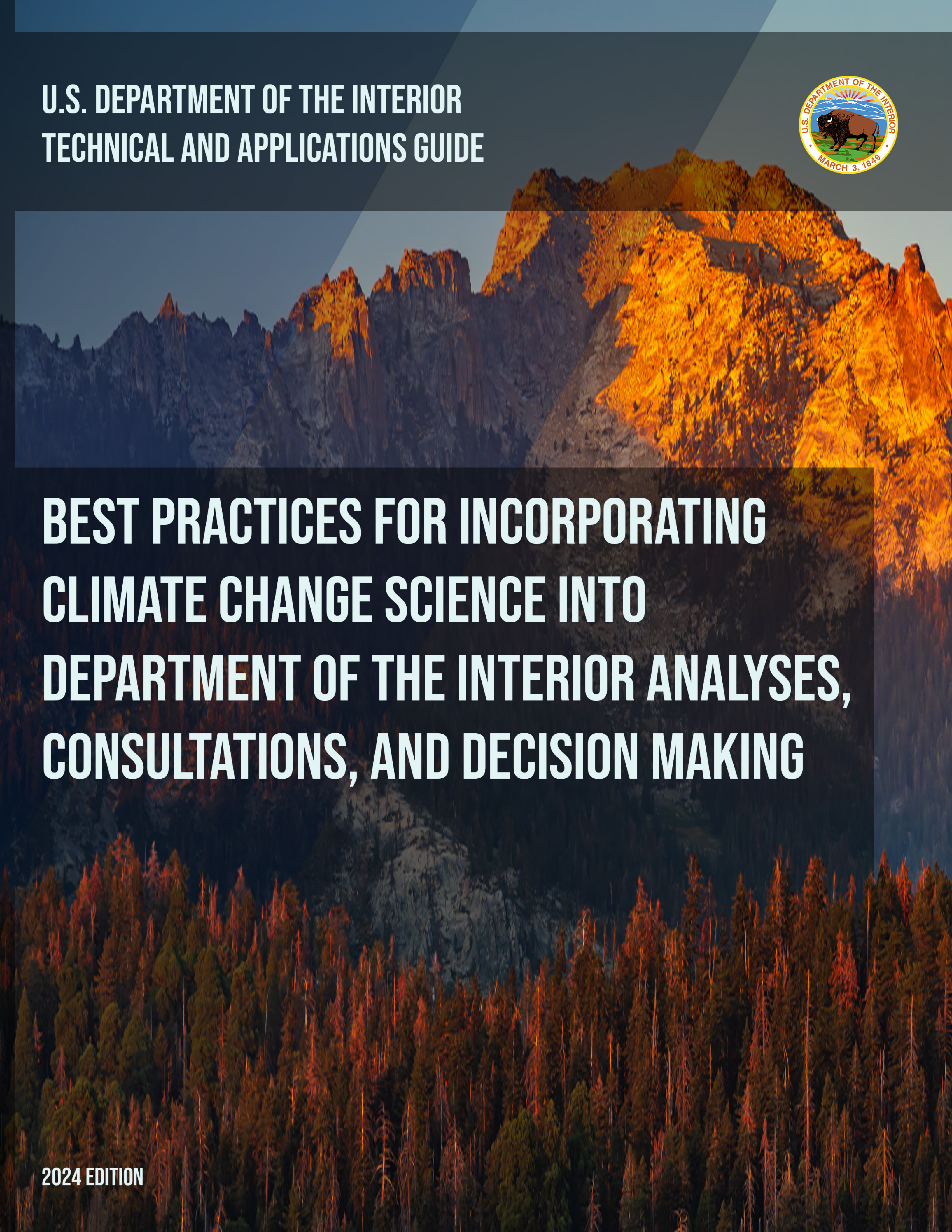

U.S. DEPARTMENT OF THE INTERIOR
TECHNICAL AND APPLICATIONS GUIDE

BEST PRACTICES FOR INCORPORATING CLIMATE CHANGE SCIENCE INTO DEPARTMENT OF THE INTERIOR ANALYSES, CONSULTATIONS, AND DECISION MAKING

