures.

Figure 5.1 provides a conceptual illustration of this division. The color coding shown in this figure (colored circles) is applied to code each of the adaptation measures set out in Table 5.1 and Table 5.2.

The adaptation measures recommended for the Port of Manzanillo are presented in Table 5.1 Table 5,2, divided into two categories:

- Priority adaptation measures: These are measures addressing priority risks identified in Section 4.2 of

BOX 5.2

Ecosystem based Adaptation

Ecosystem based Adaptation (EbA) is broadly defined as "the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people adapt to the adverse effects of climate change"[285]. Effective EbA helps to promote, maintain and support ecosystem services, defined as the social shared benefits communities and individuals obtain from ecosystems (such as clean water and air, protection from wind and waves, biodiversity, etc) and to ensure that the port maintains its current level of environmental performance in the future.

It is recommended that EbA measures are considered for the Port of Manzanillo. EbA measures are 'win win' in that they can generate multiple co-benefits (social, environmental and economic).

In the case of the Port of Manzanillo there are two main EbA measures to consider:

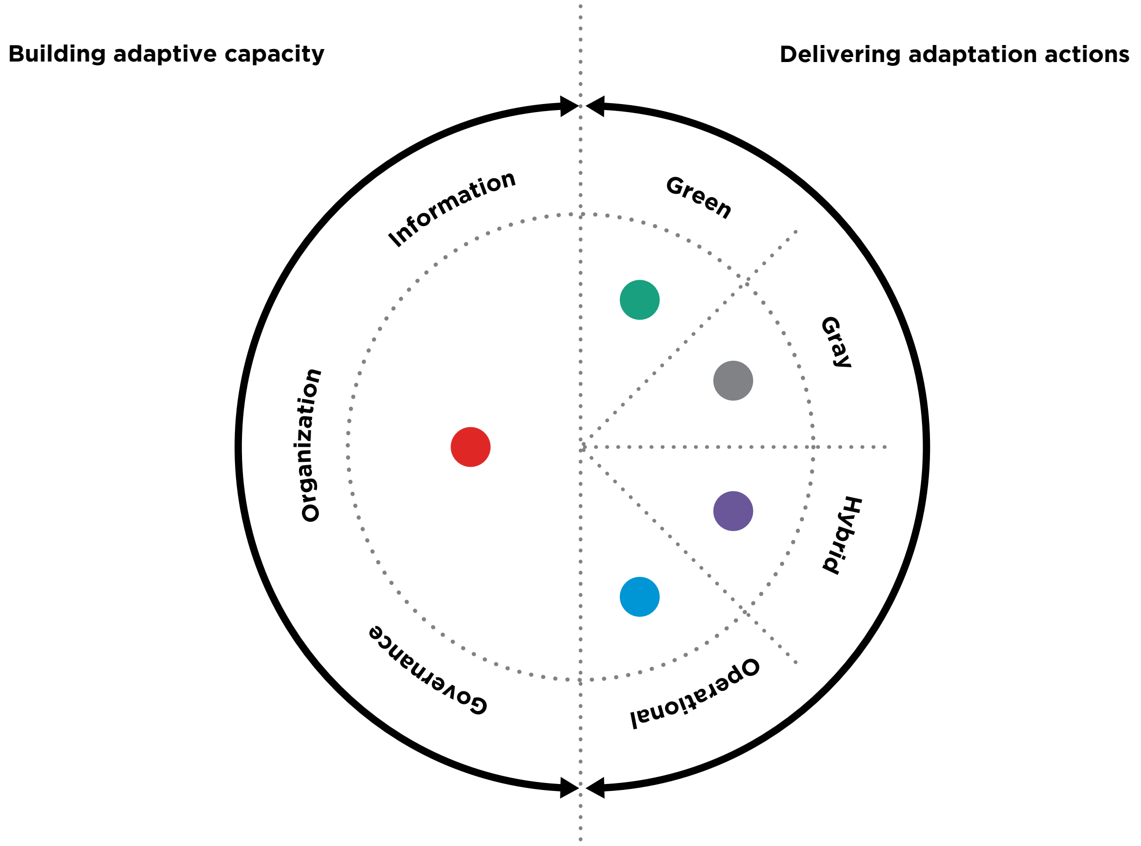
- Updating mangrove maintenance and restoration programs taking into account future climate conditions. These are a form of EbA in that they help preserve mangrove ecosystems. Ecological services of mangroves include: flood control; shoreline stabilization; sediment loss control; habitat for biodiversity; recreation and tourism, among others.

- Catchment level landscape planning efforts such as reducing deforestation and supporting afforestation in upland catchment areas is also a form of EbA. It helps regulate the hydrological cycle and reduce flood risk in the lower catchment (in this case, the port) by increasing infiltration and water retention in the soil in upper catchment. It requires strong engagement with stakeholders outside the port but that can generate significant benefits to both the city and the port communities.

Fuente: Autores de este reporte

FIGURE 5.1

Types of climate change adaptation measures recommended for the Port of Manzanillo



Source: Report authors

this study. For these measures information is provided in Table 5.1 on:

- Type of measure (i.e. Building Adaptive Capacity, Operational, Gray, Green or Hybrid);
- The relative cost-effectiveness of each measure (as presented in Section 4.2)
- The entity that should lead its implementation;
- Other important actors that should be involved in its delivery
- An adaptation indicator, to track progress in implementation
- Timing for implementation, taking account of the Port Master Planning cycles[liii]

- Adaptation measures addressing medium and low priority risks: A more extensive list of adaptation options is presented in Table 5.2 addressing medium or low priority risks. For these measures information is provided on:
  - Type of measure (as above);
  - The entity that should lead its implementation
  - Other actors that should be involved in its delivery

Each measure in Table 5.1 and Table 5.2 has a unique code number[liv]. These code numbers are utilized in Section 5.3 of the Adaptation Plan, to denote which measures are aligned with climate change objectives or actions by federal, state and municipal government. They are also used in Section 5.4 to identify where each adaptation measure can be integrated into strategic plans and operational activities undertaken by API Manzanillo and the terminals. Note that the approach to prioritization of adaptation measures was discussed in Section 1.5.5.

TABLE 5.1

Priority adaptation measures for the Port of Manzanillo

RISK AREA FOR PORT

DAMAGE TO INFRASTRUCTURE, BUILDING AND EQUIPMENT

Priority climate risk

Increased frequency of intense rainfall events causes damage to infrastructure and equipment through surface water flooding

Adaptation objective

Increase resilience to floods and intense rainfall events

COLOR CODING

The color coding used in this table is as follows:

Red = measures that Build Adaptive Capacity, (BAC)

Blue = operational measures, (OP)

Gray = engineered/hard structural solutions (ENG)

Green = ecosystem based adaptation measures (EBA);

Purple = hybrid measures (HYB, a combination of gray and green)

Adaptation measure	Type	Cost	Effectiveness
P1 Upgrade drainage system inside the port to increase maximum capacity and handle increased flow.	ENG	H	H
P2 Retrofit infrastructure or assets that are vulnerable to flooding, in particular critical infrastructure (e.g. insulate electrical equipment, use water resistant materials)	ENG	L	M
P3 Engage with stakeholders to plan landscape level flood management options	BAC	No regret	
P4 Review early flood warning systems and identify areas for improvement in light of increased risk due to climate change	BAC	No regret	
P5 Review options for using sustainable drainage systems (SUDS) taking into account potential for changes in precipitation	HYB	H	M
P6 Upgrade and improve sediment traps	ENG	M	M
P7 Undertake review and adjust maintenance program to ensure that maximum capacity of existing drainage system is being achieved e.g. frequency of drain clearance	OP	L	M
P8 Consider catchment level landscape planning and ecosystem based adaptation options for reducing risk of drainage overflow	EBA	H	M

Lead entity	Key partners	Adaptation Indicator(s)	Implement in Port Master Plan (PDMP) in:			
			2012-2017	2017-2022	2022-2027	2027-2032
API Engineering	Ayuntamiento de Manzanillo (Commission of drinking water, drainage and sewage), CONAGUA	Drainage system upgraded to accommodate increased flows				
API Engineering		Critical infrastructure vulnerable to flooding is climate proofed				
API Engineering, API Ecology	Ayuntamiento de Manzanillo (Department of Environment, INPLAN), CONAGUA	Landuse planning measures to support flood management are incorporated in Municipal land use planning programmes				
API Engineering, API Ecology	Ayuntamiento de Manzanillo (Department of Environment, INPLAN), CONAGUA	Updated flood early warning system in place				
API Engineering, API Ecology		Options for the incorproation of SUDS at the port are assessed and implemented				
API Engineering		Upgrades to sediment traps completed				
API Engineering		Increased frequency of sediment trap clearance				
API Ecologia	Ayuntamiento de Manzanillo (Department of Environment, INPLAN), CONAGUA	Catchment-based approach to managing flood risk is implemented with Municipality				

TABLE 5.1

Priority adaptation measures for the Port of Manzanillo

RISK AREA FOR PORT

PORT SERVICES

Priority climate risk

Increase in intensity of rainfall causing increased sedimentation of the port basin, reducing draft clearance for vessels and terminal access

Adaptation objective

Reduce risk of sedimentation

Adaptation measure	Type	Cost	Effective-ness
P9 Monitor levels of sedi-mentation and assess trends in historic dredging frequen-cies and quantities.	BAC	No regret	
P10 Update dredging pro-grammes and schedules to reduce loss of draft clear-ance	OP	M	M
P11 Upgrade and improve sediment traps	ENG	M	M
P12 Review and adjust frequency of sediment trap clearance to maintain effi-ciency	OP	L	M

COLOR CODING

The color coding used in this table is as follows:

Red = measures that Build Adaptive Capacity, (BAC)

Blue = operational measures, (OP)

Gray = engineered/hard structural solutions (ENG)

Green = ecosystem based adaptation measures (EBA);

Purple = hybrid measures (HYB, a combination of gray and green)

Lead entity	Key partners	Adaptation Indicator(s)	Implement in Port Master Plan (PDMP) in:			
			2012-2017	2017-2022	2022-2027	2027-2032
API Engineering		Monitoring system in place to detect trends in sedimentation and dredging				
API Engineering		Updated dredging schedules				
API Engineering		Upgrades to sediment traps completed				
API Engineering		Increased frequency of sediment trap clearance				

TABLE 5.1

Priority adaptation measures for the Port of Manzanillo

RISK AREA FOR PORT

TRADE ROUTES

Loss of Port connectivity with land transport routes

Priority climate risk

Increased intensity of rainfall causes surface water flooding of internal access road and entrance, causing disruptions to port operations

Increased intensity of rainfall causes surface water flooding of internal port rail tracks, causing disruptions to port operations

Adaptation objective

Increase resilience to floods and to intense rainfall events

COLOR CODING

The color coding used in this table is as follows:

Red = measures that Build Adaptive Capacity, (BAC)

Blue = operational measures, (OP)

Gray = engineered/hard structural solutions (ENG)

Green = ecosystem based adaptation measures (EBA);

Purple = hybrid measures (HYB, a combination of gray and green)

Adaptation measure	Type	Cost	Effective-ness
P13 Upgrade drainage system inside the port to increase maximum capacity and handle increased flow	ENG	H	H
P14 Review options for using sustinable drainage systems (SUDS) taking into account potential for changes in precip-itation	HYB	H	M
P15 Engage with stakeholders to plan landscape level flood management options	BAC	No regret	
P16 Review flood early warn-ing systems and flood manage-ment plans and identify areas for improvement in light of increased risk due to climate change	BAC	No regret	
P17 Review and update plans for evacuation and business continuity during extreme events	BAC	No regret	
P18 Undertake review and adjust maintenance program to ensure that maximum capacity of existing drainage system inside the port is being achieved e.g. frequency of drain clearance	OP	L	M
P19 Upgrade and improve sediment traps	ENG	M	M
P20 Consider catchment level landscape planning and ecosystem based adaptation options for reducing risk of drainage overflow	EBA	H	M
P21 Implement traffic manage-ment measures to minimize bottlenecks during extreme events	OP	L	M

Lead entity	Key partners	Adaptation Indicator(s)	Implement in Port Master Plan (PDMP) in:			
			2012-2017	2017-2022	2022-2027	2027-2032
API Engineering	Ayuntamiento de Manzanillo (Comission of drinking water, drainage and sewage, INPLAN), CONAGUA	Drainage system is upgraded to account for future rainfall scenarios				
API Engineering		Report setting out options for using sustainable drainage systems				
API Engineering, API Ecology	Ayuntamiento de Manzanillo (Comission of drinking water, drainage and sewage, INPLAN), CONAGUA	Landuse planning measures to support flood management are incorporated in Municipal land use planning programmes				
API Engineering, API Ecology		Updated flood early warning system in place				
API Operations	Terminals, Emergency centre, Unidad Municipal de Protección Civil	Updated business continuity and evacuation plans				
API Operations	API Engineering	Uptake of operational adjustments ensuring full performance of drainage system				
API Engineering		Upgrades to sediment traps completed				
API Ecology	Ayuntamiento de Manzanillo (Department of Environment), CONAGUA	Catchment-based approach to managing flood risk is implemented with Municipality				
API Operations	Customs, Terminals , Ayuntamiento de Manzanillo (DirecciAyuntamiento de Manzanillo (Department of Environment), CONAGUAón General de Servicios Publicos Municipales)	Reduced traffic jams and bottlenecks				

TABLE 5.2

Adaptation measures addressing medium and low priority risks for the Port of Manzanillo (continued)

Risk area for the port	Climate risk
GOODS STORAGE	Increased average and peak temperatures cause increased refrigeration and freezing costs
GOODS HANDLING	Increased intensity of rainfall events causes increased stoppages to handling equipment e.g. Crane and forklift operator visibility
	Decreased number of rain days reduces delays from rain to vessels loading\ unloading
	Sea level rise combined with storm surge causes flooding of the port result-ing in goods handling stoppages
	Increased maximum intensity and duration of maximum intensity of tropical cyclones causes increased handling downtime

Source: Report authors

Adaptation measure	Type of adaptation measure	Actions to be implemented / monitored by:
A1 Implement available technological improvements over time, increasing the efficiency of cooling / freezing equipment.	ENG	Terminals
A2 Review energy audits conducted under 2015 Carbon Footprint study (ME-T1239) in light of impacts of rising temperatures and consider additional opportunities for reducing energy consumption in line with findings	BAC	API Operations, Terminals
A3 Review climate change impacts on potential alternative energy sources (such as on-site solar power and/or wind energy) being considered following 2015 Carbon Footprint study	OP	API Engineering, Terminals
A4 Review pricing relationships between terminals and their customers i.e. evaluate whether some energy costs can be passed on to the customer	OP	Terminals
A5 Isolate electrical connections to reduce exposure to water and dust, reduced incidents of loss of power to reefers and consequent extra energy for recooling\refreezing	ENG	API Engineering
A6 Implement improved procedures for handling materials under adverse climatic conditions.	OP	API Operations, Terminals
A7 Increase in covered handling areas	ENG	API Engineering, Terminals
A8 Market this to terminals as benefit that may result in less disruption to mineral and agricultural bulk handling operations	BAC	API Commercial, Terminals
A9 Review flood response plans in light of increased risk due to climate change	BAC	API Engineering, API Ecology, Terminals
A10 Raise quay heights to prevent flooding	ENG	API Engineering
A11 Continue efforts to preserve mangrove areas acting as natural flood defenses, recognising succession between red and white may have implications in terms of levels of defense provided	EBA	API Ecology
A12 Retrofit critical equipment / infrastructure that is vulnerable to increased flood risk (e.g. insulate electrical equipment, use water resistant materials)	ENG	API Engineering
A13 Review operating thresholds for critical handling equipment. Incorporate potential impact of increase in peak wind speeds on maintenance and renewal schedule.	OP	API Operations, Terminals

TABLE 5.2

Adaptation measures addressing medium and low priority risks for the Port of Manzanillo (continued).

Risk area for the port	Climate risk
DAMAGE TO INFRASTRUCTURE, BUILDING AND EQUIPMENT	Extreme storm event wind speeds damaging handling equipment
	Sea level rise combined with storm surge causes flooding of the port resulting in damage to port equipment and infrastructure
PORT SERVICES	Increase in intensity of rainfall requiring increased maintenance of the port drainage system.
	Increased maximum intensity and duration of tropical cyclones and associated wind and wave activity leading to port closures, berthing problems, operational downtime
	Increases in mean sea level reduced berthing availability by exceeding minimum threshold dock height for vessels

Source: Report authors

Adaptation measure	Type of adaptation measure	Actions to be implemented / monitored by:
A14 Review need to undertake improvements to cranes' braking systems and wind speed prediction systems	BAC	Terminals
A15 Review need to undertake improvements to cranes' tie-down systems	OP	Terminals
A16 Review need to upgrade belts, lighting systems, general infrastructure to better withstand high wind speeds.	OP	API Engineering, Terminals
A17 Update design standards for equipment and infrastructure taking into account potential impact of future climate change over asset lifetime.	BAC	Terminals
A18 Account for sea level rise when doing inventories for replacement and refurbishment of infrastructure	OP	API Engineering, Terminals
A19 Retrofit critical equipment / infrastructure that is vulnerable to increased flood risk (e.g. insulate electrical equipment, use water resistant materials)	ENG	API Engineering, Terminals
A20 Raise quay heights to prevent flooding	ENG	API Engineering
A21 Continue efforts to preserve mangrove areas acting as natural flood defenses, recognising succession between red and white may have implications in terms of levels of defense provided	EBA	API Ecology
A22 Increase frequency of trap clearance	OP	API Engineering
A23 Carry out operability assessments for berthing and maneuvers to understand operational thresholds in light of potential changes in storminess and sea level rise	OP	API Operations, Terminals
A24 Monitor customer responses to berthing restrictions and required changes in cargo loads	BAC	API Operations, Commercial, Terminals
A25 Raise berthing\quay height to accommodate sea level rise	ENG	API Engineering
A26 Review contingency plans for delays and loss of traffic caused by reduced navigability or slower manoeuvring	BAC	API Operations, Terminals
A27 Engage with navigation authorities to ensure adequate management of risks	BAC	API Operations, Terminals

TABLE 5.2

Adaptation measures addressing medium and low priority risks for the Port of Manzanillo (continued)

Risk area for the port		Climate risk
TRADE ROUTES	Land transport on wider network	Tropical storms, flooding and snow affect the broader road and rail networks in Mexico used by port clients, causing interruption and delays in movement of goods to and from the port
	Maritime transport	Increased disruption to regional and international maritime transport from tropical storms
ENVIRONMENTAL ASPECTS		Changing climatic factors affecting APIMAN's environmental performance and insurance costs for mangrove habitat
		Increased problems of dust creation and dispersion in drier conditions, both inside the port and from surrounding municipal areas.
		Increased loss of water quality and benthic habitat due to increased maintenance dredging and disposal of dredge material

Source: Report authors

Adaptation measure	Type of adaptation measure	Actions to be implemented / monitored by:
A28 Monitor and record interruptions and delays caused by adverse weather affecting the road and rail network, in coordination with other stakeholders (port customers, other major users of transport systems)	BAC	API Operations
A29 Monitor influence of disruptions on satisfaction level of port customers and terminals	BAC	API Operations, Commercial
A30 Discuss information on interruptions and delays with SCT (Subdireccion de Obras y Subdireccion de transporte) and Ferromex and promote action by them to improve climate resilience of road and rail networks	BAC	API Planning
A31 Develop emergency plans with backup measures for re-routing cargo.	BAC	API Operations, Centre for Emergencies
A32 Provide drivers with emergency plans for extreme climatic events and alternative routes.	BAC	API Operations, Centre for Emergencies
A33 Develop supply chain contingency plans.	BAC	API Operations, Shipping lines
A34 Increase diversity of clients from international regions less subject to storms	OP	API Commercial, Terminals
A35 Develop contingency plans for national traffic to use road and rail network	OP	API Planning
A36 Develop new and potentially more robust shipping routes e.g. Northern Passage	OP	API Planning
A37 Continue mangrove maintainance and restoration programs to support the environmental services they provide e.g. Laguna de Las Garzas.	EBA	API Ecology
A38 Reduce other pressures that may affect mangrove health such as runoff water pollution	EBA	API Ecology
A39 Explore opportunities to access finance to support mangrove conservation (e.g. payment for ecosystems services schemes, carbon markets, conservation trust funds,CONAFOR)	BAC	API Ecology
A40 Review and strengthen dust suppression measures	OP	API Operations, Terminals
A41 Support the maintenance of sediment and water quality within the harbor provided by natural ecosystems such as mangroves and riparian vegetation	EBA	API Ecology
A42 Review and update water quality and sediment monitoring program	OP	API Ecology

TABLE 5.2

Adaptation measures addressing medium and low priority risks for the Port of Manzanillo (continued).

Risk area for the port	Climate risk
SOCIAL ASPECTS	Changes in temperature and relative humidity lead to more favorable conditions for mosquitoes carrying dengue and chikungunya and hence more cases of these diseases
	Increased maximum temperatures cause increased risks of heat stress and dehydration for port workers
	Increased temperatures coupled with lower precipitation leads to increased dust generation and more cases of conjunctivitis
	Increased temperatures coupled with lower precipitation leads to increased dust generation and adversely affect the port's relationship with the local community
DEMAND AND CONSUMPTION PATTERNS	Impacts of climate change on the global economy affecting trade flows at the port Impacts of climate change on the economies of the port's main trading countries affecting trade flows at the port Impacts of climate change to the economy of Mexico affecting trade flows at the port
	Changes in the production and price of climate-sensitive commodities affect demand for port's services and/or offer opportunities to develop / strengthen trade with new / existing clients
	Changes in distribution on the production of climate sensitive commodities may affect demand for port's services and/or offer opportunities to develop / strengthen trading routes with new / existing country partners.

Source: Report authors

Adaptation measure	Type of adaptation measure	Actions to be implemented / monitored by:
A43 Ensure the port community is notified by public health officials when the risk of dengue outbreaks is high	BAC	API Administration
A44 Early warning systems for dengue outbreak	BAC	API Administration
A45 Monitor weather forecasts and issue heat health warnings to terminals when apparent temperatures are forecast to exceed important thresholds	BAC	API Administration, Centre for Emergencies
A46 Providing advisory notes to terminals on recommended actions to reduce risks of heat stress	BAC	Centre for Emergencies
A47 Review and strengthen dust suppression measures	BAC	API Operations, Terminals
A48 Strengthen collaboration between the port community and local government authorities to build a shared vision of the economic opportunities at Manzanillo, to reduce competition for space between port and city and to foster synergies between their development efforts	BAC	API Planning
A49 Monitor changes in supply and demand of traded products that are climate-sensitive to refine future projections for key business lines	BAC	API Commercial
A50 Monitoring customer expectations in terms of reliability of port services and develop a communication plan on how negative effects of climate-driven disruptions are being addressed	BAC	API Commercial
A51 Monitor impacts of climate change in Mexico's economy, with a focus on production, import and exports of key commodities traded through the port	BAC	API Commercial
A52 Account for climate change and current extremes in business continuity plans, forecasts of trade patterns and strategy plans	BAC	API Planning
A53 Diversify trading partner countries	BAC	API Commercial
A54 Diversify business lines to spread the risk	BAC	API Commercial, Terminals
A55 Expand, upgrade or adjust port facilities in response to changing customer demands and trade flows	HYB	API Engineering, Terminals

TABLE 5.2

Adaptation measures addressing medium and low priority risks for the Port of Manzanillo (continued).

Risk area for the port	Climate risk
COMPETITION WITH OTHER PORTS	Changes in tropical cyclones affect the attractiveness of Manzanillo relative to other ports
IMPLICATIONS OF POSSIBLE AGREEMENTS ON GHG EMISSIONS	Increase import price of fossil fuels affecting volume flows of petroleum and its derivatives
	Effects of mitigation policy on GHG intensive cargoes (e.g. minerals and vehicles) affect cargo flows of these commodities.
IMPLICATIONS OF THE EVOLUTION OF THE INSURANCE MARKET	Increased damage and disruption due to extreme events leads to increased claims and higher insurance premiums and deductibles for APIMAN and/or terminals
	Insurers provide more favorable terms to the port due to the implementation of risk-reducing measures in the Adaptation Plan

Adaptation measure	Type of adaptation measure	Actions to be implemented / monitored by:
	OP	API Commercial
	BAC	API Planning
	BAC	API Planning
	BAC	API Administration,Terminals
	BAC	API Administration, Terminals

5.3. How this Adaptation Plan fits within Mexico's adaptation policy frameworks

Section 1.4 of this report provided an overview of the climate adaptation policy context at the federal, state and municipal levels in Mexico. (See the report developed to support this study which describes the regulatory framework in more detail[286]).

5.3.1. Federal level adaptation policy frameworks

Table 5.3 highlights key strategies and lines of action on adaptation formulated at the federal level that are most relevant to the Port of Manzanillo Adaptation Plan. The table serves as a guide to understand:

- How the Adaptation Plan for the port is aligned with federal government instruments
- How adaptation actions at the port can support federal adaptation objectives
- How the port can relate to the adaptation objectives of federal government when framing its own objectives and needs

Table 5.3 uses the unique code for each adaptation measure shown in Table 5.1 (high priority measures) and Table 5.2 (medium and low priority). The large number of measures from the Port Adaptation Plan listed in Table 5.3 indicates that there is a strong resonance between federal government adaptation objectives and the Port Adaptation Plan.

5.3.2. State level adaptation policy frameworks

The draft version of the PECC of the State of Colima[287] does not identify strategic axis or lines of action for the development of adaptation measures at the state level. Nonetheless the current draft version recommends a series of adaptation measures that resonate with measures recommended in this adaptation plan and proposes a series of adaptation actions that could provide a platform for collaboration between API Manzanillo, the port community and state authorities.

Table 5.4 highlights key adaptation actions recommended in the PECC of the State of Colima and relates them to the code numbers for the port adaptation measures, to help understand:

- How the Adaptation Plan for the port is aligned with state government instruments
- How adaptation actions at the port can support broader state adaptation objectives

This suggests that the main areas of overlap are related to ecosystem based adaptation, namely catchment level planning and management of mangrove habitats

In consultation with state level government authorities during the mission for this study it was noted that climate risks and adaptation at the port were not accounted for as part of the development of the PECC, despite the fact that the port is a very important contributor to the state's economy. The formulation of an Adaptation Plan for the port was therefore regarded by state authorities as important, as it complements other state level adaptation strategies and objectives for Colima.

5.3.3. Municipal level policy frameworks

Currently, the Municipality of Manzanillo is working towards integrating climate change strategies and objectives set out at the federal and state level into the next Municipal Development Plan and the Programa de Ordenamiento Ecologico y Territorial of Manzanillo. There is no information available at present to provide concrete recommendations on how the Port of Manzanillo Adaptation Plan can be aligned with the efforts that will be set out in the next Municipal Development Plan. Nevertheless, the current Municipal Development Plan (2013-2015)[288] indicates possible areas of overlap. These will need to be reviewed once the next plan is in place. The areas of overlap with the current Municipal Development Plan include:

- Action areas set out in the State Development Plan (2010-2015) that have not been completed by the Municipality
- Strategic areas set out in the Municipal Development Plan (2013-2015) that may still be present in the next plan

TABLE 5.4

Alignment of measures in the Port of Manzanillo Adaptation Plan and recommended actions in the Climate Change Program of the State of Colima

Actions in the State of Colima PACC	Reference in PACC	Adaptation measures in the Port of Manzanillo Adaptation Plan	
		High priority	Medium and low priority
Promote reforestation and restoration policies for catchment areas, in alignment with the state EEREDD+ strategy.	Chapter 13 p. 89	P8, P15; P20	A11, A37, A38, A39
Update land use ecological plans, with a focus on coastal areas and include considerations in conservation plans for mangrove areas.	Chapter 10 p. 7	P8, P15, P20	A11, A37, A38, A39
Design a policy to attract investment in infrastructure development for new train lines to reduce cargo transport by road between Guadalajara and Manzanillo.	Chapter 17 p. 105		A28, A29, A30
Strengthen and develop the capacity of productive sectors around climate change risks and regarding the solutions that sectors can bring.	Chapter 17 p. 105	All measures apply	
Incentivize production diversification especially in primary sectors to allow sectors to adapt to climate variability	Chapter 17 p. 105		A53, A54
Attract investments in alternative and renewable energy generation.	Chapter 17 p. 105		A3

Source: Report authors

TABLE 5.5

Alignment of measures in the Port of Manzanillo Adaptation Plan and action items in Manzanillo's Municipal Development Plan

Action items in the Municipal Development Plan (2013-2015)	Adaptation measures in the Port of Manzanillo Adaptation Plan	
	High priority	Medium and low priority
Promote a 24 hour Custom's service at the port with relevant authorities	P21	
Develop a new road and signage scheme for the city	P21	A28, A30, A31, A32, A35
Promote the commercial and tourist dimensions of the Port of Manzanillo by participating in national and international events such as conferences and congresses.		A34, A48

Source: Report authors

TABLE 5.3

Alignment of measures in the Port of Manzanillo Adaptation Plan with the strategic axes and objectives in policy instruments at the federal level

Policy Instrument	Strategic axis/ objective addressed	Lines of action with relevance to the Port of Manzanillo Adaptation Plan
National Climate Change Strategy Vision 10-20-14	Strategic axis A2. To reduce the vulnerability and increase the resilience of strategic infrastructure and productive systems in the face of climate change	A2.2 Integrate climate change adaptation criteria in existing productive systems
		A2.5 Take into account climate change scenarios when determining land uses for the establishment of productive activities
		A2.9 Implement techniques and technologies in all productive sectors promoting the efficient use of resources and managing risks associated with climate change
		A2.11 Strengthen existing strategic infrastructure (communications, transport, energy, among others) accounting for climate scenarios
		A2.12 Incorporate climate change criteria in planning and construction of new strategic and productive infrastructure
Special Climate Change Program 2014-2018	Objective 1 To reduce the vulnerability of the community and of productive sectors and increase their resilience and the resistance of strategic infrastructure	Strategy 1.3 To strengthen strategic infrastructure and incorporate climate change criteria in planning and construction 1.3.3 Develop programs to manage vulnerability and increase the resilience of infrastructure, taking into account ecosystems in the area 1.3.5 Implement programs to have a national infrastructure system with higher resilience to natural phenomena
		Strategy 1.4 To promote adaptation actions in productive systems 1.4.2 Undertake climate change vulnerability studies for the industrial sector

Source: Report authors

Lead government agency	Adaptation measures in the Port of Manzanillo Adaptation Plan	
	High priority	Medium and low priority
Not specified	All measures support this line of action[lv]	
Not specified	P8, P20	
Not specified	All measures apply	
Not specified	P1, P2, P6, P7, P10, P11, P13, P19	A1, A5, A7, A10, A12, A17, A18, A19, A20, A22, A25
Not specified		A17, A18
SENER SEGOB	P1, P2, P3, P5, P6, P7, P8, P10, P11, P12, P14, P15, P18, P19, P20	A1, A5, A7, A9, A10, A11, A12, A13, A14, A15, A16, A17, A18, A19, A20, A21
SE	This study responds to this line of action	

TABLE 5.6

Alignment of adaptation measures in the Port of Manzanillo Adaptation Plan with strategic objectives in Manzanillo's Municipal Development Plan

Strategic objective under the Municipal Development Plan	Adaptation measure in the Port of Manzanillo Adaptation Plan	
	High priority	Medium to low priority
7.1.1 Guarantee coexistence between the port and the city, ensuring that port developments generate social and economic development in an equitable parallel manner	P8, P15, P20, P21	A39, A43, A48
7.1.3 The Municipality should promote and coordinate actors in the port community to work together on issues related to the movement generated by the port and daily activities of citizens	P21	A28, A30, A31, A32, A35
7.1.7 Infrastructure services of the port, the army and local organizations need to work together to serve the community and provide support and protection when disasters occur	P4, P17	A44
7.2.3 Coordinate with the port community, the army and municipal entities to undertake and maintain a contingency plan	P17	
7.2.6. Coordinate a committee to prevent and respond to natural disasters, together with the port emergency response center, the army and local businesses	P17	
7.2.7. Increase urban areas reserved for industrial use and to serve port activities		A7, A55
7.2.9. Promote an intermodal logistics center for the port industry		A28, A29, A30, A31, A48, A55

Source: Report authors

For example, the Municipal Development Plan (2013-2015) sets out a series of activities with the objective to improve road infrastructure that are yet to be completed. These could positively support the port's Adaptation Plan, as surface water flood risk around the port entrance compounds existing traffic congestion problems. Table 5.5 sets out activities in the Municipal Development Plan (2013-2015) which aim to support consolidation and distribution activities at the port. These, in turn, can support measures in the port's Adaptation Plan.

Strategic objective 7 of the Municipal Development Plan also sets out a series of policies, objectives and actions that provide further guidance on how adaptation efforts at the port can integrate with the municipality's objectives. Table 5.6 provides more information on the areas of overlap.

5.4. Relationship between this Adaptation Plan and other plans at the Port of Manzanillo

In line with good practice, the measures in this Adaptation Plan need to be mainstreamed within the existing plans at the port where relevant. Adaptation is not a stand-alone process; it often involves modifications to existing processes. Mainstreaming is an efficient way of ensuring that actions in the plan have owners, and are delivered effectively.

There are two main areas where the adaptation measures fit, namely:

- the Port Master Plan, which is the key planning document that sets out the strategic direction for the port, and includes topics highly relevant to adaptation such as maintenance, development and investments
- operational plans and procedures

5.4.1. Linkages with the Port Master Plan (PMDP)

Every five years API Manzanillo develops a Master Plan for Port Development, according to Art. 41 of the Law of Ports, Art.39 of the Law of Ports rulebook and as part of the conditions imposed by the federal government since the creation of API Manzanillo in 1994. The PMDP is the main platform for API Manzanillo to formulate short, medium and long term development strategies to help the port reach its economic objectives.

TABLE 5.7

Linkages between components of the PMDP addressing maintenance, development and investments and the Port of Manzanillo Adaptation Plan

Infrastructure type	High priority adaptation measures	Medium and low priority adaptation measures
Roads	P2	
Customs facilities	P2	
Maritime, horizontal and vertical signage equipment	P2	
Electrical equipment / facilities	P2	A3, A5, A12
Perimeter fencing	P2	A12
Freshwater and drainage system	P1, P2, P5, P7, P11, P19, P13, P14, P18	
Storage patios	P2	A12, A20
Docks and jetties	P2	A10, A25

Source: Report authors

The PMDP currently in place covers the period 2012-2017[289]. The next PMDP is being prepared and this offers a timely opportunity to integrate adaptation measures which require additional capital and operating expenditure (CAPEX and OPEX). The suggested timings for implementation of priority adaptation measures was presented in Table 5.1.

The structure of the current PMDP (2012-2017) and the outline structure of the PMDP for the next planning period (2017-2022) has been reviewed, to identify where the findings of this study, and in particular the adaptation measures, can be integrated. Based on this review, the following recommendations are made:

1. In developing the Diagnostic section of future PMDPs, API Manzanillo should take into account climate change risks (Section 3 of this report). API Manzanillo may for example consider how climate risks identified in this study can interact with the risks in the SWOT analysis and where climate change introduces new risks or opportunities that are not currently considered.
2. In developing the Strategy section of future PMDPs, it is recommended that climate change adaptation measures are taken into account as follows:
   - API Manzanillo should review how the adaptation measures in this plan relate to its strategic objectives and lines of action. Where needed climate change considerations should be incorporated into each. This should include, for example, considering diversification of trading partners and business lines and (as described in Table 5.2 under 'Demand and consumption patterns')
   - When formulating goals and indicators for port development, it is recommended that indicators for priority adaptation measures (see Table 5.1) are considered.
3. In framing Uses, Destinations and Forms of Operation, it is recommended that operational, gray, green and hybrid adaptation measures are taken into account when calculating maintenance, development and investment requirements for different types of infrastructure (see Table 5.7 for further detail).

The incorporation of adaptation measures in the PMDP should be consulted with the relevant divisions in API Manzanillo in order to conciliate adaptation activities with other operational and strategic needs.

5.4.2. Integration of adaptation measures into operational plans

This Adaptation Plan sets out a number of adaptation measures that involve monitoring and updating of operational plans and procedures. The Port of Manzanillo Rulebook covers operations and procedures for a range of activities including:

- Berthing and mooring
- Traffic management and maneuvers
- Infrastructure and systems development
- Risk and emergency management
- Health and safety.

Other operational issues are likely to be addressed in other operational plans typically in place at ports. Table 5.8 synthesizes information showing where operational adaptation measures can be integrated into existing operational procedures, both for API Manzanillo and the terminals.

TABLE 5.8

Operations and procedures where different adaptation measures ought to be integrated.

	API Manzanillo		Terminals	
	High priority adaptation measures	**Medium and low priority adaptation measures**	**High priority adaptation measures**	**Medium and low priority adaptation measures**
Operational issues in Port of Manzanillo Rulebook				
Berthing and mooring		A23		A22, A26
Traffic management and maneuvers	P21			
Infrastructure and systems Development				A17, A18
Risk and emergency manage-ment and response	P17	A31, A32, A33, A43, A44, A45, A46, A35, A27		A52, A27, A27
Health and safety				A40, A47
Other operational issues				
Business development		A34, A36, A49, A56, A52, A54, A8		A24, A52, A8
Operations and maintenance	P18;P7	A26	P7	A6, A13, A40, A47
Sedimentation and dredging control	P9, P10, P12	A22		
Energy management/ Sus-tainability				A2,A3
Water quality management		A42		
Financial Management				A4
Communications		A28, A43, A44, A45, A46, A27		A27
Stakeholder management	P3 ,P4, P15	A24, A29, A48, A50, A51		

Source: Report authors

5.5. Stakeholder Engagement Plan

Adequate engagement of relevant stakeholders is a critical factor for the successful implementation of any adaptation plan. It can help identify synergies in adaptation objectives and avoid conflicts. Effective stakeholder engagement relies on the ability to:

- Identify which stakeholders need to be engaged
- Understand their roles and responsibilities
- Understand their level of influence and importance
- Communicate and engage in ways that are perceived as relevant and beneficial by the audience addressed

Table 5.9 summarizes, in general terms, four categories of stakeholder, identified according to their:

- level of influence – the level of power the stakeholder has to facilitate or impede the implementation of actions; and
- level of impact – a combination of the level of interest the stakeholder has in the plan (related to how closely the plan respond to roles and objectives of the stakeholder) and the importance that that stakeholder's contribution can have for its implementation.

Based on this categorization, stakeholders for the Port of Manzanillo Adaptation Plan are summarized in Table 5.10. Stakeholders whose support will be needed for implementation of priority adaptation measures are shown here as 'key stakeholders'. They include the following:

- Port community: Terminals, shipping lines, logistics operators, Unidad Municipal de Protección Civil;
- Government: SEMARNAT, INECC, SCT, CONAGUA, IMADES and the Municipality of Manzanillo

TABLE 5.9

Generic Stakeholder Engagement Matrix

		Impact (interest and importance of contribution)	
		Low impact	**High impact**
Influence (power to facilitate or impede)	**High influence**	Important stakeholders to be engaged on specific areas • **Inform and collaborate as needed** • Increase their level of interest as their disinterest can become a barrier to implementation of adaptation actions • Aim to move to High Interest/ High Influence quadrant	Key stakeholders to engage throughout for the implementation of the Adaptation Plan • **Inform, consult and collaborate** • Consider their interests and expectations in order to build their support for implementation of adaptation measures • Focus effort on this group, engage and consult regularly • Involve in decision making
	Low influence	Non-key stakeholders who should be involved in wider consultation • **Keep up-to-date** • Inform via general communications	Important stakeholders to show consideration to • **Inform and consult as needed** • Keep up to date with the information that these organizations generate • Consult on specific issues

Source: Report authors

API Manzanillo should consider the level of engagement required for each stakeholder, according to which category they belong. This differentiation helps API Manzanillo understand the level of effort it should invest in informing, consulting or collaborating with each stakeholders in order to implement the Adaptation Plan.

5.5.1. Port-city relationship

When addressing the implementation of this Adaptation Plan, API Manzanillo will need to carefully assess how adaptation measures can affect its relationship with the city and the Municipality. On one hand, without adequate engagement and communication with the Municipality and civic society groups, problems between the city and the port that are faced today could be augmented. For example, construction works that may be required to retrofit or upgrade infrastructure could generate extra dust or traffic congestion and this may be perceived negatively by citizens if they lack adequate understanding of the benefits of these measures. On the other hand however, implementation of some of the adaptation measures may help strengthen the relationship between the city and the port. API Manzanillo should seek to collaborate with the Municipality as much as possible where the implementation of adaptation actions may bring co-benefits, and when the involvement of the Municipality is needed to implement specific measures. This is the case, for example, for flood risk management measures that require changes in land use planning schemes at the catchment or municipal level.

The Emergency Centre of API should also continue supporting the community of Manzanillo by working closely with the Municipality and the Municipal Unit of Civic Protection on risk prevention and risk management responses during natural disasters.

As noted in the Municipal Development Plan of Manzanillo[290], the city and the port must co-exist in a harmonious, efficient and balanced way. As the Municipality develops its next Municipal Development Plan and the

TABLE 5.10

Stakeholder Management Matrix for the implementation of the Port of Manzanillo Adaptation Plan

		Impact (interest and importance of contribution)	
		Low impact	**High impact**
Influence (power to facilitate or impede)	**High influence**	Inform and collaborate as needed • SEMAR • CFE • SAGARPA • CENAPRED	KEY STAKEHOLDERS • Inform, consult and col-laborate • Terminals • Shipping lines • Logistics operators • Ayuntamiento de Manza-nillo • IMADES • Unidad Municipal de Pro-tección Civil • SEMARNAT • INECC • SCT • IMT • CONAGUA
	Low influence	• Keep up-to-date • Asociación Mexicana de Agente Navieros • Asociación de Agentes Aduanales del Puerto de Manzanillo Colima • Asociación de terminales remotos del Pacifico • Asociación Nacional de Importadores y Exportadores de la República Mexicana	Inform and consult as needed • Research/ data providers on climate change

Source: Report authors

Ecological and Territorial Planning of Manzanillo, the port should communicate the adaptation needs it has identified through this study and foster collaboration on adaptation measures where there are co-benefits. Furthermore, once the Municipal Development Plan has incorporated climate considerations into its strategies and lines of action, it will be important for the port to take these into account when implementing adaptation actions set out in this Plan.

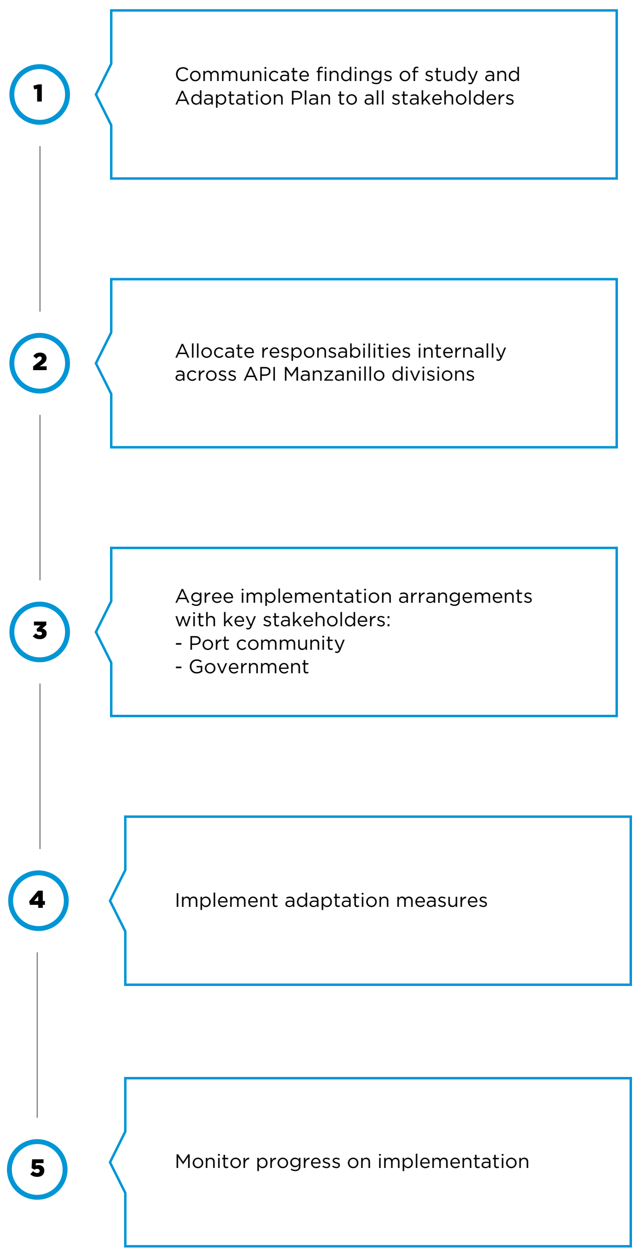
5.6. Next steps

While the completion of this study represents the end stage of an important component of the adaptation planning process, it is also the beginning of more important phase – decisions on the implementation of the measures set out in this plan (Figure 5.2). The immediate next steps for API Manzanillo are to: communicate the study findings and the Adaptation Plan; consider the measures proposed in the plan; decide on which measures to implement and when; allocate responsibilities among API Manzanillo divisions, and agree implementation arrangements with key stakeholders. With this in place, API Manzanillo and the terminals can begin incorporating the adaptation measures into their strategic and operational activities.

A plan should be developed by API Manzanillo in coordination with the terminals and other key stakeholders to monitor progress in the implementation of adaptation actions and to evaluate their performance, building on the adaptation indicators recommended in Table 5.1. API Manzanillo should also monitor trends in observed climate and oceanographic parameters at the port to understand how they are changing over time. Finally API Manzanillo is recommended to stay abreast of new developments in climate change projections, through communications with INECC.

