Climate Change: Climate Risk Assessment, Adaptation and Resilience

Key steps in Aviation Organisation Climate Change Risk Assessment and Adaptation Planning

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ENVIRONMENT

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Key Steps for Aviation Organisation Climate Change Risk Assessment and Adaptation Planning

Introduction to Aviation Climate Change Risk Assessment and Adaptation Planning

The following guidance on performing a climate change risk assessment and on developing and implementing a climate change adaptation plan is intended for use by airports, aircraft operators and air navigation service providers (ANSP) across the global aviation network. It can also be used at the National level by States that are engaging in climate change risk assessment of their aviation sector either as an aviation-specific assessment or as part of a wider national or transportation sector assessment.

Recognising the diversity within this broad stakeholder group, the guidance is widely applicable and only provides a list of generic steps. Individual organisations and States should adapt the guidance according to their specific organisational or national situation. An assessment can be as simple or complex as an organisation requires. The size, scope, and budget of the risk assessment should be tailored to address the goals and accommodate the resources of an organisation.

Note that for practical purposes the term "organisation" is used throughout this document rather than "organisation and State". However, the two terms should be considered broadly interchangeable in the guidance as the key steps proposed are applicable for both.

Definition of key terms used in this document

The Intergovernmental Panel on Climate Change (IPCC) definitions used in this document are from the Glossary of the IPCC Report on the impacts of global warming of 1.5 degrees above pre-industrial levels. Other definitions come from Transportation Research Board Airport Corporative Research Program (ACRP) synthesis documents:

- **Adaptation:** "In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects". (Intergovernmental Panel on Climate Change [IPCC] 2018, p. 542)

- **Resilience:** "The capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation". (IPCC 2018, p. 557)

- **Adaptive capacity: "**The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences". (IPCC 2018, p. 542)

- **Climate stressor**: "Changes due to or directly related to [a] changing climate. Examples include sea level rise, increased global and regional temperatures, and shifts in precipitation patterns". (Airport Cooperative Research Program [ACRP] 2014, P.71)

- **Representative concentration pathways (RCPs):** Various scenarios that cover a range of emission levels over time for the full suite of greenhouse gases (GHGs) and aerosols and chemically active gases, as well as land use/land cover (based on IPCC 2018, p556).

- **Criticality:** "The consequences of failure for an individual asset or operation with respect to the continued functioning" of the organisation (ACRP 2017, p48).

In an aviation context, climate adaptation involves adjusting, changing or improving aircraft operations and infrastructure to prepare for projected climate changes and to limit adverse impacts to an acceptable level. It may also provide opportunities to take advantage of beneficial impacts. Aviation climate resilience is the ability for aircraft operations and infrastructure to be able to withstand and recover from external perturbation resulting from the impacts of climate change.

About this Guidance

The guidance covers both carrying out a climate change risk assessment and the subsequent development of an adaptation plan and implementation of the plan's adaptation measures. For ease of use, the guidance is divided into two parts: *Stage 1 Key Steps in Aviation Organisation Climate Change Risk Assessment* and Stage 2 *Key Steps in Aviation Organisation Adaptation Planning and Implementation*. Nevertheless, the two parts should be seen as consecutive stages in the same process of aviation organisation risk assessment and adaptation planning.

Stage 1 comprises six consecutive steps. Stage 2 comprises four consecutive steps. Figure 1 sets out how the steps fit together and where there are links between them.

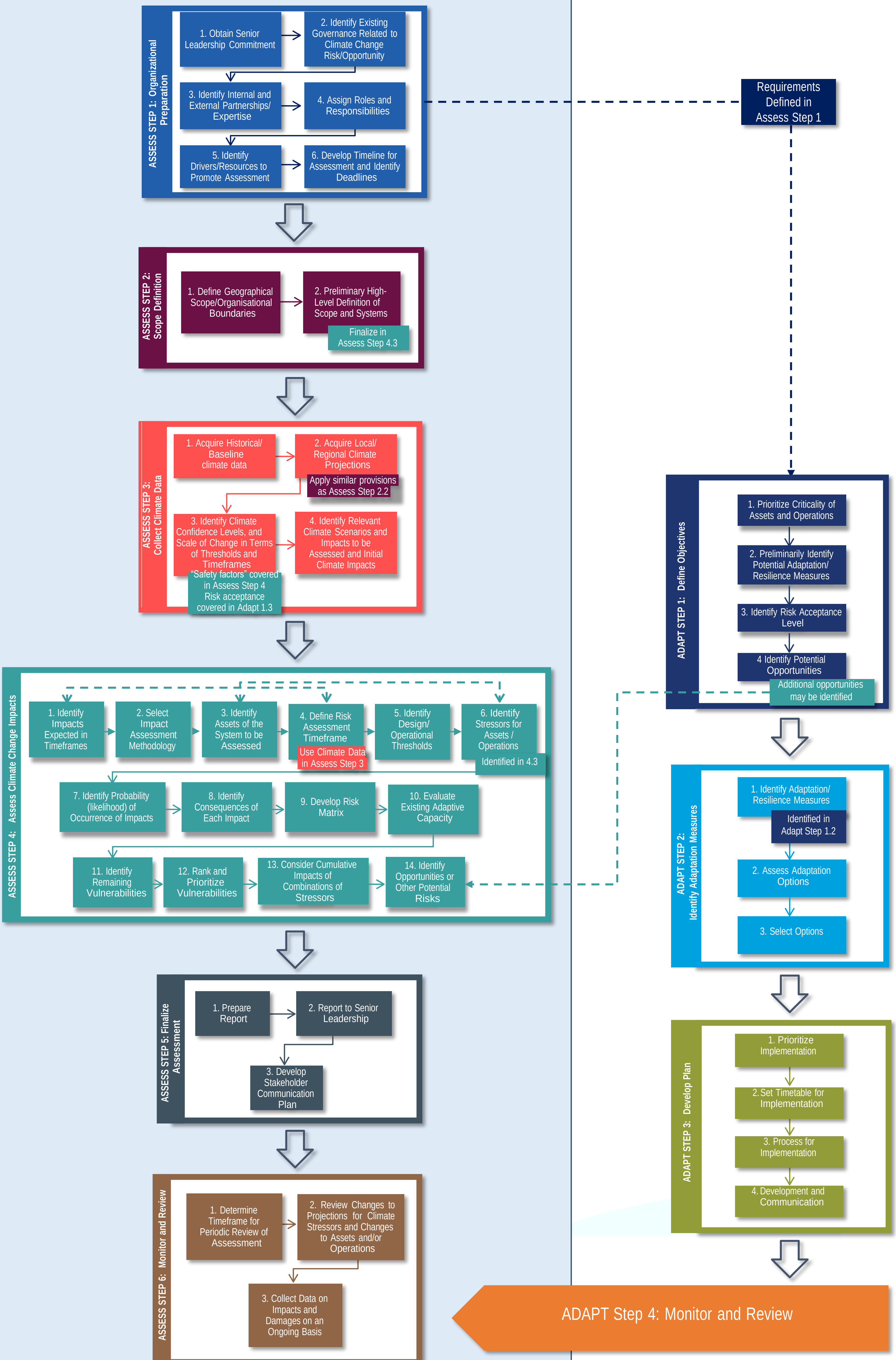

Figure 1- Steps in climate change risk assessment and adaptation planning for aviation organisations

Stage 1: Key Steps in Aviation Organisation Climate Change Risk Assessment

There are six key steps for aviation organisations to consider when carrying out a climate change risk assessment, which are depicted in Figure 2 below. These are: 1) Prepare the organisation for the assessment, 2) Define the scope of the assessment, 3) Collect climate data, including identifying climate stressors and scenarios, 4) Assess climate change impacts, 5) Finalise the assessment in preparation for adaptation planning, and 6) Monitor and review the assessment. This section will outline each of these steps and the associated actions for climate change risk assessment in detail.