2024 EDITION

BEST PRACTICES FOR INCORPORATING CLIMATE CHANGE SCIENCE INTO DEPARTMENT OF THE INTERIOR ANALYSES, CONSULTATIONS, AND DECISION MAKING

The U.S. Department of the Interior Technical and Applications Guide

Climate Science Applications Coordination Team

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PREFACE

The Department of the Interior (Department) Climate Science Applications Coordination Team (CSACT) was chartered in 2023 to provide communication, coordination, and oversight of climate science application activities supporting climate change response across the Department. CSACT membership includes representatives from across Departmental bureaus and offices.

This technical and applications guide was developed by a team of technical experts to guide implementation of Departmental policy 526 DM 1 and as a resource for consistent and effective application of climate change science and data in support of the Department's mission.

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EXECUTIVE SUMMARY

The purpose of this document is to provide technical guidance, practical application examples, and resource lists for those who conduct, manage, and/or interpret technical workflows within the Department of the Interior. This document is intended to support implementation of Department of the Interior policy 526 DM 1 and establish best practices for using climate change science to inform analysis, consultation, and decision making.

The Earth's climate is an interconnected system that distributes energy, heat, and water around the planet. Due to human-driven increases in long-lived greenhouse gases, the Earth's climate is now changing. For Departmental decision-making purposes, assuming a static, unchanging baseline climate is no longer consistent with current knowledge about the climate system.

There are uncertainties about future climate and how resources or assets (RoAs) will respond to new conditions. To depict the possibilities, the global climate science community develops scenarios and models to explore how future climate may respond to socioeconomic and technological development in the world.

Principles for informing policy development, planning and decisions, and regulatory processes using climate change science must: 1) consider the effects of future climate change, 2) characterize the risks, and 3) characterize the uncertainties.

Best practices include:

Use multiple scenarios to assess risks from a range of plausible societal pathways. When constraints prevent the use of multiple scenarios or if decision makers are risk averse, ensure that the chosen scenario considers higher risk outcomes. This is particularly important for large investments or irreversible decisions and reduces the chances of overconfident decision making.

Use multiple climate models within each scenario to account for the range of outcomes due to model uncertainty. Do not rely solely on a single model or an ensemble average.

Use relevant climate data. Use a time-period for model projections of the future climate change consistent with the relevant timeframe of the policy, action, or decision being considered. Historical observations are useful for understanding past conditions and climate trends for the next several years, but not beyond the next decade. Consult with climate data and modeling experts to assess which data and model resources are most appropriate for any given application.

Clearly describe key analysis uncertainties (including with any climate observations, models, and scenarios used), **and how they were addressed** in the analysis and/or decision process. This ensures transparency and learning among analysts and decision makers.

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INTRODUCTION

1. INTRODUCTION

1.1 Background

The Earth's changing climate is fundamentally altering how the Department of the Interior (Department) manages the Nation's most treasured natural resources and cultural heritage. Departmental personnel are already seeing changing climate affect our resources and assets, which forces them to consider challenging questions: How can the Department adjust to this rapidly changing world where the historical climate is no longer the best predictor of the future? How do Departmental staff incorporate emerging climate science into analysis, consultation, and decision making?

Knowledge gained from scientific investigations of our changing climate must be applied appropriately and effectively to help ensure that Departmental resources and assets are managed in an informed way to maximize resilience and minimize the risk of negative outcomes. Policies have been adopted to help the Department consider changing climate for planning and decision-making (523 DM 1), apply climate change science (526 DM 1), implement adaptive management (522 DM 1), incorporate climate change into landscape-level planning (604 DM 1), and implement nature-based solutions (600 DM 7). See Section 1.4 for more on the connection to Departmental policy. Readers are encouraged to utilize relevant Departmental guidance and resources to gain a deeper understanding of these policies and concepts associated with climate change adaptation as part of the broader decision process.