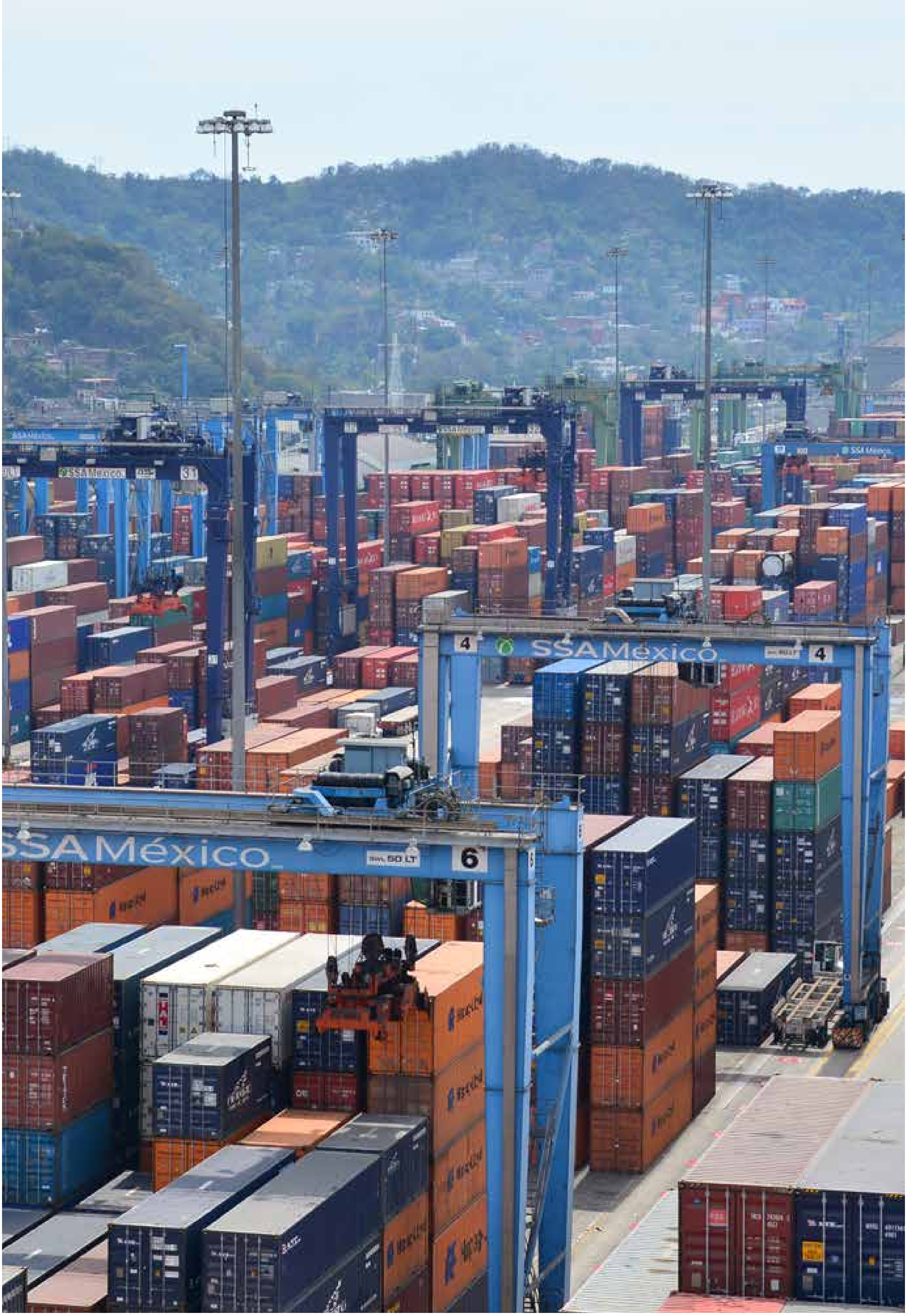
FIGURE 5.2

Next steps in the implementation of this Adaptation Plan



Source: Report authors

6. Study limitations and lessons learned for future studies


SSAMéxico
SSAMéxico
SSAMéxico
6
4
4

6.1. Overview

Climate risk and adaptation studies typically face several limitations in terms of available data and information. These limitations can affect the approaches to, and degree of confidence in climate risk assessments and consequent recommendations on adaptation actions.

The main limitations experienced in this study are summarized below. In some cases, future developments in scientific research could help to address these limitations, so it is useful to describe them, to encourage research in the right areas. Furthermore, some of the assessments could be improved by API Manzanillo working with the terminals and other stakeholders.

Nevertheless, it should be noted that uncertainties will always remain about future climate conditions, and so it is important that Adaptation Plans place an emphasis on undertaking no regret, low regret, win-win and flexible adaptation measures first. This is discussed further in Section 5.1.

6.2. Projecting changes in tropical cyclones

The study found that a high proportion of climate risks to the port were related to regional tropical cyclones and storms, which are responsible for intense rainfall events that can cause surface water flooding, and high winds which lead to disruption and, in extreme cases, closure of the port. Tropical cyclones are also responsible for creating storm surges, which have the potential to lead to sea water flooding. Therefore, an understanding of how these events will change in the future is important in order to assess the risks posed by climate change and to evaluate associated adaptation actions. However, tropical cyclones are currently not simulated in global climate models, mainly due to the relatively coarse spatial scale of the models.

The study also found that the impacts of tropical cyclones and storms on port activities depend heavily on their tracks: based on data provided by PEMEX for 2014, it was observed that most tropical cyclones or storms in the North East tropical Pacific do not affect the port. Only those cyclones or storms passing very close to Manzanillo and normally within a few tens of kilometers, led to disruption. The majority of cyclones or storms, which are more distant from the port, do not.

Therefore, simulation of tropical cyclone frequency and intensity is required of climate models in order to evaluate future risks to the port. An additional requirement is that tropical cyclones tracks at the sub-ocean basin scale should be well simulated. This is well beyond the current capabilities of climate science. Additional regional climate modelling could feasibly be carried out to investigate possible changes to tropical cycle characteristics such as frequency and intensity. However such studies would take extensive time to complete and as such were beyond the scope of the study.

Due to these limitations, sensitivity tests were developed for future changes in tropical cyclones, to provide an understanding of potential future risks facing the port (see Section 2.1.3). In addition, observed trends in rainfall intensity and wind speeds were analyzed. Where those trends were statistically significant, it was assumed they would continue linearly into the future (see Section 2.1.1, chapter “Trends in historical climate: Thresholds of rain and wind from daily data”). As new science on future tropical cyclones becomes available, this can be compared to the sensitivity tests and observed trends applied in the study.

6.3. Hydrological analysis

A hydrological analysis was undertaken to provide estimates of future changes in peak flows (discharges) for the Arroyo Camotlan stream (Drain 3 catchment) (see Appendix 6). Estimates were generated for various return period peak flows, for two future time periods (2050s and 2080s). This analysis has some limitations which are discussed further in Appendix 6. First, the method used to estimate peak flows employed formulas that are not considered 100% appropriate for the Drain 3 catchment size. Second, the percentage changes in future rainfall intensity for one frequency of return (namely, the 20-yr, 24-hr storm) were assumed to apply to all rainfall return periods. In reality, percentage changes for other return periods are likely to be different. Appendix 6 provides details on additional analysis that could be undertaken with extra resources, to provide more detailed estimates of peak flows, and associated surface water flooding and sedimentation at the port.

6.4. Sedimentation rates

For this study, there were no available estimates of present-day sediment concentrations within the Drain 3 catchment. Therefore, the potential for changes to sediment discharges under climate change were limited to a qualitative discussion.

Further, the study assumed that changes in sediment discharge would vary proportionally with changes in peak flows. However, more frequent and higher-intensity rainfall events could have the effect of causing rain drops to dislodge a greater number of soil particles upon contacting the ground surface. This would increase sedimentation non-linearly. Similarly, higher peak flows could increase channel erosion non-linearly. More detailed analysis and data, beyond the scope of this study, is required to undertake a non-linear assessment.

6.5. Engineering rational for drain upgrade

In order to estimate the costs for the upgrade of Drain 3, in the absence of detailed design data on the drain, a number of assumptions had to be made regards the flow regime, slope of the drain and depth of the outlet. Details of the full rationale are provided in Appendix 7. These estimates could be improved by API Manzanillo, based on the detailed design data they hold.

6.6. Financial analysis

Detailed responses were not received from all terminals to the data request concerning observed climate-related incidents and their impacts on terminals' financial performance (see Appendix 3).

The study was able to provide detailed financial analysis based on the data provided by the terminals. However, in light of gaps in data from some terminals, certain analyses were limited to terminals who did respond. In other cases, assumptions were made that data from a limited number of terminals was representative of all of them. For example, information was available from only a single terminal on downtime costs due to dredging vessel operations. This was then taken as an average representative figure for all terminals at the port.

6.7. Identification and appraisal of adaptation measures

The scope and budget available for the study imposed some limitations on the type and level of analysis that could be undertaken for adaptation measures (see Sections 4.2 and 5).

First, adaptation measures should ideally be identified and appraised in consultation with the stakeholders who will be responsible for implementing them, and involving other key stakeholders who can be affected by, or who have an interest in them (see Section 5.5 for further details). This was not possible within the study budget, which allowed for one mission to Mexico at the start of the study to identify risks and vulnerabilities and gather study data. Instead, the adaptation measures were identified and appraised by the study team, drawing on the principles set out in Section 5.1. As noted in Section 5.6, API Manzanillo and the terminals will, in discussion with other stakeholders, wish to consider the measures proposed, to decide which to implement, and when.

Second, the study identifies two main types of measure: those that build adaptive capacity (which are no regret), and those that deliver adaptation action. The second category includes four sub-categories (operational changes, engineered/hard structural solutions, ecosystem-based adaptation and hybrid measures – see Section 5.2). Within the scope and budget available for the study, it was not feasible to undertake quantitative analyses of all of the measures proposed. Instead, high-level cost effectiveness analyses were undertaken, to evaluate their relative costs and benefits (Section 4.2). Detailed analysis of the costs and financial performance of adaptation was instead focused on measures to address the most financially significant climate risks facing the port – namely, upgrades to the drainage system to manage surface water flood risk and sedimentation (Section 4.2.1).

Glossary[lvi]

Adaptation

Measures and adjustments in both natural and human systems as a response to climate stimuli, either current or projected. Also the effect of such measures and adjustments taken to reduce damages or take advantage of opportunities generated by the climate stimuli.

Adaptive management[lvii]

A process of iteratively planning, implementing, and modifying strategies for managing resources in the face of uncertainty and change. Adaptive management involves adjusting approaches in response to observations of their effect and changes in the system brought on by resulting feedback effects and other variables.

Climate change

Climate variation directly or indirectly attributed to human activity altering the global composition of the atmosphere, which occurs in addition to natural climate variability.

Disaster

Occurring as a result of one or several disruptive agents, either severe or extreme and not necessarily related. They can also be due to natural causes or due to human activity and when they occur in a given moment and in a certain place, they cause damage in such a way that the community affected does not have the means to respond on a timely manner.

Greenhouse Gases (GHG)

Gas components in the atmosphere, both natural and man-made, which absorb and emit infrared radiation.

Hazard[lviii]

The potential occurrence of a natural or human-induced physical event or trend, or physical impact, that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources.

Mitigation

Implementation of policies and measures destined to either reduce emissions across all sources or improve sinks of chemical compounds and greenhouse gases.

Ecological zoning

Environmental policy instrument used to regulate or promote certain land uses and productive activities. The instrument purpose is also to promote environmental protection and to ensure the preservation and sustainable use of natural resources.

Resilience

Natural or social systems' ability to recover from or cope with the effects derived from climate change.

Risk[lix]

The potential for consequences where something of human value (including humans themselves) is at stake and where the outcome is uncertain. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the consequences if these events occur.

Environmental services

Tangible and intangible benefits generated by ecosystems, which are necessary for the survival of both the natural and biological systems as a whole, and necessary to provide benefits to humans.

Vulnerability

The threshold at which a system becomes susceptible, that is not able to cope, with the negative effect of climate change, including climate variability and extreme event. Vulnerability is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.

End Notes

1. Gobierno del Estado Libre y Soberano de Colima. http://www.sefome.gob.mx/influ_puerto.php. (Accessed August 2015).

2. API Manzanillo, Top 10 Los puertos más importantes de América Latina. http://www.puertomanzanillo.com.mx/esps/2110842/top-10-los-puertos-mas-importantes-de-america-latina. (Accessed August 2015).

3. API Manzanillo, Top 10 Los puertos más importantes de América Latina. http://www.puertomanzanillo.com.mx/esps/2110842/top-10-los-puertos-mas-importantes-de-america-latina. (Accessed August 2015).

4. SEMARNAT and INECC (2015). “Elementos Mínimos para la Elaboración de los Programas de Cambio Climático de las Entidades Federativas.” [On-line resource]: http://www.inecc.gob.mx/descargas/cclimatico/2015_elem_minims_prog_cc_efederativas.pdf. (Accessed August 2015).

5. API Manzanillo. (2012). Programa Maestro de Desarrollo Portuario (PMDP) del Puerto de Manzanillo 2012 – 2017

6. API Manzanillo. (No date). Puerto de Manzanillo. Port Handbook 2014-2015

7. SCT. (2013). [On-line resource]: http://www.amivtac.org/esp/1/mapas/sistema-portuario-nacional. (Accessed September 2015)

8. UK Adaptation Sub-Committee (2014). Managing climate risks to well-being and the economy. Adaptation Sub-Committee Progress Report 2014.

9. Ley General de Cambio Climático Nueva Ley DOF 06-06-2012

10. Gobierno de la República. (2013). Estrategia Nacional de Cambio Climático. Visión 10-20-40.

11. Zorrilla Ramos, M. (2014). Evaluación del marco regulatorio para un estudio de adaptación al cambio climático para el Puerto de Manzanillo (ME-T1239): Informe Final.

12. Zorrilla Ramos, M. (2014). Evaluación del marco regulatorio para un estudio de adaptación al cambio climático para el Puerto de Manzanillo (ME-T1239): Informe Final.

13. Zorrilla Ramos, M. (2014). Evaluación del marco regulatorio para un estudio de adaptación al cambio climático para el Puerto de Manzanillo (ME-T1239): Informe Final.

14. Zorrilla Ramos, M. (2014), Evaluación del marco regulatorio para un estudio de adaptación al cambio climático para el Puerto de Manzanillo (ME-T1239): Informe Final.

15. SEMARNAT and INECC (2015) “Elementos mínimos para la elaboración de los Programas de Cambio Climático de las Entidades Federativas” [Online resource]: http://www.inecc.gob.mx/descargas/cclimatico/2015_elem_minims_prog_cc_efederativas.pdf. (Accessed August 2015)

16. IPCC, 2012: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation.A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA, 582 pp

17. INECC. (2013). Guía Metodológica para la Evaluación de la Vulnerabilidad ante el Cambio Climático, Victor Magaña (Ed.)

18. SEMARNAT and INECC (2015) “Elementos mínimos para la elaboración de los Programas de Cambio Climático de las Entidades Federativas” [On-line resource]: http://www.inecc.gob.mx/descargas/cclimatico/2015_elem_minims_prog_cc_efederativas.pdf. (Accessed August 2015)

19. Willows, R.I. and R.K. Connell. (eds.). (2003). Climate Adaptation: Risk, Uncertainty and Decision-Making. UKCIP Technical Report. UKCIP, Oxford.

20. Lal, P.N., T. Mitchell, P. Aldunce, H. Auld, R. Mechler, A. Miyan, L.E. Romano, and S. Zakaria, 2012: National systems for managing the risks from climate extremes and disasters. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 339-392.

21. Metroeconomica (2004). “Costing the impacts of climate change in the UK: overview of guidelines”. UKCIP Technical Report. UKCIP, Oxford.

22. API Manzanillo. (2015). Pers. Comm.

23. API Manzanillo. (2015). Pers. Comm.

24. API Manzanillo. (2015). Pers. Comm.

25. API Manzanillo. (2015). Pers. Comm.

26. API Manzanillo. (2015). Pers. Comm.

27. UK Adaptation Sub-Committee (2014). Managing climate risks to well-being and the economy. Adaptation Sub-Committee Progress Report 2014.

28. The Royal Society Science Policy Centre. (2014). Resilience to extreme weather.

29. GIZ and SEMARNAT. Metodología para la Identificación y Priorización de Medidas de Adaptación frente al Cambio Climático. (On-line resource): http://www.adaptacion.inecc.gob.mx/que-es-adaptacion-y-vulnerabilidad/medidas-y-acciones/metodologia. (Accessed September 2015).

30. Stern, N. (2007). The Economics of Climate Change: The Stern Review. Cambridge and New York: Cambridge University Press.

31. http://es.windfinder.com/windstatistics/manzanillo. (Accessed June 2015).

32. http://es.windfinder.com/windstatistics/manzanillo. (Accessed June 2015).

33. Gutzler, D.S., Wood, K.M., Ritchie, E.A., Douglas, A.V., and Lewis, M.D. (2013). Interannual variability of tropical cyclone activity along the Pacific coast of North America, Atmósfera, Volume 26, Issue 2, 149–162.

34. IPCC. (2012). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA, 582 pp.

35. Balogun, K. (2013). Managing loss and damage from slow onset events: Applicability of risk transfer tools including Insurance. http://www.loSSAnddamage.net/download/7271.pdf. (Accessed June 2015).

36. Cavazos, T., J. A. Salinas, B. Martínez, G. Colorado, P. de Grau, R. Prieto González, A. C. Conde Álvarez, A. Quintanar Isaías, J. S. Santana Sepúlveda, R. Romero Centeno, M. E. Maya Magaña, J. G. Rosario de La Cruz, Ma. del R. Ayala Enríquez, H. Carrillo Tlazazanatza, O. Santiesteban y M. E. Bravo, 2013: ACTUALIZACIÓN DE ESCENARIOS DE CAMBIO CLIMÁTICO PARA MÉXICO COMO PARTE DE LOS PRODUCTOS DE LA QUINTA COMUNICACIÓN NACIONAL . Informe Final del Proyecto al INECC, 150 pp. Available at: http://escenarios.inecc.gob.mx/index2.html. (Accessed April 2015).

37. IPCC. (2012). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA, 582 pp.

38. IPCC. (2012). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA, 582 pp.

39. http://escenarios.inecc.gob.mx/index2.html.

40. Romero-Vadillo, E., Zaytsev, O. and Morales-Perez, R. (2007). Tropical cyclone statistics in the Northeastern Pacific. Atmósfera. Vol. 20, No. 2. pp. 197-213.

41. Ramsay, H. (2014). Shifting storms. Nature. 509, 290-291

42. Romero-Vadillo, E., Zaytsev, O. and Morales-Perez, R. (2007). Tropical cyclone statistics in the Northeastern Pacific. Atmósfera. Vol. 20, No. 2. pp. 197-213.

43. Romero-Vadillo, E., Zaytsev, O. and Morales-Perez, R. (2007). Tropical cyclone statistics in the Northeastern Pacific. Atmósfera. Vol. 20, No. 2. pp. 197-213.

44. Kossin, J.P. Emanuel, K. A. and Vecchi, G.A. (2014). The poleward migration of the location of tropical cyclone maximum intensity. Nature. 509, 349-353. doi:10.1038/nature13278

45. Kossin, J.P. Emanuel, K. A. and Vecchi, G.A. (2014). The poleward migration of the location of tropical cyclone maximum intensity. Nature. 509, 349-353. doi:10.1038/nature13278

46. IPCC. (2007). Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp.

47. Christensen, J.H., K. Krishna Kumar, E. Aldrian, S.-I. An, I.F.A. Cavalcanti, M. de Castro, W. Dong, P. Goswami, A. Hall, J.K. Kanyanga, A. Kitoh, J. Kossin, N.-C. Lau, J. Renwick, D.B. Stephenson, S.-P. Xie and T. Zhou. (2013). Climate Phenomena and their Relevance for Future

Regional Climate Change. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1217–1308, doi: 10.1017/CBO9781107415324.028.

48. IMADES (2104) Informe - Progama Estatal De Accion Ante El Cambio Climatico – Estado de Colima

49. IMADES (2104) Informe - Progama Estatal De Accion Ante El Cambio Climatico – Estado de Colima

50. IMADES (2104) Informe - Progama Estatal De Accion Ante El Cambio Climatico – Estado de Colima

51. ERN (2008). Estudio de Riesgo por Inundacion y Marea de Tormenta, Manzanillo, Colima.

52. CONAGUA (2014) Study by Mondragon. Drainage basins and rainfall intensities feeding the Port of Manzanillo

53. ERN (2008). Estudio de Riesgo por Inundacion y Marea de Tormenta, Manzanillo, Colima.

54. CONAGUA (2014) Study by Mondragon. Drainage basins and rainfall intensities feeding the Port of Manzanillo

55. API Manzanillo Commercial Presentation 2015

56. CONSULTEC (2013) – "Assessment of discharges into Puerto de San Pedrito"

57. API Manzanillo Commercial Presentation 2015

58. Seneviratne, S.I., N. Nicholls, D. Easterling, C.M. Goodess, S. Kanae, J. Kossin, Y. Luo, J. Marengo, K. McInnes, M. Rahimi, M. Reichstein, A. Sorteberg, C. Vera, and X. Zhang, 2012: Changes in climate extremes and their impacts on the natural physical environment. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 109-230.

59. Romero-Vadillo, E., Zaytsev, O. and Morales-Perez, R. (2007). Tropical cyclone statistics in the Northeastern Pacific. Atmósfera. Vol. 20, No. 2. pp. 197-213.

60. Wada, Y., Van Beek, L. P. H., Van Kempen, C. M., Reckman, J. W. T. M., Vasak, S., and Bierkens, M. F. P. 2010. Global Depletion of groundwater resources. Geophysical Research Letters. doi: 10.1029/2010GL044571. In press

61. Hennessy, K., Page, C., McInnes, K., Walsh, K., Pittock, B., Bathols, J and Suppiah, R. 2004. Climate change in the Northern Territory. Climate Impact Group, CSIRO (Commonwealth Scientific and Industrial Research Organisation) Atmospheric Research. Consultancy report for the Northern Territory Department of Infrastructure, Planning and Environment in Australia.

62. CONTECON Terminal Technical Due Diligence Report (2013). Chapter 13 Climate Change and Sea Level Rise

63. Nicholls, Robert J.; Cazenave, Anny (18 June 2010). "Sea-Level Rise and Its Impact on Coastal Zones".Science Magazine 328 (5985): 1517–1520

64. INECC (2014) Evaluacion regional de la vulnerabilidad actual y future de la zona costera Mexicana y los deltas mas impactados ante el increment del nivel del mar debido al cambio climatico y fenomenos hidrometerologicoa extremos.

65. http://tidesandcurrents.noaa.gov/sltrends/sltrends.html (Accessed March 2015).

66. Sutherland M, Dare P, Miller K, 2008. Monitoring Sea Level Change in the Caribbean

67. SEMAR. (2015). Available at: http://oceanografia.semar.gob.mx/Templates/grafnum_manzanillo.html (Accessed August 2015).

68. http://tidesandcurrents.noaa.gov/sltrends/seasonal.shtml?stnid=830-071 (Accessed March 2015).

69. ERN (2008). Estudio de Riesgo por Inundacion y Marea de Tormenta, Manzanillo, Colima.

70. ERN (2008). Estudio de Riesgo por Inundacion y Marea de Tormenta, Manzanillo, Colima.

71. ERN (2008). Estudio de Riesgo por Inundacion y Marea de Tormenta, Manzanillo, Colima.

72. ERN (2008). Estudio de Riesgo por Inundacion y Marea de Tormenta, Manzanillo, Colima.

73. McPhaden, M. J. & Yu, X. (1999). Equatorial waves and the 1997/98 El Nin˜o.Geophys. Res. Lett. 26, 2961–2964

74. Church, J.A., P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer and A.S. Unnikrishnan, 2013: Sea Level Change. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New

York, NY, USA. [Recurso en línea]: http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter13_FINAL.pdf (Accesado en abril de 2015).

75. Hinkel, Jochen, et al. "Sea-level rise scenarios and coastal risk management." Nature Climate Change 5.3 (2015): 188-190.

76. Church, J.A., P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer and A.S. Unnikrishnan, 2013: Sea Level Change. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter13_FINAL.pdf (Accessed April 2015).

77. Church, J.A., P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer and A.S. Unnikrishnan. (2013). Sea Level Change. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. p. 1204.

78. CONTECON Terminal Technical Due Diligence Report (2013). Chapter 13 Climate Change and Sea Level Rise

79. Katsman, C., W. Hazeleger, S. Drijfhout, G. Oldenborgh, and G. Burgers, 2008: Climate scenarios of sea level rise for the northeast Atlantic Ocean: A study including the effects of ocean dynamics and gravity changes induced by ice melt. Clim. Change, 91, 351–374.

80. Vermeer, M., and S. Rahmstorf, 2009: Global sea level linked to global temperature. Proc. Natl. Acad. Sci. U.S.A., 106, 21527–21532.

81. Nicholls, R. J., et al., 2011: Sea-level rise and its possible impacts given a 'beyond 4 degrees C world' in the twenty-first century. Philos. Trans. R. Soc. London A, 369, 161–181.

82. Kossin, J.P., Emanuel, K.A. and Vecchi, G.A. (2014). The poleward migration of the location of tropical cyclone maximum intensity. Nature Vol. 509, 349-352

83. Wang, X.L., Feng, Y., Swail, V.R. (2014). Changes in global ocean wave heights as projected using multimodel CMIP5 simulations. Geophys Res Lett 41(3):1026–1034

84. Wang, X.L., Feng, Y., Swail, V.R. (2014). Changes in global ocean wave heights as projected using multimodel CMIP5 simulations. Geophys Res Lett 41(3):1026–1034

85. Lukasse, L., Baerentz, M. B., & Kramer-Cuppen, J. D. (2012). Quest II: reduction of co2 emissions of reefer containers.

86. Fitzgerald W.B., Howitt O.J.A., Smith I.J., Hume A. 2011. Energy use of integral refrigerated containers in maritime transportation, Energy Policy, doi: 10.1016/j.enpol.2010.12.015.

87. Lawton A.R., Mynott T.O., Marshall N. 2010, Energy consumption reduction in marine refrigerated containers, Proc. of 1st IIR Conference on Sustainability and the Cold Chain, IIR/IIF, Cambridge.

88. Maersk Line. (2014). QUEST II Quicker cool-down – less CO2 emissions. Available: http://maersklinereefer.com/quest/questii. (Accessed June 2015).

89. Maersk Line. (2010). Reefer Containers: The Present and The Future. Available: http://coolchain.org/Websites/cca/Images/CCA%20Workshop%20SA%202010%20Presentations/MAERSK_HenrikLindhardt_Reefers_the%20present%20and%20future.pdf. (Accessed June 2015).

90. Energy Savings in Refrigerated Warehouses. Global cold chain alliance. http://www.gcca.org/cold-facts/energy-savings-in-refrigerated-warehouses/ (Accessed June 2015).

91. Hilton (2013). Reducing energy use in the cold storage industry – A case study. http://sclaa.com.au/energy-efficiency/assets/pdfs/AIRAH_cold_storage_casestudy.pdf (Accessed June 2015).

92. ABB – Public Cold Storage warehouse reduces energy costs by 35%, via installing vfds throughout refrigeration infrastructure. http://www.abb.co.uk/cawp/seitp202/b2b8e9e76991ae12852579610063f40f.aspx (Accessed June 2015).

93. Hilton (2013). Reducing energy use in the cold storage industry – A case study. http://sclaa.com.au/energy-efficiency/assets/pdfs/AIRAH_cold_storage_casestudy.pdf Accessed June 18 2015

94. IFC. (2012). Estudio de Mercado del Financiamiento de Energías Sostenibles en México Reporte Final. Preparado para el Programa de Financiamiento de Energía Sostenible

95. Estimación de la Huella de Carbono del Puerto de Manzanillo. Informe Final · Revisión 3. Fortalecimiento de la sostenibilidad portuaria infraestructura en Manzanillo, México · Cooperación técnica (ME-T1239) 2015. TT

96. Estimación de la Huella de Carbono del Puerto de Manzanillo. Informe Final · Revisión 3. Fortalecimiento de la sostenibilidad portuaria infraestructura en Manzanillo, México · Cooperación técnica (ME-T1239) 2015. TT

97. Estimación de la Huella de Carbono del Puerto de Manzanillo. Informe Final · Revisión 3. Fortalecimiento de la sostenibilidad portuaria infraestructura en Manzanillo, México · Cooperación técnica (ME-T1239) 2015. TT

98. IPCC Special Report Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation http://www.ipcc-wg2.gov/SREX/ (Accessed March 2015).

99. Vermeer, M., and S. Rahmstorf, 2009: Global sea level linked to global temperature. Proc. Natl. Acad. Sci. U.S.A., 106, 21527–21532.

100. Vermeer, M., and S. Rahmstorf, 2009: Global sea level linked to global temperature. Proc. Natl. Acad. Sci. U.S.A., 106, 21527–21532.

101. Nicholls, R. J., et al., 2011: Sea-level rise and its possible impacts given a 'beyond 4 degrees C world' in the twenty-first century. Philos. Trans. R. Soc. London A, 369, 161–181.

102. Vermeer, M., and S. Rahmstorf, 2009: Global sea level linked to global temperature. Proc. Natl. Acad. Sci. U.S.A., 106, 21527–21532.

103. Nicholls, R. J., et al., 2011: Sea-level rise and its possible impacts given a 'beyond 4 degrees C world' in the twenty-first century. Philos. Trans. R. Soc. London A, 369, 161–181.

104. IUCN (International Union for Conservation of Nature). 2005. Mangrove forests saved lives in 2004 tsunami disaster. Press release. Bangkok, Colombo.

105. IFRC (International Federation of the Red Cross). 2002. World Disaster Report 2002 – Focus on reducing risk. Chapter 4. Box 4.4.

106. http://www.wunderground.com/tropical/tracking/ep201110.html (Accessed April 2105).

107. Secretaria de Comunicaciones Y Transportes (SCT) 2013 Port of Manzanillo Video Presentación

108. INECC (2014) Evaluación regional de la vulnerabilidad actual y futura de la zona costera Mexicana y los deltas más impactados ante el incremento del nivel del mar debido al cambio climático y fenómenos hidrometeorológicos extremos.

109. Australian Government Bureau of Meterology, http://www.bom.gov.au/cyclone/faq/ (Accessed June 2015).

110. Gaythwaite, J, G. 2004. Design of marine facilities for the berthing, mooring, and repair of vessels. American Society of Civil Engineers. Second Edition. ASCE Press.

111. API Manzanillo. (2012). Programa Maestro de Desarrollo Portuario (PMDP) del Puerto de Manzanillo 2012 – 2017.

112. Nicholls, R. J., et al., 2011: Sea-level rise and its possible impacts given a 'beyond 4 degrees C world' in the twenty-first century. Philos. Trans. R. Soc. London A, 369, 161–181.

113. Discussion API Engineering

114. Romero-Vadillo, E., Zaytsev, O. y Morales-Perez, R. (2007). Tropical cyclone statistics in the Northeastern Pacific. Atmósfera. Vol. 20, No. 2. pp. 197-213

115. Kossin, J.P., Emanuel, K.A. and Vecchi, G.A. (2014). The poleward migration of the location of tropical cyclone maximum intensity. Nature 509, 349-352

116. IMT (2008) Estudios En Modelos Numéricos Para Analizar El Efecto De Las Ondas De Largo Período En El Proyecto De Un Nuevo Muelle De Cruceros Como Ampliación Del Muelle Fiscal Ubicado En La Bahía De Manzanillo, Col PROYECTO No. VE-21/08:

117. API Manzanillo. (2012). Programa Maestro de Desarrollo Portuario (PMDP) del Puerto de Manzanillo 2012 – 2017.

118. Romero-Vadillo, E., Zaytsev, O. and Morales-Perez, R. (2007). Tropical cyclone statistics in the Northeastern Pacific. Atmósfera. Vol. 20, No. 2. pp. 197-213

119. API Manzanillo. (2012). Programa Maestro de Desarrollo Portuario (PMDP) del Puerto de Manzanillo 2012 – 2017.

120. SCT (2008) Estudio del movimiento de vehículos de carga dentro del recinto portuariode Manzanillo,Colima.

121. API Manzanillo Commercial Presentation 2015

122. SCT (2008) Estudio del movimiento de vehículos de carga dentro del recinto portuario de Manzanillo, Colima.

123. API Manzanillo. (2012). Programa Maestro de Desarrollo Portuario (PMDP) del Puerto de Manzanillo 2012 – 2017.

124. Seneviratne, S.I., N. Nicholls, D. Easterling, C.M. Goodess, S. Kanae, J. Kossin, Y. Luo, J. Marengo, K. McInnes, M. Rahimi, M. Reichstein, A. Sorteberg, C. Vera, and X. Zhang, 2012: Changes in climate extremes and their impacts on the natural physical environment. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M.

Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 109-230.

125. LBJ School of Public Affairs (2009). Evaluation of Mexican Transportation Infrastructure Projects.

126. IGRAC - International Groundwater Resources Assessment Centre http://www.un-igrac.org/publications/520 (Accessed June 2015).

127. Water encyclopedia. Factors influencing infiltration rate. http://www.waterencyclopedia.com/Re-St/Runoff-Factors-Affecting.html (Accessed June 2015).

128. CENAPRED (2012) Características e impacto socioeconómicos de los principales desastres ocurridos en la República Mexicana en el año 2011.

129. Ferromex (2012) Informe annual 2012, [On-line resource]: http://www.ferromex.com.mx/pdf/Informe_Anual_2012.pdf (Accessed April 2015).

130. Fernando Morales. (2015) Representative of Ferromex. Pers. Comm. Meeting held at Ferromex offices in Manzanillo, February 16, 2015.

131. API Manzanillo. (2012). Programa Maestro de Desarrollo Portuario del Puerto de Manzanillo 2012-2017

132. API Manzanillo. (2012). Programa Maestro de Desarrollo Portuario del Puerto de Manzanillo 2012-2017

133. Ferromex. (2012). [On-line resource]: http://www.ferromex.com.mx/pdf/Informe_Anual_2012.pdf. (Accessed September 2015).

134. Fernando Morales (2015). Representative of Ferromex in Manzanillo, Pers. Comm. February 16 2015.

135. See annual reports provided by CENAPRED at http://www.cenapred.gob.mx/PublicacionesWeb/buscar_buscaSubcategoria?categoria=SERIES+ESPECIALES+%2F&subcategoria=IMPACTO+SOCIOECON%26Oacute%3BMICO+DE+LOS+DESASTRES+EN+M%26Eacute%3BXICO&palabraClave=de+los+Desastres+en

136. IMADES (2015) Plan Estatal de Accion ante el Cambio Climatico. Capitulo 7. CURRENTLY UNDER REVIEW

137. CENAPRED (2012) Características e impacto socioeconómicos de los principales desastres ocurridos en la República Mexicana en el año 2011.

138. CENAPRED (2012) Características e impacto socioeconómicos de los principales desastres ocurridos en la República Mexicana en el año 2011.

139. Fernando Morales (2015). Ferromex Pers. Comm. 16 Feb. 2015

140. Aqueduct Global Maps 2.0 (2013), Metadata available on-line at: http://www.fao.org/nr/water/aquastat/water_use/aqueduct_metadata_global.pdf

141. The methodology used to develop the flood maps generated by Aqueduct is available at: http://www.fao.org/nr/water/aquastat/water_use/aqueduct_metadata_global.pdf

142. The methodology used to develop the map of threats from CENAPRED (2013) is available at: http://www.atlasnacionalderiesgos.gob.mx/index.php/biblioteca/category/9-iii-riesgos-hidrometeorologicos?download=41:mapas-de-riesgo-por-fenomenos-hidrometeorologicos-metodologia

143. Government of Mexico (2007) Mexico's Third National Communication to the UNFCCC.

144. Government of Mexico (2007) Mexico's Third National Communication to the UNFCCC.

145. IPCC (2014). Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

146. SCT (1996) Reglamento de Conservación de Vías y Estructuras para los Ferrocarriles Mexicanos. En vigor 01-09-1996. www.sct.gob.mx/informacion-general/normatividad/transporte-ferroviario-y-MULTIMODAL/reglamentos-federales/

147. http://www.worldclim.org/bioclim. (Accessed April 2015).

148. Secretaria de Comunicaciones Y Transportes (SCT) 2013 Port of Manzanillo Video Presentation

149. SCT (2010 to 2013) Reporte Annual Cierres de Puerto

150. SCT (2010 to 2013) Reporte Annual Cierres de Puerto

151. Emanuel, K. "Increasing destructiveness of tropical cyclones over the past 30 years," Nature, 436, 4 August 2005, pp. 686 – 688.

152. Emanuel, K. (2006) "Anthropogenic Effects on Tropical Cyclone Activity," at http://eaps4.mit.edu/faculty/Emanuel/publications/position_paper. (Accessed April 2015).

153. Secretaria de Comunicaciones Y Transportes (SCT) 2013 Port of Manzanillo Video Presentation

154. SCT (2010 to 2013) Reporte Annual Cierres de Puerto

155. API Manzanillo Impacto Annual SEMARNAT 2014. Proyecto: "Puerto De Manzanillo, Programa Maestro De Desarrollo 2000 – 2010

156. CH2MHILL (2014) Environmental and Social Due Diligence Report for the CMSA Manzanillo, Mexico Container Port and Logistic Facility.

157. The methodology used to develop the map of threats from CENAPRED (2013) [Recurso en línea]: http://www.atlasnacionalderiesgos.gob.mx/index.php/biblioteca/category/9-iii-riesgos-hidrometeorologicos?download=41:mapas-de-riesgo-por-fenomenos-hidrometeorologicos-metodologia. (Accesado en junio de 2015).

158. Inter-American Development Bank (2014). Manzanillo Port Container Terminal (Me-L1152) Environmental And Social Management Report (ESMR)

159. API Manzanillo. (2014). Proyecto: 'Puerto de Manzanillo, Programa Maestro de Desarrollo 2000-2010.' Informe Annual 2014

160. E. Mellink and M. Riojas-Lopez, "Waterbirds and human-related threats to their conservation in Laguna Cuyutlan, Colima, Mexico," ´ Revista de Biologia Tropical, vol. 57, no. 1- 2, pp. 1–12, 2009.

161. Odum, W.E, McIvor, C.C. and Smith T.J. (1982). The ecology of the mangroves of south Florida: a community profile. Office of Biological Services, U.S. Fish Wild, Serv., Washington, DC 144 pp

162. McLeod E and Salm RV. (2006). Managing mangroves for resilience to climate change. Gland, Switzerland: IUCN.

163. Schubel, J. R. (1977). Sediment and the quality of the estuarine environment: Some observations. Pg 399-424. In: I. H. Suffet (ed.). Fate of pollutants in the air and water environments. Part 1. Mechanism of interaction between environments and the mathematical modeling and the physical fate of pollutants. John Wiley and Sons, New York, NY.

164. Harvey, M., Gauthier, D. & Munro, J. (1998) Temporal changes in the composition and abundance of the macro-benthic invertebrate communities at dredged material disposal sites in the Anse a Beaufils, baie des Chaleurs, eastern Canada. Marine Pollution Bulletin, 36, 41–55.

165. Wang XL, Feng Y, Swail VR (2014) Changes in global ocean wave heights as projected using multimodel CMIP5 simulations. Geophys Res Lett 41(3):1026–1034

166. Lovelock , C.E., Skilleter, G., Saintilan, N. (2012). Marine Climate Change Impacts and Adaptation Report Card (MaRC) for Australia http://www.oceanclimatechange.org.au/content/images/uploads/Mangroves_and_tidal_wetlands_final.pdf (Accessed June 2015).

167. Lovelock , C.E., Skilleter, G., Saintilan, N. (2012). Marine Climate Change Impacts and Adaptation Report Card (MaRC) for Australia http://www.oceanclimatechange.org.au/content/images/uploads/Mangroves_and_tidal_wetlands_final.pdf (Accessed June 2015).

168. Kjerfve, B. and Macintosh, D.J. (1997). Climage change impacts on mangrove ecosystems. In " Mangrove Ecosystem Studies in Latin America and Africa" (B. Kjerfve, L.D. Lacerda and S. Diop, eds), pp. 1-7. UNESCO, Paris.

169. Estimación de la Huella de Carbono del Puerto de Manzanillo. Informe Final · Revisión 3. Fortalecimiento de la sostenibilidad portuaria infraestructura en Manzanillo, México · Cooperación técnica (ME-T1239) 2015. TT

170. Gilman E, Ellison J, Duke N, Field C. 2008. "Threats to mangroves from climate change and adaptation options". Aquatic Botany 89 (2), August 2008, Pp 237- 250.

171. Estimación de la Huella de Carbono del Puerto de Manzanillo. Informe Final · Revisión 3. Fortalecimiento de la sostenibilidad portuaria infraestructura en Manzanillo, México · Cooperación técnica (ME-T1239) 2015. TT

172. Lambrechts L, Scott TW, Gubler DJ. (2010). Consequences of the expanding global distribution of Aedes albopictus for dengue virus transmission. PLoS Negl. Trop. Dis. 4, e646.

173. MaSSAd E, Burattini MN, Coutinho FAB, Lopez LF. (2003). Dengue and the risk of urban yellow fever reintroduction in São Paulo state, Brazil. Revista de Saúde Pública 37, 477–484.

174. Cofepris. (2012). Comisión Federal para la Protección contra Riesgos Sanitarios. Informe Proyecto Servicio para la Asistencia Técnica para el Desarrollo de Escenarios de Cambio Climático para el Análisis de Impactos en el Sector Salud.

175. California Department of Public Health. (February 27, 2015). Chikungunya and Dengue in Mexico and Latin America. Health and Travel Advisory. Available at: http://www.cdph.ca.gov/programs/vbds/Documents/HealthAdvisoryforDENVandCHIKinMX2-27-2015.pdf (Accessed April 2015).

176. Cofepris. (2012). Comisión Federal para la Protección contra Riesgos Sanitarios. Informe Proyecto Servicio para la Asistencia Técnica para el Desarrollo de Escenarios de Cambio Climático para el Análisis de Impactos en el Sector Salud.

177. Campbell, L.P., Luther , C., Moo-Llanes, D., Ramsey, J.M., Danis-Lozano, R., Peterson, A.P. (2015). Climate change influences on global distributions of dengue and chikungunya virus vectors. Phil. Trans. R. Soc. B 2015 370 20140135; doi: 10.1098/rstb.2014.0135

178. Campbell, L.P., Luther , C., Moo-Llanes, D., Ramsey, J.M., Danis-Lozano, R., Peterson, A.P. (2015). Climate change influences on global distributions of dengue and chikungunya virus vectors. Phil. Trans. R. Soc. B 2015 370 20140135; doi: 10.1098/rstb.2014.0135

179. Government of Mexico (2012). Fifth National Communication to the United Nations Framework Convention on Climate Change.

180. http://www.meteor.iastate.edu/~ckarsten/bufkit/apparent_temperature.html

181. Government of Mexico (2012). Fifth National Communication to the United Nations Framework Convention on Climate Change.

182. Honda, Y., M. Kondo, G. McGregor, H. Kim, Y. Guo, Y. Hijioka, M. Yoshikawa, K. Oka, S. Takano, S. Hales, and R.S. Kovats. (2013). Heat-related mortality risk model for climate change impact projection. Environmental Health and Preventive Medicine, doi:10.1007/s12199-013-0354-6

183. D'Ippoliti, D., P. Michelozzi, C. Marino, F. de'Donato, B. Menne, K. Katsouyanni, U. Kirchmayer, A. Analitis, M. Medina-Ramón, A. Paldy, R. Atkinson, S. Kovats, L. Bisanti, A. Schneider, A. Lefranc, C. Iñiguez, and C.A. Perucci. (2010). The impact of heat waves on mortality in 9 European cities: results from the EuroHEAT project. Environmental Health, 9, 37, doi:10.1186/1476-069X-9-37.

184. Gosling, S.N., G.R. Mcgregor, and J.A. Lowe, (2009). Climate change and heat-related mortality in six cities Part 2: climate model evaluation and projected impacts from changes in the mean and variability of temperature with climate change. International Journal of Biometeorology, 53(1), 31-51.

185. Abel Meneses Fernandez, (2015). API Centro de Emergencias. Pers. Comm. April 23, 2015.

186. Centers for Disease Control and Prevention, Atlanta, USA. Available at: http://www.cdc.gov/conjunctivitis/about/causes.html. (Accessed April 2015).

187. Gobierno Municipal H. Ayuntamiento Constitucional de Manzanillo (2011), Plan Municipal de Desarrollo 2012-2015 del Municipio de Manzanillo, Col.

188. Arq. José Fernando Morán Rodríguez, Secretaría de Desarrollo Urbano del Estado de Colima and M.en C. Patricia Ruiz Moreno, (2015). Pers. Comm. Instituto de Medio Ambiente y Desarrollo Sustentable, February 17, 2015.

189. Basilio-Chávez, L. (N.D.) La relación ciudad y puerto de Manzanillo México. RETE (Asociación para la colaboración entre puertos y ciudades, [On-line resource]: http://retedigital.com/wp-content/themes/rete/pdfs/portus/Portus_7/La_relación_ciudad_y_puerto_de_Manzanillo.pdf. (Accessed April 2015).

190. Basilio-Chávez, L. (2005) Propuesta para el futuro desarrollo urbano-portuario de Manzanillo, Ciudad y Puerto de Manzanillo, Colima, México. [On-line resource]: http://www.mexicoxport.com/mx-content/pdf/1_ar27.pdf. (Accessed April 2015).

191. Arq. Ernesto Vergara Orozco, (2015). Pers. Comm. Ayuntamiento de Manzanillo 16 February 2015 and José Fernando Morán Rodríguez, Secretaría de Desarrollo Urbano del Estado de Colima February 17 2015

192. Alejandro Abundis Santamaría, (2015). Pers. Comm. Coordinador de Proyectos and Roberto López Ceballos, Auxiliar de Ecología February 9, 2015

193. Santiago Ramos Herrera (2015). Pers. Comm. Director de Regulación y Ordenamiento Urbano (SEDUR), February 17, 2015.

194. See API's press release http://puertomanzanillo.com.mx/esps/2110914/realiza-api-acciones-de-limpieza-en-carretera-a-jalipa

195. Arq. José Fernando Morán Rodríguez, (2015). Pers.Comm. Secretaría de Desarrollo Urbano del Estado de Colima, February 17, 2015.

196. Government of Mexico (2012). Fifth National Communication to the United Nations Framework Convention on Climate Change.

197. Lara-Chávez,B. And Virgen, D.E. (2014), Conceptos y criterios para lograr una relación ciudad-puerto integral en Manzanillo, La Jornada Ecológica Edición Laura Angulo, Número Especial. [On-line resource]: http://www.jornada.unam.mx/2014/07/28/eco-f.html

198. Plan Municipal de Desarrollo 2012-2015 del Municipio de Manzanillo, Col.

199. Gobierno Municipal H. Ayuntamiento Constitucional de Manzanillo (2011), Plan Municipal de Desarrollo 2012-2015 del Municipio de Manzanillo, Col.

200. OECD-FAO (2009), Agricultural Outlook 2008-2017. [On-line resource: http://www.oecd.org/trade/agricultural-trade/40715381.pdf]

201. The World Bank (2012), Trade and Climate Change: An Analytical Review of Key Issues, in Economic Premise, No.68, [On-line resource]: http://siteresources.worldbank.org/EXTPREMNET/Resources/EP86.pdf Last Accesses 8 April 2015

202. WTO-UNEP (2009), Trade and Climate Change. A report by the United Nations Environment Program and the World Trade Organization. [On-line resource]: https://www.wto.org/english/res_e/booksp_e/trade_climate_change_e.pdf . (Accessed April 2015).