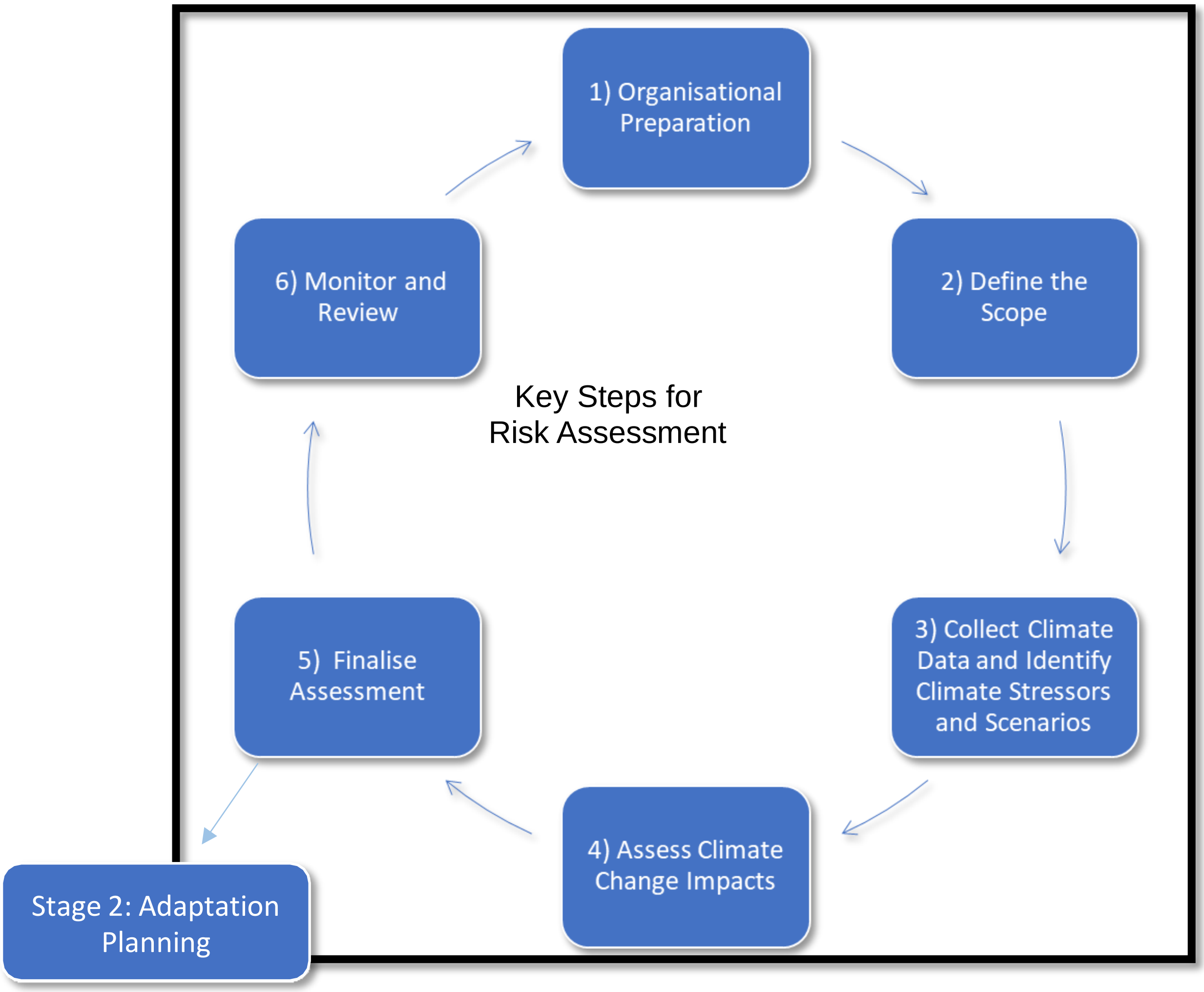

Figure 2 - Key Steps in Climate Change Risk Assessment

Details of Key Steps for Risk Assessment

Key Step 1: Prepare the Organisation for the Assessment

This step focuses on preparation for the assessment itself and developing the framework for the assessment process. There are six actions. It is recommended that the actions are followed in the order presented below. However, if required they may be adapted based on an organisation's particular circumstances and planning processes.

Action 1.1: Get senior leadership commitment

There are many reasons for initiating a climate change risk assessment. There may be a legal requirement, a senior leadership request, or the initiative may originate from within the organisation (e.g. from the environment, strategy, or finance team). Whatever the reason, senior leadership commitment should be obtained before starting the assessment. The full support of senior leadership for the risk assessment legitimizes the work and facilitates procuring required human and financial resources.

It is necessary to identify the objective(s) of the risk assessment, its expected goals, and the target audience for any recommendations. How this is achieved varies from organisation to organisation, but it may involve explaining at a high-level the following:

- The reasons for doing a risk assessment,
- The potential risks from climate change that the organisation may face,
- The potential benefits of taking action to address those risks, or
- The potential consequences and costs of not taking action.

A high-level overview of potential risks can be drawn from regional or national climate change assessments or the 2018 ICAO Climate Adaptation Synthesis and the Key Climate Change Vulnerabilities for Aviation Organisations document accompanying this guidance. Publicly available climate adaptation plans from other aviation sector organisations, and the methodologies used to develop those plans, may help develop a better understanding of possible climate change risks (and benefits) for aviation organisations.

Once organisation senior leadership support is secured, it is necessary to communicate that support across the organisation and explain both the potential risks from climate change and the benefits of addressing those risks through the processes of conducting a climate change risk assessment and developing an adaptation plan. Organisations should also coordinate with external stakeholders at this stage of the process, for example, an airport operator should consult with the main aircraft operators operating at an airport, or an Air Navigation Service Providers (ANSPs) should consult with the main aircraft operators that operate in its airspace.

Action 1.2: Identify whether the organisation has any existing governance related to climate change risk and opportunity

Check to see if the organisation has an existing framework, leadership structure, methodology or decision-making processes (e.g. a Master Plan for risk management). A key starting point could be the organisation's safety management system as the processes for assessing safety risks are similar to those for assessing climate change risks. If something does exist, then the organisation should evaluate it for usability. This may involve a review against the remaining steps in Section 1 of this guidance, or a more thorough review of whether it broadly covers the generic steps identified in the full set of key steps below.

If usable, existing governance documentation can be the starting point for the assessment. If not, it may be possible to modify it to cover any additional items or steps required. If nothing is in place, then the team can develop their own framework for the risk assessment work, as per the following steps. This can also present an opportunity to include climate considerations in existing governance documents.

Action 1.3: Identify internal expertise and input required across the organisation, and from external partners as required

Identify who needs to be involved in the assessment, internally across the organisation and from external partners and stakeholders. It is likely that a range of participants will be needed from across the organisation's departments as well as other entities the organisation works with. This may include subject-matter experts (internal and external), safety experts and operational personnel. It is also recommended to identify a champion for the project: somebody who is committed to the work and will drive it forward.

While the initial stages of the risk assessment may have an internal scope, it may also be necessary to engage external stakeholders for input. For example, it may be important to coordinate with national or local transport providers to identify risks when ground transport access routes are vulnerable to a climate impact, such as flooding or sea level rise.

Action 1.4: Assign roles and responsibilities

Decide who has overall responsibility within the risk assessment team. Although environmental personnel within the organisation may initiate the assessment, they may not necessarily take overall responsibility. Depending on the organisation's structure, overall responsibility may fall to the operations personnel, planning personnel, or another relevant team or department. However, the climate adaptation risk assessment and planning process should be multi-disciplinary and, therefore, it is important to encourage all those with key asset and operational knowledge and who have decision-making responsibilities to take ownership of the work and be engaged. Once a team is identified, the organisation should assign roles and tasks within the project.