1.2 Purpose

The purpose of this document is to provide technical guidance, practical application examples, and resource lists to support implementation of 526 DM 1 "Applying climate change science" and to articulate best practices for incorporating climate change science to inform Departmental analysis, consultation, and decision making. This document provides a consistent set of principles that can be applied to Departmental processes by staff who conduct, manage, and/or interpret technical workflows.

This guidance aims to help Departmental staff incorporate climate change considerations into relevant decision-making processes. 523 DM 1 provides that all Departmental decisions should be based on the underlying principle that climate change is happening now, and thus climate change should be considered in relevant decision processes. Decision makers should clearly articulate how and why different climate information was used in the decision process to ensure that all decisions are transparent. This guidance is intended to fit within broader decision-making frameworks that could also include multiple objectives, linked decisions, or adaptive management. The concepts discussed in this guidance are relevant for all decision making including those outside of formal planning processes. In particular, this guidance seeks to help Department staff make informed decisions in the face of uncertainty inherent in climate projections and the future status or condition of a resource or asset. This uncertainty can be challenging to incorporate into existing decision analysis frameworks, especially because most normative decision frameworks require probabilistic assessments of future conditions, i.e., decision makers want to know what the most likely outcome will be. As discussed in Section 2.3, it is not currently possible to make such statements about emissions scenarios, leaving decision makers to grapple with a wide range of plausible outcomes. Due to the high degree of diversity within the Department with regards to bureau missions and legal constraints, it is challenging to articulate a single decision-making process for all applications. Individuals should consult their Bureau or program-specific guidance to ensure they are following the recommended process.

This document is not designed to provide comprehensive guidance on problem framing and risk analysis.

Climate change is often framed as a risk management issue, and so this document frequently refers to concepts of problem framing, uncertainty, vulnerability, and risk. While the authors recognize the importance of problem framing and the challenges in assessing or reconciling risk orientation among decision makers and interested parties, comprehensive guidance on problem framing and risk analysis is beyond the scope of this document. Rather, this document assumes that users have some understanding of risk analysis, and that problem framing occurs before readers use the processes described here. Aspects of problem framing include the spatial and temporal scale of the problem, decision objectives, legal sideboards and constraints, and the risk orientation of the decision maker. These have significant influence on the process for selecting scenarios, characterizing uncertainty, and evaluating the resource response to climate change. As such, it is important to clearly articulate objectives and understand risks at the start of the decision process so relevant legal mandates and the values of interested parties and decision –making bureaus are properly reflected in the outcomes. Although individuals may have varying levels of personal risk orientation, in their official role as Departmental decision makers they assume the risk orientation of the Department or Bureau they represent. In the Department context, risk orientation is defined by legal and regulatory mandates as well as Departmental or Bureau mission and policies. Section 2.4 provides more discussion about risk orientation. Department bureaus and offices often have long-established decision-making processes that are risk-informed and tailored to objectives stemming from executive, legislative, or judicial direction. This technical guidance can serve as a precursor for use in established risk-informed decision-making processes. Recommended resources on decision analysis and risk includes Decision Analysis training provided by the National Conservation Training Center, Making Hard Decisions: An Introduction to Decision Analysis by Clemen (1996), and "Part IV, Addressing Risk" in Structured Decision Making: Case Studies in Natural Resource Management by Runge et al. (2020).

1.3 Audience

This document is intended primarily for those in the Department of the Interior who conduct, manage, and/or interpret technical workflows relating to climate science or climate change impacts. These are often analysts, scientists, and/or engineers who are proficient in fundamental climate competencies and who might be involved with application examples in Section 4. This may also include those with limited formal training in climate science but who regularly use it as part of their planning, assessments, and resource management processes.

This guidance is not designed for a broad audience and does not provide the comprehensive background needed to support all Departmental climate science applications. However, it does provide brief overviews of foundational concepts as context to support interpretation. This document is not intended to replace Departmental or Bureau training but may serve as a complementary learning resource for

Regrowth after the 2017 Sprague Fire, Glacier National Park. Photo by NPS.

more in-depth training on climate change applications (Appendix C includes a list of relevant training). This document is also intended to inform and support (but not necessarily replace) bureau-specific guidance and workflows.