203. WTO-UNEP (2009), Trade and Climate Change. A report by the United Nations Environment Program and the World Trade Organization. [On-line resource]: https://www.wto.org/english/res_e/booksp_e/trade_climate_change_e.pdf. (Accessed April 2015).

204. UNCTAD (2014), [On-line resource]: http://unctad.org/en/PublicationsLibrary/rmt2012_en.pdf. (Accessed April 2015).

205. WTO-UNEP (2009), Trade and Climate Change. A report by the United Nations Environment Program and the World Trade Organization. [On-line resource]: https://www.wto.org/english/res_e/booksp_e/trade_climate_change_e.pdf . (Accessed April 2015).

206. WTO (2013) World Trade Report: Trends in international trading. [On-line resource]: https://www.wto.org/english/res_e/booksp_e/wtr13-2b_e.pdf (Accessed April 2015).

207. UNCTAD (2012), Review of Maritime Transport, [On-line resource]: http://unctad.org/en/PublicationsLibrary/rmt2012_en.pdf. (Accessed April 2015).

208. API Manzanillo. (2012). Programa Maestro de Desarrollo Portuario (PMDP) del Puerto de Manzanillo 2012 – 2017.

209. API Manzanillo. (2012). Programa Maestro de Desarrollo Portuario (PMDP) del Puerto de Manzanillo 2012 – 2017.

210. API Manzanillo. (2012). Programa Maestro de Desarrollo Portuario (PMDP) del Puerto de Manzanillo 2012 – 2017.

211. API Manzanillo. (2012). Programa Maestro de Desarrollo Portuario (PMDP) del Puerto de Manzanillo 2012 – 2017.

212. API Manzanillo. (2012). Programa Maestro de Desarrollo Portuario (PMDP) del Puerto de Manzanillo 2012 – 2017.

213. UNCTAD. (2013). Recent developments and trends in international maritime transport affecting trade of developing countries, Trade and Development Board. Available at: http://unctad.org/meetings/en/SessionalDocuments/cid30_en.pdf. (Accessed April 2015).

214. Stopford, M. (1997), Maritime Economics. Allen and Unwin, UK.

215. UNCTAD. (2013). Recent developments and trends in international maritime transport affecting trade of developing countries, Trade and Development Board. Available at: http://unctad.org/meetings/en/SessionalDocuments/cid30_en.pdf. (Accessed April 2015).

216. Stern, N. (2007). The Economics of Climate Change: The Stern Review. Cambridge and New York: Cambridge University Press.

217. IMF. (2008). World Economic Outlook. Housing and the Business Cycle.

218. Stern, N. (2007). The Economics of Climate Change: The Stern Review. Cambridge and New York: Cambridge University Press.

219. Westphal, M., Highes, G. and Brömmelhörster, J. (Eds.) (2013), Economics of Climate Change in East Asia, Asian Development Bank. [On-line resource]: http://www.adb.org/sites/default/files/publication/30434/economics-climate-change-east-asia.pdf (Accessed April 2015).

220. Fundación DARA Internacional (2012), Climate Vulnerability Monitor 2nd Edition A guide to the Cold Calculus of a Hot Planet, [On-line resource]: http://www.daraint.org/wp-content/uploads/2012/09/CVM2ndEd-FrontMatter.pdf (Accessed April 2015).

221. Fundación DARA Internacional (2012), Climate Vulnerability Monitor 2nd Edition A guide to the Cold Calculus of a Hot Planet, [On-line resource]: http://www.daraint.org/wp-content/uploads/2012/09/CVM2ndEd-FrontMatter.pdf (Accessed April 2015).

222. CEPAL (2010), Desastres y Desarrollo: El impacto en 2010. Santiago de Chile, [On-line resource]: http://www.cepal.org/desastres/noticias/noticias/2/42102/Desastres2010_WEB.pdf (Accessed April 2015).

223. CICC (2012), México: Quinta Comunicación Nacional Ante la Convención Marco de las Naciones Unidas sobre el Cambio Climático. SEMARNAT and INECC (Eds.)

224. UNAM (2011). Por las heladas, México requiere importar tres millones de toneladas de alimentos. [On-line resource]: http://www.agua.unam.mx/noticias/2011/unam/not_unam_febrero27_2.html. (Accessed April 2015).

225. USDA. Global Agricultural Information Network. Washington D.C., 2012. [On-line resource]: http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Grain%20and%20Feed%20Annual_Mexi co%20City_Mexico_3-30-2012.pdf. (Accessed April 2015).

226. SEMARNAT (2010), ABC de Cambio Climático: Impactos y Acciones en México" Julia Martínez Fernández. Foro: Sociedad y Cambio Climático. [On-line resource]: http://participacionsocial.sre.gob.mx/docs/incidencia_social_ ambito_regional_multilateral/agenda_internacional/agenda_y_temas_internacionales/cambio_climatico/presentaciones/cc_julia_2.pdf (Accessed April 2015).

227. World Bank Framewrok for Disaster Risk Reduction, Cited in the Programa Especial de Cambio Climático 2008-2012. Government of Mexico

228. Departamento de Planeación, API Manzanillo. (2015). Pers. Comm. April 2, 2015

229. API Manzanillo. (2012). Programa Maestro de Desarrollo Portuario (PMDP) del Puerto de Manzanillo 2012 – 2017, p. 191

230. IPCC (2014): Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1132 pp.

231. Ford, J.D., T. Pearce, J. Prno, F. Duerden, L.B. Ford, M. Beaumier, and T. Smith, 2010: Perceptions of climate change risks in primary resource use industries: a survey of the Canadian mining sector. Regional Environmental Change, 10(1), 65- 81.

232. Anderson, K. (2010), Globalization's effects on world agricultural trade 1960-2050, Philosophical Transactions of The Royal Sociaty, Vol 365, pp. 3007-3021

233. WTO. (2012). [Online resource]: https://www.wto.org/english/res_e/statis_e/its2013_e/its13_merch_trade_product_e.pdf. (Accessed April 2015).

234. FAO (2013), Food Outlook: Global Market Analysis Highlights

235. Government of Canada. (2014). Agriculture, Food and Beverage Profile: Mexico. [Online resource]: http://www.ats-sea.agr.gc.ca/mex/4617-eng.htm. (Accessed April 2015).

236. OECD-FAO (2009), Agricultural Outlook 2008-2017. [Online resource: http://www.oecd.org/trade/agricultural-trade/40715381.pdf]

237. Larsen, J. (2013). Global grain stocks drop dangerously low as 2012 consumption exceeded production. Earth Policy Institute. [On-line resource]: http://www.earth-policy.org/indicators/C54/grain_2013. (Accessed April 2015).

238. IPCC (2014), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1132 pp.

239. IPCC (2014), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1132 pp.

240. OECD. (2009). Clarifying trade costs: maritime transport and its effect on agricultural trade, Trade Policy Working Paper no. 92. [Online resource]: http://www.oecd.org/trade/agricultural-trade/43996467.pdf

241. Müller, C., A. Bondeau, A. Popp, K. Waha, and M. Fader. (2010). Climate Change Impacts on Agricultural Yields, World development indicators 2010, World Bank, Washington, D.C.

242. API Manzanillo. (2012). Programa Maestro de Desarrollo Portuario (PMDP) del Puerto de Manzanillo 2012 – 2017, p. 210

243. API Manzanillo. (2012). Programa Maestro de Desarrollo Portuario (PMDP) del Puerto de Manzanillo 2012 – 2017, p. 258

244. ACT (2013), Climate Change Adaptation and Canada´s Crops and Food Supply, [On-line resource]: http://act-adapt.org/wp-content/uploads/2013/07/07-13-CFS-Background-WEB.pdf. (Accessed April 2015).

245. Cutforth, H. W., McConkey, B. G., Woodvine, R. J., Smith, D. G., & Jefferson, P. G. (1999). Climate change in the semiarid prairie of southwestern Saskatchewan: Late winter-early spring. Canadian Journal of Plant Science, 79, 343-350.

246. ACT (2013), Climate Change Adaptation and Canada´s Crops and Food Supply, [On-line resource]: http://act-adapt.org/wp-content/uploads/2013/07/07-13-CFS-Background-WEB.pdf. (Accessed April 2015).

247. Robertson, S. M., Jeffrey, S. R., Unterschultz, J. R. and Boxall, P. C. 2013. Estimating yield response to temperature and identifying critical temperatures for annual crops in the Canadian Prairie region. Can. J. Plant Sci. 93: 1237–1247.

248. An, H. and Carew, R. (2015) Effect of climate change and use of improved varieties on barley and canola yield in Manitoba. Can. J. Plant Sci. 95: 127–139.

249. [On-line resource]: http://www.indexmundi.com/agriculture/?commodity=corn&graph=imports. (Accessed April 2015).

250. USA Today. (2013) "Some crops migrate north with warmer temperatures" http://www.usatoday.com/story/news/nation/2013/09/17/climate-change-agriculture-crops/2784561/ (Accessed September 2015)

251. Bloomberg Business. (2012). "Corn belt shifts north With Climate as Kansas Crop Dies" http://www.bloomberg.com/news/articles/2012-10-15/corn-belt-shifts-north-with-climate-as-kansas-crop-dies (Accessed September 2015)

252. [On-line resource]: http://www.world-grain.com/News/News%20Home/Features/2014/1/Structural%20changes%20in%20Mexican%20corn%20market.aspx?cck=1. (Accessed April 2015).

253. [On-line resource]: http://www.indexmundi.com/agriculture/?country=mx&commodity=corn&graph=imports. (Accessed April 2015).

254. API Manzanillo. (2012). Programa Maestro de Desarrollo Portuario (PMDP) del Puerto de Manzanillo 2012 – 2017, p. 56

255. World Bank (2009) Climate Change Aspects in Agriculture: Mexico Profile. [On-line resource]: fflhttp://siteresources.worldbank.org/INTLAC/Resources/2578031235077152356/Country_Note_Mexico.pdf. (Accessed April 2015).

256. API Manzanillo. (2012). Programa Maestro de Desarrollo Portuario (PMDP) del Puerto de Manzanillo 2012 – 2017, p. 219.

257. API Manzanillo. (2012). Programa Maestro de Desarrollo Portuario (PMDP) del Puerto de Manzanillo 2012 – 2017, p. 230.

258. API Manzanillo. (2012). Programa Maestro de Desarrollo Portuario (PMDP) del Puerto de Manzanillo 2012 – 2017, p. 232.

259. API Manzanillo. (2012). Programa Maestro de Desarrollo Portuario (PMDP) del Puerto de Manzanillo 2012 – 2017

260. API Manzanillo. (2012). Programa Maestro de Desarrollo Portuario (PMDP) del Puerto de Manzanillo 2012 – 2017, p. 56.

261. INECC (2014) Evaluación regional de la vulnerabilidad actual y futura de la zona costera Mexicana y los deltas mas impactados ante el incremento del nivel del mar debido al cambio climático y fenómenos hidrometeorológicos extremos.

262. WorleyParsons Engineering Canada

263. Wikipedia uploaded by Eduardo Ferreira (2004) https://en.wikipedia.org/wiki/Port_of_Ensenada#/media/File:Ensenada23Mai2004h12m30pm.jpg (Accessed June 2015).

264. International Transport Workers Federation - http://pathfinderbuzz.com/mexico-wants-help-in-10-year-2-9bn-veracruz-expansion-project/ (Accessed June 2015).

265. http://www.tomzap.com/FLIGHTtoPuertoEscondido-3photos.html (Accessed June 2015).

266. http://www.puertoaltamira.com.mx/engs/0002161/the-port-of-altamira-ends-october-with-more-than-13 (Accessed June 2015).

267. SCT. (2010 to 2013). Reporte Annual Cierres de Puerto

268. INECC (2014) Evaluación regional de la vulnerabilidad actual y futura de la zona costera Mexicana y los deltas más impactados ante el incremento del nivel del mar debido al cambio climático y fenomenos hidrometeorológicos extremos.

269. [On-line resource]: http://www.star.nesdis.noaa.gov/sod/lsa/SeaLevelRise/ (Accessed April 2015).

270. [On-line resource]: http://www.star.nesdis.noaa.gov/sod/lsa/SeaLevelRise/ (Accessed April 2015).

271. IPCC AR5 Working Group 1 Climate Change 2013: The Physical Science Basis. http://www.climatechange2013.org/ (Accessed April 2015).

272. IPCC AR5 Working Group 1 Climate Change 2013: The Physical Science Basis. http://www.climatechange2013.org/ (Accessed April 2015).

273. API Manzanillo. (2015). Pers. Comm. (Information provided by API Finance in MXN. Converted into USD using conversion rate 1USD = 15.28MXN).

274. API Manzanillo. (2015). Pers. Comm.

275. API Manzanillo. (2015). Pers. Comm.

276. International Risk Management Institute (2010). Available at http://www.irmi.com/expert/articles/2001/berry10.aspx (Accessed April 2015).

277. API Manzanillo. (2015). Pers. Comm.

278. Munich Re. (2014). TOPICS GEO: Natural catastrophes 2013. Analyses, assessments, positions. Available from: http://www.munichre.com/site/corporateresponsibility-root/get/documents_E1043212252/mr/assetpool.shared/Documents/5_Touch/_Publications/302-08121_en.pdf (Accessed April 2015).

279. Munich Re. (2014). TOPICS GEO: Natural catastrophes 2013. Analyses, assessments, positions. Available from: http://www.munichre.com/site/corporateresponsibility-root/get/documents_E1043212252/mr/assetpool.shared/Documents/5_Touch/_Publications/302-08121_en.pdf (Accessed April 2015).

280. Munich Re (2014). Available from: http://www.munichre.com/site/corporate/get/documents_E-529855854/mr/assetpool.shared/Documents/5_Touch/Natural%20Hazards/NatCatService/Annual%20Statistics/2013/MunichRe-Nnatcatservice-Naturaldisasters2013-Countries.pdf (Accessed April 2015).

281. ClimateWise, The Munich Climate Insurance Initiative (MCII) and The United Nations Environment Programme Finance Initiative (UNEP FI) (2013). Global insurance industry statement. Building climate and disaster-resilient communities and economies: How the insurance industry and governments can work together more effectively http://static1.1.sqspcdn.com/static/f/270724/23912618/1384789435333/Global+Insurance+Industry+Statement.pdf?token=3y4nEu9ewbH0UCepcZvqH%2BQmBQA%3D. (Accessed September 2015).

282. Stern, N. (2007). The Economics of Climate Change: The Stern Review. Cambridge and New York: Cambridge University Press.

283. The Royal Society Science Policy Centre. (2014). Resilience to extreme weather

284. SEMARNAT - INECC. 2012. Quinta Comunicación Nacional ante la Convención Marco de las Naciones Unidas sobre el Cambio Climático. México: Secretaría de Medio Ambiente y Recursos Naturales - Instituto Nacional de Ecología y Cambio Climático

285. Travers, A. et al. (2012) Ecosystem-Based Adaptation Guidance: Moving from Principles to Practice. Working Document April 2012

286. Zorrilla Ramos, M. (2014). Evaluación del marco regulatorio para un estudio de adaptación al cambio climático para el Puerto de Manzanillo (ME-T1239): Informe Final.

287. IMADES (2015). Draft of the Programa Estatal de Acción ante el Cambio Climático Estado de Colima. Note: this draft is yet to be finally approved by SEMARNAT and therefore information cited in this report based on the draft final PECC may be subject to final modifications.

288. Gobierno Municipal H. Ayuntamiento Constitucional de Manzanillo Colima (2012), Plan Municipal de Desarrollo 2012-2015 del Municipio de Manzanillo, COL.

289. API Manzanillo. (2012). Programa Maestro de Desarrollo Portuario (PMDP) del Puerto de Manzanillo 2012 – 2017

290. Gobierno Municipal H. Ayuntamiento Constitucional de Manzanillo Colima (2012), Plan Municipal de Desarrollo 2012-2015 del Municipio de Manzanillo, COL.

Foot Notes

i. Aguascalientes, Coahuila, Colima, Distrito Federal, Durango, Estado de México, Guanajuato, Hidalgo, Jalisco, Michoacán, Morelos, Nayarit, Nuevo León, Querétaro, San Luis Potosí, Tamaulipas y Zacatecas.

ii. Including: Canada, U.S.A, Guatemala, Colombia, Ecuador, Chile, Japan, China, Taiwan, Korea, Indonesia, Malasia, Singapore and Philippines.

iii. 'Twenty-foot equivalent unit', used to describe the capacity of container ships and container terminals.

iv. The CICC is composed of the following Federal Secretariats: Secretaría de Gobernación (SEGOB), Secretaría de Relaciones Exteriores (SRE), Secretaría de Marina (SEMAR), Secretaría de Hacienda y Crédito Público (SHCP), Secretaría de Desarrollo Social (SEDESOL), Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT), Secretaría de Energía (SENER), Secretaría de Economía (SE), Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación (SAGARPA), Secretaría de Comunicaciones y Transportes (SCT), Secretaría de Educación Pública (SEP), Secretaría de Salud (SSA) y Secretaría de Turismo (SECTUR).

v. The other five are: i) to accelerate energy transition towards clean energy sources; ii) to reduce power consumption intensity through efficiency and rationality schemes; iii) to transit to sustainable city models, with intelligent mobility systems, integrated waste management and buildings with a low carbon footprint; iv) to encourage better agricultural and forestry practices, with schemes for Reducing Emissions from Deforestation and Degradation (REDD+); and v) to reduce "short life" pollutant emissions, such as black carbon and methane, to improve the health and welfare of Mexicans.

vi. The other two objectives are: Objective 3: Reduce GHG emissions to transit to a competitive low carbon emissions economy; and Objective 4: Reduce CCVCs to provide co-benefits for health and wellbeing.

vii. The PECC for the State of Colima is currently in draft form. For the purpose of this report, this draft version has been used. IMADES has notified the study team that the PECC has already been approved by INECC. However it is yet to be approved by SEMARNAT. This means that activities outlined in the draft PECC and mentioned in this report may still be subject to change.

viii. See Zorrilla Ramos (2014) for further information on the state regulatory framework.

ix. See for example the Guía técnica para la incorporación del análisis de riesgo en los ordenamientos ecológicos municipales y regionales. Also the PECC 2014-2018 is leading the development of other tools for incorporating climate considerations at the municipal level such as the development of criteria for climate change considerations in environmental impact assessments.

x. See for example CENAPRED (2014) "Metodología para la Elaboración de Mapas de Riesgo por Inundaciones Costeras por Marea de Tormenta" and CENAPRED (2014) Metodología para obtener Mapas de Riesgo por Bajas Temperaturas y Nevadas in http://www.cenapred.gob.mx/PublicacionesWeb/buscar_buscaSubcategoria. Also see INECC (2012) "Estudio para Sistematizar una Propuesta Metodológica del Análisis de la Vulnerabilidad actual y bajo Cambio Climático" in http://www.inecc.gob.mx/estudios.

xi. See for example INECC (2008) Guía para la elaboración de Programas Estatales de Acción ante el Cambio Climático (PEACC) in http://www2.inecc.gob.mx/sistemas/peacc/descargas/guias_prog_est.pdf. See also SEMARNAT (2011) "Guía para la elaboración de programas de adaptación al cambio climático en áreas naturales protegidas" in http://www.conanp.gob.mx/contenido/pdf/guia_cc_areas_naturales_protegidas.pdf. See also SEDESOL (2012) Guía Municipal de Acciones frente al Cambio Climático in http://www.2006-2012.sedesol.gob.mx/work/models/SEDESOL/Resource/1867/1/images/Guia_Cambio_Climatico_26-10-12.pdf.

xii. For a comprehensive review of methods and tools see for example PROVIA (2013) "Guidance on Assessing Vulnerability, Impacts and Adaptation to Climate Change", available at: http://www.unep.org/provia.

xiii. Including in the IPCC Fourth Assessment Report and in guidance published by the UNFCCC and UNEP/UNDP/GEF.

xiv. RCP 8.5 – a high concentration pathway where radiative forcing reaches more than 8.5 W/m2 by the year 2100 relative to pre-industrial values.

xv. RCP 4.5 – a scenario whereby radiative forcing is stabilized at 4.5 W/m2 shortly after the year 2100, consistent with a future with relatively ambitious emissions reductions.

xvi. RCP 8.5

xvii. RCP 4.5

xviii. Note: Adaptation measures have been identified for each risk, and each adaptation measure applying to each risk has been given a unique code number. In some cases, the same adaptation measure is relevant to addressing more than one risk.

xix. From the Arkin-Xie data set over 1980-2000.

xx. ERA-I is generally regarded as state of the art in terms of reanalysis products and the best available. No climate data set is perfect. All have disadvantages. It is important to use more than one product as a result.

xxi. RCP 8.5 is a high concentration pathway where radiative forcing reaches more than 8.5 W/m2 by the year 2100 relative to pre-industrial values. RCP 4.5 is a scenario whereby radiative forcing is stabilized at 4.5 W/m2 shortly after the year 2100, consistent with a future with relatively ambitious emissions reductions.

xxii. http://www2.inecc.gob.mx/dgioece/escenarios_cu/act_escenarios.html

xxiii. Note that this poleward migration of tropical cyclones amounts to a small adjustment within the tropical and subtropical region following an analysis of the most intense phase of tropical cyclones. The poleward migration does not include the progression of tropical cyclones to extra-tropical cyclones.

xxiv. Calculated by extrapolating the linear observed significant trend.

xxv. Infragravity waves are surface gravity waves with frequencies lower than wind waves – consisting of both wind, sea and swell.

xxvi. RCP 2.6 is a scenario where radiative forcing reaches 3.1 W/m2 before it returns to 2.6 W/m2 by 2100.

xxvii. Costs provided by WorleyParsons marine structural engineers with working knowledge of the Port of Manzanillo.

xxviii. UAB refers to unidades de arqueo bruto, or gross tonnage units, a measure of maritime vessel size.

xxix. Wave Watch III Global Ocean Hindcast Model (NOAA) 20 km WSW offshore of the port.

xxx. Manzanillo Airport 15 km WNW of the port.

xxxi. Figure provided by WorleyParsons port engineering department, Madrid.

xxxii. NOM-059-SEMARNAT-2001 and NOM-059-SEMARNAT-2010

xxxiii. ISO 14001 was first published in 1996 and specifies the requirements for a robust environmental management system.

xxxiv. The study investigated distributional changes based on six climate models (BCCR-BCM 2.0, CSIRO-MK 3.0, CSIRO-MK 3.5, INM-CM 3.0, MIROC medium resolution, and NCAR-CCSM 3.0) forced by three greenhouse gas emissions scenarios (AIB, A2 and B1).

xxxv. Hot days are commonly defined in terms of the percentiles of daily maximum temperature for a specified location.

xxxvi. Manzanillo is home to the most important Navy base in the Pacific. The Ayuntamiento acknowledges this as both a responsibility and an opportunity for the prosperity of the municipality. See Plan Municipal de Desarrollo 2012-2015 del Municipio de Manzanillo, Col.

xxxvii. TACC: Tasa Anual de Crecimiento Compuesto

xxxviii. The 'Marca de Calidad' is one of the key competitiveness strategies launched recently by the Port of Manzanillo. Additionally, the port outcompetes Lázaro Cárdenas port in terms of efficiency, being able to unload 89 containers per hour vs. the 71 containers per hour that can be unloaded at Lázaro Cárdenas (PMDP, p. 176).

xxxix. Future projections on trade through the port provided by the Planning Division and provided in the Master Plan of the Port do not include estimates of total revenue flows but are rather framed in terms of total volumes (in units, tons and TEUs depending on the type of cargo).

xl. Some of the findings presented in this section reflect the results from an ADB study in which information provided for China does not include the PRC's special administrative regions (Hong Kong, China and Macao, China). To make the distinction between information provided under the ADB study and information drawn from other sources, we use the acronym PRC to refer to the ADB data and refer to the country as "China" when drawing on other sources. See Westphal, M., Hughes, G. and Brömmelhörster, J. (Eds.) (2013)

xli. There is great variation between regions and climate scenarios ranging from less than 1% in the best eight climate scenarios to 78%–84% in the worst three scenarios.

xlii. Analysis is provided with a discount rate of 4%.

xliii. 'Elasticity' refers to the relationship between GDP and revenue, and provides a precise calculation of the effect of a change in GDP on revenue.

xliv. As noted in the PMDP 2012-2017 “El Consumo Aparente de Canola se refiere al cálculo obtenido de la suma de producción nacional, menos exportación, más importación de canola” (p. 258).

xlv. Currently these are the main areas of canola production

xlvi. At present the port does not have adequate covered facilities to store vehicles. Vehicles are stored in a 6ha area allocated in Muelle 15, but this space does not have roofing and hence does not provide any protection against weather events.

xlvii. The insurance policy IJ20001300000 provides coverage to the APIs of: Ensenada, Guaymas, Topolobampo, Mazatlán, Puerto Vallarta, Lázaro Cárdenas, Salina Cruz, Puerto Madero, Altamira, Veracruz, Puerto Madero, Altamira, Tampico, Tuxpan, Veracruz, Coatzacoalcos, Dos Bocas, Progreso, Quintana Roo, Tamaulipas and Manzanillo.

xlviii. ‘Marginal protections’ are structures aligned parallel to the coast used to separate terrestrial from ocean zones. Their main purpose is to protect the coast and coastal infrastructure from potential damaged caused by waves and longshore transport.

xlix. The first is the Port of Veracruz with over 7.5 billion MXN of assets insured.

l. It can be difficult from the data provided by API Manzanillo to establish the claim value in all cases. Hence descriptions of the financial data found are also provided.

li. The three initiatives are ClimateWise, the Munich Climate Insurance Initiative (MCII) and the United Nations Environment Programme Finance Initiative (UNEP FI).

lii. Respectively termed ‘Baseline climate’ and ‘High climate, Market impacts + risk of catastrophe + non-market impacts + value judgments for regional distribution’ by Stern.

liii. While all the adaptation measures introduced in this sub-section address priority risks, measures can be implemented at different points in time. In the presentation of priority adaptation measures an effort is made to describe whether the measure should be implemented at present, or whether in order to be implemented effectively it needs to be reflected in the next Port’s Master Development Plan (2017-2022) or later (2022-2027).

liv. Adaptation measures have been identified for each risk, and each adaptation measure applying to each risk has been given a unique code number. In some cases, the same adaptation measure is relevant to addressing more than one risk.

lv. All measures apply as ports are critical infrastructure supporting productive activities. Therefore, enhancing the resilience of ports also supports the resilience of productive systems more generally.

lvi. These definitions are as defined in the Glossary of terms of the ENCC (2013). Estrategia Nacional de Cambio Climático. Visión 10-20-40 Gobierno de la República, except where otherwise noted

lvii. From IPCC Fifth Assessment Report Working Group II Glossary.

lviii. From IPCC Fifth Assessment Report Working Group II Glossary.

lix. From IPCC Fifth Assessment Report Working Group II Glossary.

Appendices

Contents

7. Engineering rationale for drain upgrade

8. International and national context on climate change mitigation

8.1. International context

8.2. Mexico climate change mitigation law and policy

8.3. Potential impacts on demand for cargoes traded through the port

1. Approach to risk prioritization

Table 1.1 below sets out the system used to rate each of the risks identified in the study, and hence to identify priority risks.

Identified risks were attributed a score (rating) of low, medium or high for each of the four criteria listed in column 1 of the table. Where a risk scored ‘high’ against two or more of the criteria, the risk was identified as a priority. Risks where current vulnerability was rated as ‘high’ (Criterion 1) were identified as a priority, even if they did not score highly against other criteria.

Criteria 1 and 2 have sub-categories, as shown in column 2. Identified risks were rated against all of these sub-categories, and the highest sub-category score was used to determine the overall score for that criterion.

TABLE 1.1

Description of criteria for prioritizing risks and associated ratings. (Source: Report authors)**.**

Category	Performance element	Low	Medium	High
Risks where current vulnerability is high	Operational	< 1% annual stoppage of operations, on average across all terminals	1 to 10% annual stoppage of operations	> 10% annual stoppage of operations
	Financial	< 1% loss of annual revenue	1 to 5% loss of anual revenue	> 5% loss of anual revenue
	Environmental	Notices but minor non-ethal, reversible effects on protected species and habitats. Local regulatory issue.	Some deaths of flora and fauna, non-reversible impact on protected species and habitats. National regulatory issue.	Multiple deaths of flora or fauna. Severe long term damage to on protected species and habitats. International regulatory issue.
	Social	No impact on society	Localized, temporary or long-term social impacts	Loss of social license to operate: Community protests
	Reputacional	Local attention	National attention	International attention
Where the projected impacts of climate change are large	Operational	< 1% loss of annual stoppage of operations, on average across all terminals	1 to 10% annual stoppage of operations	>10% annual stoppage of operations
	Financial	< 1% loss of annual revenue	1 to 5% loss of annual revenue	> 5% loss of annual revenue
	Environmental	Noticeable but minor non-lethal, reversible effects on biological VECs. Local regulatory issue.	Some deaths of flora and fauna, non-reversible impact on biological VECs. National regulatory issue.	Multiple deaths of flora or fauna. Severe long term damage to biological VECs. International regulatory issue.
	Social	No impact on society	Localized, temporary or long-term social impacts	Loss of social license to operate; community protests
	Reputational	Local attention	National attention	International attention
Where decisions on managing these effects have long lead times or long-term effects		Planning and implementation can start immediately, or implementation can be deferred and does not hace long lead times	Planning needs to start immediately so that implementation can take place within the period of the next masterplan (2017 to 2022)	Planning needs to start immediately so that implementation can occur post 2022
Large uncertainties mean that the scale of future risk is uncertain (but could be large)		Strong scientific evidence; risk is readily quantifiable	Scientific evidence provides some quantified estimates but uncertainties remain over likelihood/magnitude	Some scientific studies indicate risk is possible, but risk can not be quantified

2. List of stakeholders consulted during the mission

Week 1: Consultations with API Manzanillo divisions and terminals

Meetings with API Manzanillo	Meetings with terminals
Director General	CONTECON
Gerencia de Administración y Finanzas	SSA
Subgerencia de Ecología	Capitanía de Puerto
Administración y Finanzas	USG
Gerencia de Comercialización	HAZESA
Gerencia de Ingeniería	MARFRIGO
Gerencia de Operaciones	LA JUNTA
Gerencia de Planeación	GRANELERA
	MULTIMODAL
	TIMSA
	OCUPA-FRIMAN
	CEMEX
	APASCO
	PEMEX

Name	Position	Institution
Manuel Rodriguez Sanchez	Director	Secretaria de Comunicacaciones y transportes (SCT)
Valeria Muriel Dosal	Subdirector	Secretaria de Comunicacaciones y transportes (SCT)
Aurora Tripp Silva	Subdirector	Secretaria de Comunicacaciones y transportes (SCT)
Aguerrebere Salido, Roberto	Coordinador Operativo	Instituto Mexicano del Transport (IMT)
Jose Adrian Trejo	Investigadora media ambiente	Instituto Mexicano del Transport (IMT)
Fernando Mendoza	Investigadora media ambiente	Instituto Mexicano del Transport (IMT)
Miguel A Backhoff	Jefe de Unidad de Sistemas de Información Geoespacial	Instituto Mexicano del Transport (IMT)
Tristan Ruiz Lang	Coordinador de ingenieria portuaria y sistemas geospaciales	Instituto Mexicano del Transport (IMT)
Dora Luz Avila Arzani	Investigador titular	Instituto Mexicano del Transport (IMT)
Carlos Martner	Coordinador de integración y transportes	Instituto Mexicano del Transport (IMT)
Noe Toledano	Division de ingeneria de puertos y costas	Instituto Mexicano del Transport (IMT)
Cap. Edward Montiel		SEMAR
Gildardo Alarcon		SEMAR
Cap. Miguel Angel Diaz		SEMAR
Jesus de Olaguibel	Division Oceanografica	SEMAR
Eloina Felix		SEMARNAT
Gloria Cuevas		SEMARNAT
Carolina Chavez Oropeza		SECTUR
Mariano Sanchez		CONABIO
Griselda Medina Laguna		CONAGUA
Noé Adolfo Salazar Ramírez		CONAGUA
Ing. Eleazar Castro Caro	Subdirector Técnico / Dirección Local Colima	CONAGUA
Jose Luis Corona López		CONAGUA
Martin Cadena Sagarda		CONANP
Cristina Argudin		CONANP

3. Data requests submitted to terminals following the mission.

Información Financiera por cada Terminal Portuario

Ingresos	Datos Históricos (Pesos)						Datos Projectados (Pesos) *si está disponible*					
Descripción 5 Primeros Productos	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Producto 1 (Indicar nombre)												
Producto 2 (Indicar nombre)												
Producto 3 (Indicar nombre)												
Producto 4 (Indicar nombre)												
Producto 5 (Indicar nombre)												
TOTAL de Ingresos de los Productos	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -

Gastos	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Tarifa Fija (APIMAN)												
Tarifa Variable (APIMAN)												
Productos de almacenamiento												
Transporte de mercancías por carretera/Ferromex												
Costes laborales												
Aduana												
Mantenimiento equipos / edificios / zonas												
Seguros												
Servicios (Electricidad/Agua/Desague y Combustibles)												
Gesión Ambiental (Gastos Inversión) e.g. polvo/residuos/reciclaje												
Gastos Capital												
Otros Gastos												
TOTAL de Gastos	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -

EBITDA Pesos (Ganancias antes de intereses, impuestos, depreciación y amortización)												

Origen de los 5 primeros bienes Importados

Si es un Producto Agricola especificar cual

Pais o Ubicación en Mexico	**Producto 1 (Indicar nombre)**	**Producto 2 (Indicar nombre)**	**Producto 3 (Indicar nombre)**	**Producto 4 (Indicar nombre)**	**Producto 5 (Indicar nombre)**
Pais/Ubicación 1 (Indicar nombre)					
Pais/Ubicación 2 (Indicar nombre)					
Pais/Ubicación 3 (Indicar nombre)					
Pais/Ubicación 4 (Indicar nombre)					
Pais/Ubicación 5 (Indicar nombre)					

Origen de los 5 primeros bienes Exportados

Si es un Producto Agrícola especificar cuál

País o Ubicación en México	**Producto 1 (Indicar nombre)**	**Producto 2 (Indicar nombre)**	**Producto 3 (Indicar nombre)**	**Producto 4 (Indicar nombre)**	**Producto 5 (Indicar nombre)**
Pais/Ubication 1 (Indicar nombre)					
Pais/Ubicación 2 (Indicar nombre)					
Pais/Ubicación 3 (Indicar nombre)					
Pais/Ubicación 4 (Indicar nombre)					
Pais/Ubicación 5 (Indicar nombre)					

Origen de los 5 primeros bienes Clientes

Nombre del Cliente	**Producto 1 (Indicar nombre)**	**Producto 2 (Indicar nombre)**	**Producto 3 (Indicar nombre)**	**Producto 4 (Indicar nombre)**	**Producto 5 (Indicar nombre)**
Cliente 1 (Indicar nombre)					
Cliente 2 (Indicar nombre)					
Cliente 3 (Indicar nombre)					
Cliente 4 (Indicar nombre)					
Cliente 5 (Indicar nombre)					

Exportación versus Importación

Descripción 5 Primeros Productos	**Compañía Naviera**	**Ruta de envío**	**% Exportación**	**% Importación**
Producto 1 (Indicar nombre)				
Producto 2 (Indicar nombre)				
Producto 3 (Indicar nombre)				
Producto 4 (Indicar nombre)				
Producto 5 (Indicar nombre)				

Interrupciones / retrasos que afectaron a la terminal debido a eventos meteorológicos que afectaron operaciones en la terminal (en la 1a y la 2nda manioba)

1) Costo aproximativo de interrupción en las operaciones (pesos mexicanos por hora)	
TOTAL:	*Completar aquí*

2) Récord de interrupciones / retrasos (en horas por mes de los últimos 5 años)

	Vientos altos (sin que conlleven a la clausura de la terminal o del puerto)	Tormentas tropicales y huracanes (con clausura del puerto)	Lluvia	Inundación	Acumulación de sedimentos en lugares de atraque	Temperaturas altas	Humedad relativa	Marejadas	Oleaje	Velocidad de la corriente
2009										
ENE										
FEB										
MAR										
ABR										
MAY										
JUN										
JUL										
AGO										
SEP										
OCT										
NOV										
DIC										
TOTAL										

Interrupciones / retrasos que afectaron a la terminal debido a otras causas

1) Debido a inundaciones que afectaron la entrada/salida de camiones del puerto

	2009	2010	2011	2012	2013	2014
Récord (en número horas) de interrupcion / retrasos						
Fechas de interrupción						
Impacto financiero causado por la interrupción (pesos por hora)						

2) Debido a inundaciones o lluvias que afectaron las operaciones ferroviarias

	2009	2010	2011	2012	2013	2014
Récord (en número horas) de interrupcion / retrasos						
Fechas de interrupción						
Impacto financiero causado por la interrupción (pesos por hora)						

3) Debido a operaciones de mantenimiento de dragado*

*Por ejemplo debido a incremento de costos en primera / segunda maniobra

	2009	2010	2011	2012	2013	2014
Récord (en número horas) de interrupcion / retrasos						
Fechas de interrupción						
Impacto financiero causado por la interrupción (pesos por hora)						

4) Debido a pérdida de electricidad causado por tormentas eléctricas

	2009	2010	2011	2012	2013	2014
Récord (en número horas) de interrupcion / retrasos						
Fechas de interrupción						
Impacto financiero causado por la interrupción (pesos por hora)						

5) Debido a operaciones internas de mantenimientos y reparaciones que han necesarias debido a impactos del mal clima

*Por ejemplo limpieza de sedimentos acumulados en patios, reparaciones a estructuras (techos, paredes, alumbraje) y maquinaria , etc.

	2009	2010	2011	2012	2013	2014
Récord (en número horas) de interrupcion / retrasos						
Fechas de interrupción						
Impacto financiero causado por la interrupción (pesos por hora)						

CAUSAS NO RELACIONADAS NECESARIAMENTE AL MAL TIEMPO

6) ¿En los últimos cinco años cuál ha sido el valor incurrido (en número de días e impacto financiero) debido a tráfico, congestión, demoras de aduana en la entrada y salida de camiones?

Número de días	
Costo total	

7) ¿En los últimos cinco años cuál a sido el valor incurrido (en número de días e impacto financiero) debido a problemas con el servicio ferroviario? (en los últimos 5 años)

Número de días	
Costo total	
Causas más frecuentes en las demoras del servicio	

8) ¿En los últimos cinco años ha habido casos en los que buques programados no atracaran en el puerto y siguieran a otros destinos? De ser así indique el número de eventos (fecha, causa e impacto financiero)

Evento*	Fecha	Causa	Impacto financiero (pesos mexicanos)
No. 1			
No. 2			
No. 3			

*Incluir más líneas de ser necesario

9) ¿Tienen arreglos contractuales que especifiquen garantías en tiempo de operación, manejo y despacho de mercancía? (SI/NO)

Completar aquí

10) Si 9) es CIERTO, ¿cuál es el costo por hora (o diá) si el arreglo contractual de tiempos de garantía en manejo y despacho de mercanías no es cumplido?

Completar aquí

11) Do you have any maximum operational thresholds for wind speed? Y/N

Equipo	Velocidad del viento (Km/hora	Sistema automático de corto de operación Y/N	Otros detalles
Grúa			
Banda			
Atraque			
Othos (expecificar)			

12) Distancia mínima de seguridad en metros entre el nivel del mar y el muelle para carga y descarga de buques

(m)

Manejo de reefers y carga fría en los últimos 5 años (*si aplica)

	Número de reefers*	% del total de la carga manipulada*	Dimensiones del área de refrigeracion* (largo x ancho x alto)	Dimensiones del área de congelamiento* (largo x ancho x alto)
2009				
2010				
2011				
2012				
2013				
2014				

Costos de refrigeración por mes en los últimos 5 años (pesos mexicanos) (*si aplica)

	Costo por reefer (refrigeracion)*	**Costo por reefer (congelados)***	**Costo por area de refrigeracion***	**Costo por area de congelamiento***
2009				
ENE				
FEB				
MAR				
ABR				
MAY				
JUN				
JUL				
AGO				
SEP				
OCT				
NOV				
DIC				
TOTAL				

Información sobre pólizas de seguros

Pólizas de seguros	Tipo de póliza*	Tipo de eventos/peligros meteorológicos que cubre la póliza	Precio de prima (en pesos)						Motivos por cambios de precio de prima (especificar causa)**
			2009	2010	2011	2012	2013	2014	
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									

Récord de reclamos debido a daños/interrupciones/retrasos ocacionados por eventos meteorológicos (pesos por año)

	Vientos extremos, tormentas tropicales y huracanes	Lluvias	Inundaciones	Altas temperaturas	Marejadas	Otros (especificar)
2009						
2010						
2011						
2012						
2013						
2014						

*Tipos de cobertura del seguro. Incluyen por ejemplo: i) daño a edificios e infraestructura; ii) daño a buques; iii) interrupción del negocio; iv) ingresos/costos; v) daño a terceros y/o a la mercancía del cliente; vi) otros.

**Motivos por causa por cambios de precio de prima. Incluyen por ejemplo: i) inversiones en nueva infraestructura/activos; ii) precedente en usos de poliza el año anterior; iii) cobertura ante nuevos riesgos (especificar); iv) otros.

(Source: Report authors)

4. Supplementary information on current and projected future climate conditions

4.1. Observed climate conditions

FIGURE 4.1

Satellite rainfall climatology for Mexico, January to December 1980-2000 in mm/day. (Source: Report authors).

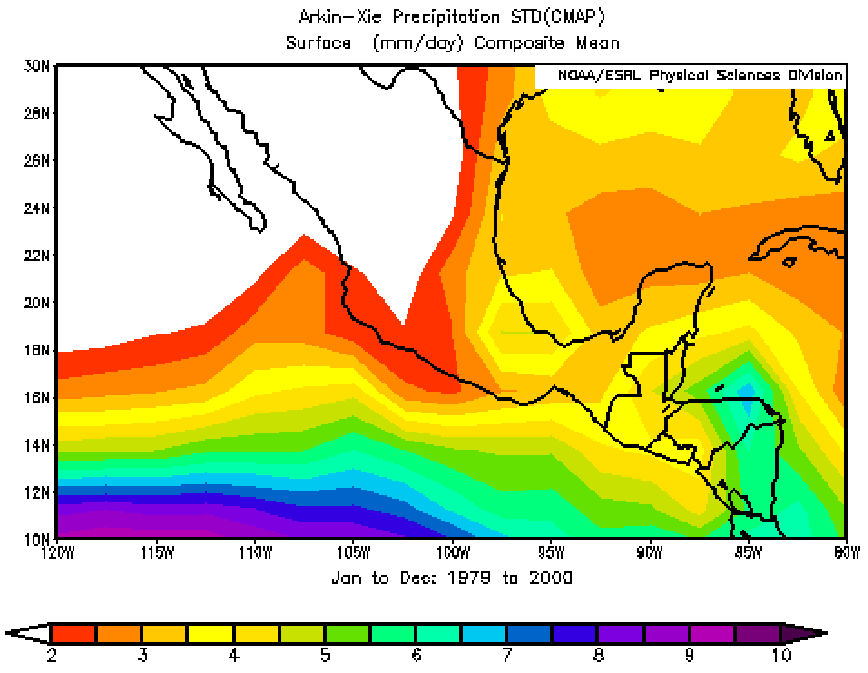


FIGURE 4.2

Satellite rainfall climatology for Mexico, December to May 1980-2000 in mm/day. (Source: Report authors).

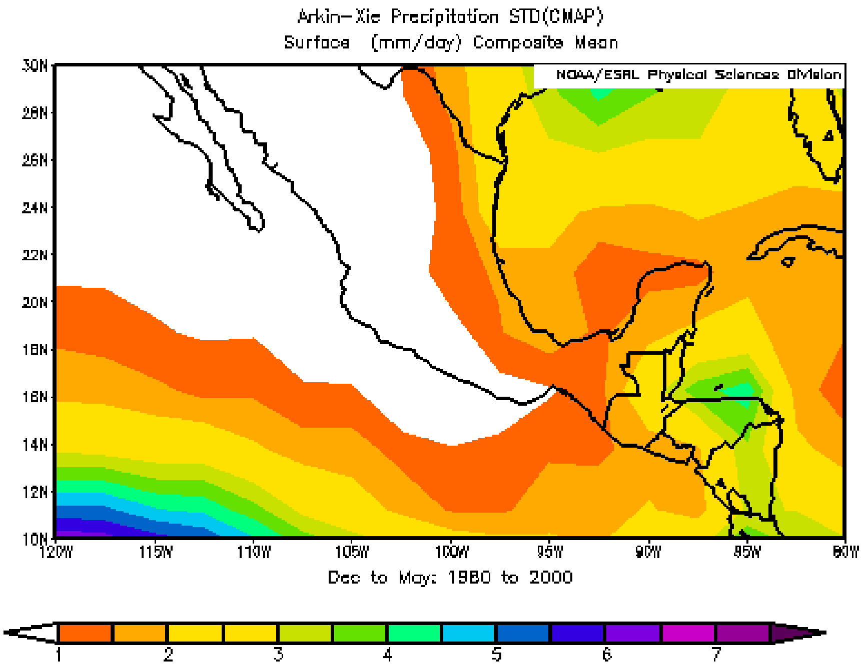


FIGURE 4.3

Satellite rainfall climatology for Mexico, June to November 1980-2000 in mm/day. (Source: Report authors).

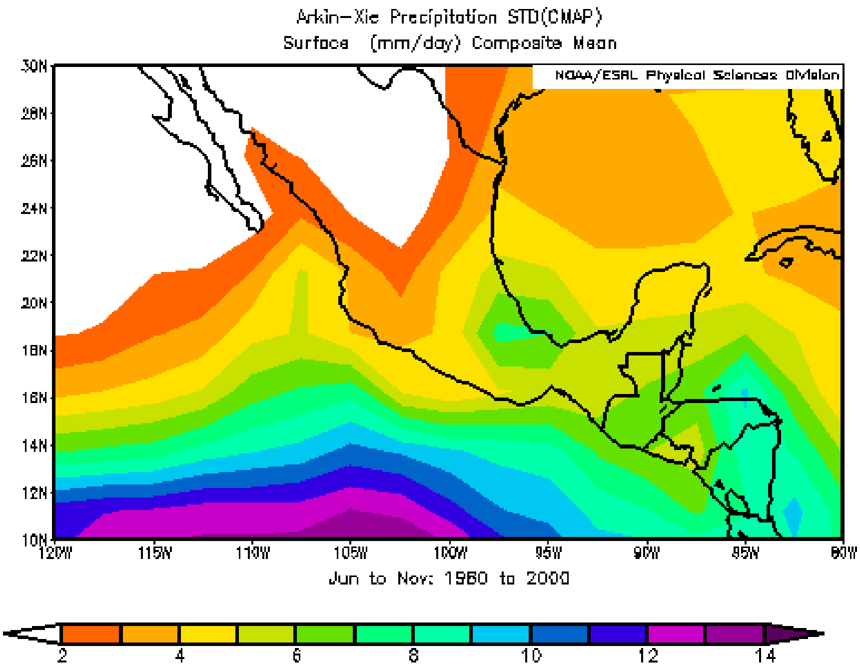


FIGURE 4.4

Trends in ERA-I rainfall over Mexico from 1979-2012 for annual (left), dry season (middle) and wet season (right). Top row is trends in maxima, bottom row is trends in mean. Stippling shows significance at 0.05 level. (Source: Report authors).