The Resource Section at the end of this document provides a list of useful expertise and stakeholders who could provide support during the risk assessment process, for example, fixed-base operators (FBOs), airlines, utilities, government agencies.

Action 1.5: Identify drivers and resources to promote the assessment

Drivers for conducting a climate adaptation risk assessment and developing an adaptation plan can include government directives and other relevant legislation, financial disclosure requirements and any information on damage and costs from previous events. Identifying the potential costs of inaction compared to taking action to reduce future risks due to climate change can give an indication of the value of taking action. A rough and initial assessment can be sufficient at this stage, as a more detailed assessment will be carried out as part of the project. Projected future conditions, such as those identified in National or regional climate assessments, can also serve as a driver. Other references include International Standards Organization (ISO) standards, and reports on climate change risk assessments carried out by other organisations.

An initial identification of the main drivers can help define priorities, including allocation of a budget. Financial resources may need to be identified and allocated, as well as additional human resources not already identified in Action 1.3.

Action 1.6: Develop timeline to perform the assessment and identify any intermediary deadlines

Define a timeline for performing the assessment, which allocates a sufficient length of time for each step. The time required will vary according to the specifics of the organisation and the scope of the assessment. However, a completion date may be driven by regulatory deadlines or senior leadership requests.

Setting a time period to perform the assessment should take account of the availability of key internal participants and consider constraints on key external stakeholders. For example, airports and ANSPs may want to avoid scheduling consultations with airlines during peak travel season.

Key Step 2: Define the scope of the assessment

This step establishes the parameters of the assessment (i.e. what is and what is not included). There are two actions for this step.

Action 2.1: Define the geographical scope and organisational boundaries of the assessment

Setting the assessment's boundaries includes defining organisational boundaries. For example, different parts of an airport may be under the control of different entities, or some infrastructure may be owned by the organisation, whilst other infrastructure may be rented. In such cases, it is important to define which entity has responsibility for the assessment. Include important elements that are not owned by the airport in the assessment. These elements may play critical roles for operations (see Action 2.2).

Best Practices/lessons learned for scope decisions

When undertaking a climate change risk assessment, one of the key challenges can be defining the assessment's scope: the scope of a risk assessment can range from an entire multi-site organisation down to an individual asset or operational procedure. While it may be clear that a risk assessment should cover key operations and infrastructure, it should also cover climate impacts to personnel, passengers and general equipment.

In some cases, the scope of the risk assessment may be limited to elements that are essential for service provision, such as airport runways and terminal buildings, or where vulnerabilities due to climate change are already evident—for example, raised sea levels encroaching on runways at coastal airports, or damage to infrastructure from stronger storms. These elements are often prioritized as they are already visible or having a tangible impact. These are clearly important elements to include in the assessment, and certainly provide a good starting point. However, if the assessment is limited to these more obvious components there is a risk of overlooking equally important elements that may be less obvious initially. For example, ground access to an airport or air navigation facility, health and wellbeing impacts on passengers and personnel due to extreme heat, or underground utilities that could be impacted by flooding and result in disruption to airport operations.

Therefore, depending on the geographical scope and specifics of an individual organisation, scope definition for a climate risk assessment should aim to identify any components of assets or operations, which are weather-sensitive and thus could be impacted by a climate-induced change in conditions. This could include electrical systems in locations, which may be vulnerable to flooding, heating, ventilation, and air conditioning (HVAC) systems which risk being overloaded in extreme temperatures, or risks to ground staff from extreme heat. It is also important to understand how climate change might affect the ability to maintain desired or required service levels.

Consequently, to ensure that the risk assessment scope covers all possible elements that may be impacted, the risk assessment team should engage with asset operators, operational staff, facility managers, and decision-makers at an early stage in the process. This can validate elements that have already been identified, identify less-obvious elements that need to be assessed, and provide an understanding of the asset and operational service levels that need to be maintained.

Action 2.2: Preliminary high-level definition of the scope of the systems to be assessed

Decisions defining the scope will vary according to the type of organisation, and the specifics of the organisation itself. It can include infrastructure and/or operations, location, age, lifespan and interdependencies.

An assessment can focus on an entire system, or be scoped to focus on specific vulnerabilities to specific aspects. In order to avoid missing key issues in one area that can have spill-over effects for another area, it is recommended to assess the whole system or organisation, also taking into account access points or key suppliers. If the assessment focuses only on a specific aspect of a system, it should clarify that scope clearly in the documentation and ensure that there are no unexpected consequences such as missing key issues or impacts that may have knock-on effects to other components of the organisation or system that were not assessed. For the most comprehensive assessments, this report recommends taking a system approach when possible. For example, assess the whole airport from an infrastructure and operations point of view, supply chain needs and surface transportation rather than assessing only a part of the airport, such as the terminal infrastructure.

For an ANSP, it is recommended to not only assess impacts on air traffic control and management but also on the organisation’s physical infrastructure. An aircraft operator is recommended to not only assess impacts at the base airport, but also en-route and key destination airports. However, airlines may focus on susceptibility of hub operations as opposed to all destinations if risks are to be addressed in a prioritised fashion. Impacts to aircraft and support equipment may also be considered.

For all assessments and as part of the scoping define criticality, the level of service required and goals for recovery time for different types of events. This is important for potential prioritisation processes later in the risk assessment. However, the level of service required and goals for recovery times should be revisited and revised as the risk assessment progresses, and according to different components of the system. Additional details about criticality are included under Key Step 4.

Key Step 3: Collect climate data, identify climate stressors and scenarios

This step recommends gathering climate data before selecting the climate scenarios to be assessed. However, if there is already a good understanding of potential climate scenarios within the team, then data can be collected only for the selected scenario(s). In most cases though, it is recommended to follow the steps in the order below. There are four actions in this Step:

Action 3.1: Acquire historical and baseline climate data including reports of previous incidents and impacts

To obtain historical climate data to establish the baseline, the organisation can contact its local Meteorological Services (MET) provider. The organisation may also have data on previous weather-related incidents and impacts, and which may be exacerbated by climate change.

Best Practices/lessons learned on determining climate projection timeframes and RCPs

Good quality, reliable climate projections are fundamental to a thorough and useable climate risk assessment that can inform adaptation planning and implementation. However, guidance on selecting appropriate climate scenarios and timeframes for the assessment remain limited. Best practices for climate studies recommend a range of RCPs (Representative Concentration Pathway emission scenarios), an ensemble approach using a range of models, and a projection timeframe of up to 100 years. While suitable for some projects, this can be resource-intensive and expensive, and may not produce results, which reflect a specific organisation's characteristics or planning horizons.

When initiating a climate risk assessment, decisions need to be taken to establish what level of certainty is needed for decision-making. If higher levels of certainty are required, then the assessment will need to be more rigorous (see action 3.3). This may entail the use of an increased number of models and RCPs, resulting in increased costs, resources and time required. Therefore, finding a balance between the required level of certainty and what is realistically achievable is necessary. This is, of course, a decision to be made by individual organisations according to their own specific context.

To choose an appropriate RCP scenario, consider organisational planning horizons and asset lifecycles. There is limited variance between the RCPs (e.g. RCP 4.5 and RCP 8.5) before 2050. Therefore, planning horizons ending before the year 2050 or assets that are likely to have a major recapitalization before this timeframe may not need to use multiple RCPs. However, new infrastructure developments with long lifespans may require a broader range of RCPs. Therefore, RCP selection and climate projection timeframes should be tailored to the characteristics and lifecycles of the individual organisation's assets and operations. This will improve the relevance of the results and should facilitate decision-making.

