

Maritime Summary Note n°219 – April 2020

« Adapting Seaports to the Impacts of Climate Change »

Ports and waterways are, by definition, vital points of interest at the heart of international trade. They are highly vulnerable due to their geographic location, being open to the coastline, situated at the mouths of deltas and estuaries, and therefore located at low altitudes. They must cope with a variety of risks associated with meteorological, hydrological, and oceanographic parameters—threats that are being made all the more acute by climate change. According to projections by the Intergovernmental Panel on Climate Change (IPCC), large-scale natural phenomena in coastal areas related to rising sea levels (such as flooding and marine submersion), which historically had a centennial recurrence, could occur much more frequently. Over the period from 1880 to 2015, the average global sea level rose by 20.2 cm due to global warming caused by human activities. Driven by warming temperatures, rising sea levels cause ocean thermal expansion, the melting of polar ice sheets and continental glaciers, and alter continental water regimes. Projections for 2100 all align on a sea-level rise of between 20 cm and 1 meter, depending on how optimistic or pessimistic the scenarios are and based on the compliance with political commitments to reduce greenhouse gas (GHG) emissions. In light of these climate-related threats, how are ports apprehending these risks? How can we ensure the resilience of port infrastructures against climate change?

A few contextual éléments

Major ports are often linked to urban areas; when natural disasters strike, they impact local populations and, by extension, socio-economic activities (halts in operations, supply chain disruptions, closures of transport routes, etc.). Technological risk is also highly prevalent. Ports frequently host industrial activities (oil refineries, chemical plants, fertilizer production, grain silos, Seveso sites, etc.). If these activities fell victim to natural phenomena, it would trigger a knock-on disaster, much like the Fukushima nuclear accident in 2011.

As a reminder, the Port of New York and New Jersey was completely closed during the passage of Hurricane Sandy in 2012. The reopening of numerous cargo terminals was delayed due to power outages and equipment damage. Another example occurred in 2017 with the Port of Itajaí in Brazil, which had to close for nearly a month due to heavy rainfall, preventing vessels from docking. Conversely, the prolonged drought during the summer of 2018 in Germany rendered certain sections of the Rhine unnavigable.

In cyclone-prone regions, the damage suffered by ports will be even more severe. In 2019, the total cost of the consequences of Hurricane Dorian in the Bahamas was estimated at \$3.4 billion¹, while hundreds of people went missing or lost their lives. The repercussions on the economy will last for several years. The situation of Small Island Developing States is delicate, as they are completely dependent on port and airport infrastructure and at the mercy of climate disruptions (coastal erosion among others) that can impact their primary economic sector: tourism. Extreme cyclonic seasons also pose a threat to the cruise industry.

Another impact of climate change and the anthropogenic pressure exerted by humans on their environment is the water deficit of the Panama Canal. This interoceanic link sees 12,000 merchant vessels transit each year, paying an average of \$65,000 to cross the isthmus. The canal contributes directly and indirectly to 40% of the country's economy. Deforestation and the lack of rainfall jeopardize its watershed, limiting the number of vessel transits and thereby disrupting maritime trade.

On the Old Continent, recent maps published by the European Environment Agency (EEA) on the consequences of climate change in Europe estimate that the average annual losses due to coastal

¹ The Inter-American Development Bank, 2019, Damages and other impacts on Bahamas by Hurricane Dorian estimated \$3.4 billion : Report, November 15th.

flooding across the 117 main coastal cities (most of which are port cities) in the EU could rise from approximately €1 billion in 2030 to €31 billion by 2100 under a high-emissions scenario. According to the EEA, 3.5 million Europeans would face a regular risk of flooding by 2100 if current flood protection structures do not evolve. In 2009, the World Wide Fund for Nature (WWF) and Allianz estimated that within the 136 port megacities worldwide, the amount of damage due to flooding could reach \$28 billion by 2050².

The three major developments that climate change implies for port infrastructure are: rising average sea levels, changes in river flow rates, and the frequency and power of storms. Their consequences are multifaceted: increased risk of flooding, changes in the hydro-sedimentary dynamics of estuaries, coastal erosion, greater stress on port structures (particularly breakwaters and dikes), and a potential shift in the distribution areas of certain species.

Ports and maritime transport infrastructures are often owned and/or operated by private stakeholders. However, the role of public authorities remains central. They determine the regulations and policies that support the adaptation of maritime transport networks and infrastructures to climate change. A legal and regulatory framework that accounts for climate change evolution, particularly for infrastructure projects, must pre-exist. By way of illustration, EU Directive 2014/52 concerning the assessment of the effects of certain public and private projects on the environment, in force since 2017, stipulates that the consequences of climate change must be integrated into the environmental impact assessments of major infrastructure projects.

Ports, as managers, are the guarantors of all these issues and consequently take measures aimed at limiting the impacts of climate change. The multiplicity of their missions can sometimes lead to conflicting demands. The port embodies the dual role of an economic developer—facing the delicate issue of land management—and a guarantor of environmental preservation when it manages natural areas (such as wetlands and alluvial plains). Finally, it ensures the safety and permanence of its facilities and the industrial sites present through flood risk prevention, which involves building structures that may, in turn, impact these natural areas. Arbitrations are sometimes difficult.