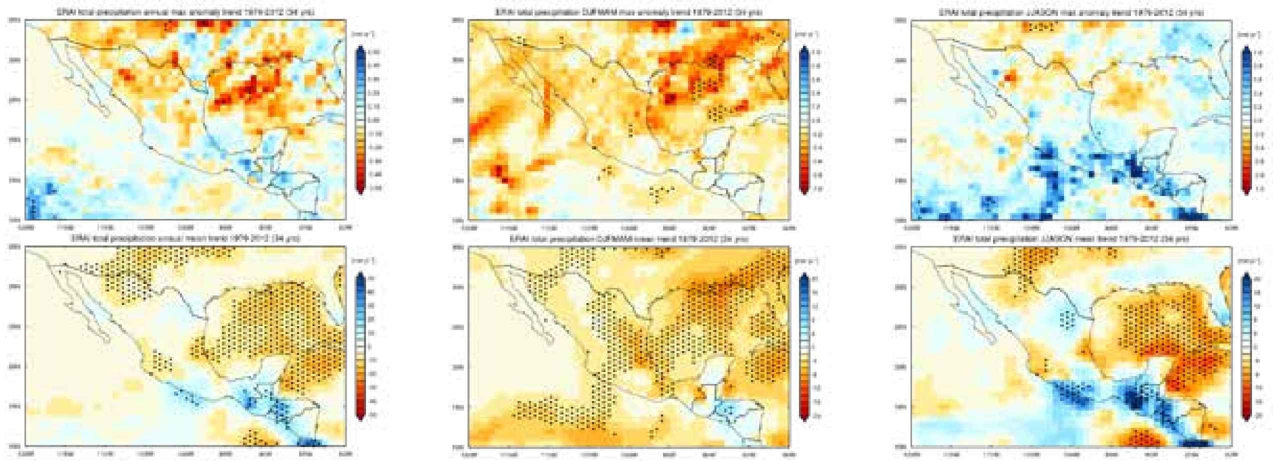


FIGURE 4.5

Trends shown as a time series for Manzanillo dry season rainfall from ERA-I data 1979-2012.
Top row is trend in extreme maxima and bottom row is trend in means. Green trends are significant at 0.05 level. Red trends are not statistically significant. (Source: Report authors).

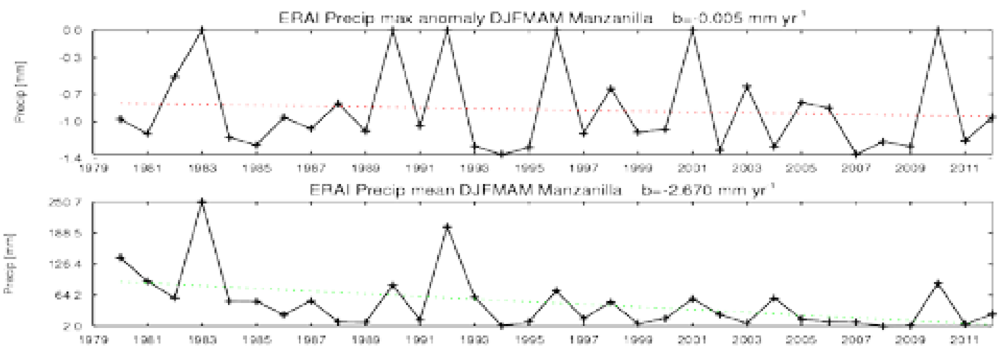


FIGURE 4.6

Trends shown as a time series for Manzanillo wet season rainfall from ERA-I data 1979-2012.
Top row is trend in extreme maxima; middle row is trend in means and bottom row trend in minima.
Green trends are significant at 0.05 level. Red trends are not statistically significant. (Source: Report authors).

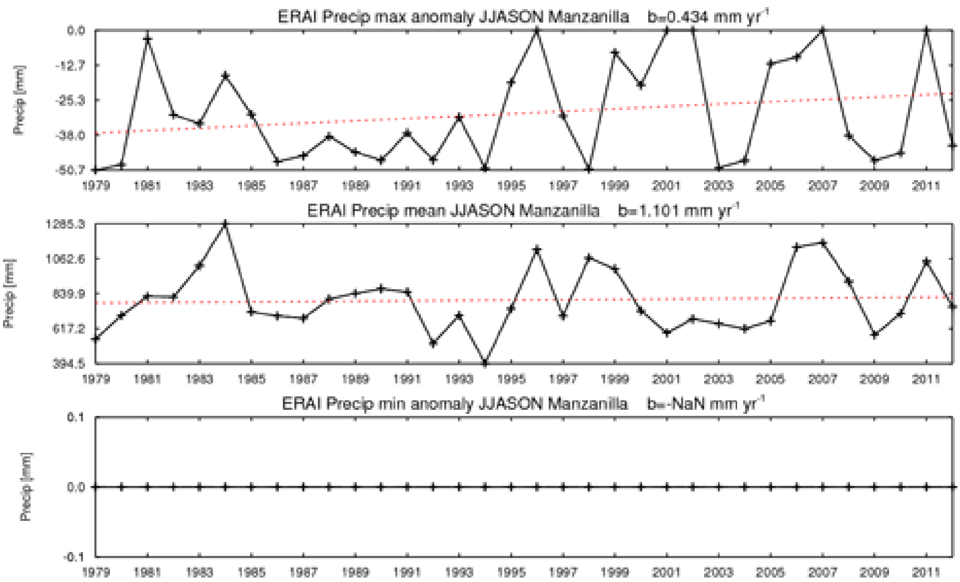


FIGURE 4.7

Trends in ERA-I temperature over 1979-2012 for annual (left), dry season (middle) and wet season (right). Top row is extremes in maxima, bottom trends in mean. Stippling shows significance at 0.05 level. (Source: Report authors).

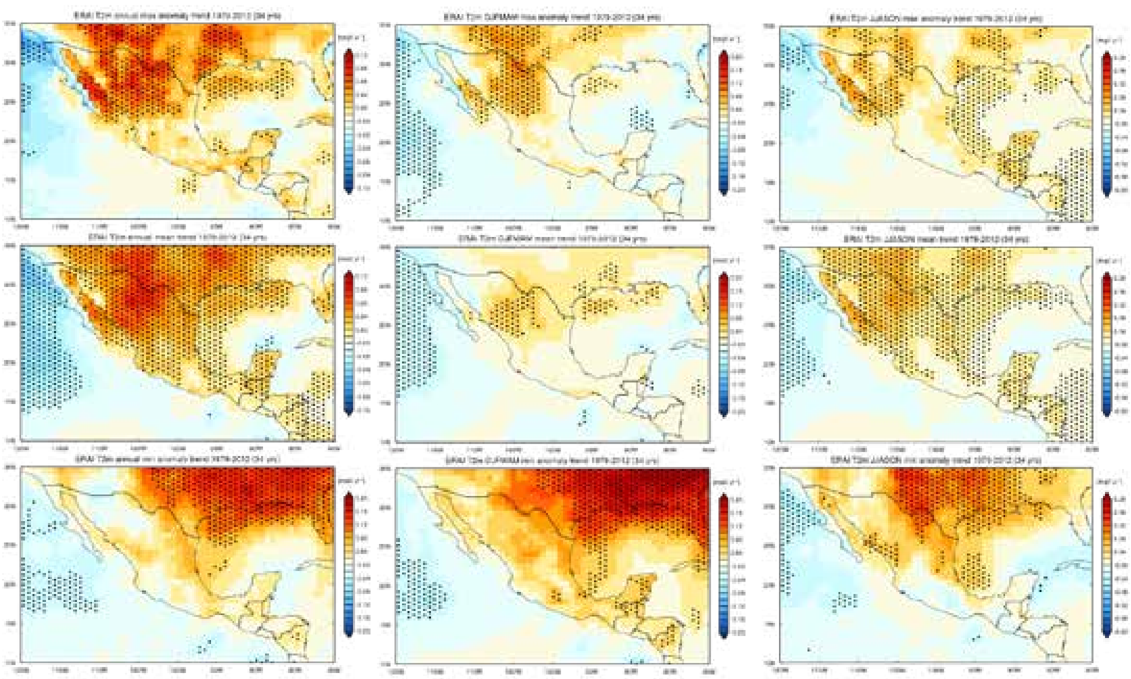


FIGURE 4.8

**Trends shown as a time series for Manzanillo dry season temperature from ERA-I data 1979-2012.
Top row is trend in extreme maxima and bottom row is trend in means. Green trends are significant at 0.05 level.
Red trends are not statistically significant. (Source: Report authors).**

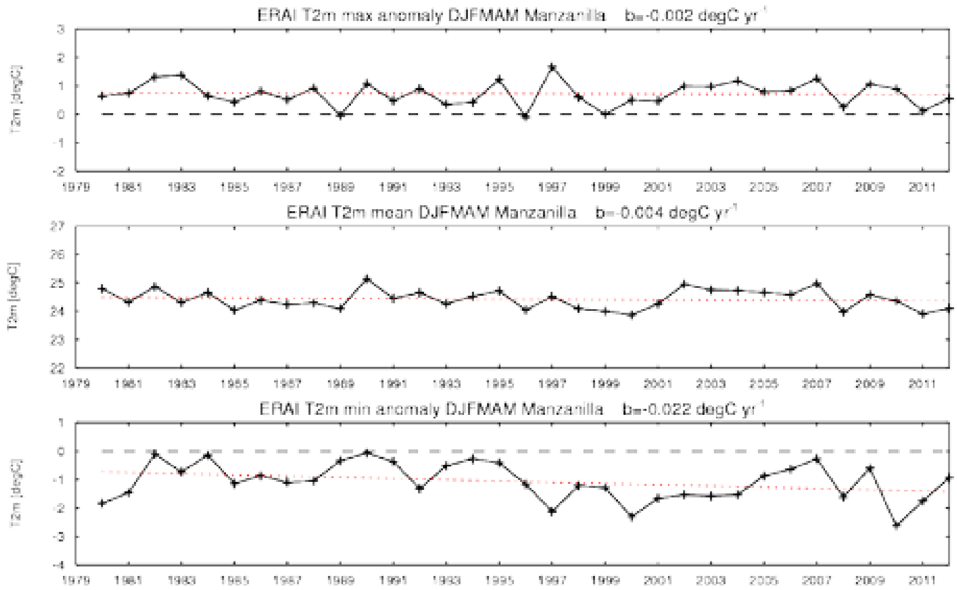


FIGURE 4.9

Trends shown as a time series for Manzanillo wet season temperature from ERA-I data 1979-2012. Top row is trend in extreme maxima and bottom row is trend in means. Green trends are significant at 0.05 level. Red trends are not statistically significant. (Source: Report authors).

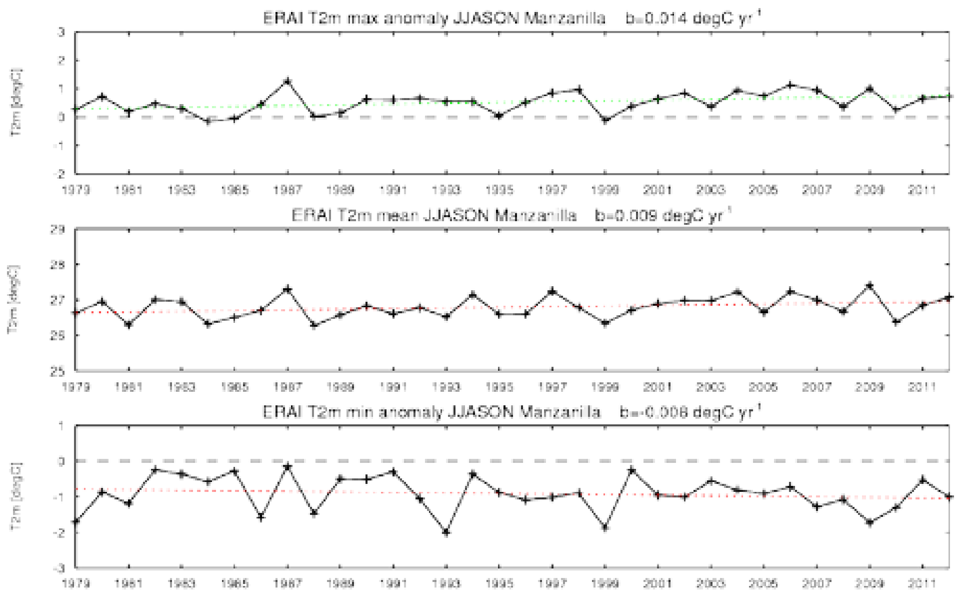


FIGURE 4.10

Trends in ERA-I wind speed over 1979-2012 for annual (left), dry season (middle) and wet season (right). Top row is extremes in maxima, bottom trends in mean. Stippling shows significance at 0.05 level. (Source: Report authors).

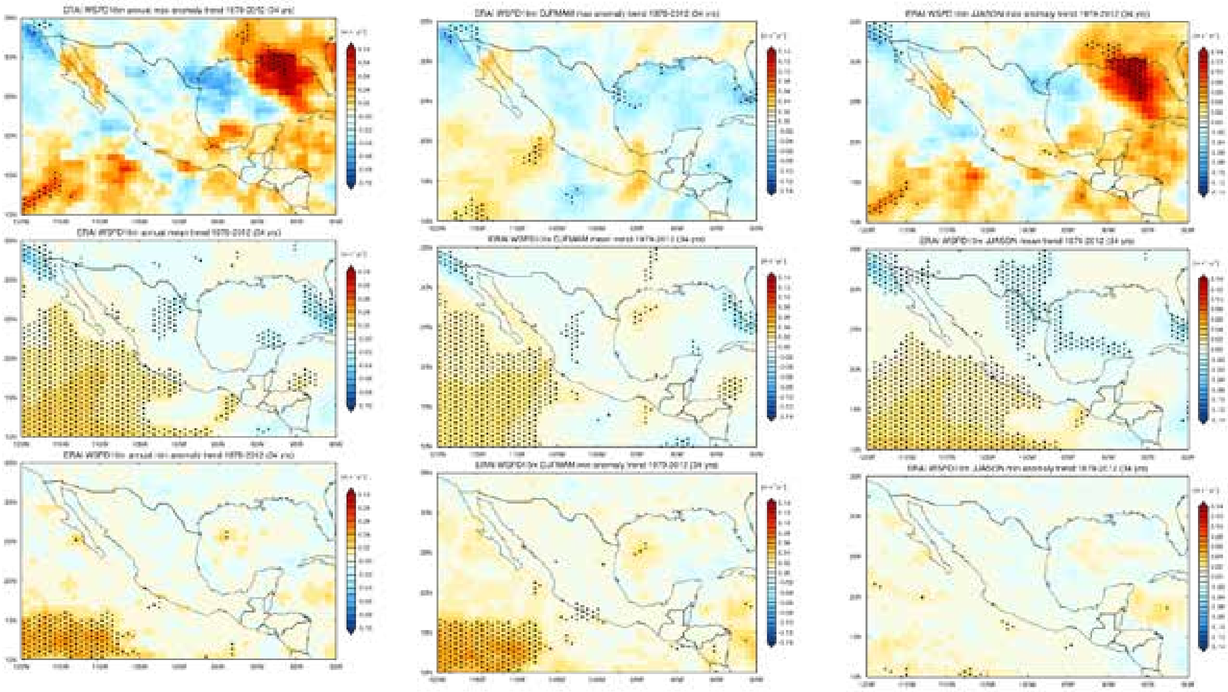


FIGURE 4.11

Availability of daily station data from Manzanillo January 1985-January 2014. (Source: Report authors)**.**

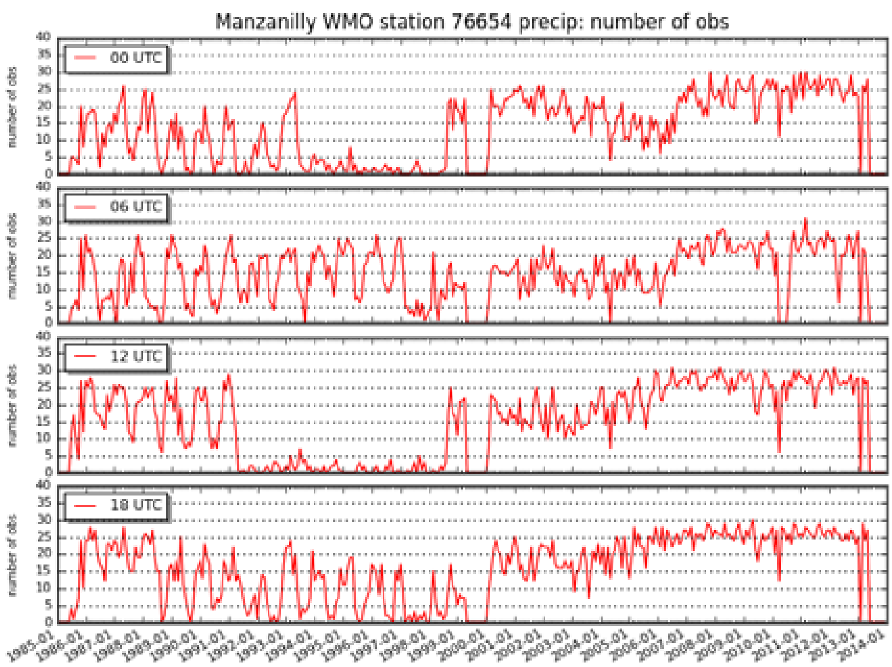


FIGURE 4.12

Trends in the frequency of occurrence of daily windspeed in excess of 1 m/s from ERA-I data from 1979-2014. Each panel is for a different month with all 12 months from January to December included. The slope of the regression line is quantified in the color shaded box. Red boxes show insignificant trends. Green boxes show statistically significant trends. (Source: Report authors).

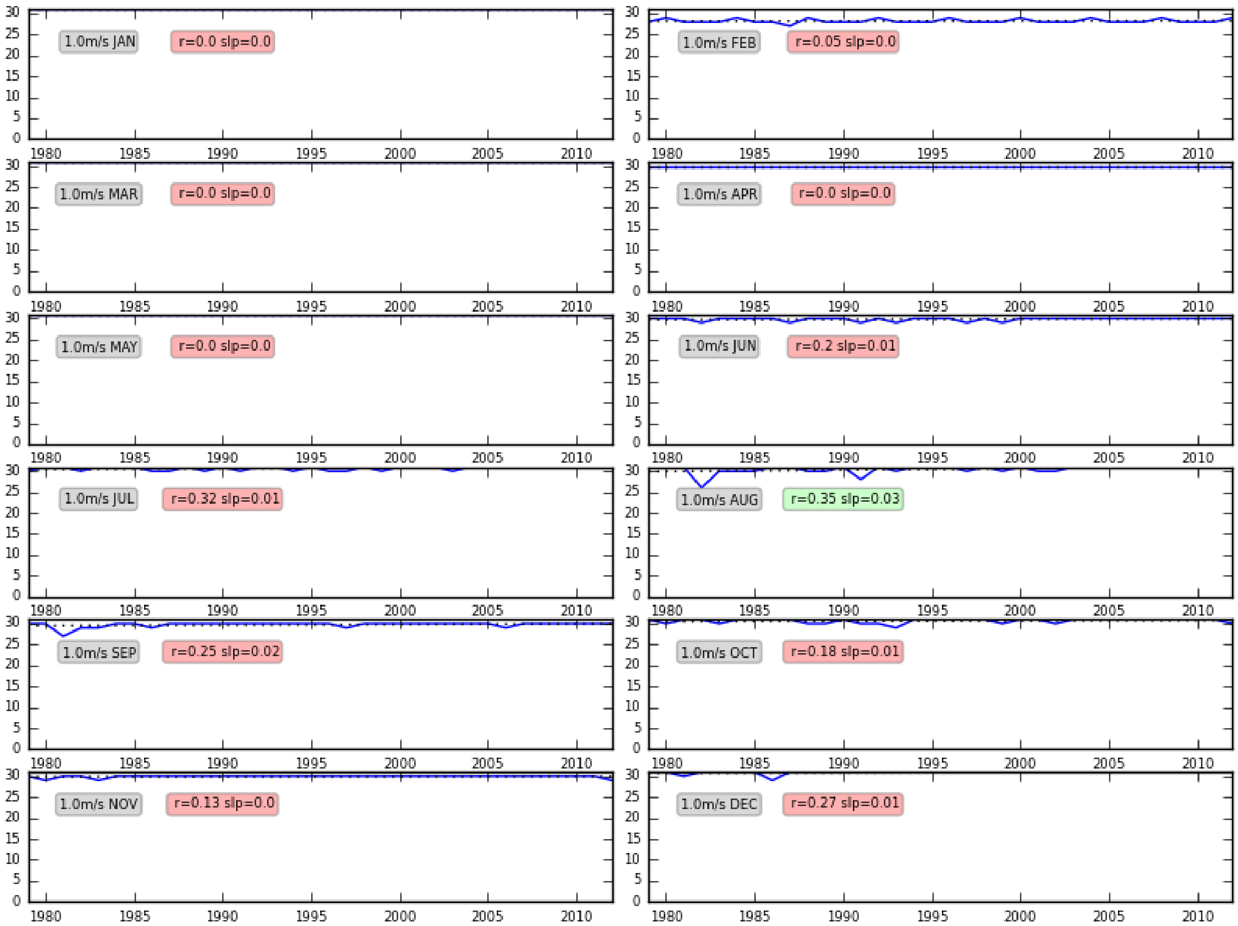


FIGURE 4.13

As for Figure 4.12 but for 2 m/s.

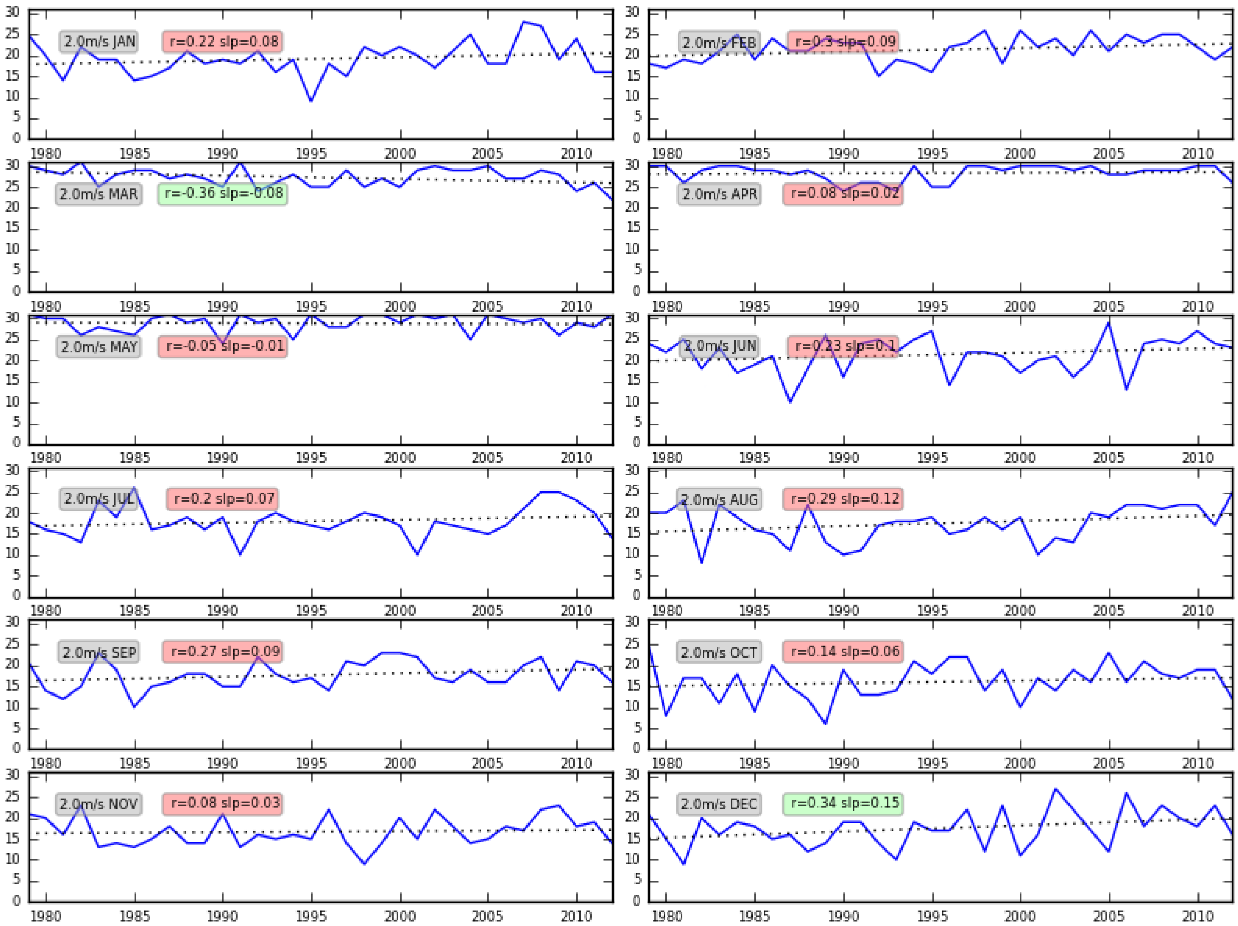


FIGURE 4.14

As for Figure 4.12 but for 3 m/s. (Source: Report authors)**.**

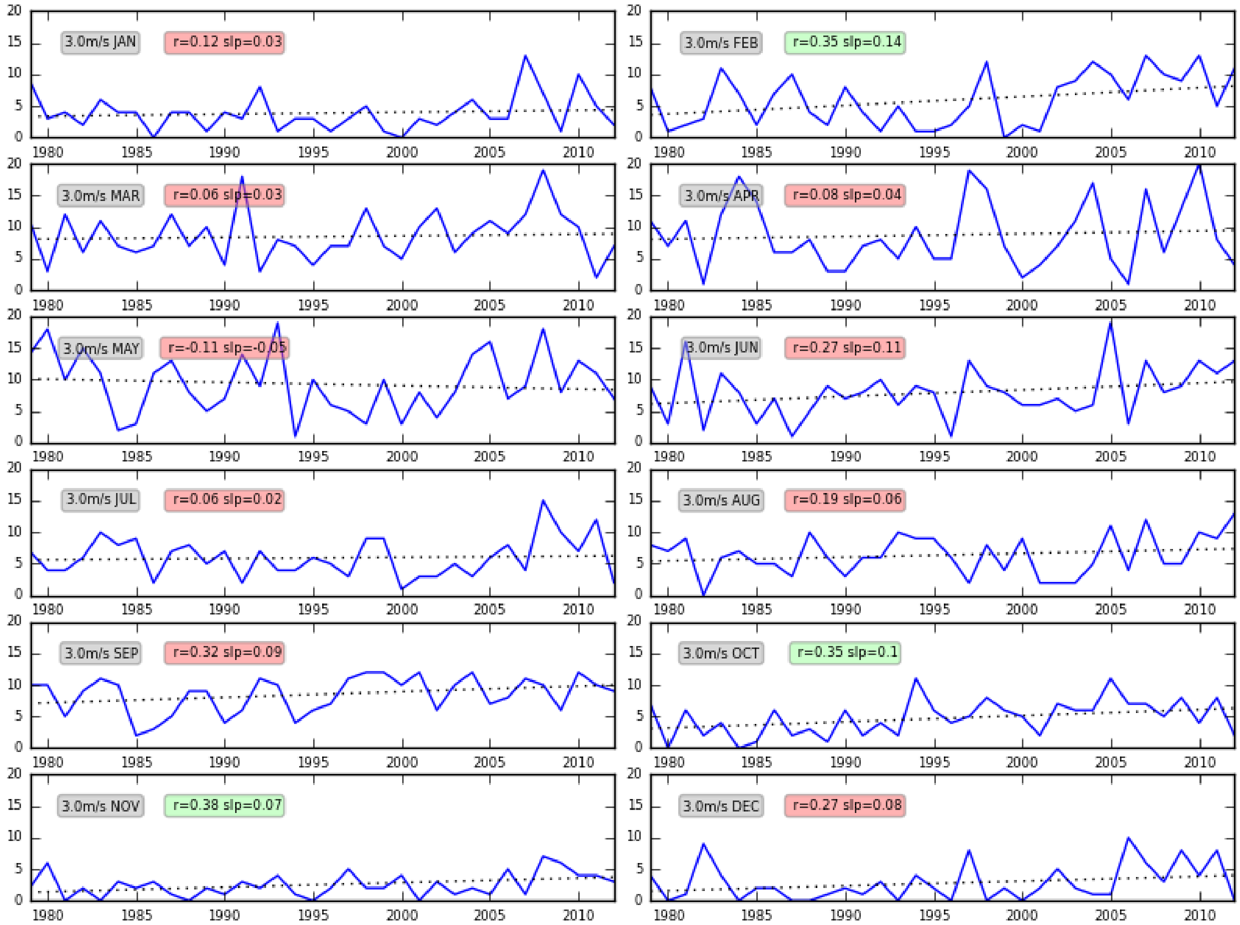


FIGURE 4.15

As for Figure 4.12 but for 4 m/s. (Source: Report authors)**.**

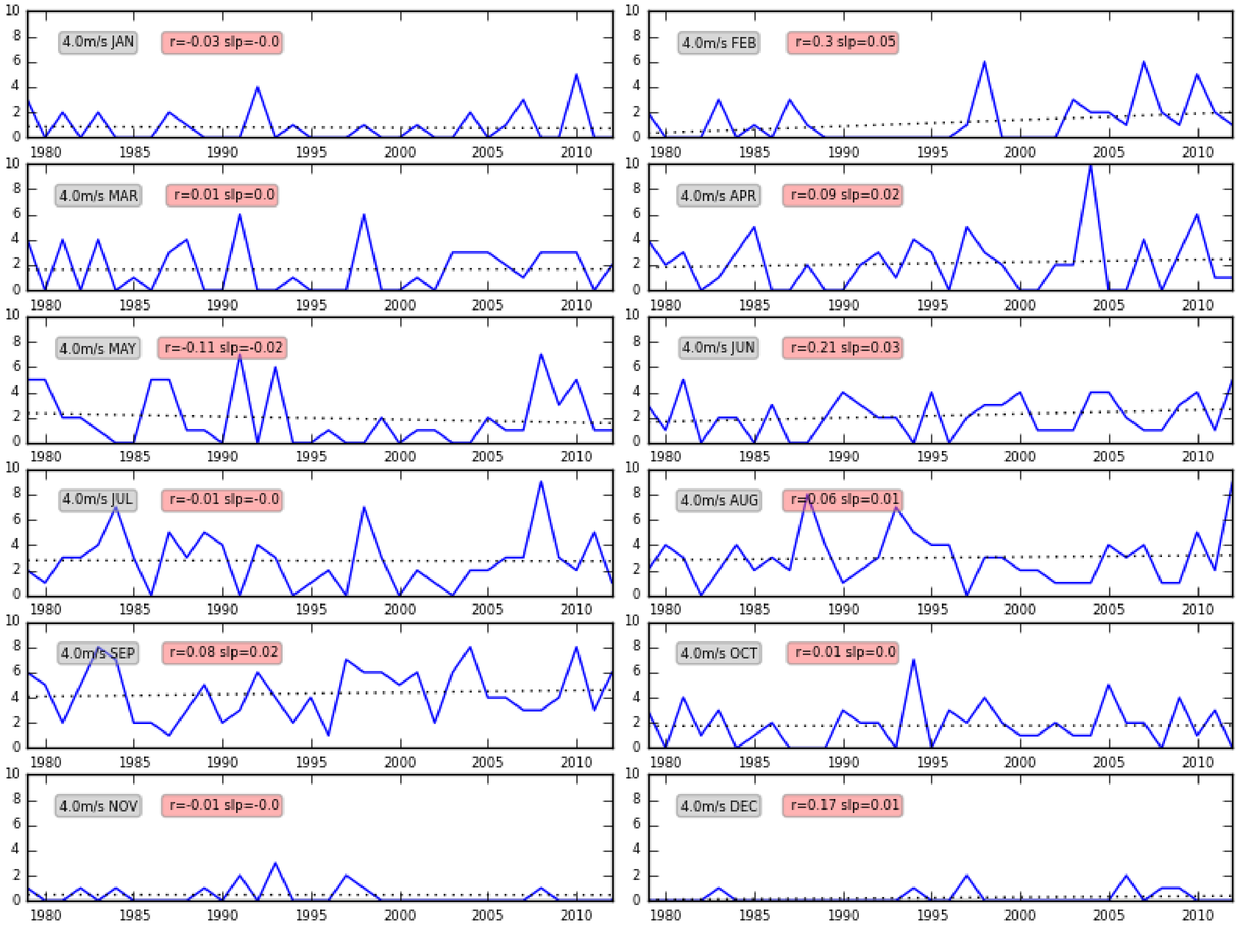


FIGURE 4.16

As for Figure 4.12 but for 5 m/s. (Source: Report authors)**.**

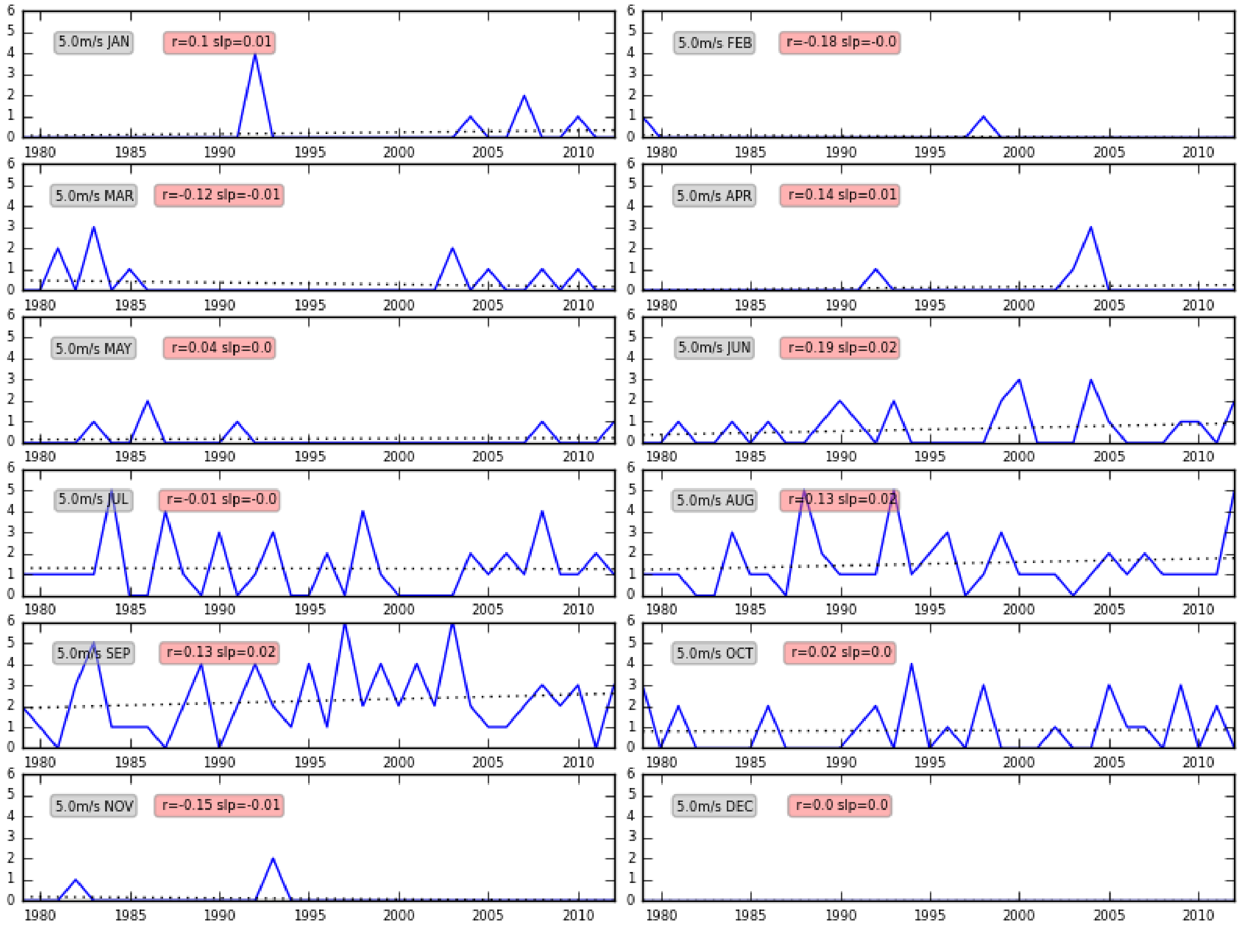


FIGURE 4.17

As for Figure 4.12 but for 6 m/s. (Source: Report authors)**.**

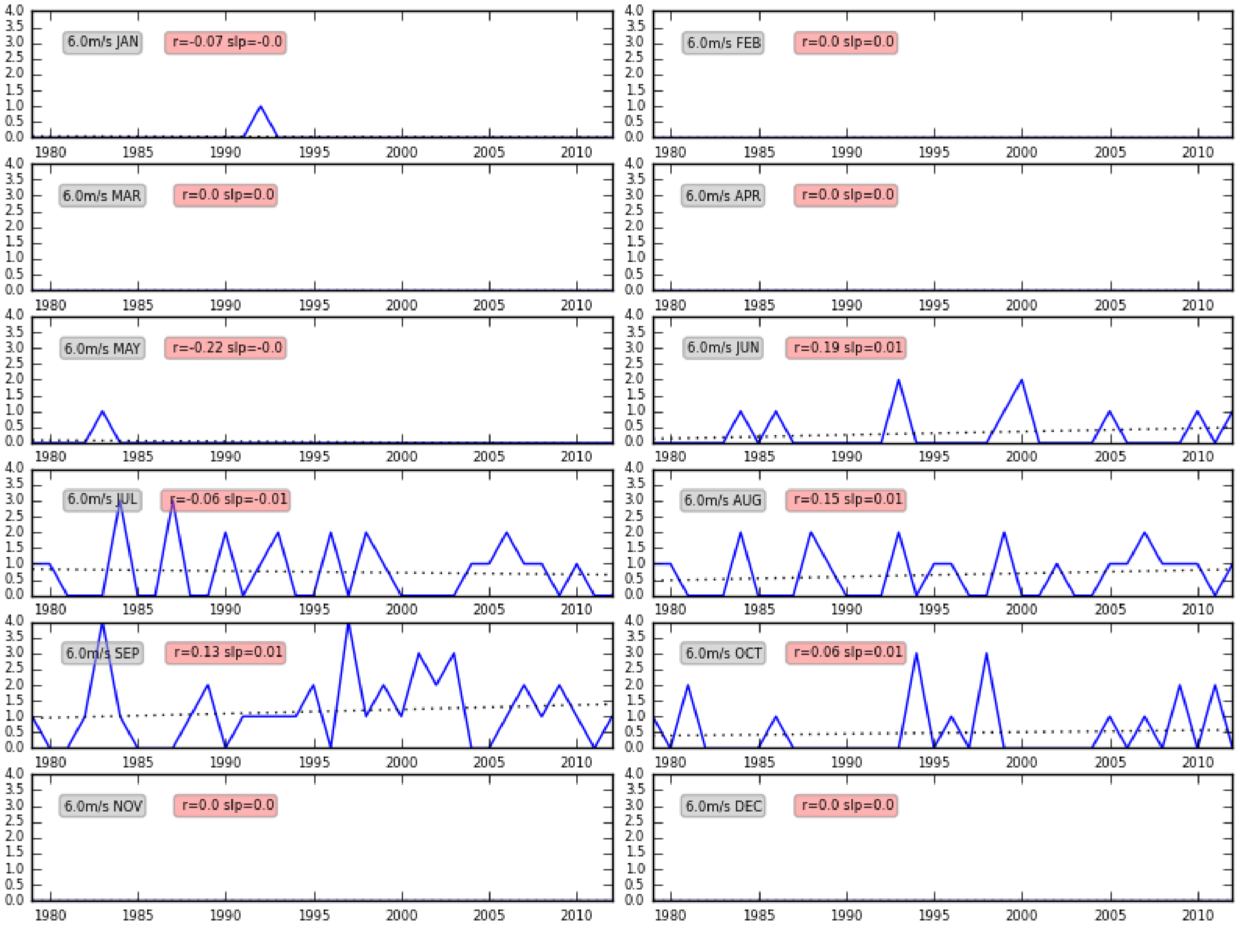


FIGURE 4.18

As for Figure 4.12 but for 7 m/s. (Source: Report authors)**.**

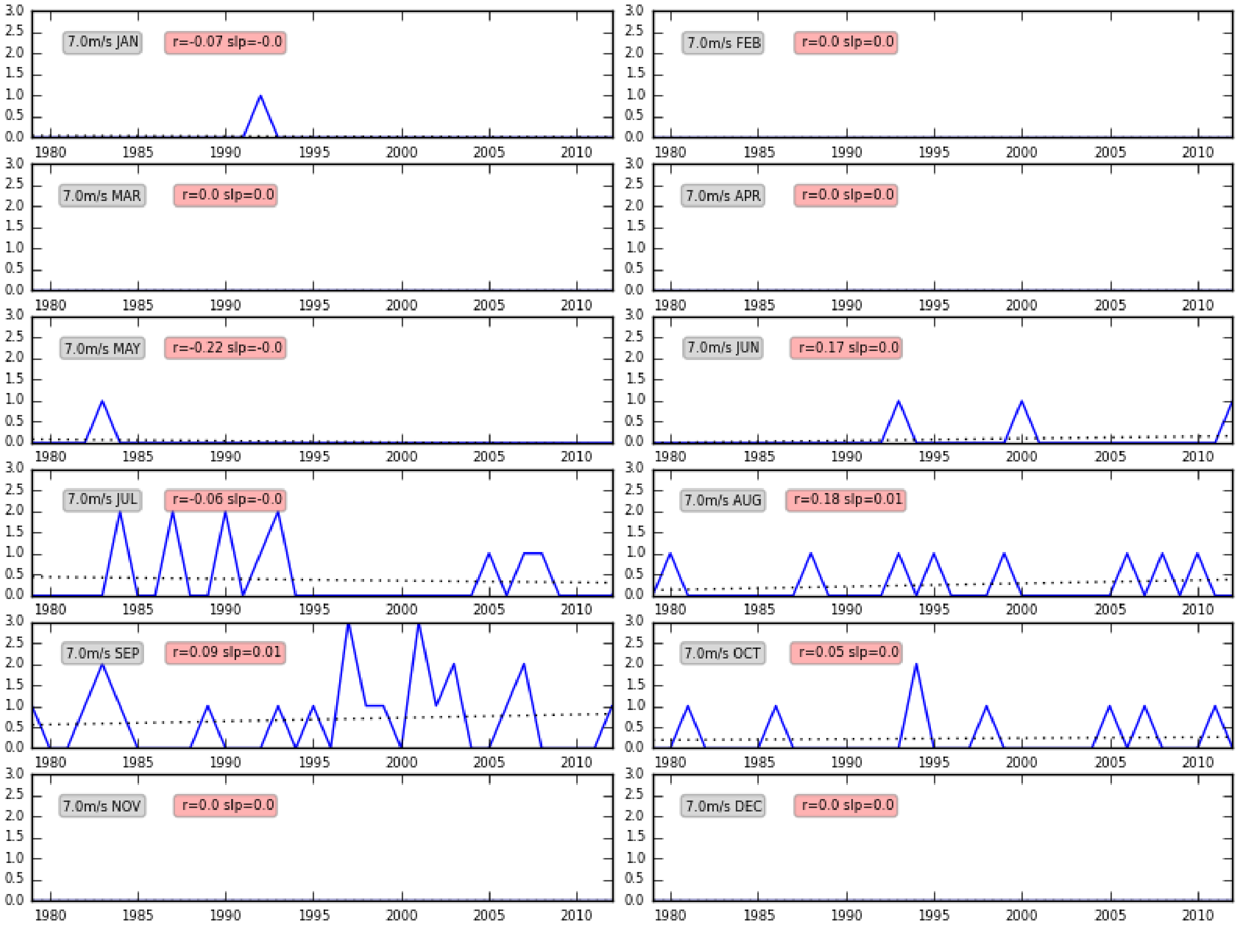


FIGURE 4.19

As for Figure 4.12 but for 8 m/s. (Source: Report authors)**.**

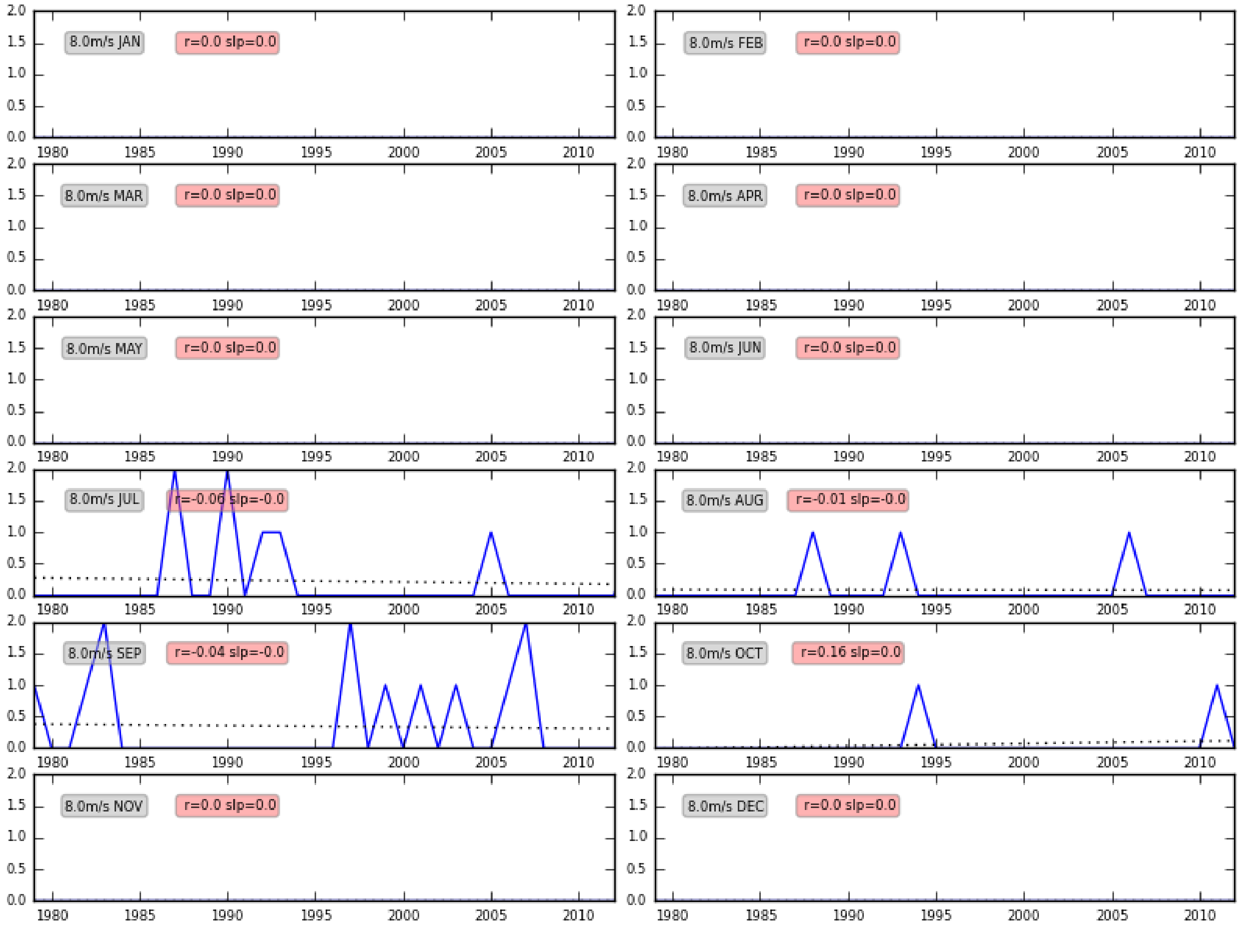


FIGURE 4.20

As for Figure 4.12 but for 10 m/s. (Source: Report authors)**.**

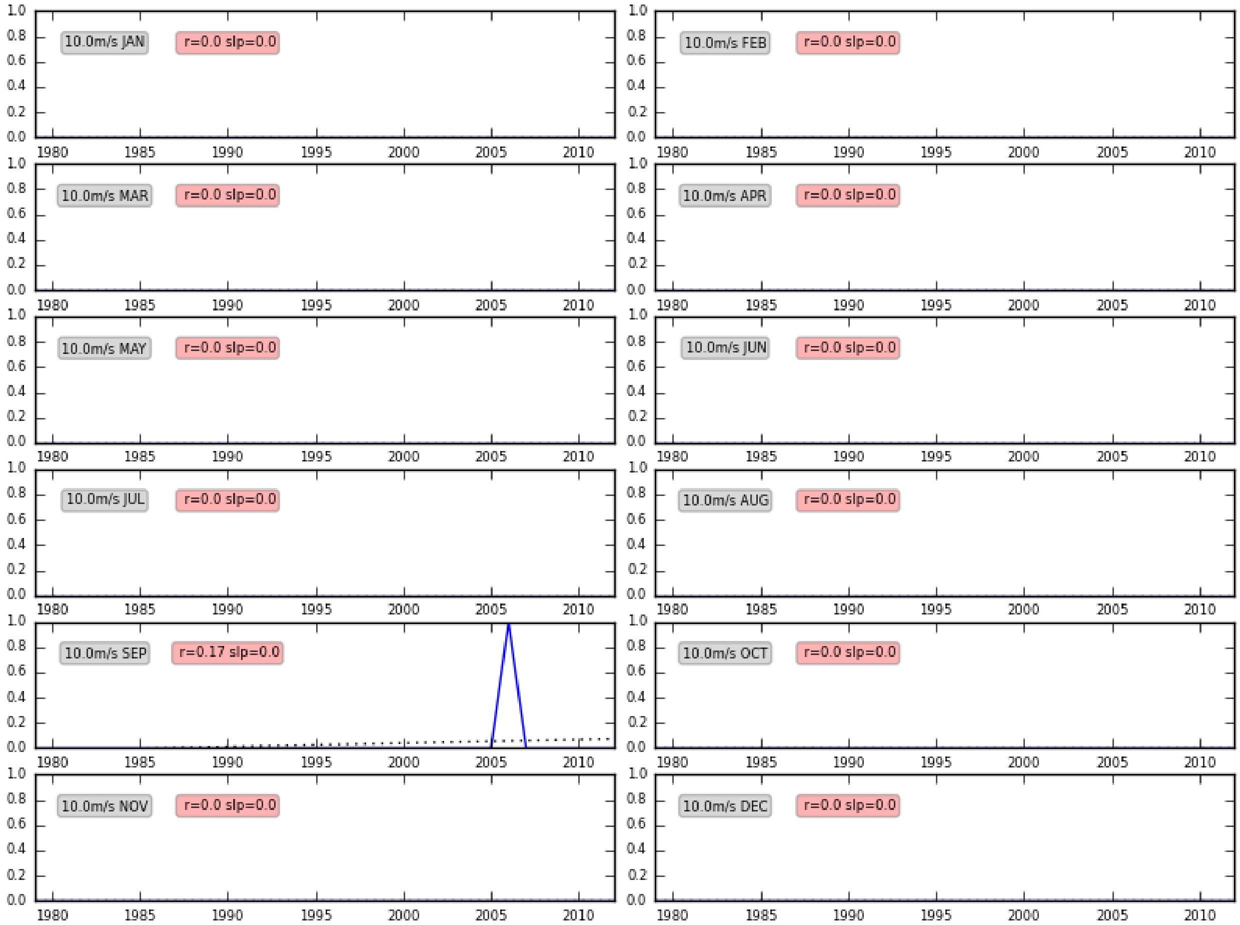


FIGURE 4.21

Trends in the frequency of occurrence of daily rainfall in excess of 1 mm from ERA-I data from 1979-2014. Each panel is for a different month with all 12 months from January to December included. The slope of the regression line is quantified in the color shaded box. Red boxes show insignificant trends. Green boxes show statistically significant trends. (Source: Report authors).