Action 3.2: Acquire local or regional climate change projections at an appropriate scale for all geographical locations

When considering geographical scale, similar provisions apply as in step 2.2 above. For example, an airline would ideally need to consider climate projections at its base airport and any en-route impacts within the scope of analysis. Partnering with key destination airports would facilitate an understanding of local climate conditions and resulting impacts. An ANSP would need to consider the location of fixed infrastructure as well as en-route impacts. Airport groups with multiple locations would need to gather data for each location.

As with the historical climate data in step 3.1 to acquire suitable climate projections, it is recommended that an organisation contact its local MET office, which may already have the required forecasts, and/or climate projections.

In most cases, a good picture of potential climate changes requires climate projections for a minimum of 30 years (the Intergovernmental Panel on Climate Change [IPCC] RCPs do not significantly diverge until the 2050s). However, results from a 2020 World Metrological Organization (WMO) Survey on the Impacts of Climate Change and Variability on Aviation indicate that many organisations believe there is more value in targeting a ten-year timeframe to understand more immediate impacts. It is recommended that the timelines are also aligned with the investment cycles, specifically for airports and ANSP infrastructure. The selection of a timeline should be tailored to an individual organisation's specific goals and objectives as indicated in "Best Practices/lessons learned on determining climate projection timeframes and RCPs".

Action 3.3: Identify climate stressor confidence levels and scale of change expected in terms of available thresholds and timeframes

The ICAO Climate Adaptation Synthesis contains information on potential climate stressors to aviation and may be a starting point to identify impacts to consider and their potential effects. The overview of *Key Aviation Climate Change Vulnerabilities* can also be referred to. Identify climate stressors that may affect the organisation and the scale of change for each stressor that could cause possible impacts. This is an iterative process as climate projections are not static and the climate may change in a different way or at a different speed than originally projected.

It is also necessary to establish confidence levels. These are the required levels of certainty of the results of the risk assessment. Establishing confidence levels requires agreement at the senior leadership level because it is related to its risk acceptance level (refer to Adaptation action 1.3), required levels of service, or threshold for disruption. This may also be an iterative process.

Not all stressors may have quantifiable data to compare to a threshold. For example, wind speed, fog, and other weather conditions are expected to change in level of frequency and intensity; however, there is currently limited confidence in the models that indicate the degree of change. Thus, in some cases, only a qualitative assessment or a site-specific scenario-based assessment is possible.

In cases where there is no data available to quantify stressors, it is advised to take a conservative approach and add a “safety factor” to the assessment to account for variability. This will depend on factors such as the organisation’s individual risk tolerance, required levels of service, threshold for disruption, insurance coverage, and the significance of the potential effects of the particular climate stressor. Any safety factor applied should be explicitly stated in the assessment. This is further detailed in Key Step 4 below.

Action 3.4: Identify relevant climate scenarios to be assessed (e.g. based on the IPCC’s RCPs), and initial climate impacts for inclusion

Identify the climate scenario(s) to be considered. This should take into account the organisation’s level of risk tolerance. For example, tolerance for long periods of operational disruptions may differ based on the type of operation or service offered. A major hub airport with many connections and feeder flights may have very low tolerance for major and prolonged disruptions, while an airport with low traffic volumes may have higher tolerance. An airport in a Small Island Developing State (SIDS) may have a very low-level of tolerance for disruptions, as airport operations are critical for the country’s livelihood and economy. In this example, the airport may choose to select a higher emissions scenario in order to plan for greater variability and extremes. Given uncertainties in the future impacts of climate change, more than one RCP scenario may be considered. Cumulative impacts of multiple stressors should also be considered. For example, a rise in sea level and an increase in wind speed can interact with each other to intensify the total impact.

Key Step 4: Assess climate change impacts

This section details the process of identifying how climate change impacts might affect the organisation and provides recommendations for the subsequent development of a risk matrix and prioritisation of risks. There are 14 actions under this step:

Action 4.1: Identify and characterize the climate change impacts expected in the selected scenario timeframe(s)

Identify the climate impacts, and the projected extent of impacts, that are expected under each scenario. All assumptions and data gaps should be recorded.

Best Practices/lessons learned on climate impact assessment

When carrying out a climate risk assessment, climate impacts may need to be assessed though expert judgement. Engaging the organisation's personnel is essential, such as asset operators, operational staff and facility managers who have hands-on experience to assess expected impacts. Such personnel are the primary knowledge holders and will be able to identify both impacts to infrastructure and operations that the changing climate may already be causing, and any potential future impacts based on climate projections. While this input is essential to the success of the risk assessment, asset owners and decision-makers may also require quantitative information to take adaptation action. For example, if an assessment is only based on qualitative assessment, the accuracy and utility of the assessment results may depend on which personnel are available and willing to engage in the process, and the overall results could be challenged. Therefore, comprehensive documentation and data tracking is advised to ensure that no key information is overlooked if the knowledge holders are unavailable or have limited ability to participate.

To ensure that such expert-led assessment of climate impacts is as accurate as possible, it is important to engage asset operators early and regularly throughout the risk assessment. Depending on the project results, and once climate vulnerabilities have been understood and prioritized, a follow-up step could include an assessment of engineering resilience. This could validate information collected anecdotally through a quantitative process (refer to step 4.3).

Action 4.2: Select impact assessment methodology

The selected impact assessment methodology will be based on the identification of the expected climate change impacts. While a number of existing methodologies exist, this guidance will focus on the methodology of identifying impacts and consequences to assess risk as indicated in Figure 3.

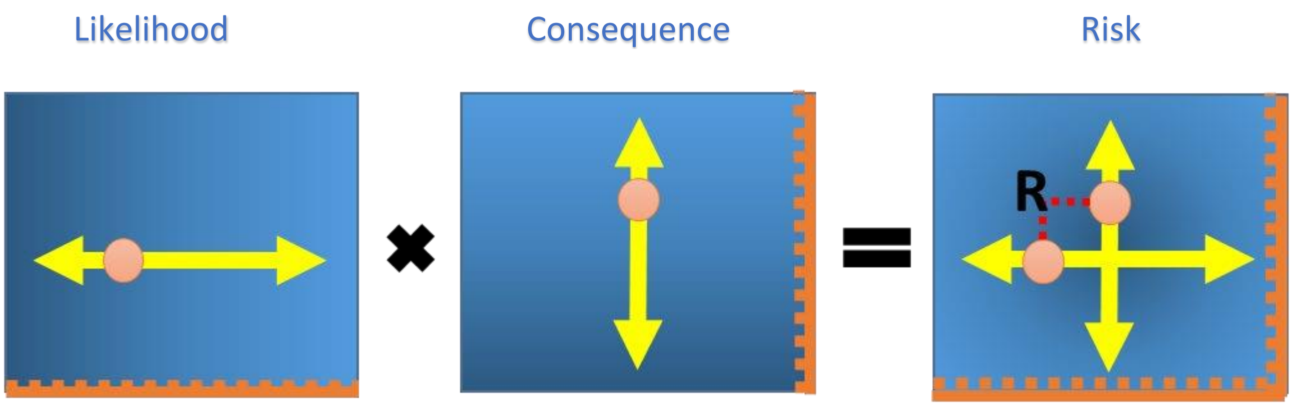

Figure 3 - Likelihood x Consequence = Risk

Examples of other methodologies are provided in the resource section at the end of this document.

Action 4.3: Identify the assets or components of the system to be assessed (*e.g. infrastructure, operations, and any critical elements)*

Identify the assets and components of the system to be assessed. This should include infrastructure, operations and any other critical elements that fall within the scope of the assessment. In some cases, assets can also encompass personnel. When considering what items to assess, the organisation should consider how it will function without each asset. For assets and infrastructure, it is important to consider its lifespan or lifecycle and if its absence affects any other assets. With assets that have a short lifecycle, the organisation should assess the feasibility of expanding or adapting the assets to accommodate future needs. For assets that have an operational impact outside the organisation, (e.g. an airport asset that has an impact on airline operations and costs), stakeholders affected by these secondary impacts should be consulted and made aware of the assessment. For assets with longer lifecycles, consider the potential impact for the duration of the assets lifecycle.