Bureau representatives on CSACT listed in the Preface can help connect readers to experts if they lack the needed background or are unsure about the best use of this guidance.

1.4 Connection to Department Policy

As stated in Departmental policy 526 DM 1 Applying Climate Change Science,

> *"Climate change poses significant risks to the Department's mission, programs, operations, and personnel. Some Departmental operations and projects can also contribute to these risks. For Departmental decision-making purposes, assuming a static, unchanging baseline climate is no longer consistent with current knowledge about the climate system. Changing temperatures, altered precipitation patterns, stronger storms, and other rapidly changing earth system processes are impacting the resources and infrastructure under the Department's jurisdiction. Understanding and addressing the risks and effects of climate change in Departmental operations, planning, and decisions is integral to the agency's ability to adapt effectively and efficiently. Successful adaptation requires that the Department's traditional approaches to planning and decision-making are augmented and informed by high-quality information about the Earth's changing climate, including information from relevant and plausible scenarios of the future and associated state-of-the-science climate models. In considering this information for planning and decision-making purposes, uncertainty about the likelihood of future climate trajectories is expected. This adds complexity to the decision-making process but should not ordinarily result in no-action outcomes. Rather, practices … should be adhered to for the use of climate modeling information in Departmental actions. This enables a rational consideration of relevant uncertainties about the future and facilitates the decision-making process even when there is ambiguity about the optimal action or decision."*

To successfully adapt to changing climate conditions, the Department must ensure planning and decision making incorporates climate change science. The Department has developed policies to 1) emphasize that the consideration of a changing climate is the default for planning and decision making to support adaptation and resilience (see 523 DM 1 Climate Change Policy for more details), and 2) incorporate high-quality information about current and future climate change into the Department's mission, programs, and operations (see 526 DM 1 Applying Climate Change Science for more details).

This guidance emphasizes several elements from 526 DM 1, including policy to:

- Incorporate high-quality information about the Earth's changing climate from climate change observations, plausible scenarios of the future, and associated state-of-the-science climate models.
- Acknowledge that the potential presence of a high degree of uncertainty about the effects of climate change on Departmental decisions adds complexity to the decision-making process but should not ordinarily result in no-action outcomes. Instead, clearly articulate the primary uncertainties and assumptions associated with analyses that incorporate climate change science and the implications of these uncertainties on the interpretation of results.
- When selecting scenarios depicting future climate change, whenever feasible use multiple scenarios that span a wide range of potential outcomes. When time, resource, or informational constraints prevent the selection of more than one scenario, ensure that the chosen scenario will enable consideration of higher risk outcomes.
- When selecting climate model projections for a given emissions scenario, whenever feasible use multiple models to capture a range of potential future climate conditions.
- Select time-periods used for model projections of the future climate change that are consistent with the relevant time frames of the policy, action, or decision being considered.

This technical guidance and application examples illustrate practices for implementing 526 DM 1. Several sections refer readers to specific components of 526 DM 1 and related Departmental policies. This document assumes that readers are generally familiar with Departmental policies and look to this guidance for further insight into best practices to implement Departmental policy.

1.5 Structure and Definitions

The document structure begins with background information about the Earth's climate system, climate models and scenarios, and how risk is considered. The subsequent section provides more detailed principles for applying climate observations and models to assess climate sensitivity, exposure, vulnerability, and risk to a resource. The final section includes a series of hypothetical, but practical, examples that illustrate how climate science might be applied to Departmental processes relevant to many bureaus across a range of complexities. Finally, Appendices contain annotated lists of climate data, tools, and training resources that are commonly used for Departmental applications. A Glossary with definitions of technical terms is provided and linked throughout the document.

Throughout this guidance, we refer to Resources or Assets (RoA). These are the tangible features (e.g. a species, a land parcel, a visitor center, an archeological site, equipment) that could be affected by climate change and any potential actions taken by the decision maker(s).