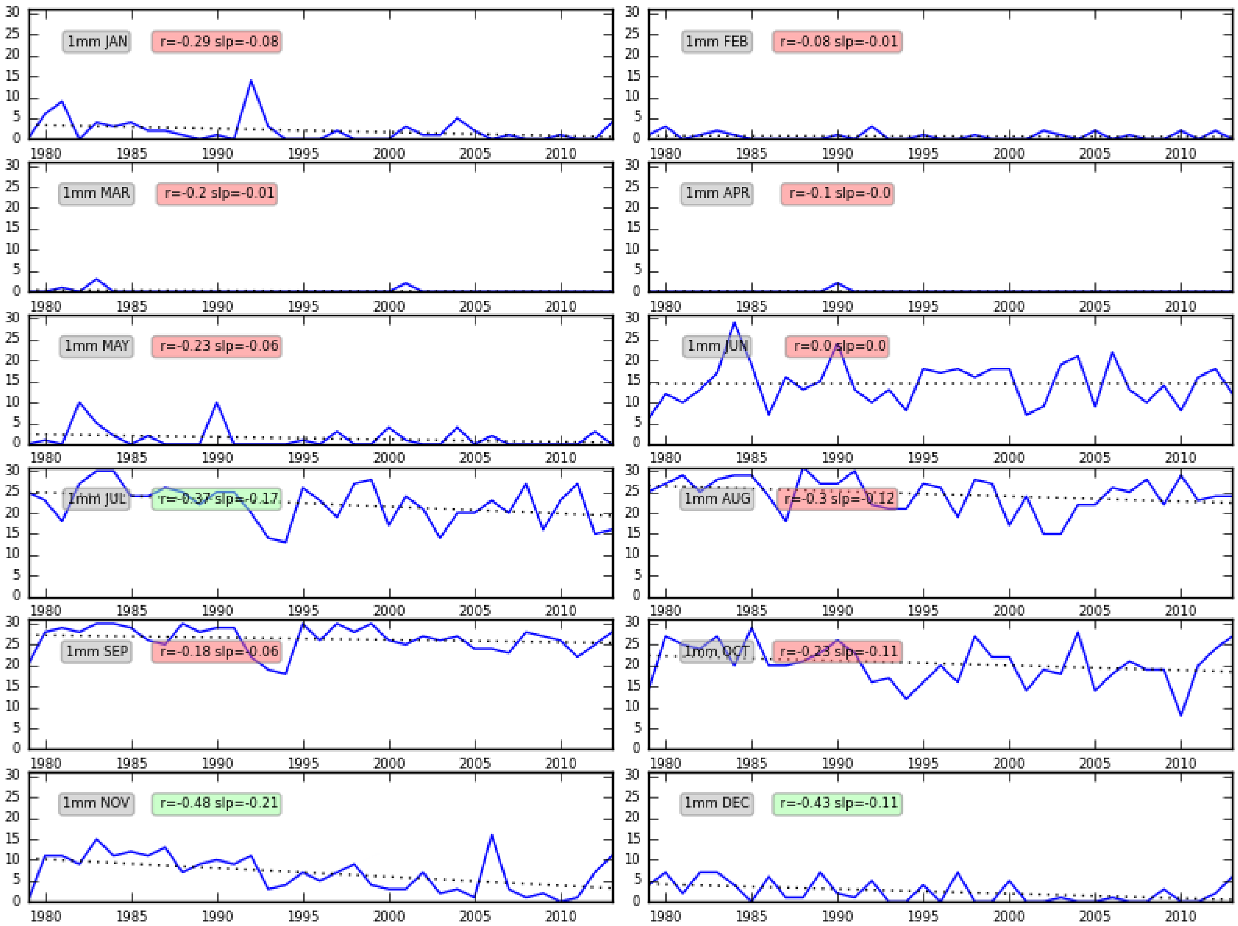


FIGURE 4.22

As for Figure 4.21 but for 2 mm. (Source: Report authors).

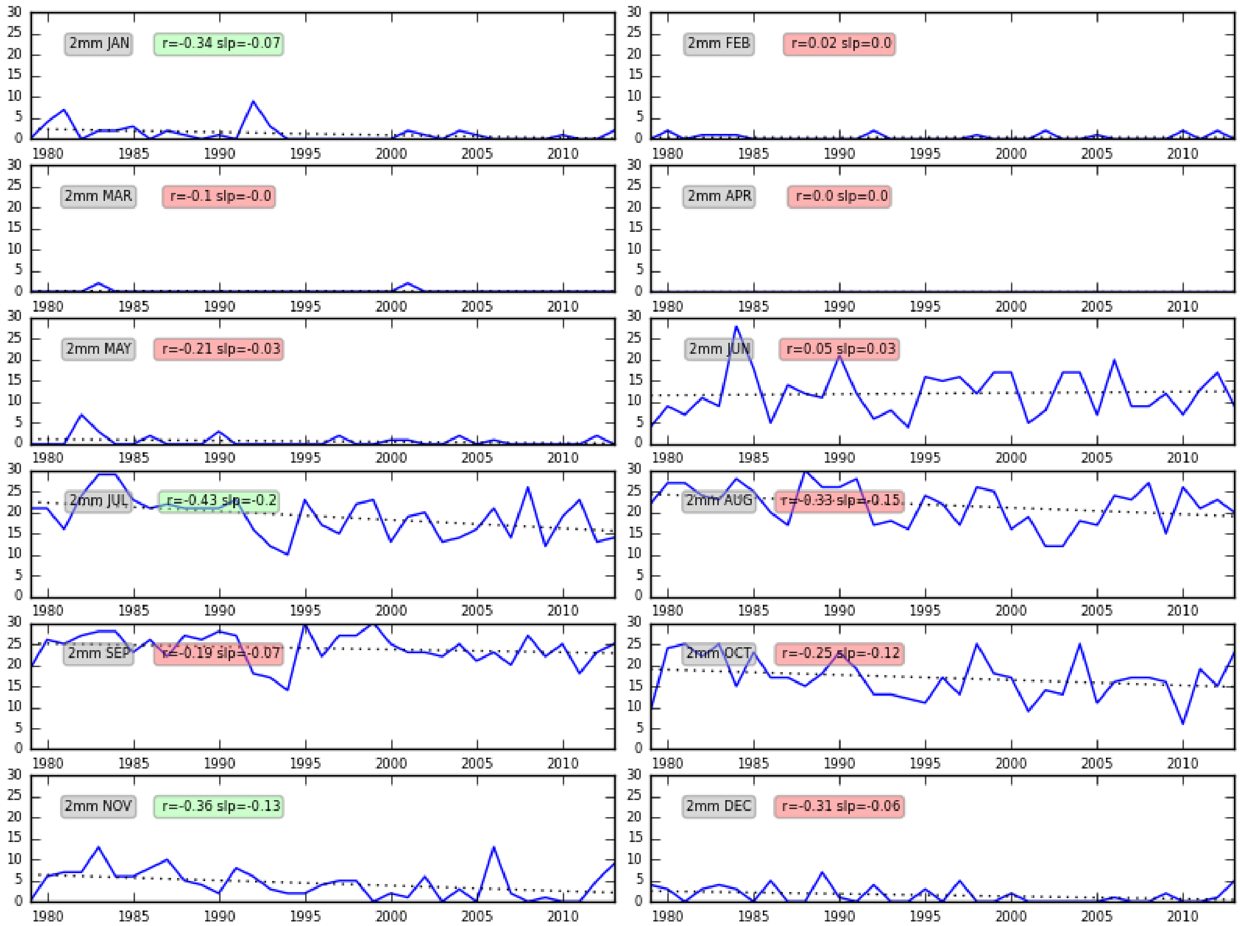


FIGURE 4.23

As for Figure 4.21 but for 3 mm. (Source: Report authors)**.**

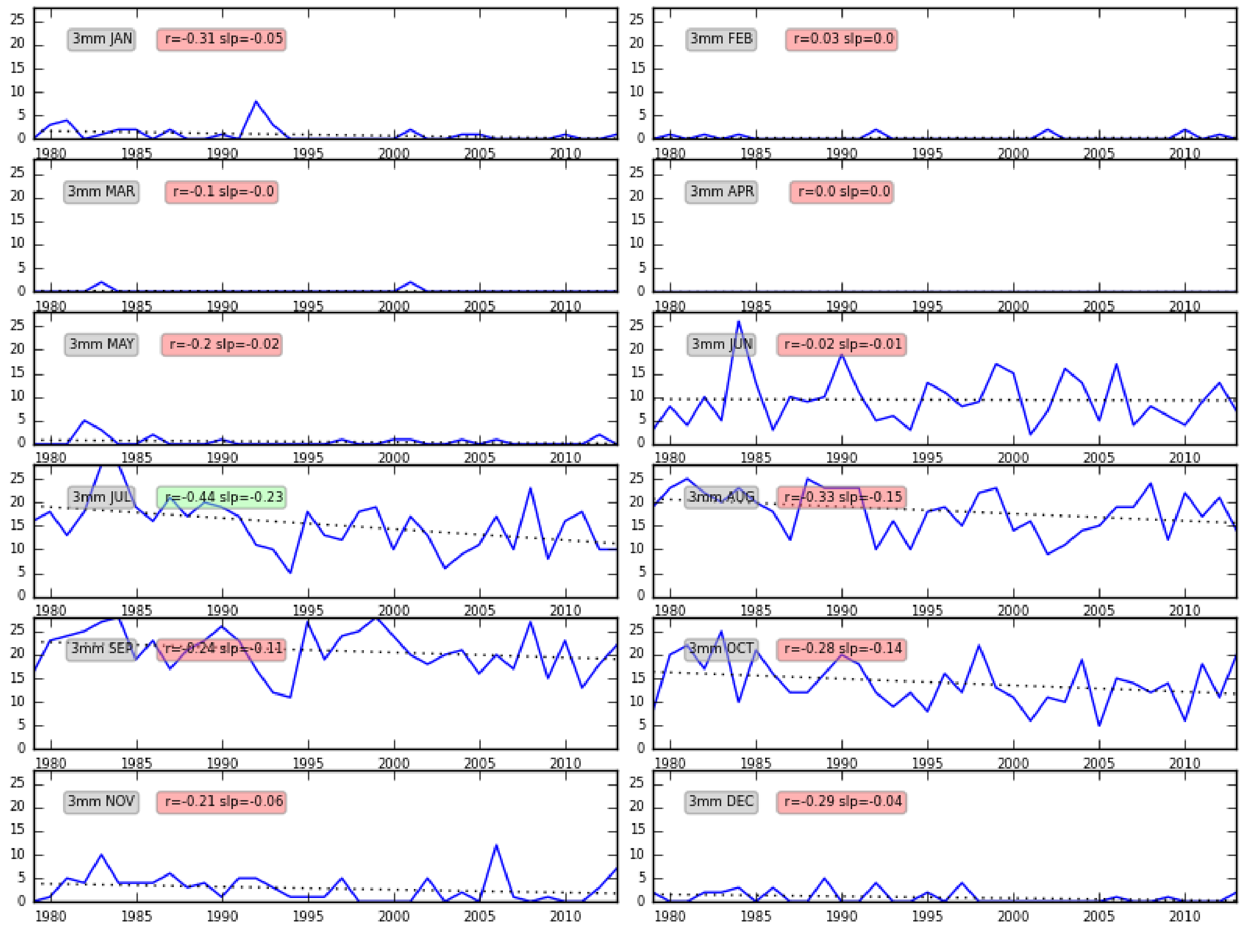


FIGURE 4.24

As for Figure 4.21 but for 4 mm. (Source: Report authors).

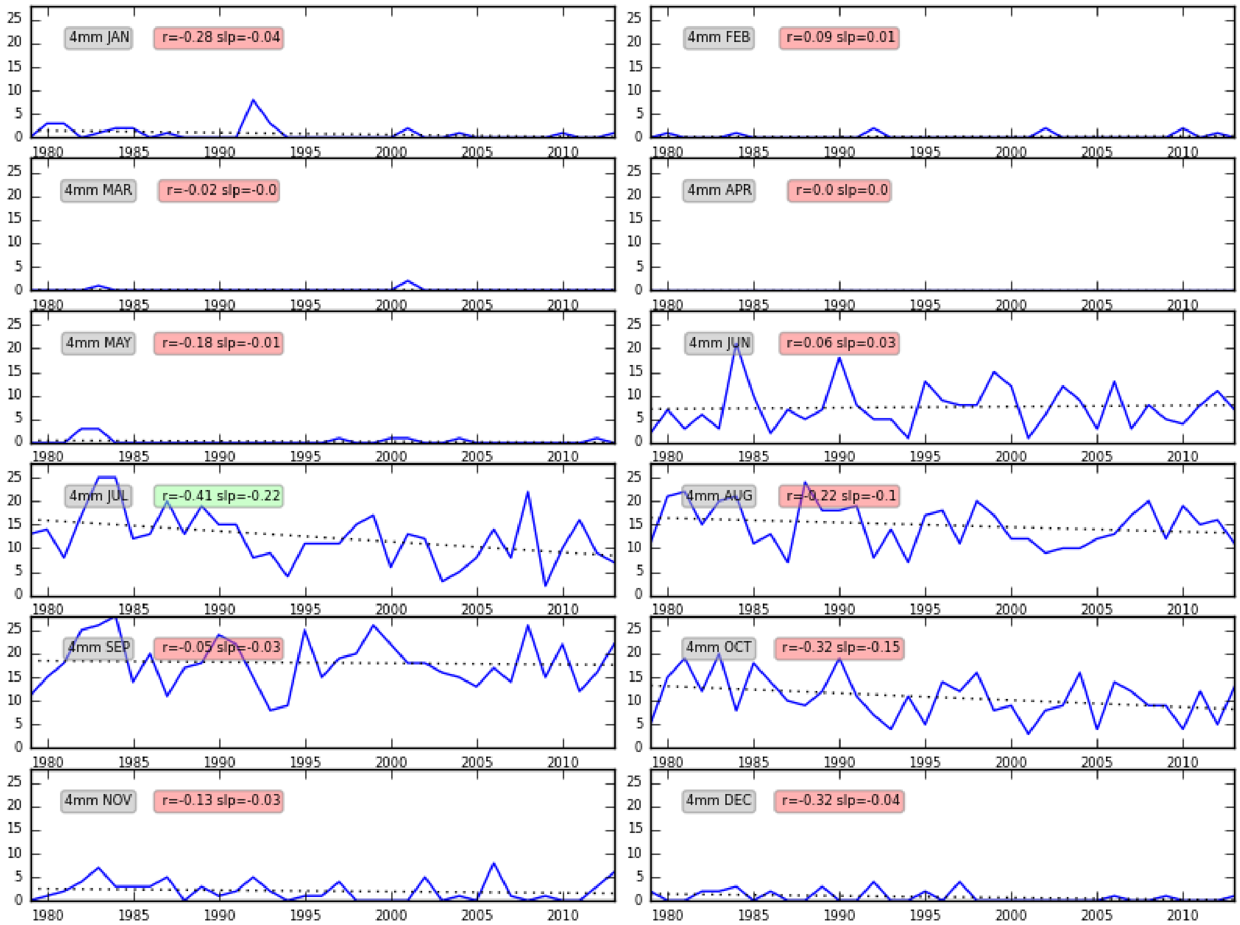


FIGURE 4.25

As for Figure 4.21 but for 5 mm. (Source: Report authors).

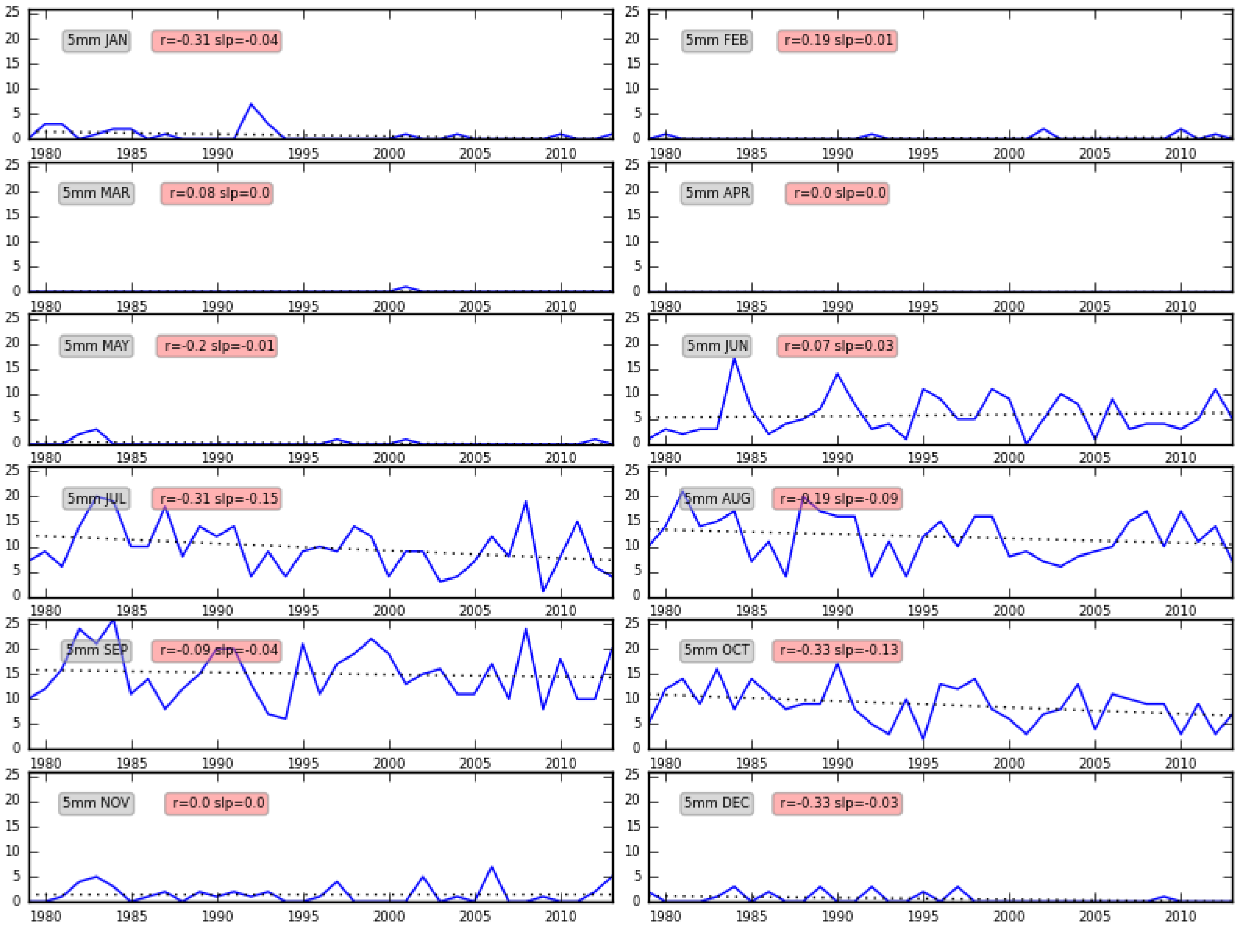


FIGURE 4.26

As for Figure 4.21 but for 6 mm. (Source: Report authors).

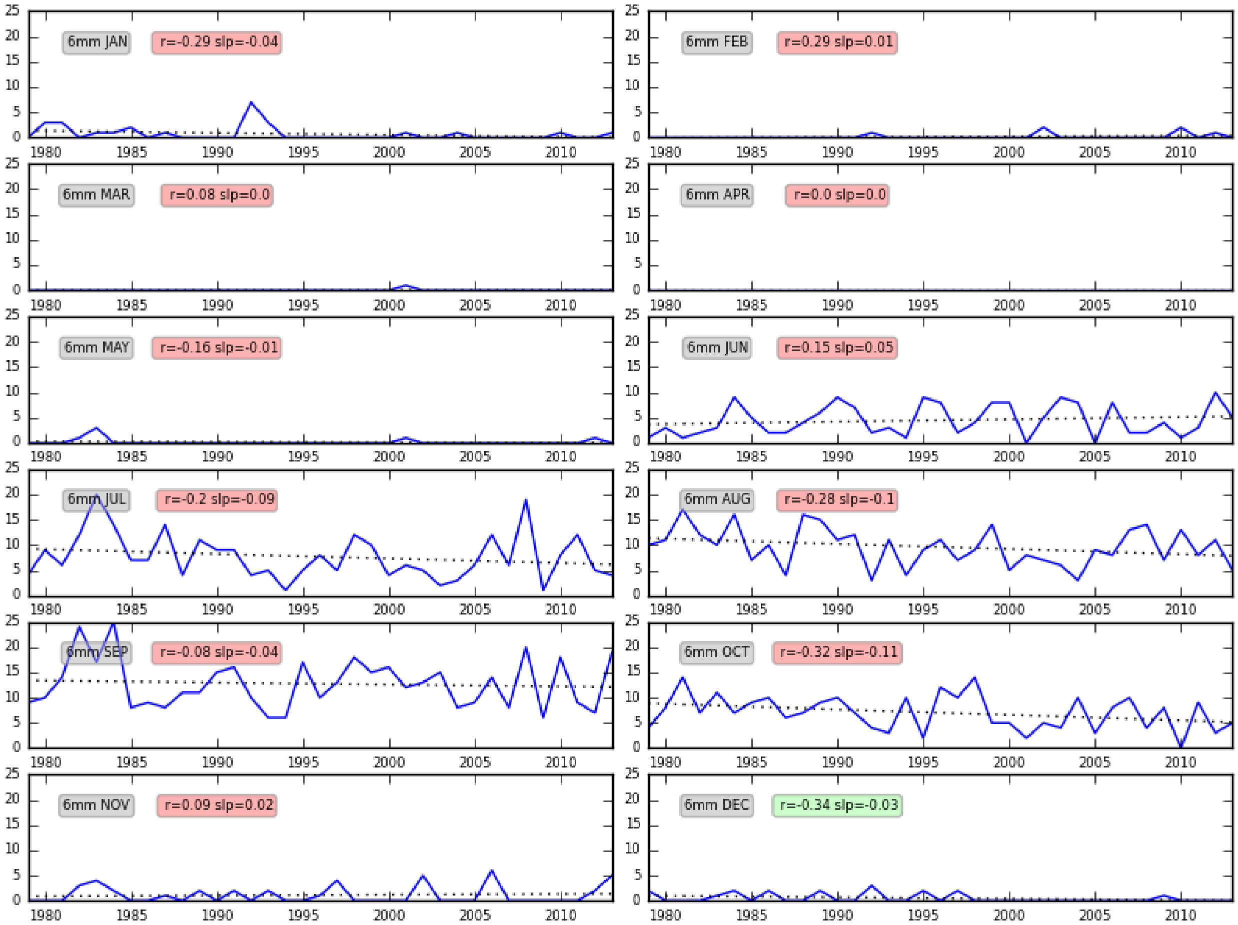


FIGURE 4.27

As for Figure 4.21 but for 7 mm. (Source: Report authors)**.**

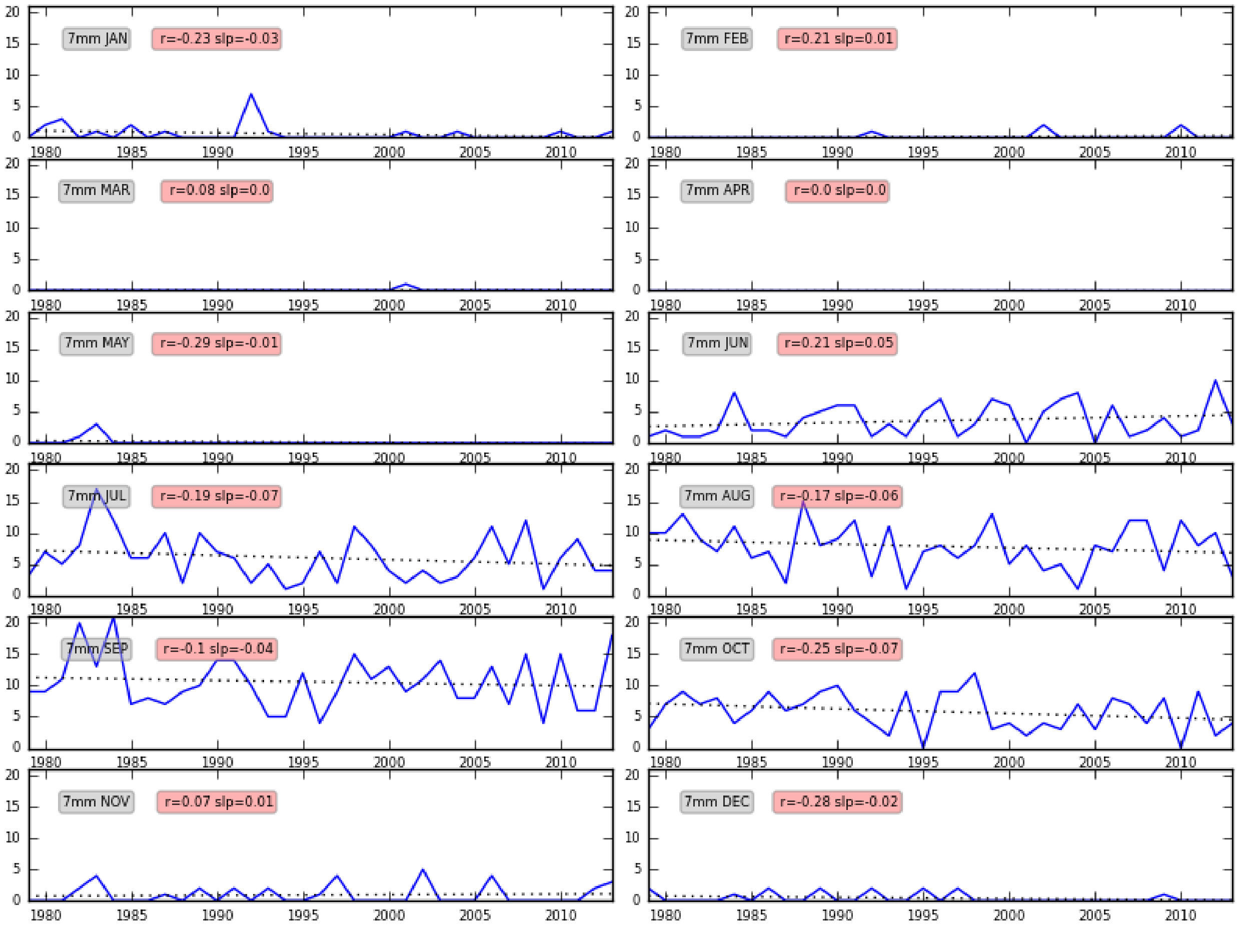


FIGURE 4.28

As for Figure 4.21 but for 8 mm. (Source: Report authors).

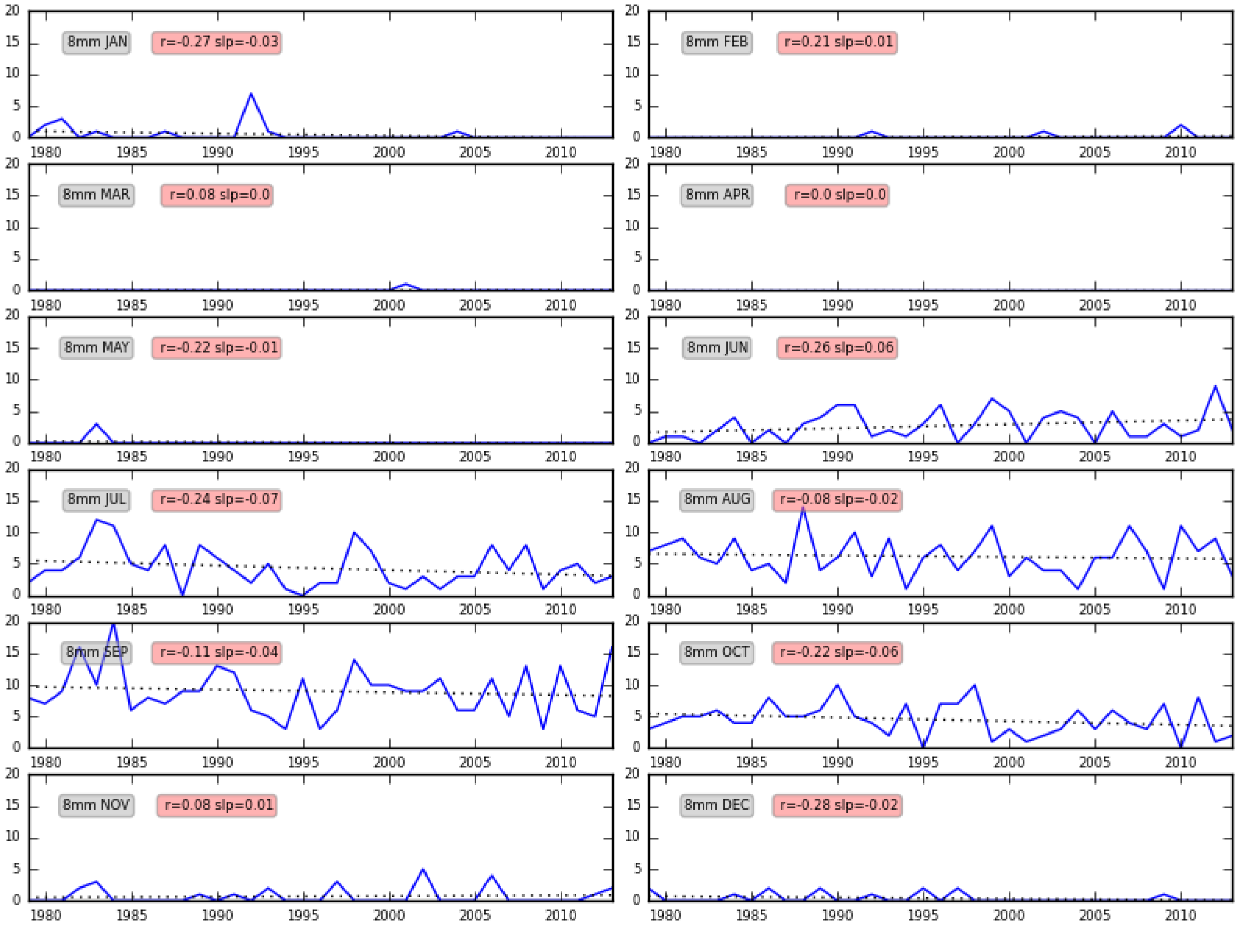


FIGURE 4.29

As for Figure 4.21 but for 9 mm. (Source: Report authors).

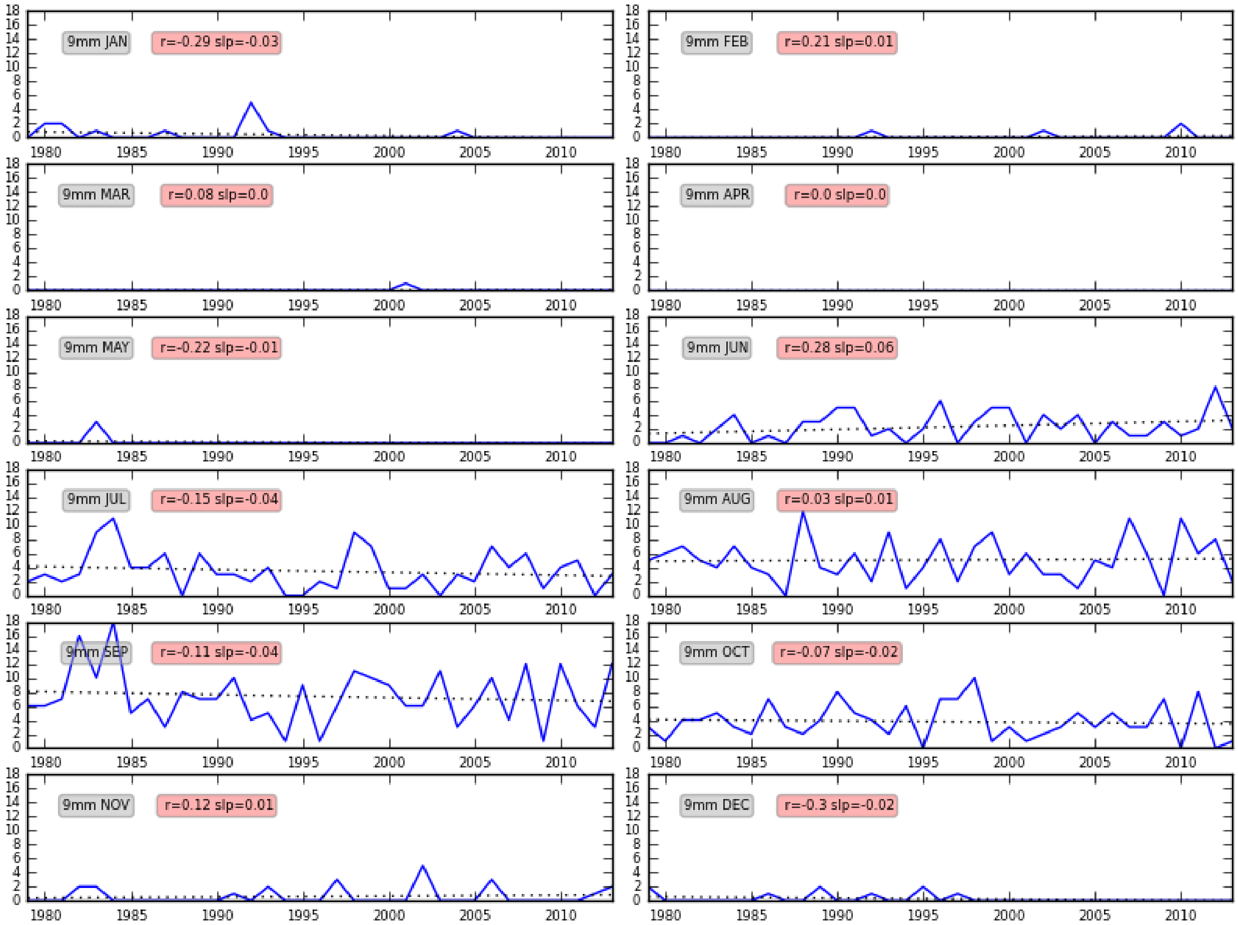


FIGURE 4.30

As for Figure 4.21 but for 10 mm. (Source: Report authors)**.**

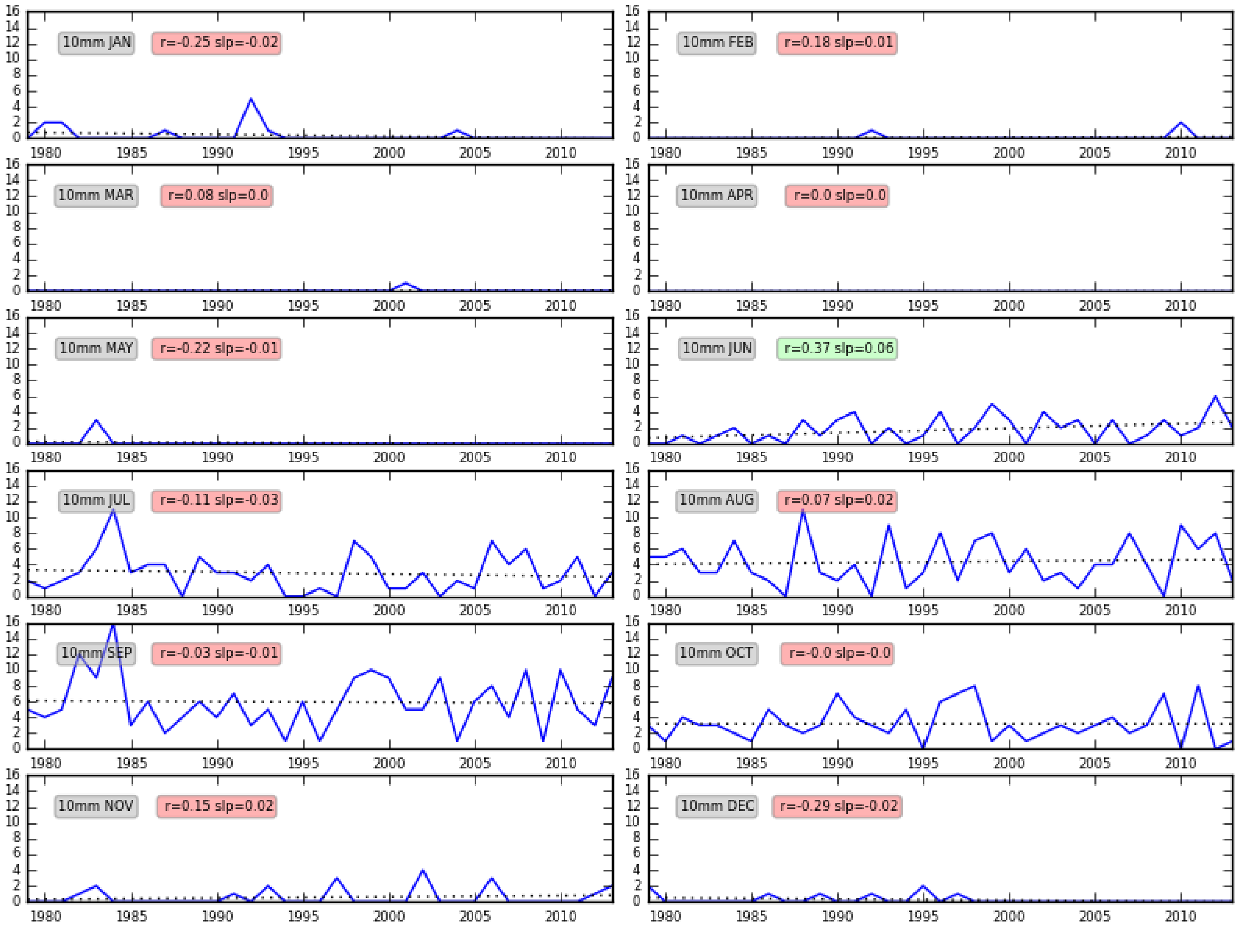
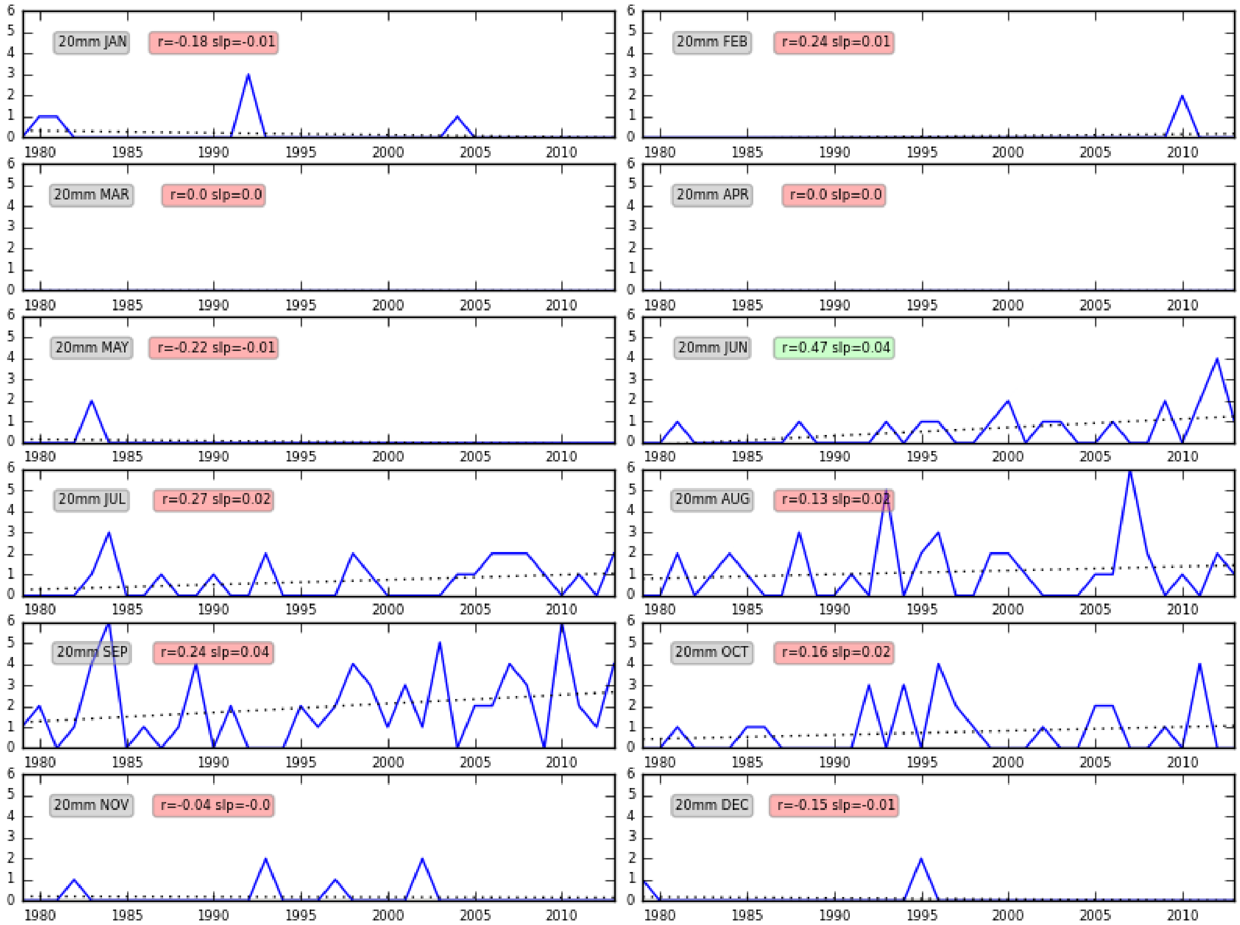


FIGURE 4.31

As for Figure 4.21 but for 20 mm. (Source: Report authors).