In addition to collecting climate data, collecting asset data can be important for assessing impact (e.g. asset condition, technical specifications, and life cycle information, for example, when the asset might be due for replacement or a major rehabilitation is a factor to be considered). Additionally, “cascading effects” should be accounted for. For example, the impact on one component of the system due to a failure or reduction in performance of another component. Secondary impacts may include supply chain failures or ripple effects in the aviation system due to disruptions elsewhere.

In some cases, a more detailed supplemental analysis may be warranted to look for specific vulnerabilities and how to address them. This can lead to a better understanding of the infrastructure and operational vulnerabilities of the asset, including their relevant socio-economic consequences and produce more tangible recommendations for action within the organisation. For example, in high temperature scenarios, a quantitative engineering analysis of airport infrastructure, including runway length, may be helpful. When looking at supplemental analysis, it is important to consider all factors, including investment cycles.

Action 4.4: Define the timeframe that the risk assessment should cover

The timeframe will be informed by the climate data, the type of organisation and the asset(s) and operations being assessed. As noted under action 4.3, asset lifecycle and investment cycles will be important to consider. There may be value in looking at more than one timeframe to capture shorter-term and longer-term impacts. For example, when considering future runway length and elevation, consider long-term planning needs. While a runway pavement's estimated lifecycle may only be twenty years, the grading, drainage, fill and orientation may exceed the lifespan of the pavement or have longer-term implications.

Action 4.5: Identify existing design or operational thresholds

For each asset, identify design and operational thresholds. As an example, snow or wind loads should be considered for buildings and high temperature extremes for pavement. Any planned capital projects such as renovations or new construction should incorporate these considerations.

Action 4.6: Identify the stressors for assets and operations identified in Action 4.3

For each group of assets or operations, identify the climate stressors that could impact it and the potential effects of those stressors. Table 1 gives an example for each organisation type. The *overview of Key Climate Change Vulnerabilities for Aviation Organisations* provides additional examples.

Organisation Type	**Climate stressor**	**Potential effect**
Airport	Sea level rise	Permanent or temporary inundation
ANSP	Increased intensity of storms	Impacts on capacity and flow management
Aircraft Operator	Higher temperatures	A reduction in payload due to reduced climb performance

Table 1: Examples of potential effects of specific climate stressors on aviation organisations

Not all assets or systems will be affected by all stressors. For example, underground utilities may be subject to flooding but are not normally affected by wind. The *ICAO Climate Adaptation Synthesis*, as well as the *Overview of Key Climate Change Vulnerabilities for*

Aviation Organisations, can be referred to as a starting point for information on impacts per climate stressor.

Action 4.7: Identify the probability (likelihood) of occurrence of each impact

Different impacts will have different probabilities of occurrence and may use different metrics. Meteorological (MET) services or external climate experts may be able to advise on probabilities of future occurrences of weather events. Additionally, climate projections are updated periodically, and may contain information on probability. It is important for an organisation to have not only the most up-to-date projections but to review them periodically and update their risk assessment as necessary.

For example, major flood events may be projected to occur once in 100-years whereas for extreme temperature days the key information may be the number of expected annual occurrences when the daily temperature hits a threshold temperature (e.g. number of days). Flood events that used to be considered 100-year events may now be less than 100-year events, not only due to climate change but also because of urbanization where increased impervious surfaces have increased runoff.

Action 4.8: Identify the consequences of each impact at the identified level of probability

Identify the expected effects on each group of assets or operations. As an example, for a 100-year flood, the organisation should review what measures are in place and how such an event may impact the assets and operation. Impacts from a flood event will not be uniform and could range from minor to significant depending on adaptation measures that may already be in place, and the location and resilience of assets that may be within the projected flood area.

Action 4.9: Develop risk matrix

The IPCC defines risk as, "The potential for adverse consequences where something of value is at stake and where the occurrence and degree of an outcome is uncertain". The IPCC also states that, "In the context of the assessment of climate *impacts*, the term risk is often used to refer to the potential for adverse consequences of a climate-related *hazard*, or of *adaptation* or *mitigation* responses to such a hazard, on lives, *livelihoods*, health and *well-being*, *ecosystems* and species, economic, social and cultural assets, services (including *ecosystem services*), and infrastructure. Risk results from the interaction of *vulnerability* (of the affected system), its *exposure* over time (to the hazard), as well as the (climate-related) hazard and the *likelihood* of its occurrence" (IPCC 2018, p. 557).

A risk matrix is used to assess risk by considering the likelihood or probability of occurrence of an event happening, and weighs that against its corresponding impact. When completing a risk matrix, assign each potential impact a risk rating according to how likely it is to happen and what the consequences (severity) would be if it did happen.

For example, a one in 500-year flood would have a low probability of happening but if the projected consequences are high, it would sit in the upper-left hand side of a risk matrix table, (i.e. high consequence, low likelihood). Conversely, an exceedance of the average number of extreme heat days per annum might have a high probability of occurring but with a medium to low impact on the organisation so it might sit in the middle right of the table, depending on how well-prepared the organisation is to handle such an event. Figure 4 below demonstrates how the matrix can be used. The severity of an event depends on how well the organisation is already prepared to handle it.

Different organisations will be subject to varying impacts and probabilities of events, and will also be differently prepared to address those impacts. Therefore, the risk matrix may look very different for individual organisations.

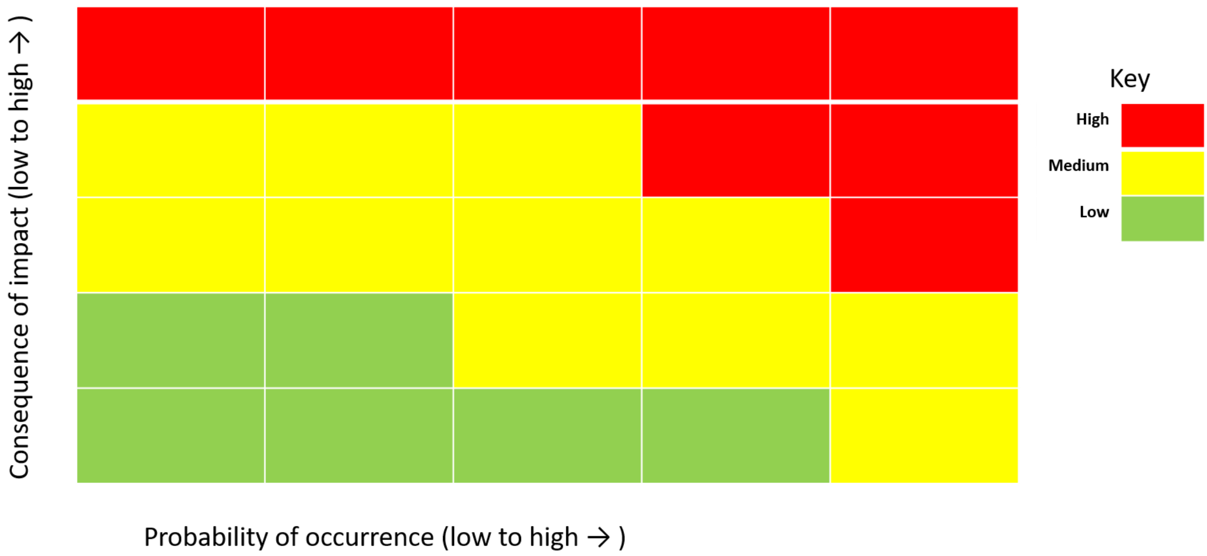

Figure 4 - Example risk matrix (note: this will vary according to the specific risks and consequences an organisation faces.)