The adaptation of port infrastructure responds to different strategies depending on the type of risk. Faced with the risk of episodic marine submersion caused by extreme phenomena, risk reduction will be achieved through coastal protection works. Faced with slow-onset risks, such as permanent flooding, the solution lies more in long-term risk management and resilience actions, including the maintenance and development of natural ecosystem services, for example.

In parallel, though unevenly across the globe, port stakeholders are taking action through GHG reduction policies (energy savings, cold ironing, Environmental Ship Index, etc.), the promotion of energy efficiency, and the use of clean energy sources. All of these measures contribute to global climate goals and secure the energy supply of ports.

What is certain is that the climate is changing; what is less certain is to what extent. Ports must equip themselves with management plans in order to anticipate the occurrence of such phenomena and thus be able to manage crises. A first phase consists of assessing current and potential risks within the context of climate change. Different scenarios with variable parameters (sea-level rise, temperature, heavy rainfall, wind, tidal waves, etc.) must be understood, or even modeled, across several time horizons. The next step is to determine which infrastructures and related activities will be affected, and finally to evaluate their degree of vulnerability. Best practice guides, methodologies, and decision-support tools for this necessary adaptation do not exist on a global scale. But that was without counting on the seven centuries of feedback and experience from the Netherlands.

The Dutch example: the Port of Rotterdam

In the Netherlands, the 1953 floods were catastrophic; with a high tidal coefficient and a rapid rise in river levels, the country's dikes breached, causing the death of 1,800 people and the evacuation of 70,000 residents. In response, the Dutch State launched a vast forty-year civil engineering program (the Delta Plan) to protect itself against this phenomenon. A new funding envelope of €20 billion by 2050 is being used to maintain existing structures. The lack of sufficient groundwater tables and/or wetlands to absorb and store water remains a shortcoming.

² Major Tipping Points in the Earth's Climate System and Consequences for the Insurance Sector (Gland, Suisse, et Munich, Allemagne), 2009.

With a quarter of its territory below sea level, the Netherlands boasts some of the major ports in Europe, including Rotterdam, Amsterdam, and Vlissingen. In response, the country has built an impressive system of dams, breakwaters, storm surge barriers, the reshaping and widening of riverbeds and waterways, and the construction of dikes (22,500 km), of artificial sandbanks all along its coastline. Dikes are being raised, and dunes are being nourished. These constructions raise questions as they contribute to the phenomenon of subsidence (sinking of the soil) and do not halt the rise in ocean levels. The abandonment of lands and cities will only be considered as a last resort. From now on, the engineers' objective is no longer to go "against" the sea, but to work "with" it, demonstrating adaptation and resilience³.

The goal of the *Rotterdam Climate Proof* program is to make the city and port "fully" resilient to climate change and to turn Rotterdam into "the safest port city in the world." Rotterdam, the economic capital of the Netherlands, has a population of 1.4 million and accounts for 65% of the country's GDP. It is Europe's leading port, employing 350,000 people. The drawback is that the city is located at the shared mouth of the Rhine and Meuse rivers and is also the lowest point in the country (-6 meters below sea level).

The adaptation strategy focuses on flood control, vessel accessibility, and adaptive construction. Every available means is deployed for defense: green roofs designed to retain moisture, parking structures convertible into water retention tanks, and landscaped promenades concealing a vast drainage network. It was in Rotterdam that a new generation of public squares and adaptive structures was invented: the *waterplazas*. These sunken esplanades host sports facilities or public gardens and transform into lakes in the event of a deluge.

On the port side, Rotterdam conducted a study between 2015 and 2016 entitled "Botlek Water Safety" (focusing on the Botlek and Vondelingenplaat areas located outside the primary flood protection system) to determine the consequences of flooding resulting from sea-level rise. This project is the result of a collaboration between the Port of Rotterdam Authority, the municipality, the Ministry of Infrastructure and the Environment, as well as private sector companies. Various climate change scenarios were factored in, followed by a risk assessment and the identification and prioritization of adaptation measures. Climate change is fully integrated into its spatial planning, and its openings to the open sea can be locked down within minutes thanks to warning systems. Among the numerous devices is the *Maeslantkering* ("Meuse country protection barrier"). This giant computer-operated gate protects the main shipping channel connecting the port to the sea. The machine automatically decrees the closing of the gates when the water level exceeds the normal threshold of three meters, thereby preventing the North Sea from flooding Rotterdam. Since its inauguration in 1997, however, the *Maeslantkering* has only closed its gates twice. The engineering expertise of the Dutch enjoys international recognition in terms of coastal management face to coastal risk, urban planning, and access to clean drinking water.