4.2 Future climate change

TABLE 4.1

List of climate models from the Coupled Climate Model Intercomparison Project 5 (CMIP5) used to analyze future climate change

ACCESS1.0	CSIRO-Mk3 6.0	HadGEM AO
ACCESS1.3	CSIRO-Mk3L-1-2	HadGEM2 CC
Bcc-csm1.1	EC-EARTH	HadGEM2-ES
Bcc-csm1.m	FGOALS-g2	Inmcm4
BNU-ESM	FIO-ESM	IPSL-CM5A-MR
CanESM2	GFDL-CM3	IPSL CM5B LR
CCSM4	GFDL-ESM2G	MIROC5
CESM-BGC	GFDL-ESM2M	MIROC-ESM
CESM-CAM5	GISS E2	MIROC-ESM-CHEM
CESM1-WACCM	GISS E2 CC	MPI-ESM-LR
CMCC-CESM	GISS E2 R	MPI-ESM-MR
CMCC-CM	GISS E2 R CC	MRI-CGCM
CMCC-CM5	HadCM3	

FIGURE 4.32

Coupled Model Intercomparison Project 5 (CMIP5) model ensemble mean precipitation change in mm/day for RCP 8.5. Left column is December to May; right column is June to November. Top row: 2020-2029 minus 1979-2000, Middle row: 2040-2049 minus 1979-2000, Bottom row: 2070-2079 minus 1979-2000. (Source: Report authors).

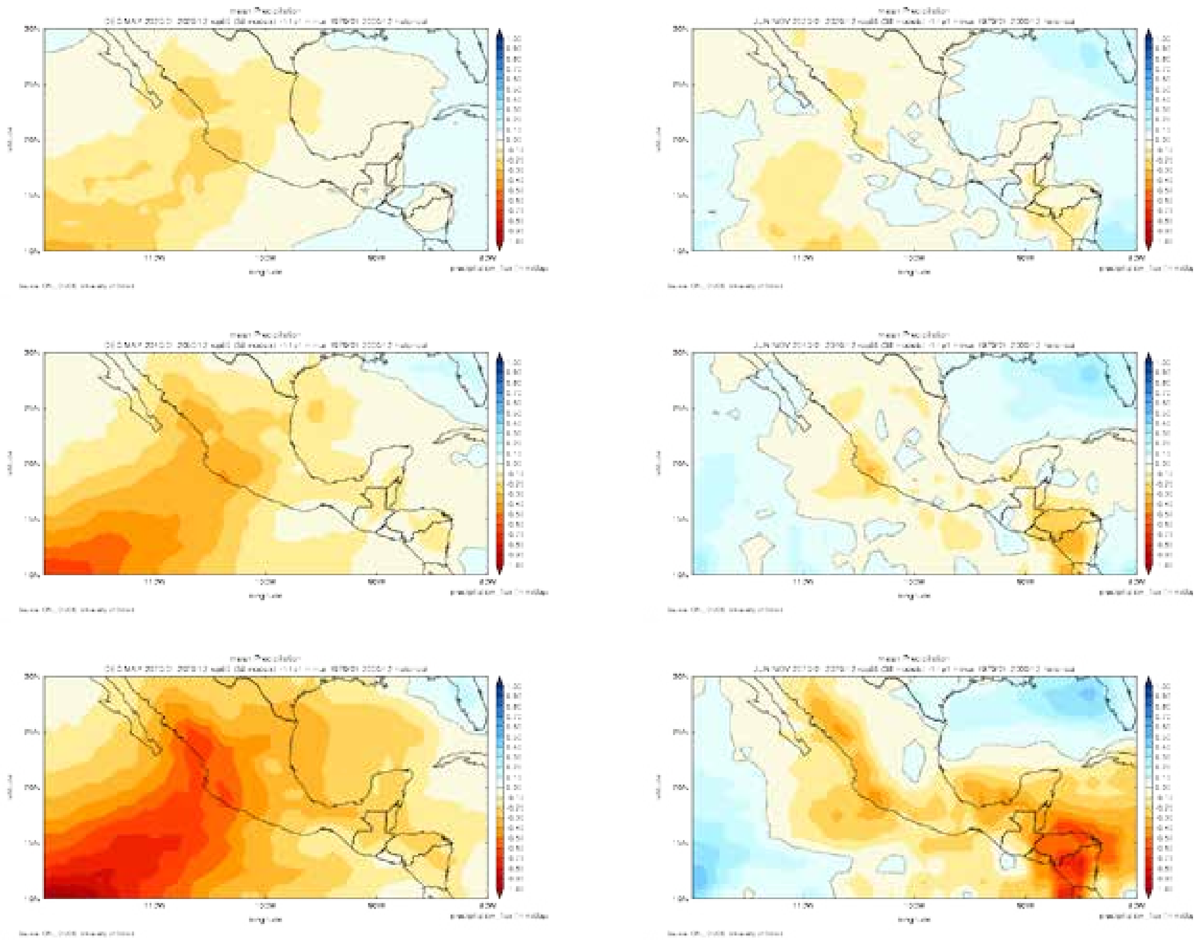


FIGURE 4.33

Coupled Model Intercomparison Project 5 (CMIP5) model ensemble mean precipitation change in mm/day for RCP 4.5. Left column is December to May; right column is June to November. Top row: 2020-2029 minus 1979-2000, Middle row: 2040-2049 minus 1979-2000, Bottom row: 2070-2079 minus 1979-2000. (Source: Report authors).

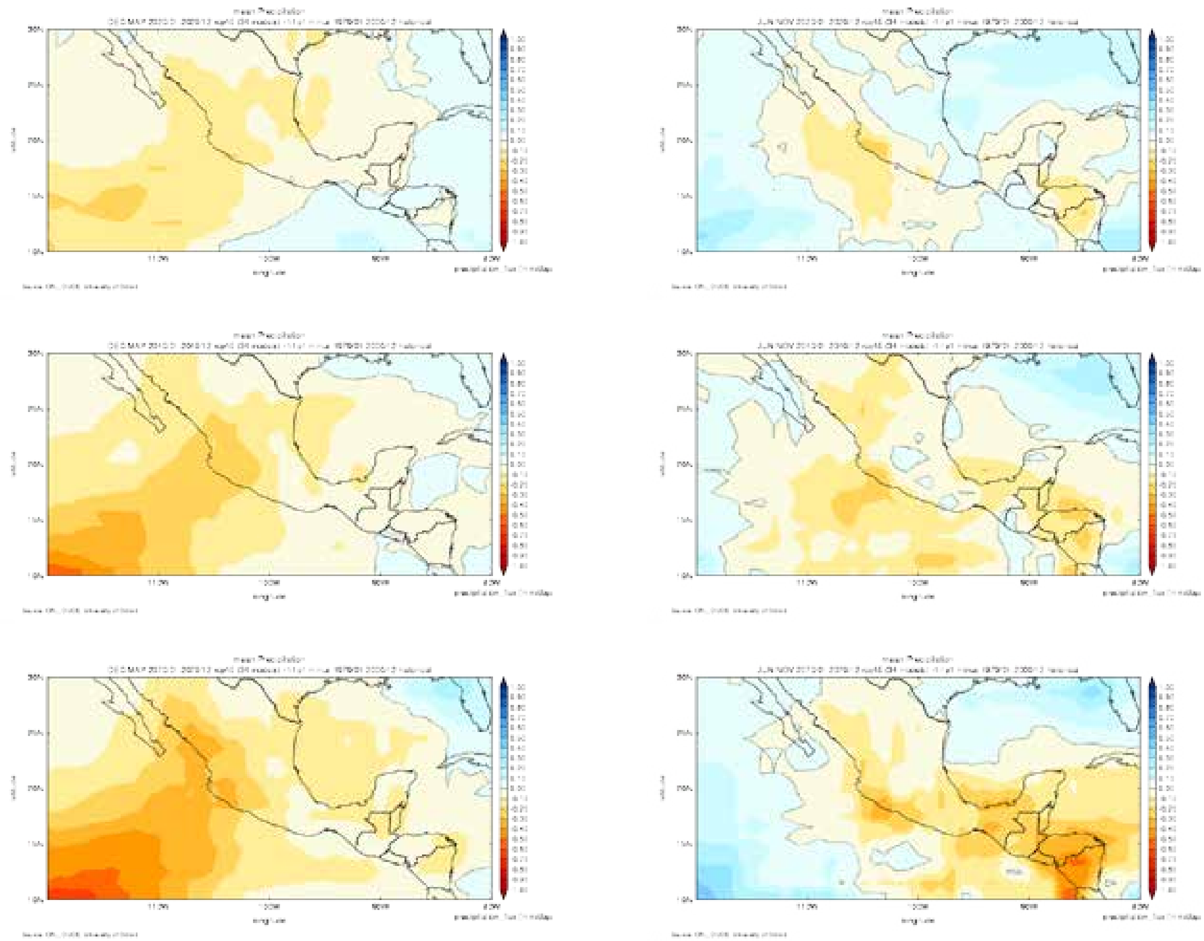


FIGURE 4.34

Coupled Model Intercomparison Project 5 (CMIP5) model ensemble mean temperature change in deg C for RCP 8.5. Left column is December to May; right column is June to November. Top row: 2020-2029 minus 1979-2000, Middle row: 2040-2049 minus 1979-2000, Bottom row: 2070-2079 minus 1979-2000. (Source: Report authors).

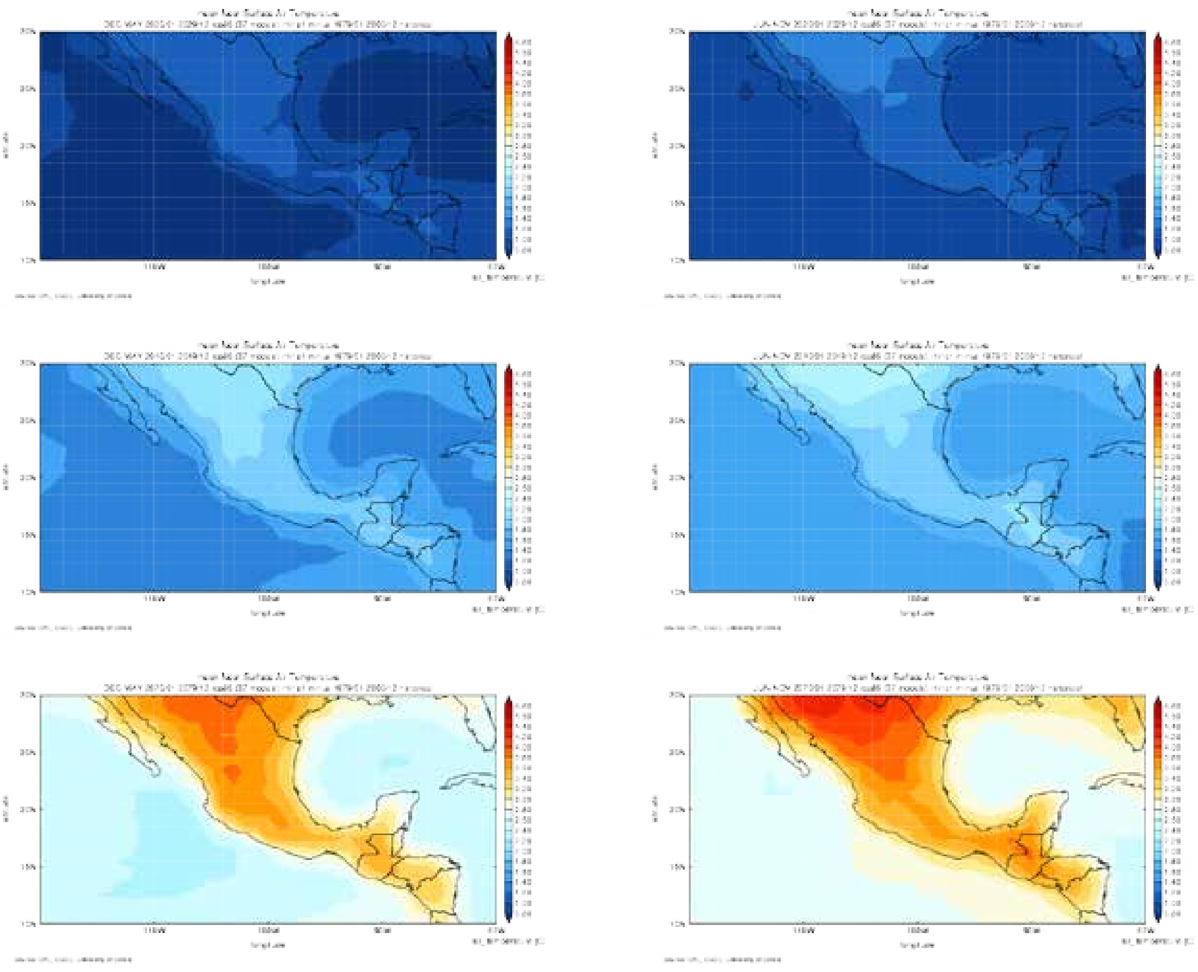


FIGURE 4.35

Coupled Model Intercomparison Project 5 (CMIP5) model ensemble mean temperature change in deg C for RCP 4.5. Left column is December to May; right column is June to November. Top row: 2020-2029 minus 1979-2000, Middle row: 2040-2049 minus 1979-2000, Bottom row: 2070-2079 minus 1979-2000. (Source: Report authors).

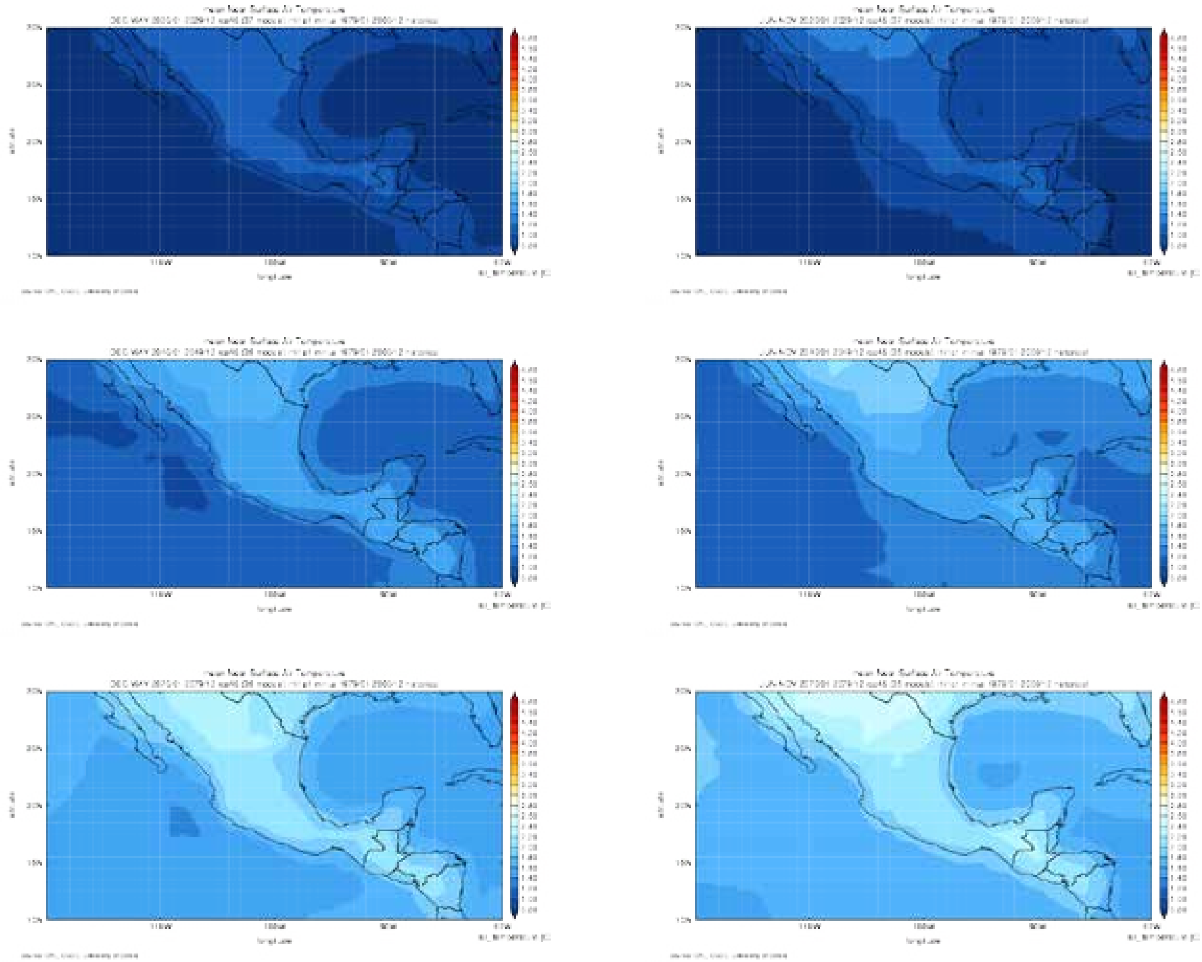


FIGURE 4.36

Coupled Model Intercomparison Project 5 (CMIP5) model ensemble mean wind speed change in m/s for RCP 8.5. Left column is December to May; right column is June to November. Top row: 2020-2029 minus 1979-2000, Middle row: 2040-2049 minus 1979-2000, Bottom row: 2070-2079 minus 1979-2000. (Source: Report authors).

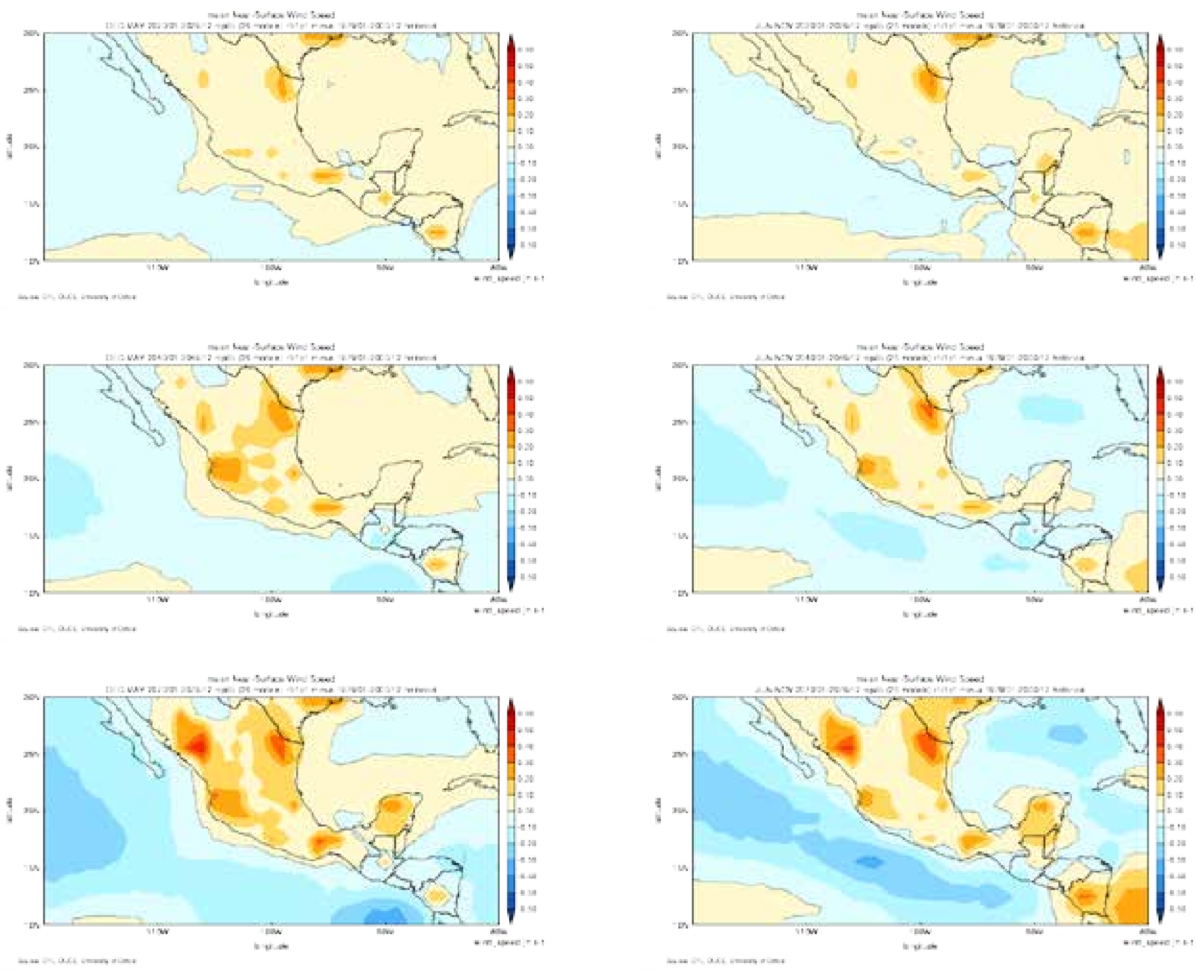


FIGURE 4.37

Coupled Model Intercomparison Project 5 (CMIP5) model ensemble mean wind speed change in m/s for RCP 4.5. Left column is December to May; right column is June to November. Top row: 2020-2029 minus 1979-2000, Middle row: 2040-2049 minus 1979-2000, Bottom row: 2070-2079 minus 1979-2000. (Source: Report authors).

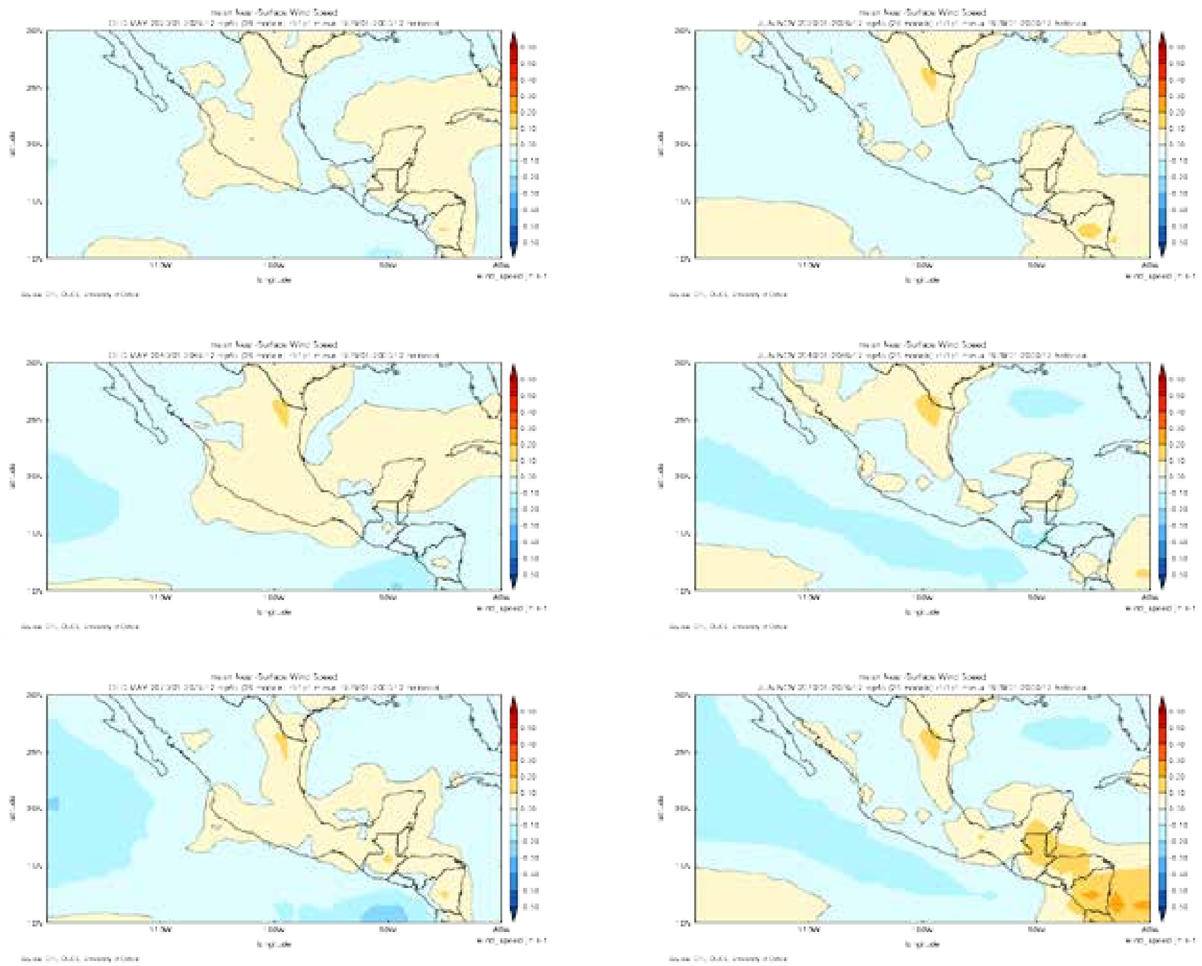


FIGURE 4.38

Scatterplots of temperature change (deg C) and precipitation change (mm/day) for dry season months from CMIP5 models forced with RCP 8.5 for Manzanillo for the 2020s. Red circles are models used in the Mexican national climate change scenarios. Additional CMIP5 models are shown in gray circles. Red and gray squares are the mean of the red and gray circles respectively. Blue squares are the mean of all models. Individual scatterplots are for the months December to May. (Source: Report authors).

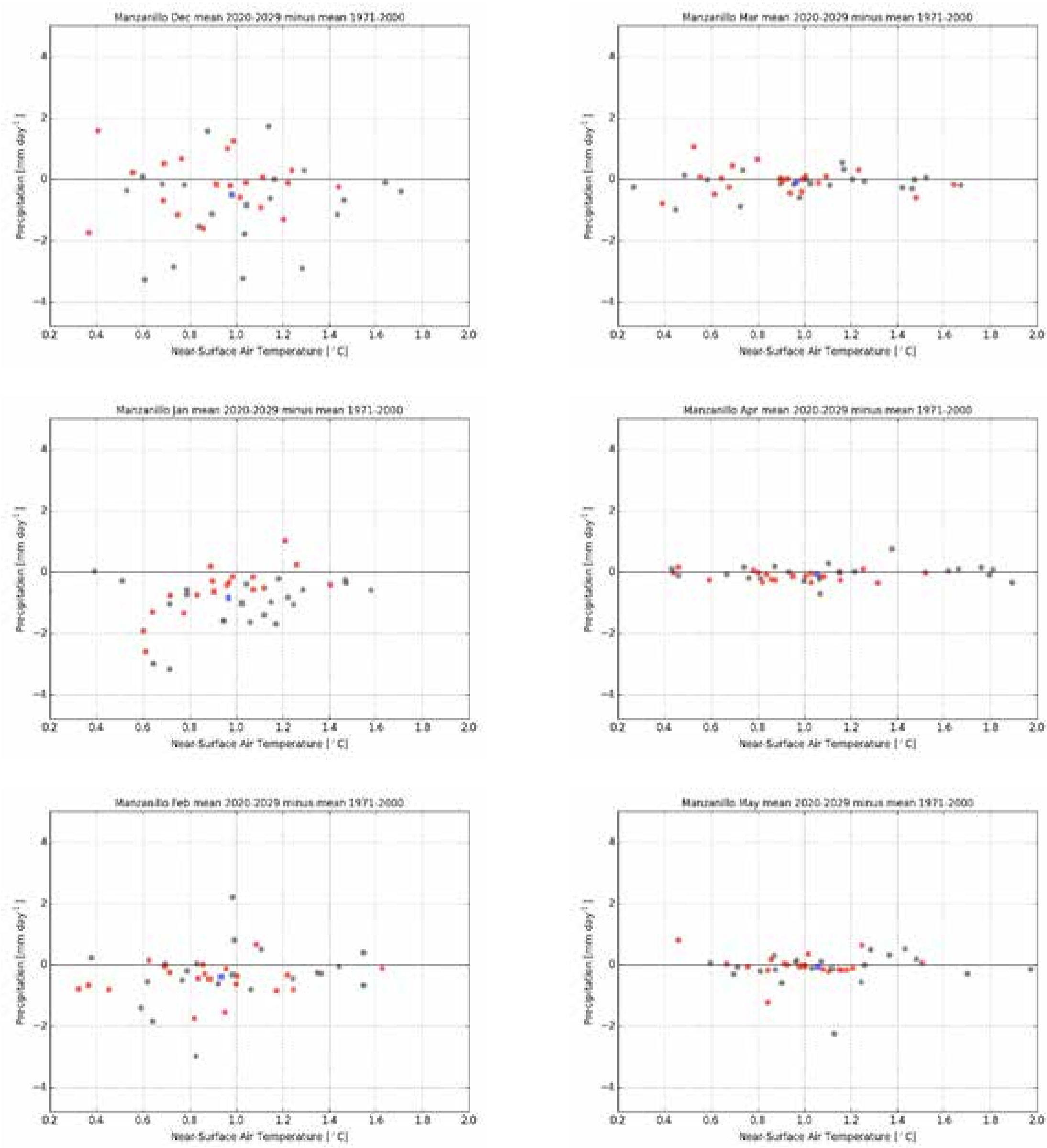


FIGURE 4.39

As for Figure 4.38 but for wet season months of June to November. (Source: Report authors)**.**

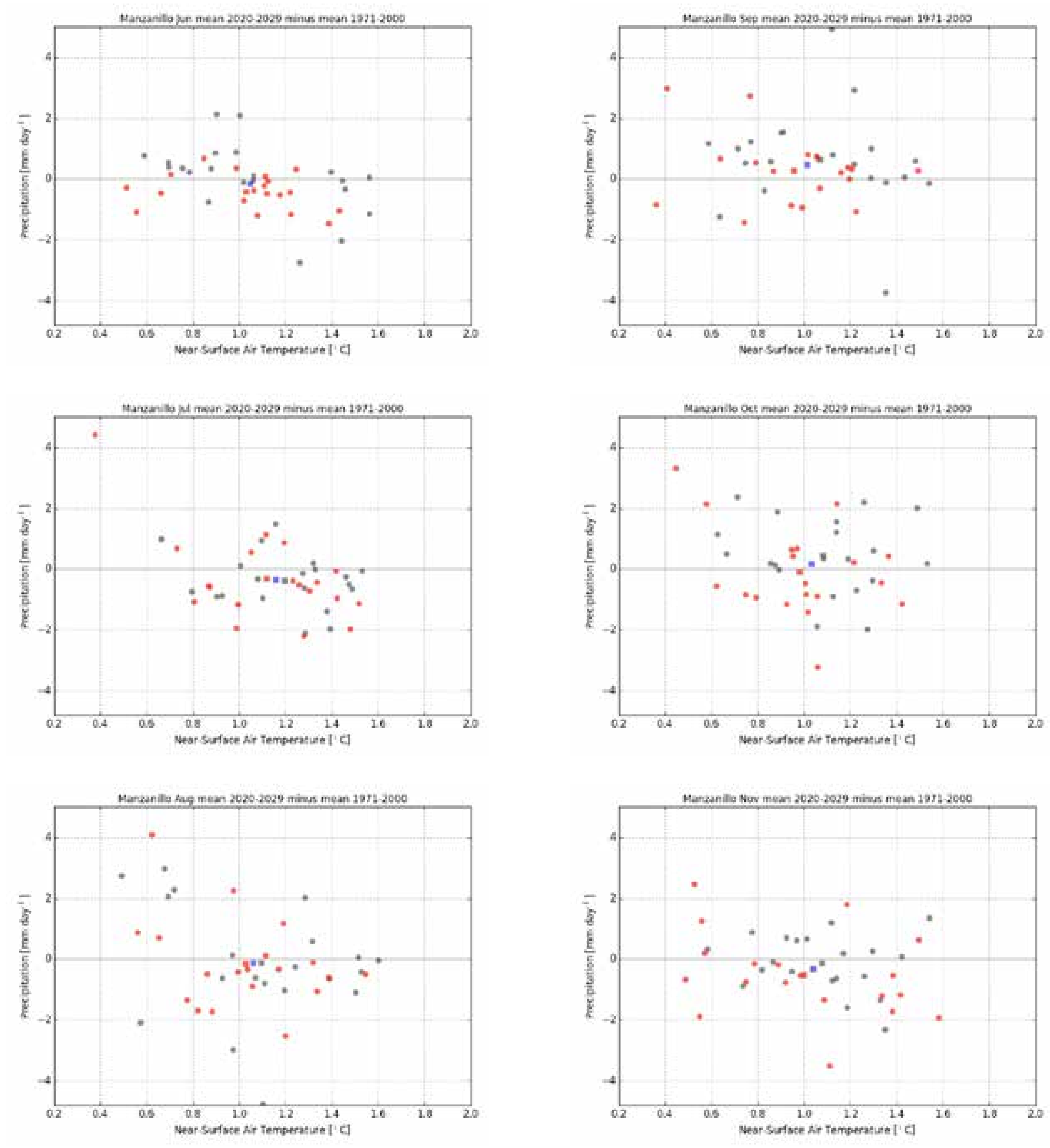


FIGURE 4.40

Scatterplots of temperature change (deg C) and precipitation change (mm/day) for dry season months from CMIP5 models forced with RCP 8.5 for Manzanillo for the 2040s. Red circles are models used in the Mexican national climate change scenarios. Additional CMIP5 models are shown in gray circles. Red and gray squares are the mean of the red and gray circles respectively. Blue squares are the mean of all models. Individual scatterplots are for the months December to May. (Source: Report authors).

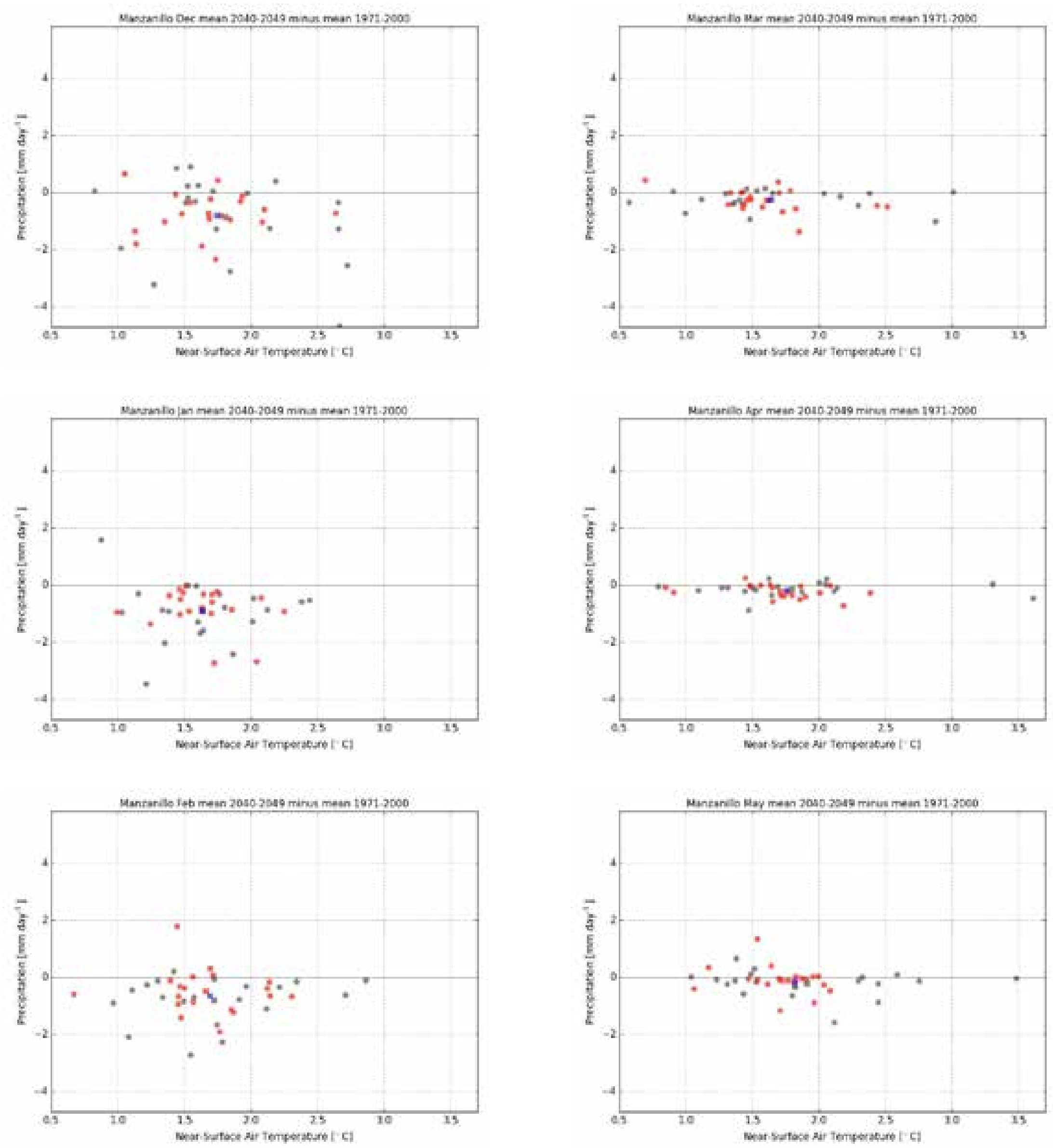


FIGURE 4.41

As for Figure 4.40 but for wet season months of June to November. (Source: Report authors)**.**

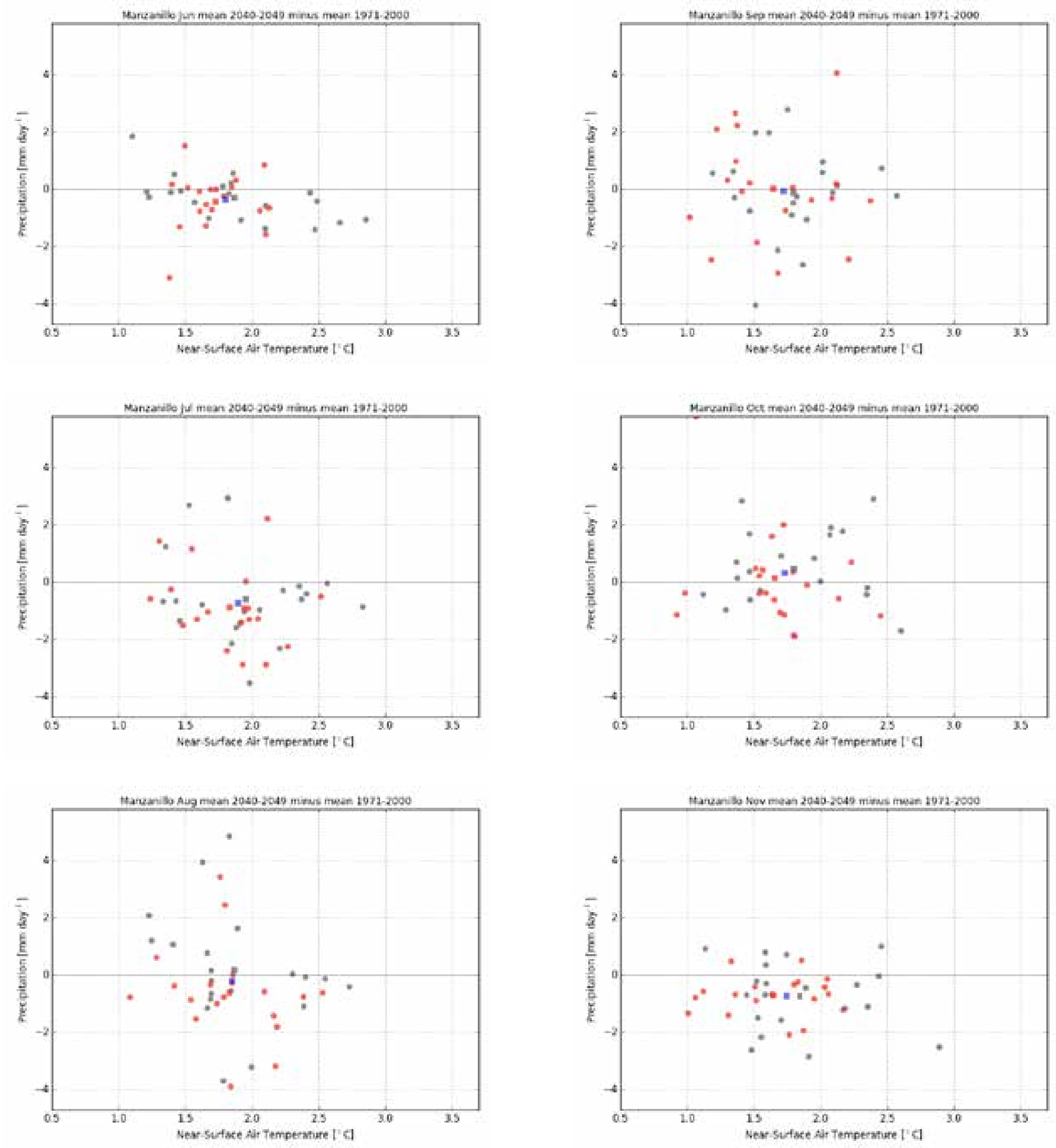


FIGURE 4.42

Scatterplots of temperature change (deg C) and precipitation change (mm/day) for dry season months from CMIP5 models forced with RCP 8.5 for Manzanillo for the 2070s. Red circles are models used in the Mexican national climate change scenarios. Additional CMIP5 models are shown in gray circles. Red and gray squares are the mean of the red and gray circles respectively. Blue squares are the mean of all models. Individual scatterplots are for the months December to May. (Source: Report authors).