Action 4.10: Evaluate existing adaptive capacity

Adaptive capacity is “The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences.” (IPCC 2018, p. 542). For an organisation to evaluate its existing adaptive capacity, it should assess how prepared it already is by systematically reviewing each climate stressor and considering what capabilities it has to address it.

For example, depending on the organisation, some elements to consider while evaluating existing adaptive capacity include:

- Does the organisation's heating, ventilation, and air conditioning (HVAC) system have the ability to accommodate projected changes in temperature over a lifespan of 10 to 15 years? If not, is the physical space to increase cooling capacity available?
- If an airport's automated people mover (APM) system for travel between terminals is not functioning due to a disruptive weather event, is there an alternative mode of transport available?
- Is there more than one access road to the airport? If not, can provisions be made for additional access?
- Is the capacity available to increase aircraft de-icing in the case of unexpected levels of snowfall?
- Do existing sea-level defences have the capacity to increase height in the case of higher projected sea level rise?

Such consideration will help identify where adaptive capacity is available. However, the amount of adaptive capacity may be limited. For example, an airport may only be able to raise its sea defences by an additional two feet while projections may indicate three feet is necessary. As a result, while some adaptive capacity is available, some vulnerabilities may remain. Therefore, where there is insufficient adaptive capacity in place, the organisation has some vulnerabilities to acknowledge and address. If there is uncertainty about the availability of adaptive capacity, then additional analysis and data should be gathered before confirming any vulnerabilities that should be addressed.

Action 4.11: Identify remaining vulnerabilities

After identifying existing adaptive capacity, assess remaining vulnerabilities and decide whether they need to be addressed and how. The process to review existing adaptive capacity should isolate where there are potential risks that are not being fully addressed. In order to quantify the vulnerabilities associated with such risks, it is necessary to evaluate to what extent existing adaptive capacity, if any, can reduce the vulnerability (refer to the section below on Quantifying Adaptive Capacity). Whether and how vulnerabilities should be addressed will be considered in *Stage 2 Key Steps for Adaptation Planning*.

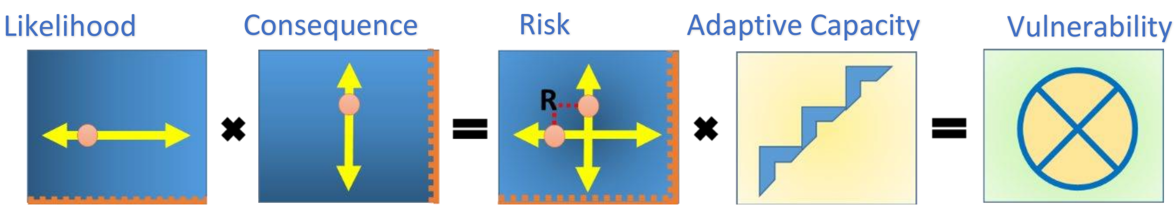

Figure 5 - Risk X Adaptive Capacity = Vulnerability (note: adaptive capacity is inverse, therefore the vulnerability score of a risk with high adaptive capacity would be lower than a similar risk with low adaptive capacity)

The Figure 5 uses five terms that are common in risk assessment and adaptation planning, “likelihood”, “consequence”, “risk”, “adaptive capacity”, and “vulnerability”. For the purposes of this document, these terms are defined by the Intergovernmental Panel on Climate Change (IPCC) as follows:

- **Likelihood: “**The chance of a specific outcome occurring, where this might be estimated probabilistically” (IPCC 2018, p. 553).
- **Consequence: “**The consequences of realised risks on natural and human systems” (IPCC 2018[2], p. 551).
- **Risk:** “The potential for adverse consequences where something of value is at stake and where the occurrence and degree of an outcome is uncertain” (IPCC 2018, p. 557).
- **Adaptive capacity**: “The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences.” (IPCC 2018, p. 542).
- **Vulnerability: “**The propensity or predisposition to be adversely affected” (IPCC 2018, p. 560).

Quantifying Adaptive Capacity and Vulnerability

Figure 5 shows that risk x adaptive capacity = vulnerability. The intention of accounting for adaptive capacity when calculating risk is to try to separate a possible risk from the actual vulnerability when site conditions/operations are considered. Adaptive capacity is the level of effort required to protect the asset from a specific event. For example, a particular infrastructure/system/operation (e.g., an electrical generator) may be at risk of flooding due to sea level rise/storm surge. Therefore, it is important to identify that the risk exists for future planning, and the risk calculation is used to determine and compare those risks. However, if the risk has already been mitigated (e.g. with a protective wall or facility raised above flood stage), the necessary adaptive effort required to protect the asset from that event would be low, hence it is assigned a low adaptive capacity number as the vulnerability is already reduced.

When using numbers to reflect low, medium and high necessary adaptive effort models generally usually use 1, 2, and 3. The same applies with risk in its relation to ongoing operations. If risk of an impact, e.g. a generator going out, is high (3) it will affect the vulnerability number. Hence, a high risk and a high level of effort required to protect that risk (adaptive capacity) would be 3x3 or 9. While a low risk that has been protected by already putting the effort of minimizing impacts would be 1x1 or 1. The asset/operations that is at high risk but has already been protected would be 3x1 or 3, and if it has only been partially protected then ~~it~~ may have a medium adaptive capacity i.e. require a medium level of adaptive effort and would be 3x2 or 6. Therefore, an organization is less vulnerable when it does not have any assets that are high risk or the assets have been protected already from the risk. The numbers are primarily for comparison and identification of high versus low risks/vulnerabilities. Individual organizations may wish to define the scoring numbers to align with their own organisation's approach to risk and vulnerability determination.

Action 4.12: Rank and prioritize organisational vulnerabilities from climate stressors

There may not be resources to address all identified vulnerabilities. It is also not possible to prepare for every possible event. Therefore, focus on the most critical based on priorities as determined by goals, operation type, business, and risk tolerance. This kind of prioritization emphasises the importance of leadership buy-in.

Action 4.13: Consider the cumulative impacts of combinations of different stressors

Based on the understanding of each individual impact, consider how cumulative or cascading impacts can increase risks. For example, consider how a combination of a rise in sea level and an increase in wind speed affect storm surge impacts, or the combination of storm surge, sea level rise, and a king tide occurring simultaneously with an intense precipitation event affect flooding impacts.

Action 4.14: Identify any opportunities or other potential risks in the assessment

Identify potential opportunities, such as an increase in tourism demand due to changing climatic conditions, or a reduction in de-icing requirements due to a decrease in ice and snow conditions that could result in decreased sewage pollution and wear and tear on aircraft pavements. In this example, a reduction in snow and ice may also increase airport capacity by reducing delay times due to de-icing operations. The reduction in snowfall over many areas will positively impact the operation of aerodromes from an economic point of view, e.g., from fewer flight cancellations or delays, or a decrease in heating requirements due to warmer winter temperatures. Identifying opportunities can be done systematically by considering each climate stressor.

This stage could also include consideration of potential unknown effects from external factors, including:

- Possible changes in wildlife migration patterns or timing.
- Possible increase in vector-borne diseases.
- Changes in traffic demand.
- Expansion of areas subject to forest fires, exposing aerodromes that were previously not vulnerable to fire. Smoke from forest fires can disrupt aircraft operations (visibility) and/or impact traffic flows or increase a demand for fuel if an airport becomes a hub for firefighting.
- A decrease in air and water quality due to higher temperatures and drier conditions, may lead to more stringent regulation.
- An increase in lightning strikes, which has safety implications for airside operations (especially personnel).

Key Step 5: Finalising the Assessment in preparation for adaptation planning

After risks and vulnerabilities are clearly identified and prioritized, consolidate and finalise the assessment, in preparation for adaptation planning. There are three actions to this step:

Action 5.1: Prepare report of assessment

A report of the assessment should provide the main findings for example, climate stressors, expected risks and the associated confidence levels, current adaptive capacity and vulnerabilities. At this stage, adaptation measures should not be proposed. Formulating measures to address the risks will be addressed under *Stage 2 Key Steps in Adaptation Planning*.

