AIRPORTS COUNCIL INTERNATIONAL

AIRPORTS' RESILIENCE AND ADAPTATION TO A CHANGING CLIMATE

More extreme weather- and climate-related events are expected as the climate continues to change. The frequency, intensity, spatial extent, duration and timing of events are expected to increase while slow-onset incremental changes may lead to fundamental transformation of the socio-economic system. Many airports may remain vulnerable to these events as the risks of flooding, flight disruptions and cancellations become more likely. Airports need to understand the risks and initiate adaptation measures for both existing and new infrastructure, as well as managing critical operations to become more resilient to the changing climate.

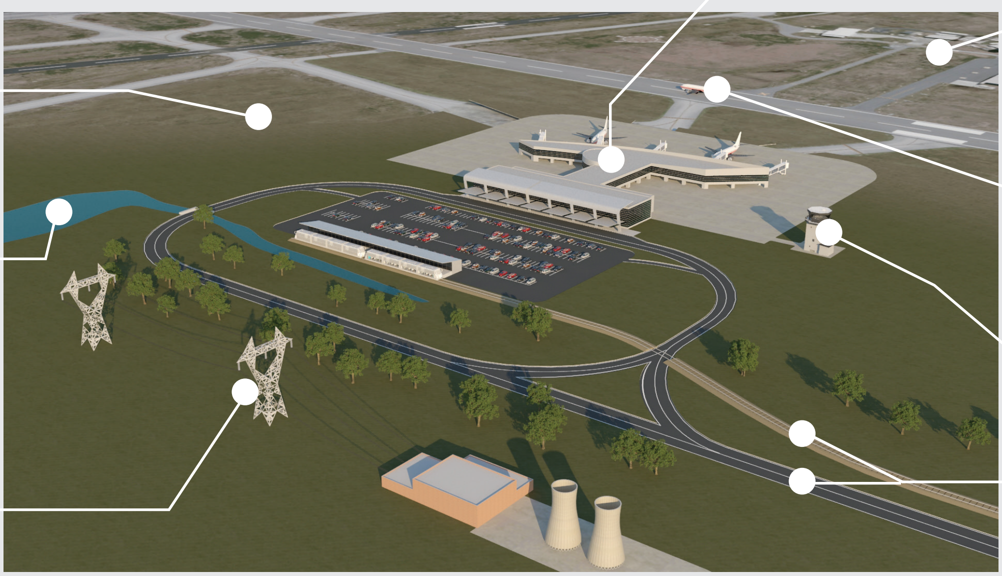
ACI members adopted a resolution (ACI Resolution 3/2018 on resilience and adaptation to climate change) in Brussels in June 2018 recognizing the potential impact of climate change on airport infrastructure and operations, and encouraging member airports to conduct risk assessments, develop mitigation measures and communication channels, and take climate resilience and adaptation into consideration for their master plans.

QUESTIONS FOR AIRPORTS:

Are you aware that there is an increased fire risk due to higher temperatures?

Are you aware that more airports may be used as a shelter or relief hub for weather-related disasters?

Do you know how climate change may affect the foundations of terminal buildings?



What should you do to prevent increasing wildlife-strike risks due to changes in the local ecosystem?

Will there be enough water available with increasing desertification around your airport?

What would happen to your airport if the electrical power supply failed during strong winds and storms?

Is your airport safe from potential inundation due to sea-level rise?

Have you considered whether your runway will be long enough for aircraft to take off at higher temperatures?

How will temperature change affect navigational signals and satellite coverage?

Can ground access be maintained with more extreme disruptive weather?

An airport is a business, multimodal transport interchange, employment node, and essential piece of regional and national infrastructure for the communities it serves. As an essential service provider to a wide range of stakeholders and users, the airport infrastructure and operations must have high levels of availability, reliability and resilience. Vulnerabilities to ongoing services from short- and long-term projected climate changes must be identified as part of a responsible business continuity plan.

Compiling potential impacts and consequences of extreme weather events on all aspects of the airport business and operation can enable airports to prioritize and better respond to these risks. This may be based on the airport's exposure to changing climate conditions, its sensitivity to adverse impact, or the adaptive capacity when faced with such challenges. Those impacts ranked the highest priority or of prime concern should be addressed first through detailed investigation of mitigation options and assessment of cost-benefits as part of an airport's resiliency plan.