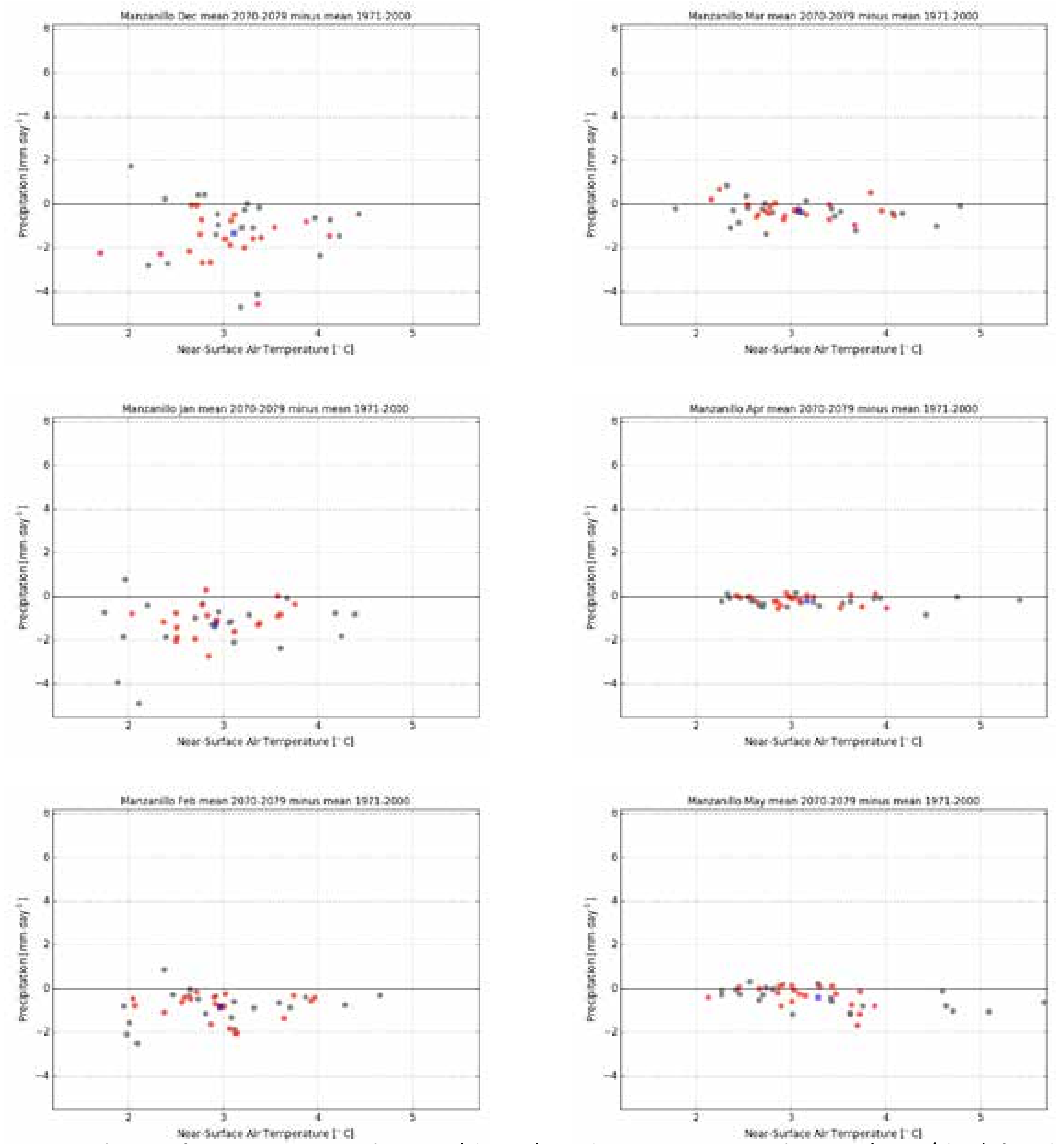
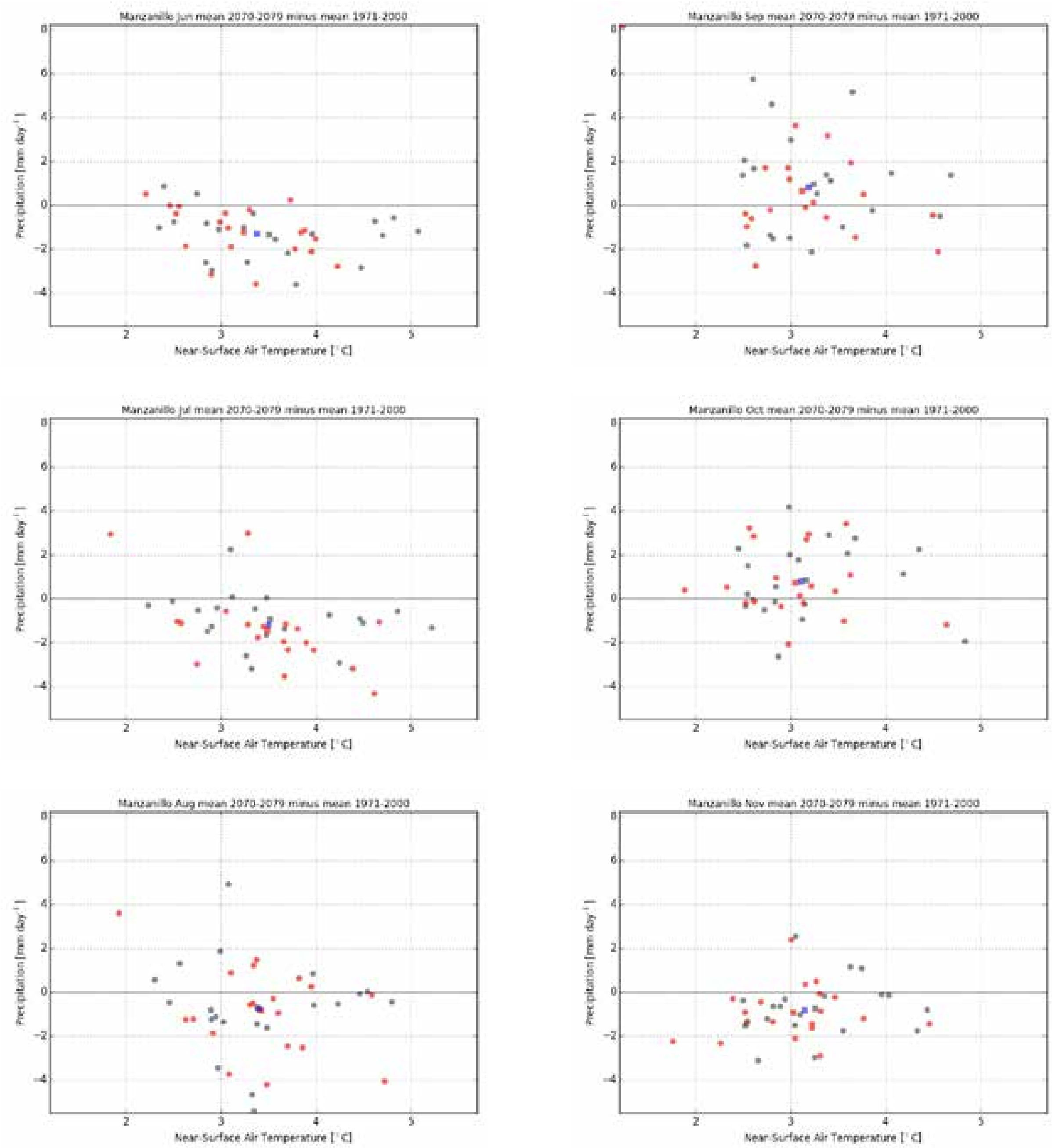


FIGURE 4.43

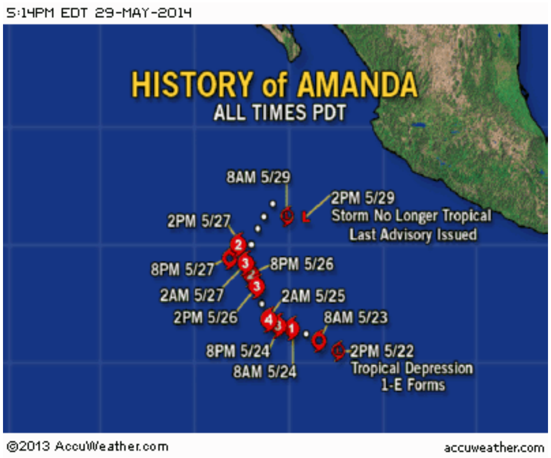
As Figure 4.42 but for wet season months June to November. (Source: Report authors)**.**

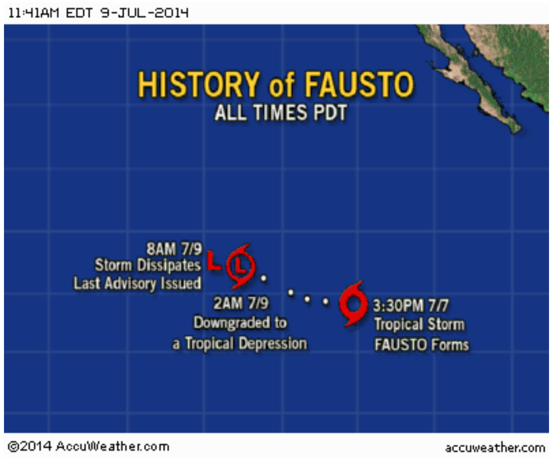


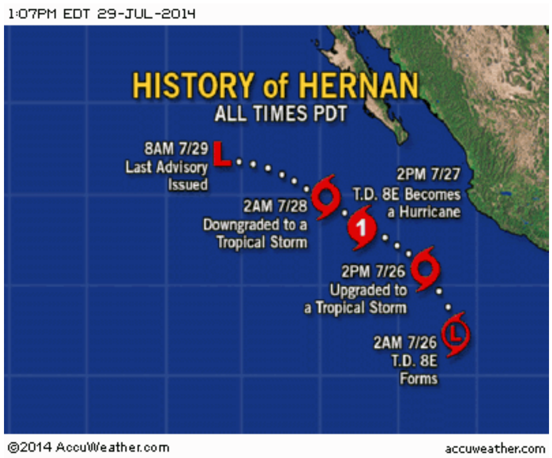
4.3. Tropical cyclones

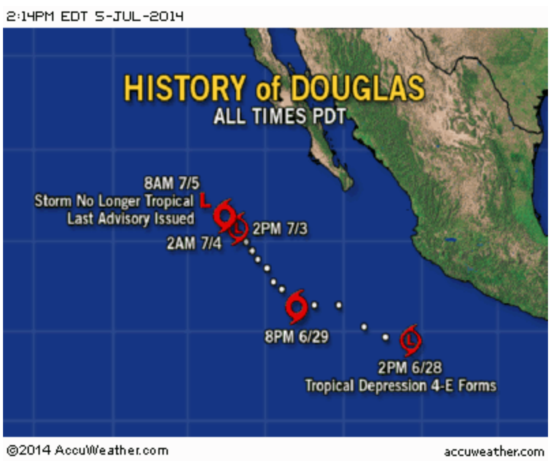
FIGURE 4.44

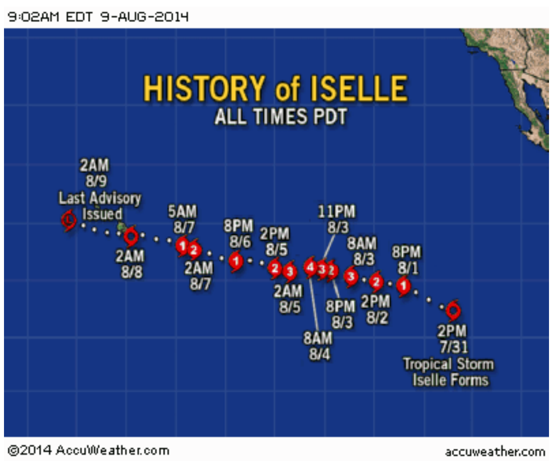
Tracks of tropical storms in 2014 not responsible for limiting availability of facilities at PEMEX. (Source: AccuWeather.com).



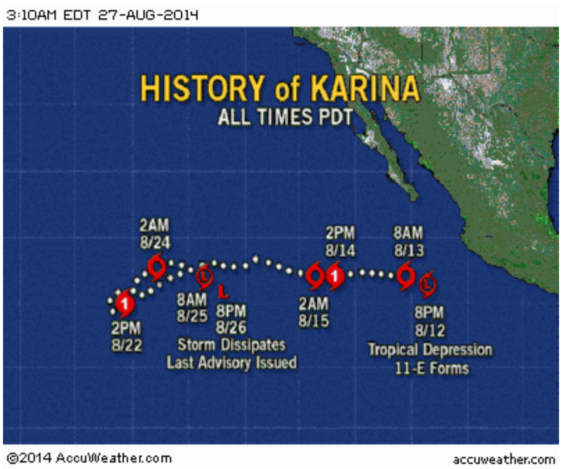


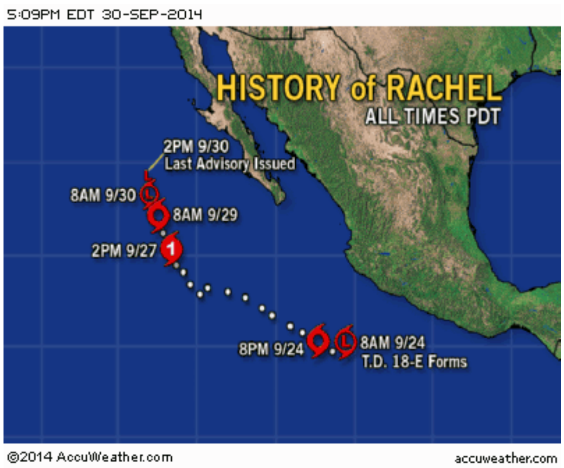


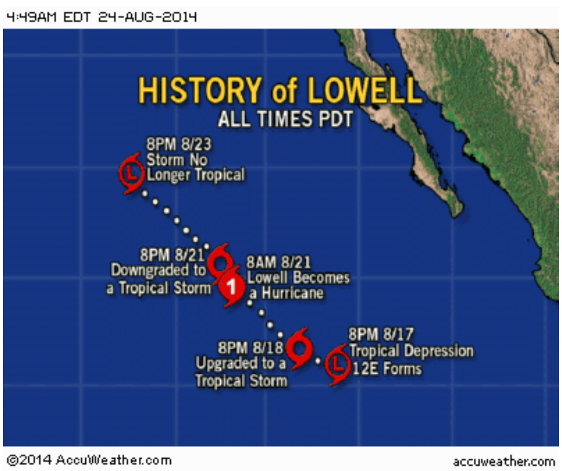




Continued: Tracks of tropical storms in 2014 not responsible for limiting availability of facilities at PEMEX







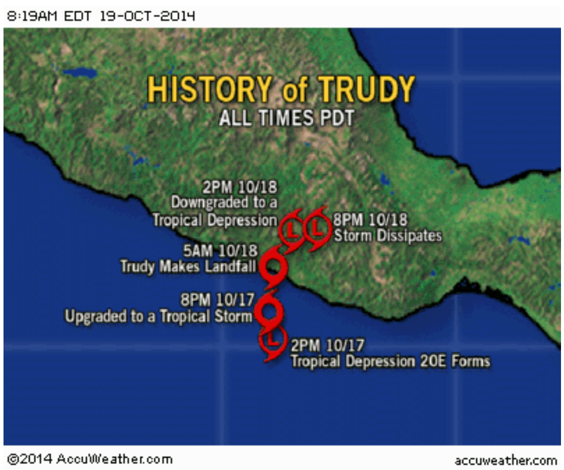
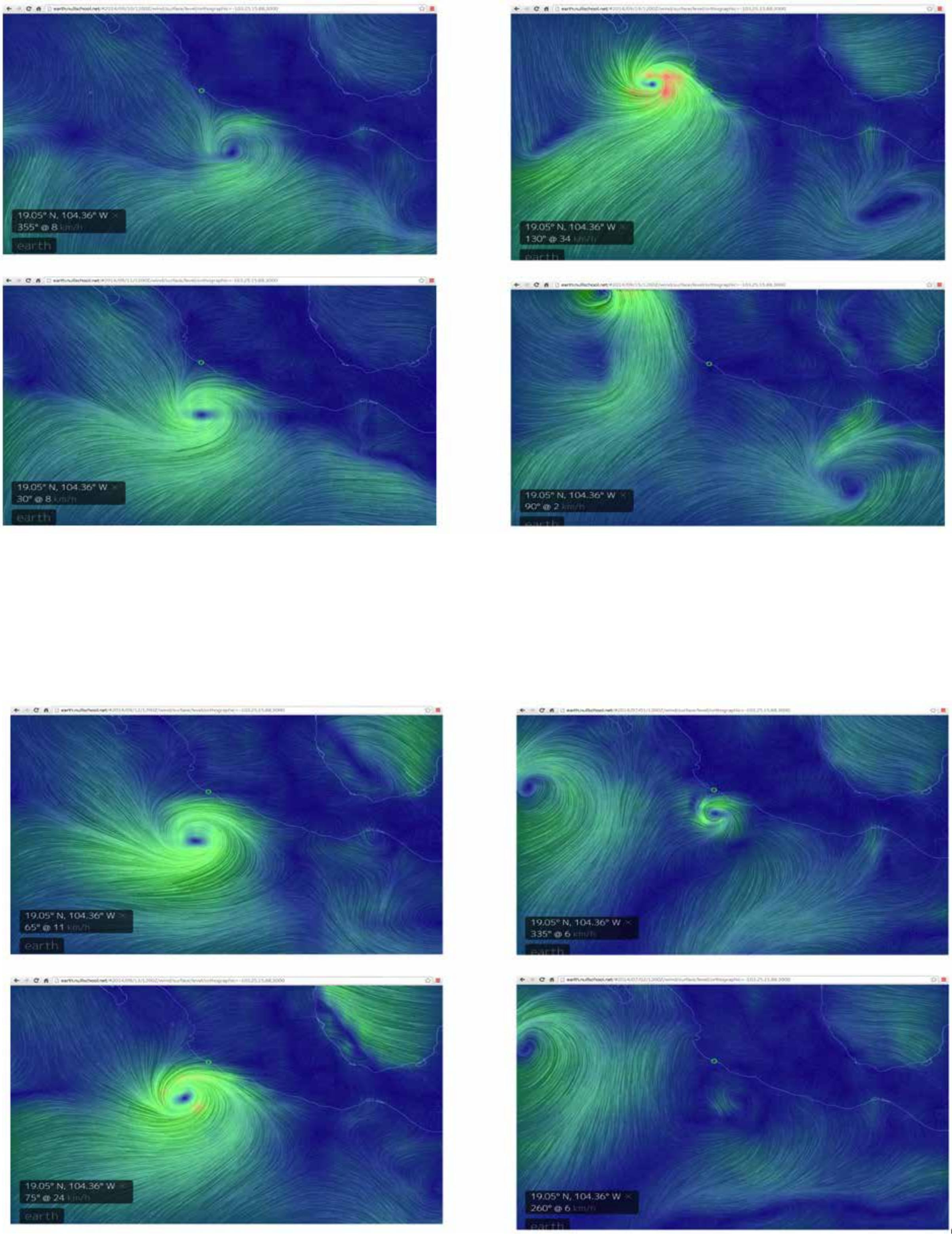


FIGURE 4.45

Near-surface winds from a sample of days in 2014 on which PEMEX facilities at Manzanillo were inoperable. Left column: 10, 11, 12, 13 September 2014. Right column: 14, 15 September, 1, 2 July 2014. (Source: http://earth.nullschool.net/1).



5. Potential impacts of climate change on design flows at the Port of Manzanillo

5.1 Introduction

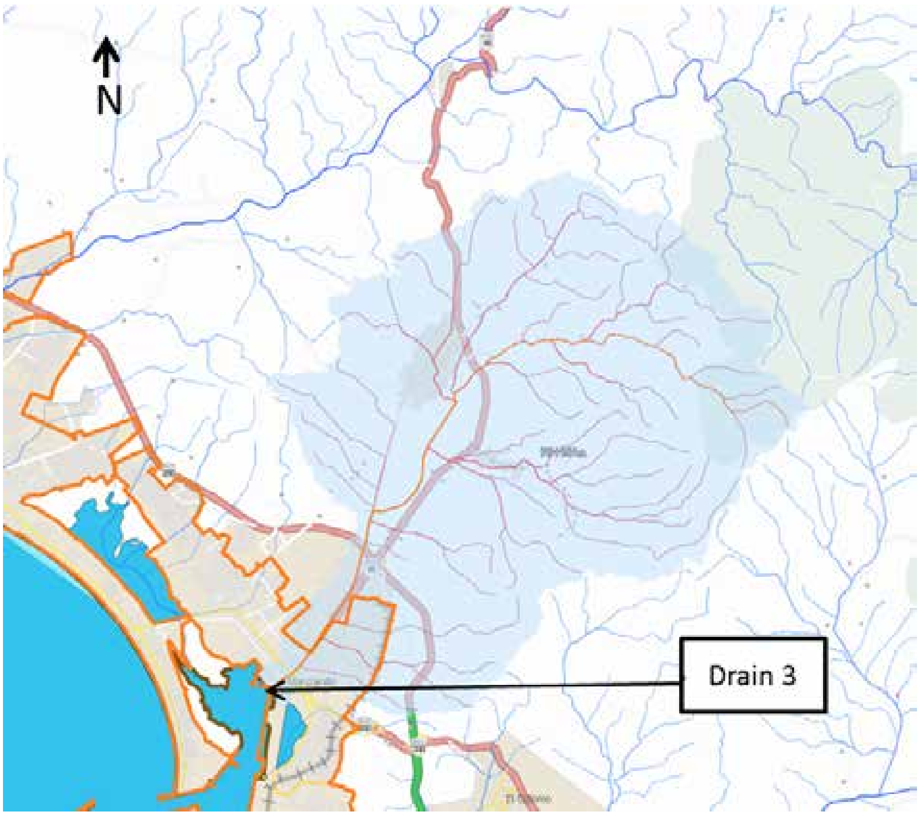
The objective of this assessment is to estimate the impacts of climate change on flooding at the Port of Manzanillo. The analysis focuses on flooding resulting from surcharging of the Arroyo Camotlan stream, where flooding events were observed in 2011, 2012, and 2014. The Arroyo Camotlan stream discharges through Drain 3 (Figure 5.1).

For the purposes of this study, flood flows are assessed according to the peak flows calculated for the Drain 3 catchment. A method has been developed to provide a first approximation of the change in magnitude of peak flows for this catchment under climate change. The United Nations Intergovernmental Panel on Climate Change documents related to the Fifth Assessment Report (IPCC AR5) are used for the climate change projections and related discussion.

The results can be extrapolated to other catchments of concern in the Port area; they are also used within a qualitative discussion on the issue of sedimentation in the Port area.

FIGURE 5.1

Port of Manzanillo and Arroyo Camotlan Catchment. (Source: CONAGUA, 2014[2]).



5.2 Peak flow changes to the Drain 3 catchment

The catchment characteristics and peak discharge values were determined with a model used by the Comisión Nacional del Agua (CONAGUA). Within the model, the Rational Formula was used to estimate peak discharge for various return periods for Drain 3. It is noted that the delineated catchment area of 39.4 km^2 is considered to be at the upper limit of the applicability of the Rational Formula[3]. The catchment runoff coefficient was estimated to be 0.25.

To obtain the catchment rainfall intensity, the catchment time of concentration was estimated using the Kirpich equation:

$$T_C = 0.0663*(L/S^{0.5})^{0.77} \qquad (1)$$

Where TC is the time of concentration in minutes, L is the length of the channel from the divide to the culvert (km), and S is the average channel slope (m/m). L and S were estimated to be 11.7 km and 0.069, respectively. TC was thus calculated to be equal to 70 minutes. It is noted that while the Kirpich equation was used in this assessment, the equation was developed for use in catchments with sizes up to 80 ha.

Table 5.1 shows the rainfall intensities and estimated peak flow estimates for various return periods relative to the Drain 3 catchment.

TABLE 5.1

Estimated Rainfall Intensities and Return Period Flows for the Drain 3 Catchment. (Source: Report authors)**.**

Return Period (years)	Intensity (mm/hr)	QPeak (m /s)
2	38.3	107
5	58.8	165
10	74.3	208
20	89.8	252
50	110.3	309
100	125.1	350
200	141.3	396

Estimating the expected peak discharges for the Drain 3 catchment resulting from climate change requires an assessment of the potential changes in rainfall intensity as projected under climate change. This requires an analysis of intensity-duration-frequency (IDF) data for the area, which is dependent upon extreme precipitation projections.

5.3. Challenges with future IDF estimation

In the IPCC AR5 assessment, representative concentration pathways (RCPs) are used to represent potential greenhouse gas (GHG) emissions scenarios. The RCPs are used to run global climate models (GCMs) that output projections for parameters such as temperature and precipitation for future time periods. Projections suggest that in the future, there will be a shift to more intense individual storms and fewer weak storms[4].

While methods to update IDF data considering climate change are emerging[5], the capability of GCMs to project changes in extreme precipitation is limited. Sources of uncertainty include:

- GCMs do not generally produce a daily rainfall climatology which matches the observed[6]
- Precipitation extremes are associated with the coincidence of specific weather patterns, for which the return period and persistence is not well understood (Boucher et al 2013)
- GCMs simulate thermodynamical components better than they simulate dynamical components. Therefore, projections may be more accurate for some areas of the globe (e.g. extratropics) compared to others (e.g. tropics)[7].

Compared to extreme precipitation projections, there is more confidence in GCM model simulations of total precipitation[8]. However, a relationship between changes in total precipitation and extreme precipitation has not yet been identified[9]. Generally, the frequency and intensity of extreme rainfall events are expected to increase more than total rainfall. For example, researchers in Canada10 observed that for a climate station in northwestern British Columbia (BC) Canada, the 25-yr, 24-hr rainfall event was projected to increase by 25%. In contrast the average annual rainfall was projected to increase by a smaller amount, or approximately 6% annually by the 2050s.

5.4. Rainfall intensity and peak flow estimates

For the Central America/Mexico region under the RCP 4.5 scenario, annual precipitation is projected to decrease by up to 10%[11]. However, for the same region, the 20-yr median return value for 24-hr precipitation is projected to increase by approximately 8% for the period 2046-2065 (2050s) and approximately 10% for the period 2081-2100 (2080s)[12].

For the purposes of this high-level assessment, the projected extreme precipitation increases stated above were applied to the values in Table 5.1. Note that the scaled increase that has been projected for the 20-yr, 24-hr storm was applied to the other rainfall return periods. However, based on the experience of researchers in Canada[13] for the climate station in BC, it was observed that rainfall intensity changes were projected to differ for each duration and return period, depending on the RCP model output. Therefore, the numbers in Table 5.2 represent possible changes in IDF values only and should be considered with caution.

The Rational Formula's linear function means that the return period peak discharge values are projected to increase by a proportion equivalent to the change in rainfall intensity, namely 8% for the 2050s and 10% for the 2080s. Table 5.2 compares the estimated return period peak discharges for the Drain 3 catchment for the various return periods and future time periods.

TABLE 5.2

Return period peak discharge projections for the Drain 3 catchment. (Source: Report authors)**.**

	Historical		2050s		2080s	
Return Period (years)	I70 (mm/hr)	Qp (m /s)	I70 (mm/hr)	Qp (m /s)	I70 (mm/hr)	Qp (m /s)
2	38.3	107	41	116	42	118
5	58.8	165	64	178	65	181
10	74.3	208	80	225	82	229
20	89.8	252	97	272	99	277
50	110.3	309	119	334	121	340
100	125.1	350	135	379	138	386
200	141.3	396	153	428	155	435

5.5. Changes to sedimentation rates

Sediment discharge varies proportionally with flow discharge, for example according to Equation 2 (Maidment 1993):

$$Q_S = Q \times C_S \times k$$

Where QS is the sediment discharge (tons/day), Q is the water discharge, CS is the concentration of suspended sediment and k = 86.4 (assuming a sediment specific gravity of 2.65).

To the author's knowledge, there are currently no estimates of sediment concentrations within the Drain 3 catchment; therefore, estimates on the potential for changes to sediment discharges under climate change are restricted to the following qualitative discussion.

Based on Equation 2, it is likely that increasing peak flows will lead to increasing sediment loading. However, it is unknown to what degree the increase might be. If changes in the IDF and peak flows do not affect sediment concentrations, then sediment loading could be expected to increase proportionally with peak flows. However, more frequent and higher-intensity rainfall events could have the effect of causing rain drops to dislodge a greater number of soil particles upon contacting the ground surface. This would increase sedimentation non-linearly. Similarly, higher peak flows could increase channel erosion non-linearly.

5.6. Conclusion and recommendations

An analysis has been completed to obtain a first approximation of the change in peak flows for the Arroyo Camotlan stream (Drain 3 catchment). Estimates were generated corresponding to various return periods and two future time periods (2050s and 2080s).

There are several limitations to the results of this high-level assessment. First, it is noted that the method used to estimate peak flows, including the time of concentration, employed formulas that are not considered appropriate for the Drain 3 catchment size. Second, the changes to the rainfall intensity for one frequency of return were applied to all return periods. The numbers were generated to provide possible future values to comment on the various relationships discussed in this study.

While there is low confidence in climate change projections for precipitation extremes, generalized values were obtained as reported by the IPCC for the Central America/Mexico region for two future time periods under one RCP. The results suggest that both the rainfall intensity and peak flows for the Drain 3 catchment will increase in magnitude in the future under climate change projections. This will likely have the effect of increasing the potential of problems caused by flooding at the Port. One of the stated potential issues would be that of increased sedimentation.

The following activities are recommended to obtain more detailed estimates of flooding and sedimentation potential at the Port of Manzanillo:

- Obtain land use information to allow a more robust determination of peak flows and annual runoff for the 10 identified catchments that drain to the Port
- Develop a rainfall-runoff model for catchments upstream from the 10 drainage points
- Apply the method outlined by Srivastav et al. (2015) to update the IDF data for Manzanillo climate station
- Develop a hydraulic model that links runoff with the drainage network capacities and sea levels

Data requirements include:

- LiDAR topography
- sediment concentration
- Land use and land cover
- Confirm ground survey information of the 10 drains and outlet channels, including invert and culvert capacities for all drains
- Dimensions of the Laguna de la Garzas spillway, and invert elevation.

6. Climate change risks, opportunities and adaptation in ports

The following sub-sections describe how a changing climate can affect key aspects of port operations and provide examples of adaptation measures which can be considered. Case studies from across the globe are provided under each of the subsection.

6.1. Demand, trade levels and patterns

Being sensitive to commodity price and volume fluctuations, ports are vulnerable to changes in the production and demand for goods, effects of global and regional trade dynamics and changes to, or emergence of new, shipping routes. Due to climate change, some industries and sectors may see drastic changes in the geographical distribution of exports and imports, with some regions drastically reducing their overall production of a commodity while others in contrast increase their production and overall economic performance. There are also likely to be changes in the share of trade globally, with regions more negatively affected by a changing climate losing their comparative regional advantage and regions less negatively impacted (or benefited) by new climatic conditions gaining comparative regional advantage and proportion of global trade. This is likely to be the case for example in agricultural trade where, as a result of climate change impacts, some regions may experience a radical reduction in food production due to increased temperatures and water stress while others may benefit from shorter winters and better overall production conditions.

Labor migration and population growth can also affect the demand for port services and the location of the customer base. The use of port facilities may additionally become dependent on: customers' perceived reliability of the port in the face of extreme weather events; the performance of other industries which ports are heavily reliant on (such as tourism, agriculture and manufacture); and the ability of ports to keep up with changing conditions in other industries and their related service and facilities requirements.

Shipping routes may also be transformed by the expected opening of new routes across the Arctic and the expansion of their annual availability due to receding ice, offering another trading route between Europe and Asia. This for example could reduce shipping journeys by about 4,000 miles (30%) from the current alternative via the Panama Canal and enable new entrants to the global trade market[14]. How changes in productivity and other impacts are reflected in changing prices and competitiveness will drive the changes in world trade development, with impacts varying considerably across sectors and regions[15].

Trade is therefore a potentially significant risk area for ports that warrants further consideration. However, due to the uncertainties associated with future demand, supply and trade patterns, it can be difficult to quantify climate impacts with a high degree of confidence.

Adaptation options	
Informational measures	• Monitor changes in supply and demand of traded products (e.g. changes in price and volume) that can be caused by climate change impacts, particularly on productive systems that are highly sensitive such as agricultural products. • Refine business forecasts and strategies to account for potential changes in trade that may be influenced by a changing climate. • Monitor customer expectations in terms of reliability of port services and negative effects of disruptions. Develop a communication plan on how these are being addressed. • Monitor research on climate change impacts on shipping routes. • Monitor shipping routes and ports which are projected to see significant changes in trade volumes and access to new markets.
Operational measures	• Develop new and potentially more cost-effective shipping routes.
Technical / physical measures	• Expand, upgrade or adjust port facilities in response to changing customer demands and flow patterns.
Governance and capacity building measures	• Explore investment opportunities in new product/business lines and shipping routes. • Account for climate change and current extremes in business continuity plans, forecasts of trade patterns and strategy plans.

Box 61 Case study: Planning for Future Growth (Source: NOAA, 2015[16])

The selection of Tampa Port's capital investment projects is based on a strategic assessment of industry trends, local traffic and use data, and projected future freight requirements. As a result of the assessment, the port is planning and implementing projects that increase the performance and longevity of the existing infrastructure.

One of the most critical priorities for Tampa is to preserve and enhance vessel access to multiple port terminals, making passageways accommodate the growing size of the ships coming to port. Key projects include strategically deepening channels and berths and widening a portion of the channel to accommodate two-way traffic. Other infrastructure investments that are important to help meet increasing freight demands include the phased expansion of the port's container terminal and the reconstruction of the port's liquid bulk petroleum terminal.

(Source: NOAA, 2015[17])

Box 62 Case study: Effects of storms in seaborne trade of coal in Australia (Source: Port World, 2007[18])

In 2007 shipping delays and congestion due to storminess and bad weather in coal terminals of Australia resulted in losses of more than US$950 million. Inadequate rail and terminal capacity created severe bottlenecks that tied up many large vessels in Australian ports. Vessels had to wait on average more than 32 days to load coal, compared with 18 hours for general cargo. At its worst, congestion at Australian ports saw queues of more than 50 vessels. This experience has forced buyers in Asia to seek alternative suppliers in South Africa and Indonesia. Delays also drove shipping rates up by 40% for dry bulk (such as coal and iron ore) shipping.

Prior to the storm, there were ongoing problems of congestion 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 aggravated export capacity constraints[19]. 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[20].

6.2. Navigation, shipping and berthing

Changes in water depths, sedimentation rates, and river flows can affect navigation, shipping and berthing at ports. Accelerated sea level rise is likely to result in increasing water depths, which may be beneficial to ports as it generates a higher draft and leads to lower reliance on dredging maintenance. However, sea level rise may surpass operability thresholds for a range of infrastructure, for example in terms of bridge clearance for larger vessels and water level to dock height, which affect the vertical operability range of quays, piers and material handling. This may result in an increase in capital expenditure.

Similarly sea level rise and high wave intensity may result in an increase in coastal erosion, especially for locations with high tidal ranges. Coastal and riverine erosion may also be driven by high rainfall events and extreme wind speed, resulting in greater accumulation of sediments at the coast, potentially increasing costs of dredging maintenance. Investments may also be required to protect land stability in areas were critical infrastructure is threatened by erosion.

Reduced precipitation may also pose a problem as lower water flows can hinder navigability in rivers, lakes and channels, affecting port access. Extreme wind conditions may also affect navigability and maneuvering of large vessels carrying empty containers or very large/bulky cargo.

Adaptation options	
Informational measures	• Carry operability assessments for berthing and maneuver to understand operational thresholds in light of sea level rise and potential changes in storminess. • Monitor customer responses to berthing restrictions and required changes in cargo loads. • Review contingency plans for delays and loss of traffic caused by reduced navigability or slowed maneuvering. • Monitor levels of sedimentation and assess trends in historic dredging frequencies and quantities. • Monitor changes in regional and international shipping conditions and costs due to weather events.
Operational measures	• Update dredging programs and schedules. • Implement sea level monitoring at key locations in the port.
Technical / physical measures	• Account for sea level rise when doing inventories for replacement and refurbishment of infrastructure. • Use vessels with shallower/deeper drafts according to changing conditions. • Construct sediment traps. • Management of inlets. • Raise berthing height to accommodate sea-level change.
Governance and capacity building measures	• Engage with navigation authorities to ensure adequate management of risks. • Engage with relevant planning authorities for the design and construction of adaptation measures. • Engage with local / city administrators to ensure monitoring of sea level is undertaken at key locations on the coast. Alternatively, discuss the potential for use of remote sensing satellite data.

Box 6.3 Case study: Port Canaveral Port Authority Sediment Trap (Florida, US)

(Source: Canaveral Harbor, Florida Integrated Navigation Study Report and Environmental Assessment, 2012[21])

After several hurricanes in 2004, Port Canaveral in Florida had to be dredged to enable ships to reach the port. As a result, the South Jetty Sediment trap was excavated in 2007, with an offshore disposal system for non-beach compatible material. Subsequent sand bypass operations were also carried out. Some of the material excavated has been further re-used for dune restoration. The trap, which is aimed to prevent the build-up of sand barriers during storm events, has withstood two hurricane events including one in 2009 when it held back 100,000 cubic yards of sediment. This sediment was then used for beach nourishment projects.

6.3. Goods handling and storage

Handling and storage of goods in port facilities can be affected by climate change in several ways, depending on the sensitivity of the type of cargo being handled and the equipment used.

High wind, extreme rainfall and lightning can affect crane operations and damage their mechanical and electrical systems. The use of cranes over a certain height may be temporarily halted resulting in commercial delays. The loading and unloading of very weather-sensitive goods can be affected by climatic conditions. For example in the case of highly water sensitive goods such as agricultural and mineral bulk, operations have to be stopped even under light rain when goods storage facilities are uncovered. Increased rainfall and storm intensity may, on the other hand, also result in higher risk of flooding of storage areas.

High temperatures may have positive or negative effects. One the one hand, it can improve port operations in cold regions, on the other hand, in tropical regions higher temperatures may affect the work force and result in an increased occurrence of heat stress events. Additionally, high temperatures and changing rainfall may affect the occurrence of pests, rust, mold and diseases, increasing the need for the use of pest and humidity control techniques.

For goods requiring refrigeration or cooling facilities, increases in temperature may result in higher cooling demand with consequential increase in energy expenditure and potentially increased maintenance costs. Access to water and energy services may additionally be affected by climate change due to power and water disruptions. Countries that are heavily reliant on hydropower and will experience lower annual precipitation may be more prone to power shortages. Thermal plants where water is cooled by freshwater bodies can also be affected by incoming water being too warm to cool the plant efficiently, or the discharge body accepting coolant discharge is already approaching environmentally acceptable temperature thresholds.

Areas already affected by dust may see problems exacerbated under drier, hotter and windier conditions.

Adaptation options	
Informational measures	• Review utility contracts to determine whether the port has priority rights over others in the local area in terms of supply continuity. • Assess condition of storage areas and vulnerability to climatic events. • Carry out an energy audit and identify opportunities for reducing energy consumption. • Monitor dust problems and review dust mitigation measures to take into account changing conditions.
Operational measures	• Implement procedures for handling materials under adverse climatic conditions. • Implement procedures for quality checks on perishable goods before, during and after climatic events. • Re-organize container storage and handling equipment to increase resilience to aspects such as flooding.
Technical / physical measures	• Select equipment used for handling cargo on the basis of the sensitivity of the products, aiming to increase the climate resilience of the handling system. • Proactively manage cooling, insulation, refrigeration and ventilation systems (keeping in mind replacement technologies will have a lower carbon footprint than others) and consider use of natural ventilation. • Reduce water use (e.g. water recycling and rainwater harvesting) and consider use of sea water for cooling and non-potable use. • Implement flood management and defense mechanisms for storage facilities.
Governance and capacity building measures	• Discuss with utility providers the resilience of supply and sources of concern in a changing climate. • Engage with on-site users of goods handling and storage facilities to assess how they are impacted by climatic events. • Review contingency plans for alternative storage areas and locations. • Engage with relevant authorities for the design and construction of climate resilient goods and storage facilities.

Box 6.4 Case study: A very green terminal. (Source: Portsmouth International Port, 2015[22])

The new terminal at Portsmouth International Port is the first public building in the UK to be heated and cooled using thermal energy from seawater. This has reduced the port's carbon footprint, using only 20% of the energy of a traditional boiler/chiller system. Seawater is also used to flush toilets, drastically cutting potable water consumption.

'Windcatchers' on the roof are being used for natural ventilation, reducing the need for costly mechanical air-conditioning. Higher coastal wind speeds allow the system to supply and extract air to and from the terminal.

Thanks to its sustainable features, the building has achieved a BREEAM (the international environmental rating system for buildings) rating of "very good".

(Source: Portsmouth International Port, 2015[23])

6.4. Vehicle movements inside ports

Being located in low-lying coastal areas, ports are vulnerable to the effects of sea level rise and to changes in wave regimes, which can result in coastal flooding. These events can be exacerbated during storm events by the presence of high storm surges. Additionally, where ports are located near river systems or at the basin of river catchments, intense rainfall can lead to surface flooding. The extent of flooding can be easily exacerbated by changes in land use in the river catchment such as urban growth, deforestation and construction of impervious surfaces. During storm events, heavy downpours of water may overwhelm the drainage system of the port causing surface flooding.

Extreme events can cause delays and interruptions to port operations, disrupting the connectivity within the port and with its external road and rail networks. While most of the delays will have a duration equal to the length and the severity of the flood, in some cases further delays are experienced. For example, in cases where surface runoff has carried significant amounts of sediment and solid deposits, the interruption of road operations may be delayed until full clearance of the additional material is completed.

Adaptation options	
Informational measures	• Carry out a flood risk assessment for the port and identify key areas where vehicle movement can be interrupted. • Review (and upgrade where necessary) standards for flood risk protection in light of knowledge on climate change impacts. • Monitor on-site road condition and maintenance costs.
Operational measures	• Implement safety procedures for cargo movements during adverse climatic conditions. • Implement site transport emergency lock-down plans.
Technical / physical measures	• Retrofit infrastructure or assets that are vulnerable to flooding, in particular critical infrastructure (e.g. insulate electrical equipment, create flood defenses, use water resistant materials). • Adopt measures to improve drainage systems or create smart drainage designs taking into account potential for changes in precipitation. • Upgrade road surfaces to make them more climate resilient. • Traffic management measure to minimize bottlenecks during extreme events / site evacuation. • Coastal re-vegetation/afforestation above the inter-tidal zone to reduce pluvial flooding. • Protective defenses to reduce coastal flooding (coastal barrages, dykes, mangrove re-establishment and maintenance, coral reef establishment and maintenance)
Governance and capacity building measures	• Avoid port expansions into very low lying areas. • Review plans for evacuation and business continuity during extreme events.

Box 6.5 Case study: Storm water management and the Port of Brisbane smart drainage system

(Source: Brisbane Port Land Use Plan, 2013[24])

Implementing the principles of water sensitive urban design, the drainage system at the Port of Brisbane (in Australia) has accounted for a series of features, including:

Integrative measures for storm water management to reduce reliance on traditional tools (e.g. pipes and open concrete drains). For example, an increased use in bio-retention basins, filter strips and swales.

Providing opportunities for water infiltration through the use of permeable or semi-permeable surfaces in areas previously covered by traditional concrete (e.g. car parks).

Installation of rainwater tanks.

Development of a recycling water system for the irrigation of green spaces within the port's premises.

6.5. Infrastructure, building and equipment damage

Damage to infrastructure, buildings and equipment are amongst the most evident direct impacts of severe weather and a changing climate. Since most of a port's infrastructure is built with a projected lifetime of several decades, the impacts of climate change can materialize both in the short term (e.g. due to the destructive power of hurricanes) or in the long term (due to slow onset events such as sea level rise).

Increased flood risk is one of the key impacts of climate change on infrastructure. In most cases the implications of both coastal and pluvial flooding are the same, although salt water intrusion into groundwater can also have a corrosive and deteriorating effect on construction materials and equipment, increasing the need for repairs and maintenance. While shallow and temporary flood events may have minimal impacts on infrastructure and equipment (unless they become highly recurrent), extreme flooding risk associated with tropical storms and storm surges can cause far greater damage. The U.S. Environmental Protection Agency cautions that "stronger wave action and higher storm surges, especially when coupled with higher sea levels, are the primary threat to ports".25 Storm surges and sea level rise can damage quay and pier infrastructure, knock down buildings and storage areas and undermine infrastructural foundations and land stability. Strong wave action and fast moving waters can also dislodge containers and general cargo. When security and protection equipment are damaged during storm surge and flooding events (e.g. monitoring cameras are damaged or access gates and fences destroyed), the port may become temporarily vulnerable to other losses such as theft. Additionally, electrical equipment exposed to water or flooding of electricity sub-stations can result in black-outs, short-circuits and risk of fire.

Infrastructure, buildings and equipment may also be affected by extreme winds associated with tropical storms and hurricanes. Winds can detach lightweight unreinforced structures (e.g. metal roofs), with potential to damage other buildings and infrastructure. During Hurricane Katrina for example, extreme winds knocked doors off warehouses and blew off roofs[26]. Extreme winds also can halt the operation of equipment requiring stop-work and lock-down procedures for equipment such as cranes. This can lead to the suspension of full yard operations causing business delays.

Adaptation options	
Informational measures	• Improve understanding of extreme precipitation and temperature impacts on the maintenance requirements of infrastructure, buildings and equipment. • Monitor robustness of equipment and response of port users to extreme weather. • Develop wind precaution plans and early warning systems. • Monitor quay and pier foundations and other infrastructure (e.g. breakwaters and sea walls) for maintenance requirements due to increased under-scouring.
Operational measures	• Safety procedures for working in or near to buildings during adverse climatic conditions. • Site safety and infrastructure checklists and plans for assessing damage following extreme events.
Technical / physical measures	• Reinforcement of harbor infrastructure. • Upgrade of flood and erosion defenses. • Build protective defenses (coastal barrages, dykes, mangrove re-establishment and maintenance, coral reef establishment and maintenance). • Build permanent or transient wind protective walls[27]. • Coastal re-vegetation/afforestation (above inter-tidal zone) to reduce pluvial flooding. • Change design standards for lighting systems, cranes and other infrastructure to better withstand storms. • Insulate electrical systems and make water resilient. • Raise port elevation.
Governance and capacity building measures	• Enhance standards for port activities to deal with changing frequency and intensity of extreme events. • Update management guides for infrastructure development, taking into account design life and potential impact of future climate change. • Engage with stakeholders to plan landscape level flood management options.

Box 6.6 Case study: Early warning systems for "Wind Gusts" in the Port of Hong Kong (Kwai Chung and Tsing Ty Container Terminals)

In addition to local wind gauges installed on top of various quay cranes, container operators at Port of Hing Kong have started to work in closer collaboration with the Hong Kong Observatory and have installed advanced alarm systems. These systems provide 15 minutes advance notice before the gust wind arrives to the Kwai Chung and Tsing Ty Container Terminals area. Depending on conditions, containers may be re-positioned or brought down from the wind line. The terminals also keep a free area designed for empty containers where stacking up of containers can be up to 8 high.

(Source: South China Morning Post, 2015[28])

6.6. Inland transport beyond port

Inland transportation networks are a critical part of the supply chain for ports. 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 reduce a port's competitive advantage over others in the same region.

Transport systems can be affected by climate change in a number of ways. Longer periods of extreme heat, combined with traffic loading, speed and density can soften roads, leading to increased wear and tear such as rutting[29]. As a result, road surfaces are likely to require greater maintenance in higher temperatures. 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. However, in high latitudes where roads are built on frozen grounds or ice, melting due to higher temperatures will lead to road deterioration[30].

Extreme temperatures are also associated with increased incidences of rail buckling and it has been found that the temperature at which buckles occur can be significantly reduced by poor levels of track maintenance[31]. At a minimum, buckling can result in speed restrictions and, at worst, causing derailments[32]. Where there is an electric rail network, more extreme temperatures can damage overhead power cables through thermal expansion and line-side fires are an additional hazard during prolonged periods of drought, in which case trains may not be able to run [33 34 35].

Changes in precipitation can affect soil moisture levels, which can impact slope stability and result in more landslides affecting roads and railways embankments[36] and has the potential to impact on the structural integrity of roads, bridges and tunnels. Increases in heavy rainfall and snowfall events are likely to cause increases in weather-related accidents and traffic disruptions. Flooding will also occur more frequently where road drains are unable to cope[37], and combined with rutting of surfaces in high temperatures, increases the likelihood of standing water with consequences for road safety.

More frequent inundation and interruptions to travel on coastal and low-lying roads due to sea level rise and storm surge will occur in some locations. As a result, goods vehicles could be forced to seek alternate routes resulting in delays and additional fuel and personnel costs to the operator, as well as economic impacts along the supply chain. Underground tunnels and other low-lying infrastructure will also potentially be at risk of more frequent and severe flooding. Higher sea levels, changes in wave regimes and storm surges are likely to erode shorelines, road bases and undermine bridge supports[38].

Flooding can lead to damaged rail support structures and closure of terminals[39 40]. For railways that run close to the coast there could be an increased risk of coastal flooding due to sea level rise and storm surges. 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[41].

Research suggests that globally there could be fewer tropical cyclones overall, though there could be an increase in the frequency of the most intense tropical cyclones, this remains uncertain and is an area of active research[42]. More intense storms would lead to rapid deterioration of driving conditions, increase accidents and cause delays on roads. For example: high sided vehicles become increasingly unstable in gusts of over 45mph[43], there is a greater probability of infrastructure failures such as highway bridge decks being displaced as a result of strong winds[44]; and debris can be left on roads following storms.

Adaptation options	
Informational measures	• Assess how sea level rise and road drainage capacity may impact on the local road networks. • Assess how extreme weather events have impacted commonly used inland transport routes, and time & resource cost of past disruptions. • Determine locations / transport nodes that represent the highest risk if disrupted (e.g. key distribution centers, bridges (mountainous, riverine), coastal and mountain roads).
Operational measures	• Develop emergency plans with backup measures for re-routing cargo. • Subscribe to weather alert services or monitor climate and weather information covering the main transport routes45. • Provide drivers with emergency plans for extreme climatic events and alternative routes. • Undertake emergency event scenarios to determine whether on-site and off-site responses are adequate. • Develop supply chain contingency plans.
Technical / physical measures	• Ensure adequate communication links are available between transport operators and drivers (mobile phones, text alerts etc). • Logistics control rooms with live access to latest weather forecasts / warnings, preferably mapped onto the transportation network.
Governance and capacity building measures	• Engage with national road and rail transportation agencies and operators to ensure emergency plans are in place to manage disruptions. • Engage with the local highways agencies to contribute to future network infrastructure plans that incorporate climate resilience. • Engage with central government to discuss the economic importance of the port, and wider economic consequences related to poor transportation infrastructure.