Action 5.2: Report to senior leadership

Senior leadership will need to decide on the final risk acceptance level and minimum service levels to be maintained in the adaptation planning**.**

Action 5.3: Develop a plan to communicate the outcomes of the risk assessment with stakeholders

Developing a plan to communicate the outcomes of the risk assessment is key to ensure the outcomes of the assessment are effectively communicated to internal and external stakeholders given the importance of damages, disruptions and costs from potential climate impacts.

Key Step 6: Monitor and review the assessment

Review the assessment periodically, as both climate projections and the organisation's operations and assets, and the condition of those assets, may change. There are three actions in this step:

Action 6.1: Decide on a timeframe for periodic review

Decide on a time frame for the periodic review (e.g., every five years). Ad-hoc or interim reviews may be of value when significant new climate projections are released that may affect the model(s) and assumptions that were used in assessing risks.

Action 6.2: Review changes to projections for climate stressors and any changes to assets or operations

If there are changes to projections for climate stressors, the risk assessment should be updated. This information should also be considered during the process of asset replacement or operational change.

Action 6.3: On an ongoing basis, collect data on impacts and damages that occur including types and intensity of impacts and costs

Collect data on impacts and damages that occur on an ongoing basis. Such information will inform any review of criticality, prioritisation and resource allocation. It will also serve to monitor how impacts and costs evolve over time

Stage 2: Key steps for aviation organisation climate change adaptation planning

There are four key steps for aviation organisations to consider for climate adaptation planning, these are: 1) Define adaptation and resilience objectives, 2) Identify adaptation and resilience measures to address prioritized vulnerabilities, 3) Develop and implement a climate adaptation plan, and 4) Periodic monitoring and review (Figure 6). This section will outline each of these steps and sub-steps for adaptation planning in detail.

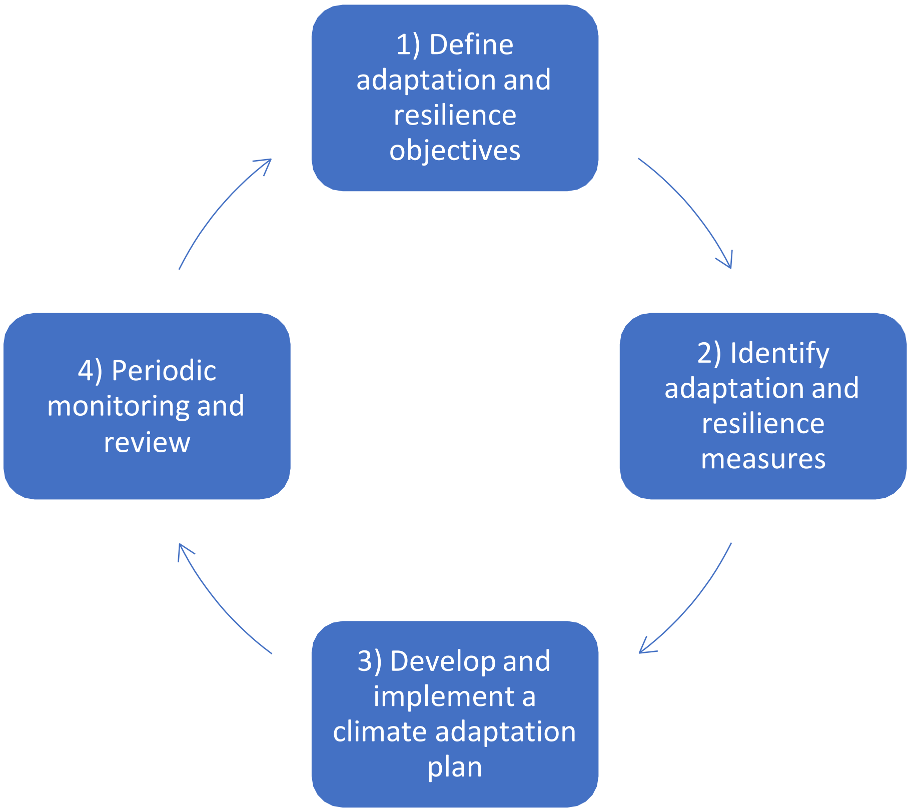

Figure 6 - Key Steps in Climate Change Adaptation Planning

Details of Key Steps for Adaptation Planning

Key Step 1: Define adaptation and resilience objectives

Action 1.5 in the *Key Steps in Climate Change Risk Assessment* identified legislative requirements and organisational drivers to be incorporated into the process of defining adaptation and resilience objectives. It is important to refer to and adhere to these when developing and implementing the Climate Adaptation Plan. This step has four actions:

Action 1.1: Prioritize the criticality of assets and operations

Action 4.3 of the *Key Steps in Climate Change Risk Assessment* identified critical assets and operations that are within the scope of the risk assessment and adaptation process. Action 4.11 in the Risk Assessment Key Steps then identified where, after assessing existing adaptive capacity, vulnerabilities remain for those assets and operations. Action 4.12 then prioritised the criticality of those vulnerabilities.

The next step is to further prioritize the vulnerabilities for those critical elements and decide which of the vulnerabilities are the most essential to address to ensure reliable and safe functioning of the asset or system.

Action 1.2: High-level identification of potential adaptation and resilience measures

The goal of implementing an adaptation or resilience measure is to reduce the risk of a climate impact to an acceptable level of risk. Before identifying a risk acceptance level, it is necessary to have a broad idea of the types of adaptation and resilience measures available for various risk levels. A preliminary high-level set of potential adaptation and resilience measures can be identified from the *ICAO Climate Adaptation Synthesis* or in the *Menu of Adaptation Options* accompanying this guidance.

Action 1.3: Identify risk acceptance level

Identifying an acceptable risk level, or risk tolerance, is an iterative process to identify the needed adaptation and resilience measures. There are many factors that come into play when determining an appropriate and achievable level of adaptation and resilience; for example, useful life of an asset, cost-benefit of the adaptation measures, and uncertainty in the assessment. Moreover, individual vulnerabilities may differ in risk acceptance levels based on factors stated above and their criticality level (Adaptation Planning Action 1.1).

Different systems (assets and operations) may have different requirements and risk acceptance levels. The more critical the asset or operation then the lower the risk acceptance level would normally be. When deciding on risk acceptance level, a decision needs to be taken in terms of which timeframe to plan for (e.g. for ten years, fifty years). This may vary according to the asset and/or its operations.

Consideration needs to be given to level of protection required versus costs and any financial constraints. Adaptation solutions do not always have to be large investments. In some cases it may be more feasible to make smaller fixes more often at a lower cost, rather than making a one-time more substantial investment. For example, a culvert with an expected 1 in 50-year flood protection level may be more economical and manageable overall than a bridge with a 1 in 500-year flood protection level. Other factors such as environmental and operational impacts and costs should also be considered.

Defining risk acceptance levels is an iterative process. For example, an organisation may initially decide on a low risk acceptance level (e.g. for a 1 in 500-year event). However, to achieve that level of resilience may require major investments, for example a sea-wall or structural elevation, at the expense of other projects from which the organisation could benefit (i.e. lost opportunities). Therefore, there may be a need to balance higher risk acceptance (e.g. only preparing for a 1 in 50-year event) with cost and operational implications.

Costs of adaptation can also be balanced against cost savings from some of the potential benefits of climate change. For example, milder winters may lead to reduced de-icing activities, and thus fewer de-icing operations and associated operational and economic costs.