The work on climate-change adaptation and resilience should include operational considerations on safety and security, and also legal, environmental, financial and business effects on airport operations. Only comprehensive climate-change risk-management strategies will ensure the continuity of operation, profitability and asset value. Some airports are already witnessing gradual change in the investment environment, whereby investors are keen to evaluate climate-change-related risks and opportunities in accordance with the framework recommended by the Task Force on Climate-related Financial Disclosures (TCFD).

Another important element of an adaptation plan is the coordination with broader airport stakeholders and surrounding communities. An inclusive, systematic approach to collect intelligence, assess risks, and interact proactively with these stakeholders will help mitigate long-term financial, economic and operational impacts. Furthermore, as a networked infrastructure, disruptions in one airport may have a cascading impact on other airports, the wider economy, and even national resilience.

A number of airports around the world have already begun to assess infrastructure and operational vulnerabilities from a variety of climate- and weather-specific risks. The matrix in **Annex A** demonstrates how airport facilities and operations can be vulnerable to certain climate and weather stressors. This matrix can be used as a starting point for airport management to develop resiliency and adaptation plans. **Annex B** provides a sample list of airports that have already initiated preparation: from vulnerability assessment to identification of measures, and from design guidelines to reconstruction. Case studies in **Annex C** provide additional insight and background on airports' adaptation and resiliency activities.

ACI RECOMMENDATIONS

Most airport infrastructure was designed and constructed in the era when climate variation was not appreciated as it is today, and adaptive measures were not readily available. However, with more studies presenting financial and economic benefits from introducing preventive measures compared to reactive response post-impact, ACI recommends that airports consider:

- taking into consideration the potential impact of climate-change as they develop their Master Plans;
- conducting risk or criticality assessments for their operational procedures and existing infrastructure from more adverse weather events and climate change;
- developing and incorporating actions at an early stage, in accordance with both their risk/criticality assessments and with their overall business continuity plans and emergency planning; and
- planning and developing effective communication channels with airport staff, and aviation stakeholders, including airlines, air navigation service providers, off-airport service providers, academia, communities and municipal authorities responsible for weather monitoring, climate analysis, and disaster management.

ANNEX A. POTENTIAL IMPACTS OF CLIMATE STRESSORS ON INFRASTRUCTURE AND OPERATION

Potential Impacts and Climate Stressors	Sea-Level Rise	Increased Intensity of Storm	Temperature Change	Changing Precipitation	Changing Icing Conditions	Changing Wind	Desertification
INFRASTRUCTURE							
Airfield (including Runways, Taxiways and Aprons)							
Damage to and deterioration of pavement structure	■			■	■		■
Deterioration of pavement surface (and breakup into Foreign Object Debris (FOD))	■	■	■	■	■		■
Increased contamination of pavement surfaces (snow, ice, water)	■	■	■	■	■		
Drainage and run-off systems capability	■	■		■	■		
Electrical systems (including lighting and signage)	■	■	■	■	■	■	■
Terminals and Landside Infrastructure							
Impeded ground access, circulation, loading and parking	■	■		■	■		
Damage to buildings and structures	■	■	■	■	■		
Undermined ground foundations	■			■	■		■
Support Facilities, Navigational Aids, Fuel Storage, and Others							
Deteriorated facilities and equipment	■	■	■	■	■		■
Navigational signal distortion and satellite coverage			■				
Increase in maintenance, repair, and overhaul	■	■	■	■	■	■	■
Electrical system failure/shortage/spike	■	■	■	■	■	■	■
Increased fire risk (flashpoint of jet fuel is around 100°F/38°C)			■				■
SERVICE, ACCESS, MAINTENANCE, AND OPERATIONS							
Aircraft Operation							
Increased runway length needed due to decreased lift and thrust at higher ambient temperature			■				■
Reduced rate of climb and increased fuel consumption			■				
Need for change in flight path (approach routes, landing, and take-off)		■	■			■	