Box 6.7 Case study: California Department of Transportation Realigns Highway 1. (Source: EPA, 2015[46])

The California Department of Transportation (Caltrans) is integrating climate change into its strategic planning. Caltrans is moving part of Highway 1, located in San Luis Obispo County, inland due to current and projected coastal erosion and sea level rise. Caltrans expects the realignment to protect the road for the next 100 years. In addition, the realignment is designed to minimize impacts to coastal resources by taking into account existing land use and conservation agreements.

(Source: EPA, 201547)

Box 6.8 Case study: Federal Highway Administration assesses the vulnerability of transportation networks. (Source: EPA, 2015[48])

The Federal Highway Administration (FHWA), California, developed a conceptual model for assessing the vulnerability of transportation systems to climate change. FHWA is working with five teams of transportation planners to test the model. These teams include the Metropolitan Transportation Commission in San Francisco, the New Jersey Department of Transportation/North Jersey Transportation Planning Authority, Washington State Department of Transportation and the Oahu Metropolitan Planning Organization in Hawaii. Lessons learned from these pilot projects will inform future efforts to develop guidance for other transportation agencies addressing impacts of climate change.

FHWA is also studying climate change impacts on transportation networks in the Central Gulf Coast region and evaluating adaptation options. The study is focused on:

- Understanding climate change effects on transportation infrastructure
- Identifying vulnerable transportation infrastructure in Mobile, Alabama
- Conducting detailed engineering and risk studies to identify options for strengthening critical transportation infrastructure
- Developing adaptation tools and methods that can be applied to other locations

6.7. Insurance availability and costs

Ports may face changes in insurance terms and costs as the incidence of severe weather-related events increases due to climate change. As port loss claims increase, especially in already vulnerable locations, insurance companies may ask more questions of ports about their resilience. Increasing climate variability and extremes will also drive an increased need by insurers to develop catastrophe models that take into account climate change[49]. Ports that are more vulnerable are likely to see increases in insurance premiums and excesses for asset damage, and in extreme cases, insurance may be restricted or no cover offered. It is likely that ports will also need increasingly to demonstrate that they have considered climate change and adaptation to future risks in their own asset planning, design and operation. Port operators with robust climate risk management strategies and business continuity plans could obtain more favorable insurance conditions than their competitors[50].

In terms of business interruption policies, disruptions to business operations may become more frequent, more unpredictable and more financially relevant to insurance companies[51]. This in turn may result in restrictions on the level of cover offered, an increase in premiums or changes in the definitions and severity of events that are covered by the insurance.

Changes in sea level rise, wave regimes and storm frequency and intensity may impact on the navigability and berthing of ships potentially resulting in more accidents and uncontrolled pollution incidents. The availability and level of marine public liability insurance may therefore change on the basis of insurers taking into account a changing climate and its effects on return periods of climatic events.

Adaptation options	
Informational measures	• Review insurance policies for Force Majeure or Act of God definitions, exclusions and adequacy of cover across all port operations. These should assess cover for asset damage, business interruption, maritime public liability, contingent business interruption and ingress/egress. • Analyze past claims triggered by weather-related events and costs to the port of excesses, lack of cover or outright exclusions. • Monitor insurance industry publications and research on including climate change risks in insurance policies. Determine how these could affect port cover, premiums and exclusions in the future.
Operational measures	• Raise awareness amongst port operators of insurance cover inclusions, exclusions and actions that can be taken to minimize weather-related losses. • Implement business disruption / continuity plans that take into account changing climate variability and extremes.
Technical measures	• Implement cost-effective adaptation actions across the port's operations and build resilience to weather-related events.
Governance and capacity building measures	• Prepare for questions from insurers by undertaking risk assessments and updating management and business continuity plans. • Engage with insurers on resilience actions that can be taken to manage risks and reduce premiums.

Box 69 Case study: Adapting to the problem. (Source: Allianz Group and WWF, 2006[52]).

The U.S. insurance industry has taken an adaptive approach to the impacts of increasing wind damage from hurricanes, lobbying for improved building codes as suitable technology and mitigation products come on the market (such as better hurricane shutters and wind resistant glass). In some instances individual insurance companies have required individuals to build with these materials in order to qualify for coverage.

Also referred to as form of adaptation, some insurers began withdrawing from high-risk coastal locations in Florida. This was seen as being in part due to regulators preventing insurers from raising premiums to reflect the increasing risk and hampering the market's ability to send price signals to educate consumers on the vulnerability of assets on exposed coastlines. The American International Group (AIG) is no longer writing new property policies in some parts of the Gulf Coast and another company, MetLife, stated that it would require extra inspections and storm shutters for new customers living within five miles of the sea before issuing cover.

While this form of adaptation is seen to protect insurance companies, it creates a shift in risk burden away from insurance companies and onto asset owners.

6.8. Social performance

Ports are commonly located near to or within large economic centers and surrounding communities. They bring wider economic and therefore social benefits both locally and nationally. A buoyant economic climate acts as a driver and need for port authorities to expand their operations and increase throughput. Alongside the positive socio-economic benefits, this can also lead to competition with surrounding communities over land and other resources. Located in low lying coastal areas at risk from sea level rise and coastal erosion, some ports may already be restricted in the land available to them, especially if surrounding communities are also impacted. Climate impacts on water resources and supply of utilities can all act as additional stressors on port-community relationships.

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 and my lead to pressure at some passenger ports.

Higher temperatures, heavier rainfall and increased wind speeds resulting from climate change can create additional health & safety risks for port workers, especially in relation to hazardous activities (e.g. flammable material storage and handling, use of machinery). Low level flood which allow work to continue can increase the risk of occupational hazards, while extreme flooding can lead to deaths and injuries.

Climate change may also affect worker exposure to air pollutants, generation and dispersion of dust, ozone and volatile organic compounds which are all sensitive to factors such as changes in temperature and rainfall. Impacts on pollution risk have the potential to affect the health and livelihoods of the wider surrounding community.

Safety management systems aimed at regulating movement of vessels within harbors and protection of the wider community from dangerous marine activities could fail under more extreme climatic conditions. Extreme rainfall, wind and/or wave conditions could also increase the risk of chemical or oil spills at ports and from ships in harbors.

Ports located close to vulnerable coastal communities such as 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. Elevated pollution risk also has the potential to impact on tourism facilities such as beaches, hotels and coastal ecosystems, adding additional stressors to the local community delivering tourism related services.

Adaptation options	
Informational measures	• Analyze previous social impacts to determine cause-effect pathways. • Monitor weather events for resulting social impacts and cause-effect pathways.
Operational measures	• Update operational, health & safety plans to modify working practices during heatwaves, extreme precipitation events and storms.
Technical / physical measures	• Use brownfield sites for expansion where available and economically viable if greenfield land is restricted or at risk from sea level rise / erosion. • Provide adequate safety equipment and emergency refuge facilities for site personnel.
Governance and capacity building measures	• Train site personnel to raise awareness of climate change and potential changes in frequency and magnitude of extreme events. • Liaise with emergency planners and the local community to ensure site evacuation procedures don't conflict with community evacuation procedures. • Develop port specific planning tools that take into account climate change and impacts on community and port sustainability[53]. • Integrate port planning with local plans, taking into account impacts of climate change on the port and local community.

Box 6.10 Case study: Catastrophic Storm Scenario. (Source: NOAA, 2015[54])

(Source: NOAA , 2015[55])

The Tampa Bay Regional Planning Council, in cooperation with local governments, businesses, and communities, developed a joint hazard preparedness plan. Nine counties surrounding the Tampa metro area were involved.

The plan used a fictional Category 5 Hurricane as a worst-case scenario, with a nine foot water surge at the port and with expected economic losses of $250 billion due to damaged and delayed cargo and infrastructure. The scenario planning allowed the port and communities to identify and better prepare for the compound effects of an extreme natural disaster.

6.9. Environmental performance

Coastal and estuarine ports may see increasing amounts of sedimentation deposition as a result of changes in sea level rise, coastal erosion, precipitation and river flows. Changes in dredging frequency and quantities driven by climate change will have implications for environmental performance. In locations where sea level rise results in increased draft (vertical distance between the waterline and the bottom of a ship's hull) the need for dredging and consequential environmental impacts may be reduced. 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[56].

Climate change could affect the frequency and intensity of poor air quality episodes during which ports may be required to minimize activities such as loading or unloading fuel to avoid Volatile Organic Compound (VOC) emissions[57]. Climate change may also lead to additional dust creation and dispersion due to changes in air humidity, temperature and wind. 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. In a warming world, changes in cooling degree days and risk of heat waves could increase cooling demand, in turn increasing greenhouse gas emissions if the energy mix includes thermal power generation. Increased cooling demand would also impact on sustainability targets and emissions caps.

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 unless there are adequate control measures. However, safety margins in, for example control measures such as liquid tank bunding may not be adequate in areas where frequency and intensity of rainfall may change.

Due to their locations, ports are invariably close to sensitive habitats and ecosystems that are particularly vulnerable to climate change. Changes in water levels, rates of erosion, salinity and sedimentation due to climate change will change some of the major natural controls of coastal wetlands[58], potentially putting at risk 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[59]. 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[60]. In a changing climate, it may be difficult to determine whether climate change or a port's operations are the primary factors resulting in species migration. This makes continuous environmental monitoring an important tool for developing a knowledge base and determining trends in changes.

Ports may also indirectly contribute to environmental damage in other locations around the world. Greater access to remote and cold regions and increased shipping activity in these areas due to melting of sea ice, could lead to environmental degradation of fragile ecosystems[61] that are likely to already be under stress due to changes in sea temperature and acidity.

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. Healthy habitats are considered to contribute to the ability of natural resources to recover quickly from impacts as well as providing valuable ecosystem services to the community. Assessments of marine transportation system resilience should take into account efforts to minimize degradation in water quality and habitat impacts from freight transportation[62; 63].

Adaptation options	
Informational measures	• Monitor and assess the current state of water and air quality, and the health of the local marine ecosystem. Assess how climate change and port operations may create negative impacts. • Assess how climate change may interact with freight transportation and affect air and water quality. • Assess the port and its surroundings for potential areas at risk of uncontrolled pollution – critical for hazardous material storage areas.
Operational measures	• Ensure on-site management and action plans include mitigation, clean up and restoration methods for uncontrolled releases.
Technical / physical measures	• Restore land through beneficial use of dredge spoil. • Pollution control equipment in key locations - critical for hazardous material storage areas. • Bunding for liquid storage tanks with safety margins that take into account simultaneous extreme rainfall events. • Alarm systems on tanks for uncontrolled releases and pump shutdown.
Governance and capacity building measures	• Collaborate in city initiatives to increase resilience to a changing climate, and gain knowledge from other international projects. • Work with local environmental health and habitat experts to formulate management and action plans that include extreme events and gradual, longer term changes impacts. • Work with government ministries responsible for environmental protection to ensure international best practice is adopted. • Increase awareness of site personnel as to how climate change may result in uncontrolled environmental incidents.

Box 6.11 Case study: Beneficial Use of Dredge Materials. (Source: NOAA, 2015[64])

The Tampa Port Authority, Hillsborough County, and the Southwest Florida Water Management District completed an environmental restoration project in an area that faced habitat degradation, invasive species, and worsening water quality. Since 1991, 500 acres of wetland and upland habitat have been restored, treatment of agricultural runoff has been upgraded, and water quality has improved.

Beneficial use of dredge spoil from port navigation channels contributed significantly to the restoration. Using dredge material for restoration purposes saved money for the restoration project and prolonged the life of the spoil sites.

(Source: NOAA, 2015[65])

Box 6.12 Case study: Taking a port-city approach to resilience

(Source: Rotterdam Climate Initiative, 2015[66])

The City of Rotterdam recognizes that the climate is changing and Rotterdam will be affected. Rainfall is already becoming heavier and causing more flooding in the city. As a low-lying delta city, Rotterdam will have to cope with the effects of an increase in the sea level and with varying river levels. The temperature in the city is also projected to increase, with more people becoming susceptible to heat stroke. The Rotterdam Climate Proof Program aims to make the city and port "fully" resilient to climate change impacts by 2025 and ensure that it remains one of the safest port cities in the world. The adaptation strategy focuses on flood safety, accessibility for ships and passengers, adaptive building, the urban water system, and city climate. New port developments including port reconstruction are designed to be climate-proof and climate change assessments are integrated into the port's spatial planning. To allow for dealing with uncertainties, knowledge development is considered an important pillar of the strategy[67].

7. Engineering rationale for drain upgrade

In order to estimate the necessary upgrade of drain 3 of Puerto de Manzanillo, these steps were followed:

1. **Determining the flow regime:** A supercritical flow was assumed, since the critical depth yc= (Q2/g·b2)1/3 exceeds the clear height of the drain for very small return periods (a flow of 95.08 m^3/s results in yc=1.6), lower than 5 years according to the available flow predictions. Therefore, and given the fact that typically these kind of drains are designed for return periods higher than 5 years, it's assumed that the depth of water at the outlet is the normal depth (yn) of the drain.

2. **Determining the slope of the drain and current discharge capacity:** This task involved some assumptions about the elevations of the drain, in order to establish its slope. From an approximate topography obtained from NASA's Shuttle Radar Topography Mission, and making some reasonable assumptions (such as the coverage between the drain and the finished grade or the quay's crane beam), an average slope of 2% was determined. After that, assuming a normal depth yn= 1.55 m for the main drain and 1.15 m for the additional culvert (drain's clear height minus 5 cm), an overall maximum discharge capacity (calculated with Manning's formula) of 140 m^3/s was calculated. If we consider the flow predictions proportioned by the ERN report, this means that the current discharge capacity of the drain approximately corresponds to a return period of 10 years, which can be considered as low, given the economic impact that entails having the main access of the port flooded.

3. **Estimating the drain's upgrade:** An additional chamber with the same dimensions as that of the existing drain (5x1.6 m) is proposed. An alternative horizontal alignment for this new chamber was considered, as there's no available space next to the existing drain. With this new chamber, the calculated discharge capacity amounts up to 173 m^3/s, which means that by the year 2080, the T=50 years flow could be drained.

8. International and national context on climate change mitigation

8.1. International context

As part of the process for the design of the new international climate change regime after 2012, the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) decided in Bali in 2007 to launch the Bali Action Plan and a program of work that should have culminated in 2009 by COP15 in Copenhagen. In Copenhagen, Parties were unable to conclude the negotiations initiated in 2007 and failed to provide a final answer to the establishment of a new climate regime. However, at COP15 the Copenhagen Accord was negotiated and the vast majority of UNFCCC Parties associated themselves with it shortly afterwards.

The 17th session of the Conference of the Parties (COP17) of the UNFCCC held in Durban in 2011 decided that the negotiations for a global agreement on climate change applicable to all Parties and to take into effect from 2020 should conclude at COP21 in Paris in 2015.

The year 2015 is therefore a critical one for climate change, with the international community trying to finalize the 2015 agreement where new global and individual countries' goals to reduce greenhouse gas (GHG) emissions are to be set. The first iteration of the draft negotiating text agreed by all Parties to the UNFCCC under the Ad-hoc Working Group on the Durban Platform for Enhanced Action (ADP) was made public on February 25th, 2015. This was the basis for further negotiations that began on June 1st, 2015 in Bonn, Germany and will continue with two additional negotiating sessions before COP21 in Paris.

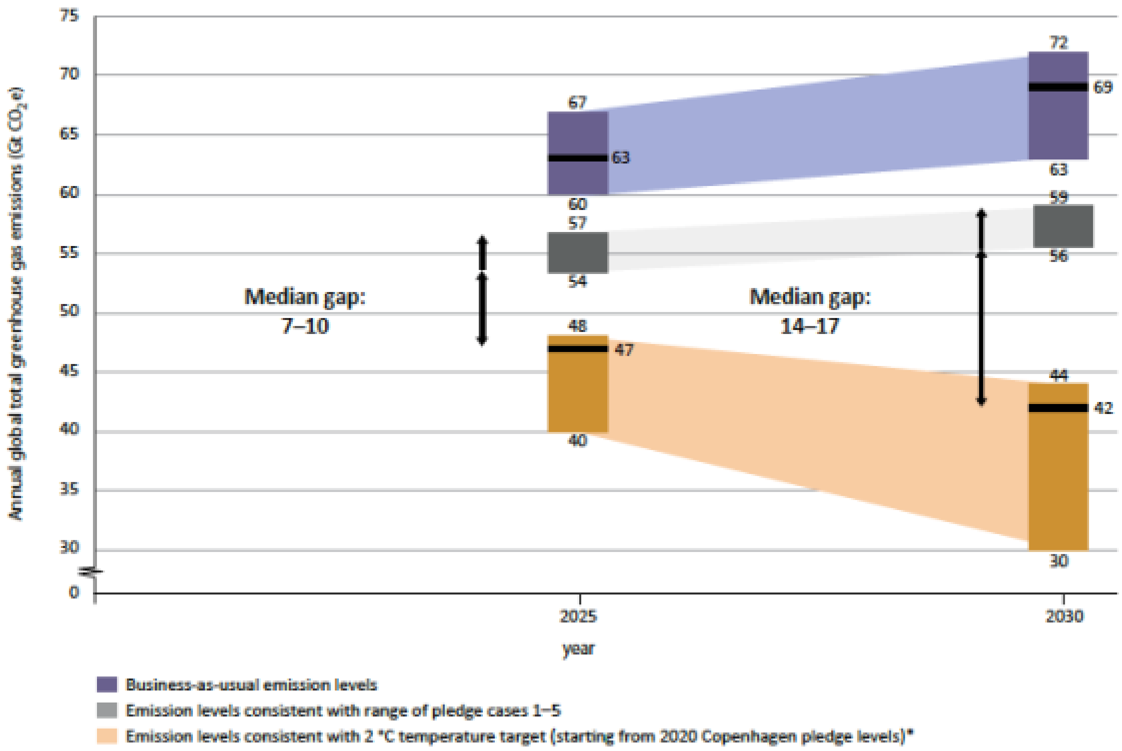
At the time of writing, in the absence of a clear indication of what will be the mitigation commitments embedded in the 2015 agreement, there are still many speculations about the level of ambition of those commitments by developed countries and major developing countries. The mitigation section of the draft negotiating text remains full of options and proposals that make it impossible to assess what will be the result at the end of 2015.

However, as part of the process for the establishment of the 2015 agreement, Parties agreed in Lima at COP20 that intended nationally determined contributions (INDCs) should be submitted "well in advance of COP21 (first quarter 2015 by those Parties ready to do so)".

It is becoming apparent that current efforts and projections to reduce the concentration of greenhouse gases in the atmosphere will not be sufficient to keep global temperature increases below the 2°C target. This is recognized by both the Intergovernmental Panel on Climate Change (IPCC) in its last two reports, (2007 and 2013), and the international community, as noted in in the Copenhagen Accord negotiated within the framework of COP15 in 2009. The 2014 United Nations Environment Programme (UNEP) Emissions Gap Report68 indicates that in 2012 global greenhouse gas emissions were 45% higher compared to 1990 levels (54 Gt CO2e in 2012) with a 2020 trajectory estimation of a 55 GtCO2e if countries do not go beyond their existing climate change policies. As shown in Figure 8.1 below, the report also estimates a gap of 14-17 GtCO2e between expected emissions in 2030 with current planned policies and a level of emissions in 2030 consistent with having a likely chance of meeting the 2°C target.

FIGURE 8.1

The emissions gap in 2030. (Source: UNEP, 2014[69])

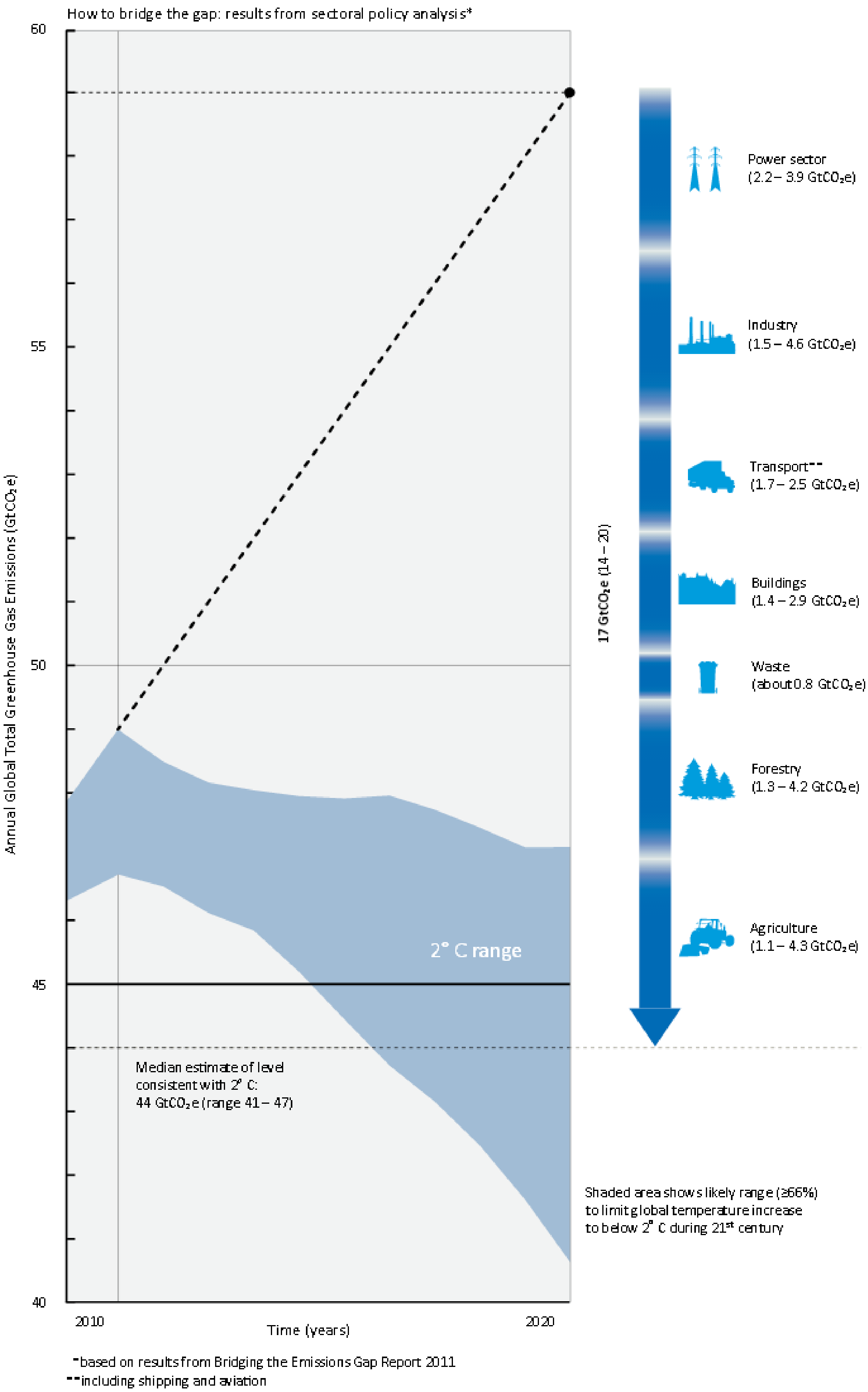


The emissions gap can be met by the introduction of more specific climate change measures. Figure 8.2 below identifies the contribution to bridge that gap that could come from different sectors, as estimated by UNEP[70]. The emissions gap as estimated by the Climate Action Tracker (CAT)[71] is significant, and taking into consideration countries' pledges, it estimates that warming would only be limited to 2.9 to 3.1°C above pre-industrial levels. However, the IPCC 5th Assessment Report suggests that more mitigation action is technically and economically feasible, thus increasing the expectations and the probabilities that Parties may take important steps towards new and ambitious mitigation commitments in Paris at COP21.

As noted in the 2014 UNEP Emissions Gap Report four parties – Australia, Canada, Mexico and the USA – "are likely to require further action and/or purchased offsets to meet their pledges, according to government and independent estimates of projected national emissions in 2020"[72]. The report also notes that recent policy developments in Mexico could bring the country nearer to meeting its pledge, but that further action may be necessary in the near future.[73]

FIGURE 8.2

How to bridge the emissions gap: Results from sectoral policy analysis. (Source: UNEP, 2014[74]).



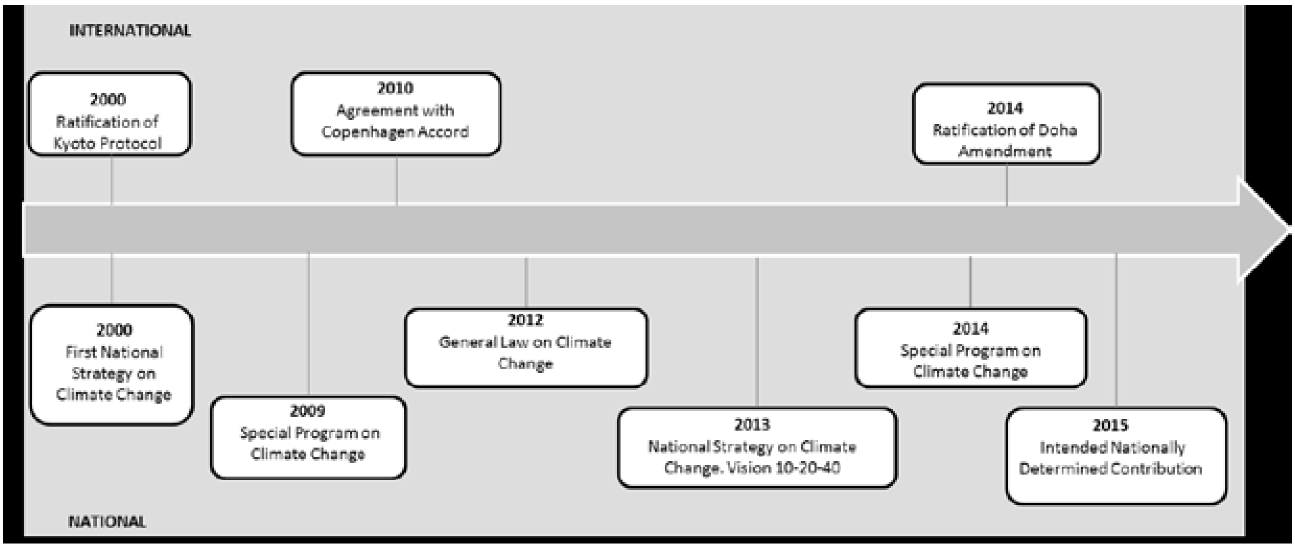
8.2. Mexico climate change mitigation law and policy

Changes in regulations, standards and investors' expectations in Mexico due to international and national commitments by the Mexican government to reduce greenhouse gas emissions may have implications for port business activities, presenting both challenges and opportunities. National and international obligations to reduce emissions of greenhouse gases ("mitigation actions") undertaken by the national government may therefore have an impact on different sectors (energy; industrial processes and product use; agriculture; land-use, land-use change and forestry; waste) and products (petroleum products and derivatives, vehicles, minerals, others).

Figure 8.3 provides a summary of the policy instruments developed in Mexico over the last fifteen years to tackle climate change mitigation. These policy measures have the potential to influence sectoral and economic activities that are relevant to the Port of Manzanillo and are discussed briefly below.

FIGURE 8.3

Pathway for the development of climate change mitigation institutional instruments. (Source: Report authors)**.**



Mexico gives strong importance to climate change issues both internationally and nationally. Mexico signed the UNFCCC on 13 June 1992 and ratified it on 11 March 1993. Mexico is not included in the list of Annex I Parties to the Convention, and therefore it does not have specific mitigation obligations in terms of greenhouse emissions reductions. As a non Annex I Party, Mexico has assumed obligations about reporting information on its level of greenhouse gas emissions as well as the implementation of the Convention[75]. Mexico signed and ratified the Kyoto Protocol respectively on 9 June 1998 and 7 September 2000. Mexico is not included in the list of Annex B to the Protocol and is therefore not required to fulfill any quantified limitation and reduction commitment (QELRC) as per article 3.1 of the Protocol. Nonetheless, through its Special Program on Climate Change (PECC), Mexico has set voluntary and nationally appropriate mitigation targets, aiming to reduce its GHG emissions up to 30% by 2020, provided that developed countries provide adequate financial and technological support.

The position of Mexico towards COP21 in Paris is very clear.[76] Mexico is in favor of a legally binding instrument to be adopted in Paris that should be based on the participation of all Parties in accordance with their specific national circumstances. Mitigation should be among the central elements of the 2015 agreement 'and as such all Parties must take appropriate commitments of same international legal form and under same rules (e.g., same time periods, under same MRV provisions) at different depths according to the principles of common but differentiated responsibilities and respective capabilities (CBDR/RC) and equity, and commensurate to the scientific recommendations for reducing global GHG emissions'[77]. Mexico also supports a differentiation among Parties so that developed countries take the lead with quantified economy-wide emission reduction targets; Parties in a position to do so follow with quantified economy wide emission reduction targets; other Parties to adopt commitments in accordance with their specific national circumstances; and finally Least Developed Countries (LDCs) to take appropriate actions to engage in low-emissions development planning processes.

Mexico's submitted Intended Nationally Determined Contributions (INDC) indicates an unconditional mitigation effort by Mexico equivalent to a reduction of GHG and short lived climate pollutants emissions of 25% by 2030 below BAU. This commitment is in line with the General Climate Change Law and equivalent to a reduction of 22% of GHG emissions and 51% of black carbon emissions. The INDC also refers to a conditional effort of GHG emissions by 40% by 2030 below BAU, provided that adequate resources and technology are provided and a satisfactory international agreement concluded, which is therefore partly dependent on the outputs of COP21. Mexico's INDC covers greenhouse gases and short lived climate pollutants in the following sectors: energy; industrial processes and product use; agriculture; land-use, land-use change and forestry; and waste. Mexico's INDC also leaves open the possibility for Mexico to access the international market-based trading mechanisms.

Through the General Law on Climate Change (GLCC) Mexico has established institutions and effective instruments to reduce greenhouse gases and particulate emissions. On mitigation, the GLCC sets a clear obligation to give priority to cost effective mitigation actions, and centrality to health and well-being co-benefits to the Mexican population. The GLCC confirmed the pledge made under the Copenhagen Accord, namely the commitment of Mexico to reduce GHG emissions by 30% below business-as-usual by 2020, subject to the availability of financial resources and technology transfer.

The 10-20-40 strategy defines reinforces Mexico's mitigation these and set a target of 50% emission reductions by 2050, as compared with emissions in 2000.[78] The strategy also includes an official 2020 trajectory of 830 Mt CO2e.[79]

Given the specific focus created by the General Law on Climate Change (GLCC) on co-benefits, both the National Strategy on Climate Change adopted in June 2013 and the Special Program on Climate Change 2014-2018 incorporate greenhouse gases and particulates, also known as Short Lived Climate Pollutants (SLCPs).

On energy, Mexico has also developed several legislative initiatives at the national level aiming at the reduction of greenhouse gas emissions as well as the promotion of renewable energy and energy efficiency. The Law for the Use of Renewable Energies and Funding the Energy Transition (LAERFTE) promotes the use of renewable energy sources and clean technology for electricity generation. It establishes the Special Program for Renewable Energy Use, the National Strategy for Energy Transition and Sustainable Energy Use and the Energy Transition Fund. The LAERFTE is supported by the Estrategia Nacional de Energia 2013-2027, which sets the frame for major evolution of the energy sector over the next fifteen years and aims to increase non-fossil fuel based power generation to 35%[80].

Another important instrument is the Law for Bioenergy Promotion and Development, which promotes the production and commercialization of bioenergy inputs from activities in rural areas related to agriculture and animal husbandry, forests, seaweed, biotechnology and enzymatic processes.

Mexico has also developed the basis for a Low Emission Development Strategy (LEDS) addressing not only GHG emission reduction, but also promoting sustainable economic growth[81]. Among its objectives, Mexico seeks to support the development of clean technologies, energy efficiency and the incorporation of international standards for vehicle emissions. These actions will support the country reaching its GHG emission reduction targets.

8.3 Potential impacts on demand for cargoes traded through the port

The main potential implication of climate change mitigation commitments on the Port of Manzanillo relates to the price of petroleum products and the demand for different fuel types. The introduction of emission reductions caps and/or policies and legislation aimed at the promotion of renewable energies and fuels, energy efficiency measures and cleaner transport may increase the price of those fuels. Consequently, the demand for those products may be negatively affected. Other cargoes where demand could be affected by climate change mitigation commitments may include vehicles and minerals.

Petroleum products represent a major cargo moved through the national port system in Mexico (SPN), mainly due to the demands of the transport sector[82]. In 2011, PEMEX moved 3.2 million tons of petroleum and derivatives through the Port of Manzanillo. The price of these products could potentially be impacted by international and/or national mitigation commitments applying to Mexico.

Other cargoes through the port that could be affected by climate change legislation include vehicles, minerals, as well as household appliances and car components in containers, as a result of a reduction in their demand due to growing pressure to reduce the use of fossil fuels, to improve renewable energy or to develop cleaner transport. In particular, vehicles imported from Asia could potentially be affected by specific national measures in the transport sector, for instance aimed at the promotion of public transport or cleaner vehicles. Transport by road is by far the most widely used mode in Mexico, in part due to the quality of rail transport.

As indicated above, there is considerable speculation about the outcome of the forthcoming COP21 in Paris. It is therefore uncertain whether in the short term (at least by 2030, considering the average range and timing of current national and international voluntary mitigation commitments) the volumes of exports and imports of various materials through the Port of Manzanillo will be affected directly or indirectly by the 2015 agreement as result of strong and advanced climate change legislation. In addition, it must be emphasized that the various efforts will most likely determined at the national level. As the INDC process has shown, countries will voluntarily propose the scale of their own reduction commitments on the basis of national circumstances and considerations. Furthermore, Parties to the UNFCCC were not able to agree on a common base year and time frame applicable for all INDCs, thus giving every state the liberty to decide the magnitude and the main components of their mitigation contribution. It is therefore possible that national and voluntary decisions will be designed in a way so that national economic sectors are not going to be severely affected by those decisions. That applies also to the level of national commitments undertaken by Mexico as highlighted in the previous section. In particular, the choice of a "BAU scenario of emission projections based on economic growth in the absence of climate change policies, starting from 2013" for measuring the various mitigation targets adopted by Mexico, leaves some uncertainty regarding the level of ambition of those national targets.

Another potential factor that has the potential indirectly to affect the trade volume at the Port of Manzanillo is mitigation commitments undertaken by other countries, particularly those of relevance for the port in terms of imports and exports[83].

End Notes for Appendices

1. http://earth.nullschool.net/ (Accessed April 2015).

2. CONAGUA (2014) Estudio por Mondragón. Drenaje de cuencas e intensidad de lluvias que alimentan al puerto of Manzanillo

3. Maidment, D. R. Handbook of Hydrology. McGraw-Hill. 1993.

4. Seneviratne, S.I., N. Nicholls, D. Easterling, C.M. Goodess, S. Kanae, J. Kossin, Y. Luo, J. Marengo, K. McInnes, M. Rahimi, M. Reichstein, A. Sorteberg, C. Vera, and X. Zhang, 2012: Changes in climate extremes and their impacts on the natural physical environment. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 109-230.

5. Srivastav, R.K., A. Schardon, and S. P. Simonovic. Computerized Tool for the Development of Intensity-Duration-Frequency Curves under a Changing Climate. The University of Western Ontario Department of Civil and Environmental Engineering. February 2015.

6. Maraun, D., F. Wetterhall, A.M. Ireson, R.E. Chandler, E.J. Kendon, M. Widmann, S. Brienen, H. W. Rust, T. Sauter,M. Themeßl, V. K. C. Venema, K. P. Chun, C. M. Goodess, R. G. Jones, C. Onof, M. Vrac, I. Thiele-Eich. 2010. Precipitation downscaling under climate change: Recent developments to bridge the gap between dynamical models and the end user. Review of Geophysics. 48(3).

7. Collins, M., R. Knutti, J. Arblaster, J.-L. Dufresne, T. Fichefet, P. Friedlingstein, X. Gao, W.J. Gutowski, T. Johns, G. Krinner, M. Shongwe, C. Tebaldi, A.J. Weaver and M. Wehner, 2013: Long-term Climate Change: Projections, Commitments and Irreversibility. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

8. Seneviratne, S.I. et al (2012). Ibid.

9. Seneviratne, S.I. et al (2012). Ibid.

10. Srivastav, R.K. et al (2015). Ibid.

11. IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

12. Seneviratne, S.I. et al (2012). Ibid.

13. Srivastav, R.K. et al (2015). Ibid.

14. Foresight International Dimensions of Climate Change (2011) Final Project Report. The Government Office for Science, London

15. Van der Mensbrugghe, D and Roson, R. (2010). Climate, Trade and Development: Thinking Ahead on International Trade (TAIT) -2nd conference Climate Change, Trade and competitiveness: Issues for the WTO, Centre for Trade and Economic Integration, [Source on-line]: www.wto.org/english/res_e/reser_e/climate_jun10_e/background_paper1_e.pdf

16. www.coast.noaa.gov/port/#Vulnerabilities (Accessed April 2015)

17. www.coast.noaa.gov/port/#Vulnerabilities (Accessed April 2015)

18. Port World (2007). Australian Port Congestion Burns Coal Companies. 11 July 2007. Available at www.bunkerworld.com/news/Australian_port_congestion_burns_coal_companies-68425 (Accessed April 2015).

19. Ship Chartering (2009). Congestion at Australia's coal, iron ore and grain ports. 24 February 2009. Available at shipchartering.blogspot.com/2009/02/congestion-at-australias-coal-iron-ore.html (Accessed April 2015)

20. Financial Times. 2007. Xstrata seeks curbs on new mines. 23 August 2007. Available at www.ft.com/cms/s/0/09cb7a24-5199-11dc-8779-0000779fd2ac,dwp_uuid=e8477cc4-c820-11db-b0dc-000b5df10621.html?nclick_check=1 (Accessed April 2015)

21. http://www.saj.usace.army.mil/Portals/44/docs/Planning/EnvironmentalBranch/EnvironmentalDocs/CanaveralHarbor-FLSec%20203ReportFinalEA.pdf (Accessed April 2015)

22. http://www.portsmouth-port.co.uk/about_us/port_information (Accessed April 2015)

23. http://www.portsmouth-port.co.uk/about_us/port_information (Accessed April 2015)

24. http://www.portbris.com.au/PortBris/media/General-Files/Land%20Use%20Planning/PBPL-Land-Use-Plan-2013.pdf (Accessed April 2015)

25. 25 U.S. Environmental Protection Agency (2008). Planning for Climate Change Impacts at U.S. Ports: White Paper.

26. U.S. Environmental Protection Agency (2008). Ibid.

27. Paulauskas V, Paulauskas D, Wijffels J (2009) Ships safety in open ports. Comput Model New Technol 13(2):48–55

28. http://www.scmp.com/lifestyle/technology/article/1554128/how-hong-kong-observatory-combines-computer-modelling-and (Accessed April 2105)

29. United States Department of Transportation (2013). Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: The Gulf Coast Study, Phase 2 - Screening for Vulnerability.

30. Stenek, V. et al (2011). Climate Risk and Business: Ports. International Finance Corporation.

31. K. Dobney et al. (Undated). Quantifying the Effects of High Summer Temperatures due to Climate Change on Buckling and Rail Related Delays in the UK. University of Birmingham, UK http://www.uic.org/cdrom/2008/11_wcrr2008/pdf/I.3.1.1.1.pdf (Accessed April 2015)

32. Dobney, K. et al (2010). The future cost to the United Kingdom's railway network of heat-related delays and buckles caused by the projected increase in high summer temperatures owing to climate change. Proc. IMechE Vol. 224 Part F: J. Rail and Rapid Transit. Pp 25-34.

33. Dobney, K. et al (2010). Ibid.

34. Wilson, M, I and Burtwell, M, H. (2002). Prioritising Future Construction Research and Adapting to Climate Change: Infrastructure (Transport and Utilities). Report prepared by TRL for the CRISP Commission.

35. Rail Safety and Standards Board (2003). Safety implications of weather, climate and climate change. Report prepared by AEA Technology. March 2003. RSSB Research Programme: Engineering. London. 153pp.

36. Winter, M, G. et al (2008). Landslides, Climate, Rainfall and Forecasting. In Scottish Road Network Landslides Study: Implementation, eds. Winter, G, Macgregor, F, and Shackman, L. November 2008. Transport Scotland. Pp 115- 128. www.transportscotland.gov.uk/report/j10107-00.htm (Accessed April 2015)

37. United States Global Change Research Program (2009). Transportation Chapter. In Global Climate Change Impacts in the United States. Karl, T, R., Melillo, J, M., and Peterson, T, C (eds.). Cambridge University Press, 2009. pp 61-70.

38. United States Global Change Research Program (2009). Ibid.

39. United States Global Change Research Program (2009). Ibid.

40. Rail Safety and Standards Board (2003). Ibid..

41. Rail Safety and Standards Board (2003). Ibid..

42. Knutson et al. (2010). Tropical Cyclones and Climate Change. Nature GeoScience.

43. Government of Scotland (2005). Road Impacts and Network Management Issues. Chapter 5 in Scottish Road Network Climate Change Study. Eds. R, M, Galbraith., D, J, Price., L Shackman www.scotland.gov.uk/Publications/2005/07/08131510/15226 (Accessed April 2015)

44. US Transportation Research Board (2008). Potential Impacts of Climate Change on U.S. Transportation. Committee on Climate Change and U.S. Transportation. Transportation Research Board Special Report 290.

45. United States Department of Transportation (2013). Ibid.

46. http://www.epa.gov/climatechange/impacts-adaptation/transportation-adaptation.html#adaptcalifornia (Accessed April 2015)

47. http://www.epa.gov/climatechange/impacts-adaptation/transportation-adaptation.html#adaptcalifornia (Accessed April 2015)

48. http://www.epa.gov/climatechange/impacts-adaptation/transportation-adaptation.html#adaptcalifornia (Accessed April 2015)

49. http://www.lloyds.com/news-and-insight/news-and-features/emerging-risk/emerging-risk-2014/keying-climate-change-in-to-catastrophe-models (Accessed April 2015)

50. U.S. Environmental Protection Agency (2008). Ibid.

51. Pew Center on Global Climate Change (2008). Adapting to Climate Change: A Business Approach http://www.c2es.org/docUploads/Business-Adaptation.pdf (Accessed April 2015)

52. Allianz Group and WWF (2006). Climate Change and Insurance: An Agenda for Action in the United States. http://www.climateneeds.umd.edu/pdf/AllianzWWFreport.pdf (Accessed April 2015)

53. http://www.coast.noaa.gov/port/#Vulnerabilities (Accessed April 2015)

54. http://www.coast.noaa.gov/port/#Vulnerabilities (Accessed April 2015)

55. http://www.coast.noaa.gov/port/#Vulnerabilities (Accessed April 2015)

56. Stenek, V. et al (2011). Ibid.

57. Department for Environment, Food and Rural Affairs, UK (2007). Air quality and climate change: a UK perspective. Report by the Air Quality Expert Group (AQEG). London. Pp 102-150

58. US Climate Change Science Program (2008). Impacts of climate change and variability on transportation systems and infrastructure: Gulf coast study I, Phase 1. Synthesis and Assessment Product 4.7. Washington DC, 445pp.

59. US Climate Change Science Program (2009). Coastal Sensitivity to Sea level Rise: A Focus on the Mid-Atlantic Region. Synthesis and Assessment Product 4.1. Washington DC. 790pp.

60. Intergovernmental Panel on Climate Change (IPCC) Working Group 1 (2007). Climate Change 2007: The Physical Science Basis; Contributions of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, ed. S. Solomon, D. Qin, M. Maning, Z. Chen, M. Marquis, K. B. Avery, M. Tignor, and H. L. Miller. Cambridge: Cambridge University Press. 996pp.

61. US Transportation Research Board (2008). Ibid.

62. Stenek, V. et al (2011). Ibid.

63. http://www.coast.noaa.gov/port/#Vulnerabilities (Accessed April 2015)

64. http://www.coast.noaa.gov/port/#Vulnerabilities (Accessed April 2015)

65. http://www.coast.noaa.gov/port/#Vulnerabilities (Accessed April 2015)

66. http://www.rotterdamclimateinitiative.nl/en/programme-sustainability-and-climate-change/preparing-for-the-consequences-of-climate-change?doelen_id=57&resultaat=1 (Accessed April 2015)

67. Becker, A. et al. (2013). Ibid.

68. UNEP. (2014). The Emissions Gap Report 2014, a UNEP synthesis report, p. 20.

69. UNEP. (2014). The Emissions Gap Report 2014, a UNEP synthesis report.

70. UNEP. (2013). The Emissions Gap Report 2013, Executive Summary, p. 5.

71. The initiative Climate Action Tracker (CAT) studies countries' pledges and compares them with emissions levels consistent over time with the 2°C target.

72. UNEP. (2014). Ibid. p. 21.

73. 2014 Emissions Gap Report, UNEP, p. 31; Climate Action Tracker, 2013; World Resources Institute, 2014.

74. UNEP. (2013). The Emissions Gap Report 2013, Executive Summary.

75. See Article 12 of the UNFCCC: Mexico's obligations under the Convention refer mainly to the submission of a national inventory of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol and a national communication on steps undertaken to implement the Convention.

76. Submission by Mexico to the ADP, 29 May 2014, http://unfccc.int/files/bodies/application/pdf/submission_by_mexico,_indicative_elements_for_a_lbi.pdf.

77. Submission by Mexico to the ADP, 29 May 2014, http://unfccc.int/files/bodies/application/pdf/submission_by_mexico,_indicative_elements_for_a_lbi.pdf, p. 2-3. (Accessed August 2015)

78. GLOBE International (2014), Ibid. p.5.

79. The UNEP gap report (2014) also provides a 2020 trajectory of 765 (715-830) GtCO2e as independent estimates based on information provided by Climate Action Tracker (2013) and Roelfsema et al. (2014).

80. SENER, Secretaria de Energia. (2013). National energy strategy 2013-2027.

81. SEMARNAT. (November 2012). Bases para una estrategia de desarrollo bajo en emissiones en Mexico.

82. API Manzanillo. (2012). Programa Maestro de Desarrollo Portuario (PMDP) del Puerto de Manzanillo 2012 – 2017, p. 69.

83. As noted in the Programa Maestro de Desarrollo Portuario del Puerto de Manzanillo 2012 – 2017 (p. 42), the first countries in terms of volume of exports are: China 39%, Japan 14%, South Korea and Colombia 6%. In terms of volume of imports: China 26%, South Korea 19%, Japan and Chile 12%, USA 10%.

INTER-AMERICAN DEVELOPMENT BANK
1300 New York Avenue, NW
Washington, DC 20577, USA

For more information, please contact us:
futurefinance@iadb.org
www.iadb.org/scf