Consistent with Department guidelines, this document uses "high-quality information" to refer to information developed from reliable data sources based on accepted practices and policies that utilize accepted methods for information collection and verification. High-quality information is reproducible to the fullest extent possible and is produced with a high degree of transparency about data and methods. More details on the Department's information quality guidelines are available from the Office of the Chief Information Officer (DOI 2024).

High Park fires, Colorado. Photo by USAF

SECTION 2
TECHNICAL GUIDANCE: THE BASICS

2. TECHNICAL GUIDANCE: THE BASICS

2.1. Defining climate and climate change

The Earth's climate is an interconnected system that distributes energy, heat, and water around the planet. Due to human-driven increases in long-lived greenhouse gases, the Earth's climate is now changing. For Departmental decision-making purposes, assuming a static, unchanging baseline climate is no longer consistent with current knowledge about the climate system.

Scientists typically use two types of definitions when discussing the Earth's climate: one statistical and one based on a systems-approach. The statistical definition is that climate is simply the average meteorological conditions for a given location. This definition gives rise to familiar descriptions of 'the climate' for different places, such as the average summer temperature in Phoenix, Arizona (93.7°F) or the average winter temperature in Fairbanks, Alaska (-4.1°F). NOAA's National Centers for Environmental Information (NCEI) typically calculates these climatological averages (or 'normals') over a 30-year period to smooth out variations in the year-to-year weather (details on the science and methodology used to generate official climate normals is available in Arguez et al. (2012) and WMO (2017)). The second definition takes a more systems-oriented approach and defines the climate system as primarily consisting of the atmosphere, the ocean and other liquid water bodies (the hydrosphere), semi- or permanently frozen areas (the cryosphere), the land surface and areas that interact with the atmosphere and oceans (the lithosphere), and living systems (the biosphere). This interconnected system distributes energy, heat, and water around the planet, giving rise to the environmental conditions experienced by all living organisms.

Humans now exert a strong, unequivocal influence on the global climate system by introducing an imbalance in radiant energy that then accumulates in the climate system. This imbalance is mainly due to the release of large amounts of long-lived greenhouse gases into the atmosphere, primarily carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The increase in these greenhouse gases results from the production and use of fossil fuels and other aspects of our industrialized society. As a result, the planet has experienced approximately 2°F (1.1°C) of surface warming as of 2020 compared to average global temperatures over 1850-1900, a period before there was a substantial amount of climate warming due to human influence (IPCC 2012). This warming has induced other changes in the climate system, such as melting glaciers, rising ocean levels, and more intense rainstorms. The ocean is also becoming more acidic as a chemical response to the increased atmospheric CO_2 concentrations, with attendant impacts on marine ecosystems such as weakening of calcareous shells and exoskeletons in calcifying organisms (USGCRP 2023). The totality of these direct and indirect responses of the climate system to human activities encompasses what is known as anthropogenic, or human-caused, climate change.

The current rate of change in Earth's climate system is unprecedented over many thousands of years (IPCC 2021). As a result, all aspects of planning and decision making that are sensitive to climate considerations can no longer assume that the basic statistical definition of a location's climate will continue to be a reliable predictor of future conditions over subsequent years and decades.

2.2. Modeling the climate system

Climate models incorporate the body of scientific knowledge from observations, theory, and experiments to represent our understanding of the physical climate system.

Scientists have developed powerful tools to understand how the climate system is likely to respond to continued human influence. These computer-based models incorporate the body of scientific knowledge from observations, theory, and experiments to represent our understanding of the physical earth system. A core component of all climate models is the mathematical application of the fundamental laws of physics and chemistry to represent the most important processes in the climate system such as energy transfer and fluid motion. Armed with the mathematical representation of these physical processes, scientists have continuously developed and improved these 'numerical' models since the first computational experiments were conducted in the 1960s (Edwards 2012). Advancements over time in the accuracy and complexity of depictions of the climate system have occurred alongside increasingly powerful computers and improved understanding of climate system processes.