Potential Impacts and Climate Stressors

Potential Impacts and Climate Stressors	Sea-Level Rise	Increased Intensity of Storm	Temperature Change	Changing Precipitation	Changing Icing Conditions	Changing Wind	Desertification
Greater turbulence		■	■			■	
Reduced visibility		■		■		■	■
Potential for damage to aircraft (structural, avionics, etc)	■	■			■	■	■
More maintenance, repair, and overhaul	■	■	■	■	■	■	■
De-icing needs		■	■		■		
Air/Ground Navigation Control							
Reduced visibility (visual and signal line of sight issues)		■	■	■		■	■
Increased levels of communications system failure		■		■			
Wildlife Hazard Management							
Changes in ecosystems and distributions of wildlife and wildlife attractants	■		■	■		■	■
Increased risk of wildlife strikes			■			■	■
Emergency Management							
Weather-related emergencies	■	■	■	■			■
Use of airport as shelter or as hub for relief operations	■	■					
Other Operational Aspects							
Reduced water availability due to drought			■				■
Increased heating, ventilation and air conditioning demand and duration			■				■
Delays and flight cancellation	■	■	■	■	■	■	■
Environment Management							
Changes to noise emission pattern and increased complaints		■	■			■	■
Changes in ecosystems and associated risks	■		■	■			■
Reduced air quality			■				■
Personnel and Passengers							
Risk of heat-related exhaustion			■				■
Changes in tourism patterns	■	■	■	■			■
Risks of communicable diseases and epidemics	■		■	■			■

ANNEX B. SAMPLE OF AIRPORTS' INITIATIVES FOR ADAPTATION

REGION	STATE	AIRPORT	TYPE	DESCRIPTION
Asia Pacific	Australia	Adelaide	Assessment Strategy	• Incorporate climate adaptation into Airport Master Plan 2014-2034 • Conducted vulnerability study and infrastructure review • Currently, in the process of incorporating, where required, new pavement and building standards into development and construction guidelines
		Brisbane	Assessment Infrastructure Upgrade	• New parallel runway to be built fully integrating climate adaptation • New Auto Mall / Central parking area built on integrating adaptation
		Cairns	Assessment	• Undertook an internal risk screening assessment process and produced risk register
		Mackay	Assessment	• Undertook an internal risk screening assessment process and produced risk register
	China	Hong Kong	Coordination	• Coordination with national authority, and airport stakeholders
	India	Vishakhapatnam	Brief Study	• USAID supported brief city-wide infrastructure climate risk case study on resilience
	Japan	Kansai	Strategy	• Received the national resilience certification by the government as the first airport operator for business continuity planning
	Korea	Korea Airport Corp	Strategy	• Received Green World Awards 2017 for climate adaptation strategy • Participating in a government-wide adaptation strategy task force
		Incheon	Strategy	• Participating in a government-wide adaptation strategy task force
	Singapore	Changi	Assessment Infrastructure Upgrade National Strategy	• New terminal to be built 5.5m above mean sea level • Drainage system upgraded • Incorporated in national strategy

REGION	STATE	AIRPORT	TYPE	DESCRIPTION
Europe	Denmark	Copenhagen	Assessment	• Conducted vulnerability assessment and developed first emergency plan for extreme rainfall events
	Ireland		Assessment	• Conducted vulnerability assessment
	Norway	Avinor	Assessment Guideline Integration into master planning	• Conducted risk analysis • Airport design handbook includes specific requirement for future climate factors • Standards for buildings including climate adaptation • Integrated adaptation planning into airport master plan
	Spain		Assessment	• Conducted vulnerability assessment for transport infrastructure in Spain
	UK	Birmingham Gatwick Glasgow Heathrow Manchester Stansted	Assessment Progress review	• UK's key infrastructure providers are required to submit adaptation plans and progress reports under the Climate Change Act 2008

REGION	STATE	AIRPORT	TYPE	DESCRIPTION
North America	Canada	Churchill Inuvik Cambridge Bay	Assessment	• Conducted vulnerability assessment with 30-year projected trend in climate conditions
		Iqaluit	Assessment Infrastructure Upgrade	• Permafrost vulnerability assessment conducted • Realignment of taxiway alpha based on recurring frost heaves, and geological and climate modeling
		Toronto Pearson	Assessment	• Conducted vulnerability assessment for selected storm water infrastructure
	USA	Barnstable	Assessment	• Cape Cod commission conducted vulnerability assessment for critical transport assets including airports to sea level rise, 2015
		Boston Logan	Design Guideline	• Launched FAA Sustainability Master Plan Pilot Program, 2013 • Developed 'Floodproofing Design Guide', 2014
		JFK	Design Guideline Infrastructure Upgrade	• Adopted design guidelines for climate resilience • Installation of tide gates
		LaGuardia	Design Guideline Infrastructure Upgrade	• Adopted design guidelines for climate resilience • Replaced damaged electrical substation placing it well above the 100-year flood elevation
		Newark Liberty	Design Guideline Infrastructure Upgrade	• Adopted design guidelines for climate resilience • Terminal A project will be required to adopt the Port Authority's Design Guidelines for Climate Resilience
		Oakland	Assessment	• Conducted vulnerability assessment, resilience study, esp. against rising tides
		Philadelphia	Assessment Infrastructure Upgrade	• Vulnerability assessment conducted • Integrated climate change issues into strategic planning and operational activities • Electrical substations upgraded
		San Diego	Infrastructure Upgrade	• Designed and installed demo project for pervious and permeable pavement to drain storm water • Conducted vulnerability assessment
		San Francisco	Assessment Design Guideline	• Vulnerability assessment conducted • Developed resilience planning, design, and construction guideline
		Seattle-Tacoma	Integration to master planning	• Workshops for vulnerability identification and integrate adaptation planning into airport master plan
		Stewart	Infrastructure Upgrade	• Installed permeable pavement to drain storm water