Action 1.4: Identify Potential Opportunities

Changes in climate may also result in opportunities. Risk Assessment step 4.14 already identified some potential practical examples (e.g., to operational procedures). There may also be an opportunity to reallocate scarce resources for other purposes. For example, although some organisations will need to expand assets or operations to handle increased impacts (e.g., stormwater retention facilities in areas where rainfall is expected to increase), other organisations may see a reduction in demand for such facilities (e.g., areas where rainfall is expected to decrease).

Key Step 2: Identify adaptation and resilience measures to address prioritized vulnerabilities

In Adaptation Planning action 1.2 high-level options were identified. This step moves on to identify more detailed adaptation and resilience options that could be implemented according to the level of risk acceptance identified in action1.3 above. This Key Step has three actions:

Action 2.1: Identify detailed adaptation and resilience options

Using the high-level set of adaptation and resilience options identified in Adaptation Planning action 1.2 as a starting point, and taking account of the risk acceptance level identified for each vulnerability and the available budget, draw up a short-list of potential measures. A design of how the measures will fit into the system or operations in practice may be beneficial. Potential adaptation and resilience measures can be identified from the *2018 ICAO Climate Adaptation Synthesis* or in the *Menu of Adaptation Options*.

Action 2.2: Assess the potential adaptation options

Assess the suitability of the potential options to address each vulnerability and categorise the options according to feasibility. Such an evaluation should consider different elements, such as: low- or no-regrets, win-win options (e.g. opportunities for adaptation measures that reduce GHG emissions), trade-offs (e.g. would implementing an option have an adverse effect on an existing asset or operation?), phased implementation, synergies with other programs/projects, and the availability of regional initiatives and funding. Cost benefit analyses (CBA) can be used to gauge the feasibility and relative benefits of various options. It can also help put a value on an option. For example, in some cases based on the cost of the action and the impacts of failure, it may be acceptable to allow the asset to fail and then rebuild. For critical assets this would not be an option. A State or organisation could develop a CBA "Scorecard" to assess the costs and benefits of different options over time. The results of a CBA can then be used as one of the criterion in a multi-criteria analysis which also covers non-financial aspects (e.g. suitability, flexibility, implementation timeline). The analysis may need to consider environmental, economic and social factors.

It is also recommended to consult with key stakeholders on potential measures.

Action 2.3: Select options

Once the previous actions are complete, select which option(s) are most suitable to address each vulnerability. There may be budget or resource constraints that preclude the implementation of some options. Therefore, there could be a need to prioritise the proposed options. Once the final options are selected, senior leadership approval may be required.

Key Step 3: Develop and implement climate adaptation plan

A climate adaptation plan can be developed for the short-term, mid-term, or long-term, or a combination of time frames. However, whatever the timeframes selected it would normally be an iterative process. There are four actions to this Step:

Action 3.1: Prioritisation of implementation

Establish an order or prioritisation for the implementation of each measure. The prioritisation should consider which measure is the most critical to implement and which measures are linked to other actions. For example, if resilience is improved in one part of a system but not in another part, the overall resilience of the system may not be increased.

Action 3.2: Timetable for implementation

Develop a timeline for implementation based on both criticality and practicality. This may be across a range of timeframes from months, years or even decades, and may be tied to longer term or wider infrastructure or operational improvements. Several elements should be considered when defining the timeline, such as: the asset lifecycle and existing age of the asset, total costs of improvement and costs of failure. There is also a need to evaluate what is most important in each case (e.g. cost of replacement, cost of damage, cost of service failure). The timeline for implementation may also be dependent on available resources. Flexibility in defining and revising the timeline is key. For example, from a practical perspective, it may not be possible to make infrastructure improvements during peak season. Moreover, during quieter periods reduced operations may make certain upgrades less costly in terms of downtime.

Action 3.3: Process for implementation

Once the timeline is in place, develop a step-by-step process for the implementation of each measure. A checklist approach may be helpful for tracking this action.

To the extent possible, embed adaptation into existing strategies and plans. For example, short term measures can be implemented directly but long term measures may need to be integrated into master plans or investment plans as actual implementation may be at a later stage.

Action 3.4: Development and communication (internal and external)

Once the implementation plan is agreed, communicate the measures to be implemented, the rationale for the measures and the timeline and process for implementation to both employees and external stakeholders. Additional coordination or training may be required, especially when new operational procedures or new equipment are introduced.

Develop an approach that captures and leverages knowledge and learning from the implementation experience (e.g. best practices). Organisations that have developed adaptation plans should share their experience, when relevant and appropriate, to help build overall aviation sector resilience.

Key Step 4: Periodic monitoring and review

It is important to regularly review both the Adaptation Plan and Climate Change Risk Assessment (refer to Risk Assessment Key Step 6) to verify that the measures that have been implemented are achieving the required results and, if not, then to be able to take remedial action. Periodical review of the risk assessment can also help identify any new risks, and adaptation and resilience measures for those risks can be developed and implemented in a timely manner. There are two actions to this Step:

Action 4.1: Monitoring

Develop a monitoring plan for the adaptation process. This should cover the implementation schedule and how any implemented measures are functioning. It should monitor the performance of each adaptation measure against the defined risk acceptance level and minimum service levels (defined during the risk assessment phase). In the case of major infrastructure improvements, the timescales for monitoring may be longer. As part of a monitoring plan, it is important to report and communicate successes (e.g. where the measures implemented maintained agreed upon service levels during disruption). This can also include cost savings due to the increased resiliency. Understanding successes depends on the ability to identify where progress has been satisfactory or unsatisfactory and develop remedial actions if required.

Finally, the implementation plan itself should also be monitored (e.g. is the plan still valid? Does it need to be updated?). This step is closely connected to Key Step 6 of the *Key Steps in Risk Assessment*.

Action 4.2: Review

Periodically review the adaptation plan and update it if new adaptation requirements are identified. This is strongly connected to Key Step 6 in the *Key Steps in Risk Assessment* which reviews the climate change projections and associated impacts. The timescales for review will be dependent on both the measures being reviewed, the expected life of those elements and the organisation’s timeline for planning.

Climate Change Impact Assessment Methodologies

Section 4.2 focuses on the impact assessment methodology of identifying impacts and consequences to assess risk (likelihood x consequence = risk). This section presents a non-exhaustive selection of other methodologies which are available.

Scenario Planning

According to the Airport Cooperative Research Program (*ACRP) 33* report *Airport Climate Adaptation and Resilience* (2013) Scenario Planning can be used when there are too many uncertainties remain to progress to risk-based prioritization. Scenario planning can be used to identify potential climate scenarios and the associated changes to climate that might be expected, their potential impacts and possible vulnerabilities or opportunities they could cause. It is usually a qualitative process, which draws on expert and stakeholder input.

After defining a set of variables (both climate and non-climate) consideration is given to the possible variations and implications for each variable and for combinations of variables so as to develop "plausible futures" based on combinations of the variables identified as most significant. This can support climate change decision-making by highlighting the need for specific adaptation measures, which can then be examined across the range of potential futures to examine their feasibility in different climate situations. This can be complemented by system mapping to demonstrate links between changes to climate and other drivers or barriers for the organisation.

Real Option Analysis (ROA)

According to the *International Transport Forum* (ITF) (2013) Real Option Analysis (ROA) is one method which can assist with taking account of some of the inherent uncertainties of climate change impacts. It is particularly suited for large, potentially irreversible investments which may have significant upfront costs. The method creates flexibility as to the timing of the investment decision for example is it more effective to make the investment now or to wait. It also considers if and how the infrastructure could adjust to changing conditions over time.

Robust Decision Making (RDM)

The ITF (2013) propose Robust Decision Making (RDM) for decision-making where no probabilistic information is available on either impacts or outcomes. The process begins by selecting the desired *outcomes* and then testing those outcomes for their robustness under a wide range of potential climate scenarios. This allows the selection of "strategies and investments that are consistently robust under the widest range of plausible climate outcomes and impacts" (ITF, 2013 p9) without having to find a consensus on what potential future climate change impacts will be