Today (as of 2024), the most complex climate models, referred to as Global Climate Models (GCMs) or Earth System Models (ESMs), include numerous physical and biological processes that play a critical role in the earth's climate system. Because these models require enormous amounts of computing power and significant resources to develop and maintain, only a few dozen have been developed to date and they are run primarily at large governmental or academic research institutions.

Importantly, the fact that there are multiple climate models used today highlights there are still significant uncertainties about how best to accurately represent such a large, complex, and interconnected Earth system. Although the core physics across these models is similar, there also can be different model structures to represent processes within the climate system (see Section 2.3 where uncertainty in climate model projections is covered in more detail). Note that the differences in model structure are scientific, rather than geographic in nature i.e., even though several climate models are funded and developed by the US Government and associated research laboratories, these simulations are not expected to be any more proficient within the boundary of the US compared to other climate models developed by other academic or government laboratories.

While global climate models are complex, they allow for scientists, decision makers, and the public to have greater confidence in their outputs compared to simpler empirical or statistical models. As the planet warms in response to human activities, climate models can explicitly simulate the mechanistic processes that will determine the physical responses of the climate system. In contrast, purely empirical models would be more likely to rely on historical patterns, trends, and correlations that run the risk of providing less reliable predictions about the future.

2.3 Uncertainty

There are uncertainties about future climate and how resources or assets will respond to new conditions. To depict the possibilities, scenarios ***explore how future climate may respond to socioeconomic and technological development in the world. Uncertainty adds complexity to the decision-making process but can be characterized and should not ordinarily result in no-action outcomes.***

Uncertainty in climate science refers to how much about the future is unknown. Uncertainty about predicting future climate conditions arises because the models are inherently limited in their ability to represent the complex climate system, and because it is not known which decisions society will make regarding future emissions and climate mitigation activities. There is also uncertainty about how climate change will interact with other stressors to affect people and natural systems.

Uncertainty is ubiquitous in natural resource management, so there are many well-established methods for decision making in the face of uncertainty (Williams et al. 2009, Gregory et al. 2012). Some uncertainties are reducible, meaning that we can gain more precision through further research, experimentation, or monitoring. Examples of reducible uncertainties include the estimated demographic rates of a wildlife population (more observations could reduce the sampling uncertainty) or the effect of a given management action on plant communities (experimenting across different actions can reveal the response). Other uncertainties are irreducible; we cannot eliminate them, but we can account for the randomness they introduce in the system. Irreducible uncertainties are quite common, such as natural variation in year-to-year weather conditions or fluctuations in the number of visitors to a national park or wildlife refuge. Climate change introduces additional uncertainties, many of which are irreducible. This may add complexity to the decision-making process but should not ordinarily result in no-action outcomes given the suite of tools available to characterize and quantify uncertainty.

Three primary sources of irreducible uncertainty are pertinent to Departmental use of climate models:

1. **Scenario Uncertainty:** There is uncertainty about the future trajectory of global climate-influencing emissions (or climate forcings) produced by humans.
2. **Model or Scientific Uncertainty:** There is uncertainty in projected climate conditions due to differences in climate model structures that reflect either incomplete understanding of certain phenomena, or differing choices about how to represent simplified versions of what are typically small-scale phenomena that cannot be fully resolved in models due to computation limitations. Note these uncertainties are reducible through the process of scientific investigation and computational advances. However, this process is usually not part of a typical Departmental analysis. Thus, the level of uncertainty across simulations from global-scale climate models can be considered irreducible.
3. **Internal Variability or Environmental Stochasticity:** There is natural variability in the climate system that is unpredictable beyond certain time periods due to numerous complex and, often, nonlinear interactions.

For example, for a decision involving a listed species sensitive to drought, decision makers may consider:

1. the mean expected annual precipitation under different emissions scenarios (scenario uncertainty),
2. the range of projected precipitation under different models within each scenario, possibly categorizing models as “dry models” or “wet models” (model uncertainty), and
3. the probability of a drought occurring in any given year or the cumulative drought frequency over some time horizon (environmental stochasticity).

Any of these uncertainties could influence the expected outcome of different management actions and, therefore, the best decision. Additional background on these uncertainties is provided in Box 1 and Figure 3.