ANNEX C. CASE STUDIES

NORWAY

Wetter and wilder weather
Preparing for more water at Norwegian airports

In Norway, a warmer, more volatile, and wetter climate with wide regional and local variations is expected. Increased precipitation and freak rains challenge the drainage of runways, aprons, buildings and other infrastructure. Extreme weather events and natural disasters will be more frequent, resulting in serious physical and financial damage without proper adaptation planning.

Avinor, the operator of Norway's 45 airports, has been looking systematically into climate adaptation since the turn of the century. Most of Avinor's airports are scattered along the rugged Norwegian coastline, with several runways less than 4 meters above sea level. When new legislation was introduced in 2006, requiring safety areas at the sides and ends of runways at several airports to be expanded, theory had to be turned into practice. The seabed close to the runways in question was very deep in some places. This required looking into projections for future sea levels, wind directions, wave directions and – in some instances – the underwater topography to calculate the size, shape and amount of rocks needed to make robust fillings which would be able to withstand future storms.

A comprehensive risk assessment of all Avinor airports, connected navigation systems and surface access to the airports was undertaken in 2013-14. During the planning phase of the terminal expansion at Oslo Airport and the related work on the apron, for example, it was revealed that the new drainage systems needed 50% added capacity compared to the 1990s when the airport was constructed. It was also discovered that the batteries for some of the navigation equipment were placed on the floor at airports at risk of flooding.

To ensure lessons learned are used and embedded, a procedure was developed for dimensioning criteria for safety areas close to the sea, as well as a set of guidelines for low-lying coastal runways and strengthened requirements for potential runways – they now have to be established at least 7 meters above sea level. Also, through the establishment of standards for buildings, it is expected that new infrastructure projects will have a greater emphasis on climate adaptation. An example of this is the project planning work for a new airport in Bodø, which started in 2017.

Avinor's approach to climate adaptation starts from the very beginning of planning, from selecting materials and conducting capacity assessments. Its experience also shows that minor adaptation investments in pre-planned and/or ongoing projects can not only have a positive impact on punctuality and regularity, but also save on future resources.

BRISBANE

Preparing for sea-level rise yet minimizing costs of airport development

Recognizing the potential risks and impacts from climate change and given the vital importance of the infrastructure and its long-term operating life, Brisbane Airport Corporation (BAC) implemented a 'Climate Change Adaptation Plan' to detail potential vulnerability to climate change and corresponding actions to mitigate based on current modeling and research.

Among others, sea-level rise, increased frequency of cyclonic events, increasing drought durations, more frequent occurrences of extreme heat days, and warmer winters and summers are identified as key risks to Brisbane airports. Particularly, a sea-level rise of approximately 0.14m (0.09-0.18m) from 2005 to 2030 is expected under every climate change scenario.

To address this issue, BAC has implemented detailed flood and drainage planning which required Minimum Design Levels (MDLs) for all new green-field developments. The MDLs primarily address a critical flood threat of 1 in 100 year cyclonic storm tidal surge event, without relaxation for land use or operational risk. As a result, even remote carparks were subject to this high standard, increasing the potential costs of construction.

Such strict design regulation affected the planning of a flagship project of BAC to develop an Auto Mall that delivers a multi-purpose auto retailing hub in Brisbane airport's green-field land. Initially, the Auto Mall design employed standard MDLs, which led to an economically infeasible estimated budget of 125 million Australian dollars, with the costs of filling and surcharging representing 60% of the total budget.