The example of the Port of Long Beach

The vulnerability of the Port of Long Beach in California was brought to light in August 2014, when storm surges from Hurricane Marie hit the Southern California coast, damaging the port. Following this event, the port developed a Climate Adaptation and Coastal Resilience Plan (CRP) to manage direct and indirect risks associated with climate change and coastal hazards. The CRP includes a review of the best available climate data, an inventory of the port's assets, and detailed mapping of sea-level rise and storm surge flooding. The CRP recommends short-term solutions to protect the port's most vulnerable areas and long-term strategies that can help the port maintain business continuity across its infrastructure and operations into the next century. It provides a framework for the port to incorporate climate change adaptation measures into its spatial planning policy, construction practices, infrastructure design, and environmental documentation.

Slightly further south in California, the Port of San Diego has also mapped its vulnerable areas and implemented a strategy to mitigate the potential consequences of climate change. One of these solutions lies in the three-year construction of 72 water retention basins (ECONcrete's Coastal Star) to replace traditional ripraps. They serve simultaneously as armoring, breakwaters, and dikes that stabilize the shoreline. They also function as marine mini-ecosystems. Other adaptation measures include non-building zones, minimum elevation requirements for certain buildings, the restoration of natural buffer zones (wetlands), and beach nourishment. But what about France ?

³ In geography and spatial planning, the concept of resilience refers to the capacity of cities to limit the effects of disasters and to quickly return to normal operations following a shock.

In France

Flood risk constitutes the primary natural hazard. Storm Xynthia, which swept through France during the night of February 27 to 28, 2010, caused the deaths of 53 people and constituted a breaking point in the understanding of submersion risks. Several factors combined to cause the disaster: a violent wind episode, a storm surge, a high tidal coefficient, and high tide. This created a sudden and severe marine submersion across the Charente-Maritime and Vendée departments. Xynthia is considered a benchmark storm, with a return period exceeding 100 years, and serves as a reference point for mapping (Xynthia +20/60/100 cm projections)⁴.

The National Climate Change Adaptation Plan (*Plan National d'Adaptation au Changement Climatique* – PNACC), overseen by the Ministry for the Ecological and Inclusive Transition (under the "Infrastructure and Transport Systems" section, action 1), addresses the potential impacts of expected climate developments on transport infrastructure, and more specifically on port and maritime infrastructures (regarding temperatures, rainfall, wind, sea levels, and wave modification). Its general guidelines can be supplemented by various local policies, such as risk prevention plans developed between decentralized State services, the DDTM (*Direction Départementale des Territoires et de la Mer*), local authorities, port authorities, and onsite industrial operators. Natural risks are also regulated through PAPI, SLGRI, SGLBC, PLUi, and other frameworks.

A better understanding of the impact of climate change on coastal processes, through scientific and technical knowledge-gathering, must be undertaken to map current risk hazards. Spatial planning documents are then enacted. Port areas can fall simultaneously under Technological Risk Prevention Plans (PPRT)—due to the presence of Seveso-classified industrial sites—and Coastal Risk Prevention Plans (PPRL), which address both marine submersion and erosion risks. Land use is regulated within these areas, risk zones are mapped, and measures are taken to mitigate hazards. These regulations range from building prohibitions to conditional building permissions, as well as mandatory modifications for existing structures.

Beyond spatial planning, port infrastructure climate resilience studies are conducted on a port-by-port basis to better understand the impacts on infrastructure, corrective measures, and warning systems emergency services coordination, business continuity planning, and dredging requirements. The first French study of this kind was the Sao Polo project in 2012. CEREMA (*Centre d'Études et d'Expertise sur les Risques, l'Environnement, la Mobilité et l'Aménagement*) is currently working with the Grand Port Maritime (GPM) of Bordeaux to implement a risk analysis methodology. This will help the port identify vulnerable infrastructure and functionalities to define a comprehensive climate change management and adaptation strategy.

The Port of Le Havre, in close collaboration with the local authorities where it is located and with the state administration, has conducted statistical analyses of water levels and numerical modeling of marine submersion to characterize flood risks on its territory. This ongoing work extends to defining programs aimed at improving the understanding of these phenomena, preventing risks to enhance regional resilience, and managing events to facilitate a swift return to normal operations.

In the Loire Estuary, the C3E2 research program (2014)—coordinated by Ifremer with contributions from Artelia, the University of Western Brittany, and the GIP Loire-Estuaire—highlighted the "Consequences of Climate Change on the Eco-geomorphology of Estuaries" through predictive models looking ahead to 2040. The study accounts for rising sea levels, rainfall patterns, and changes in sediment inputs. Expected impacts include the upstream migration of salt and the turbidity maximum zone ("bouchon vaseux"), as well as a probable increase in the frequency of marine submersions in the alluvial plain, and altered physicochemical parameters of the water. The GPM of Nantes Saint-Nazaire will launch a dedicated study in the second half of 2020 to reduce its vulnerabilities to climate change.

Effective adaptation policies, combined with enhanced climate resilience and port carbon neutrality, constitute true strategic and economic imperatives. Transport infrastructures, which represent a vital link between domestic economies and the global economy, must prepare to adapt their spaces to climate change.

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⁴ Submersion levels for Storm Xynthia incorporating a 20 cm sea-level rise to account for short-term climate change, as well as a +60 to 100 cm scenario to factor in predictable climate change by the 2100 horizon.