Given the situation, BAC adopted a value engineering approach to balance the cost and value, and improve the project's viability. A number of measures was taken accordingly: a reduction in the design life of the project from 100 years to 50 years; relocation of a flood conveyance drain out of the Auto Mall site; utilization of man-made bunding afforded by the surrounding perimeter road network; and installation and closure of flood/tidal gates in road culverts in combination with a series of flood-storage basins within the site.

These measures significantly reduced the Auto Mall's MDLs by 0.8m, resulting in a reduction of 400,000 cubic metres of fill and 1 million linear metres of wick drains originally required over the 51-hectare site. The revised estimated project cost was reduced to 85 million Australian dollars – almost one third decrease from original estimate – on top of the increase in leasable area of 1.5 hectares, restoring the project's economic viability. Additional environmental benefit would be achieved as the volume of required fill decreased, not to mention the mitigated risks of climate change and adverse weather conditions.

HONG KONG

Rapid response and recovery from adverse weather

Airport Authority Hong Kong (AAHK) has been working closely with the airport community to strengthen its ability to prepare for and respond to potential weather disruptions. Prior to the onset of extreme weather, AAHK liaises closely with the Hong Kong Observatory (HKO) and Air Traffic Control (ATC) to assess the potential impact and prepare for critical contingency measures.

Based on the weather information from HKO and advice from ATC on runway capacity, AAHK may trigger the Flight Rescheduling Control System (FRCS) to handle the airlines' rescheduling requests, with a view to quickly resuming normal airport operations in an orderly manner once the extreme weather has abated. The Airport Emergency Centre (AEC) may also be activated for multi-agency coordination in support of the FRCS activity and contingency arrangements such as aircraft ground holding, ramp handling of baggage, passenger crowd management, extended Automatic People Mover service hours, as well as extended public transportation between the airport and downtown areas. On the other hand, plans for active media engagement included regular updates to the media with latest information, joint media briefings with local carriers at the airport, terminal announcements, website and mobile app announcements, etc, so as to keep passengers and the public abreast of the latest situation. When the situation resolves and flight movements resume, AAHK works closely with the airlines, ground handlers and line maintenance operators to ensure that sufficient resources are available to handle the flights and serve the passengers.

One successful example of coordinated response was in August 2017, when Typhoon Hato hit Hong Kong and wreaked havoc on the city. One day prior to the typhoon, AAHK had already proactively communicated with the HKO and the ATC, to monitor the development for impact assessment. Weather briefings were held to coordinate contingency measures, and the timing of FRCS activation was announced. Flight consolidation and the public communication plans were also prepared.

Upon issuance of Typhoon Signal No. 3, AAHK activated the AEC for monitoring. All relevant organizations sent their representatives to the AEC when Signal No. 8 was in force to ensure a coordinated response. The mass communication plan was activated to alert the public about the impact via digital displays in the terminals, public announcements through the local media, airport website, mobile application and media briefings. Within hours, Typhoon Hato escalated rapidly to typhoon Signals No. 8, 9 and 10 consecutively. Most of the aircraft were grounded, and ferry and land transportation were suspended.

While the airlines' flight consolidation, the FRCS and the suspension of transfer passengers had significantly alleviated pressure on crowd management in the airport, AAHK strategically deployed manpower in the terminals to handle passenger enquiries and to monitor irregularities during the typhoon and its recovery. Service hours of public transport and catering outlets were also extended to cater for the needs of passengers. The typhoon Signal was lowered to No. 3 in the late afternoon the same day. As soon as the weather constraints eased, the two runways maintained operation overnight to clear the backlog of more than 600 flights in accordance with the FRCS approved schedule, nearly doubling the number of flight movements compared with normal days.

The early planning and collaborative effort of the entire airport community had ensured a swift, orderly and efficient typhoon response and recovery. Airport operations returned to normal the next day. More than 1,300 aircraft movements were recorded on that day and the number of passengers handled reached a new single-day record of more than 234,000.

ISTANBUL

Comprehensive study for climate adaptation planning

From the outset, Istanbul Grand Airport (IGA) aimed at identifying, analyzing and managing climate risks affecting the planning, construction and operation of the airport as part of a climate-change adaptation study. Furthermore, airport assets will be investigated for parametric change in 2030, 2050 and 2080.

IGA's methodology for it's climate adaptation study was as follows:

- Definition of current climatic baseline
- Modelling of future climate change for 2030, 2050 and 2080
- Literature review and consultation
- Risk identification and prioritization
- Response identification and prioritization
- Reporting, governance and monitoring

Analysis was done in terms of potential impact vis-à-vis airport assets/operations:

- Physical disruption: abrupt disturbances and impact to business continuity due to loss of function (service disruption) caused by extreme weather events and natural hazards
- Loss of performance: gradual loss of performance from variations in normal weather patterns such as increases in peak electricity demand, excessive wind, changing soil composition due to precipitation change, less water availability for cooling purposes

From the analysis, clear recommendations to address the gaps and to implement the adaptation strategies were provided, including an emphasis on the potential financial and economic impact of loss of function at IGA. Potential impacts were assessed in terms of loss of number of passengers, days lost and infrastructure to be renovated. In addition, a programme for community outreach and stakeholder involvement was designed, including methods for community mobility, well-being and resource preservation, as well as a grievance mechanism.

Beyond the scope and boundaries identified above, an upcoming study by the Greater Metropolitan Municipality of Istanbul with an overarching analysis of cumulative impact will be available, including the access to the airport by private and public transport as well as water supply and sanitation, energy transmission and waste management.

AMSTERDAM

Flood-proofing Schiphol Mainport

Situated in a very complex urban area and more than four meters below the sea level, Schiphol is highly vulnerable to the impact of climate change. Various climate scenarios, including the 21st century climate change scenario by Royal Netherlands Meteorological Institute (KNMI) and IPCC's 5th Assessment Report, have already indicated that the temperature in the Netherlands is expected to rise, with more intense and extreme rainfall, hail and thunderstorms. Furthermore, the sea level is expected to continue to rise by as much as 100cm by 2100. Accordingly, weather variability – and thus unpredictability – is also expected to increase, leading to more frequent disruptions in scheduled (and increasingly automated) flight operations and routes.

To ensure the sustainability of Schiphol's business operations and contribute to the development of national climate-proof knowledge, Schiphol participated in the national 'Knowledge for Climate' research programme and developed future perspectives for adaptation strategy. Through this programme, potential impacts to reliability of airport operation – departure, arrival, and ground operations, damage to physical assets – infrastructure and equipment, and associated expenses were studied. Furthermore, given the unique challenge that Schiphol faces, particular consideration was given to spatial design elements pertaining to water management, such as the airport's drainage system, water buffers and flood-risk management.

The findings of the study identified that flood-risk at Schiphol is in fact quite well managed, to the point that the airport, with minor interventions to further improve flood safety, may be one of the safest polders of the Netherlands. As it happens, in the advent of flooding elsewhere in the Netherlands, Schiphol airport may function as a 'safe haven' or 'air bridge' to safer areas. Likewise, for other weather stressors such as wintery conditions and convective events, it was found that Schiphol is managing the impact of climate change well through its present-day operational and management practices.

SINGAPORE

Preparing the airport for the effects of climate change

Recognizing the potential challenge and impact of climate change, the Singaporean government, including the Civil Aviation Authority of Singapore (CAAS), has introduced a whole-of-government approach to coordinate on climate change policies. CAAS has been working to enhance Changi airport's resilience, especially against coastal erosion and inundation associated with rising sea levels coupled with weather variability such as storm surge.

Impact assessment on airport physical assets and operation was conducted as a precursor to formulating an adaptation pathway. Short-term (2030) to long-term (2100) scenario analyses against possible climate stressors identified vulnerabilities in the physical asset, with minimal impact on operations due to Changi airport's runway orientation.

To address potential damage to infrastructure, comprehensive approaches targeted at individual airport assets as well as broader district-level protections – such as levees, tidal gates, holding ponds and pumping stations – were established. For example, raising the road level surrounding the airport can act as a levee for district level flood protection, as well as a de-facto fixed flood barrier. The 1km stretch of Nicoll Drive, which hugs the shoreline near Changi Beach, was raised by 0.8m in 2016, which is above the Singapore Government's 0.76m sea level rise projection for 2100.

Furthermore, to ensure that the Changi East site is resilient to future climate change conditions, the Changi East site has been designed with a higher platform level at 5.5m above mean sea level. Four new drains will be built to ensure that flooding does not occur within the new airport site, with a total of around 10km of drains built, and the longest being around 3km long and 40m wide.

Mega infrastructure projects are typically designed for a long-term horizon, requiring sufficient infrastructure provisions to be included at the beginning of the project to ensure its sustainability in the long run. With these preventive measures to protect infrastructures, Changi airport is expected to remain resilient against future climate changes and adverse weather conditions well into the future.