Decision makers and analysts should explain key uncertainties and how they were addressed. 526 DM 1 states it is Departmental policy to *“Clearly articulate the primary uncertainties and assumptions associated with the analysis and the implications of these uncertainties on the interpretation of results.”* It is also important to note there may be cases where the decision is not sensitive to a given source of uncertainty (Canessa et al. 2015). For example, uncertainty in future emissions does not affect a decision about whether or not to carry an umbrella on a potentially rainy day. Considering the time horizon of the decision can help identify which sources of uncertainty are most influential to the decision. The contribution of different sources of uncertainty to the total expected amount of uncertainty can change as the projection timeline increases (Hawkins and Sutton 2009, USGCRP 2017). For example, over the very short-term (0-10 years), most uncertainty about future global mean surface temperature is due to natural climate variability. Over the medium-term (10-25 years), model uncertainty contributes the most to overall uncertainty. Over the long-term (25+ years), scenario uncertainty contributes the most to overall uncertainty for this climate variable. Therefore, the choice about which scenarios to use will have a lower overall impact on a decision with a very short time horizon, while accounting for natural variability in the system is less important for decisions operating over a longer time horizon. Note the relative importance of these different sources of uncertainty also depends on the climate variable being examined (for example, temperature versus precipitation) as well as the size of the area (for example, global versus regional). Importantly, natural variability may remain the most important contribution to the overall amount of uncertainty for some key variables, in which case, the decision may not be sensitive to future emission trajectories.

Another key uncertainty introduced by climate change is incomplete knowledge of how the system or the RoAs under consideration will respond to new conditions (Box 3). This uncertainty is reducible through further research or monitoring, but decisions must often be made without such additional efforts. Analysts should rely on high-quality information and document uncertainties regarding system and RoA response to climate change. All tools for decision making under uncertainty remain relevant. If the issue at hand is a recurring decision and the uncertainty about RoA response to new climate conditions is highly influential to the decision, adaptive management is a useful tool for incorporating continued learning with management over time. In addition, information gained from one decision process may provide useful insights relevant to future decisions. As stated above, even a high degree of uncertainty in system response to climate change should not ordinarily result in a no-action outcome.

2.3.1 Using scenarios when the uncertainty is 'deep'

Ideally, society would be able to convey uncertainty about the future using probabilities, allowing us to quantify the expected likelihood of different outcomes. This is quite difficult to do, however, when considering the long-term effects of climate change. Beginning at time scales of 20 years or more, the dominant driver of uncertainty for many climate variables is more likely to stem from uncertainty about how much influence humans will have on the climate system (i.e., the level of future greenhouse gas emissions). Furthermore, accurate and reliable prediction of future societal actions and policies around greenhouse gas emissions is much more difficult than predicting the response of the physical system to the forcing itself. One solution to characterize this type of uncertainty, often referred to as 'deep uncertainty', is to use scenarios. These are internally consistent depictions of the future that meet a broad standard of being 'plausible', and typically do not explicitly state the probabilistic likelihood of the scenario.

526 DM 1 Section 1.5.A(3) states that it is Departmental policy to *"use climate change scenarios that have been published by or developed for the Intergovernmental Panel on Climate Change (IPCC) or the USGCRP. This can include scenarios that are not time-dependent, such as 'Global Warming Level' scenarios."*

2.3.2 IPCC Scenarios

Scenarios have been co-developed between the climate science community under the World Climate Research Programme to form the Coupled Model Intercomparison Project (CMIP) and the integrated assessment modeling community to support IPCC Periodic Assessment Reports. These two interrelated efforts have produced a set of scenarios that span a wide range of plausible climate futures that reflect different potential emissions pathways. The IPCC process for developing scenarios is based on a rigorous and collaborative effort that has the support of the vast majority of governments across the globe. Because of this process, these scenarios, and the resulting climate model outputs from CMIP, form the backbone of most climate change projections used in decision making in the United States. Climate scientists then use information from these scenarios

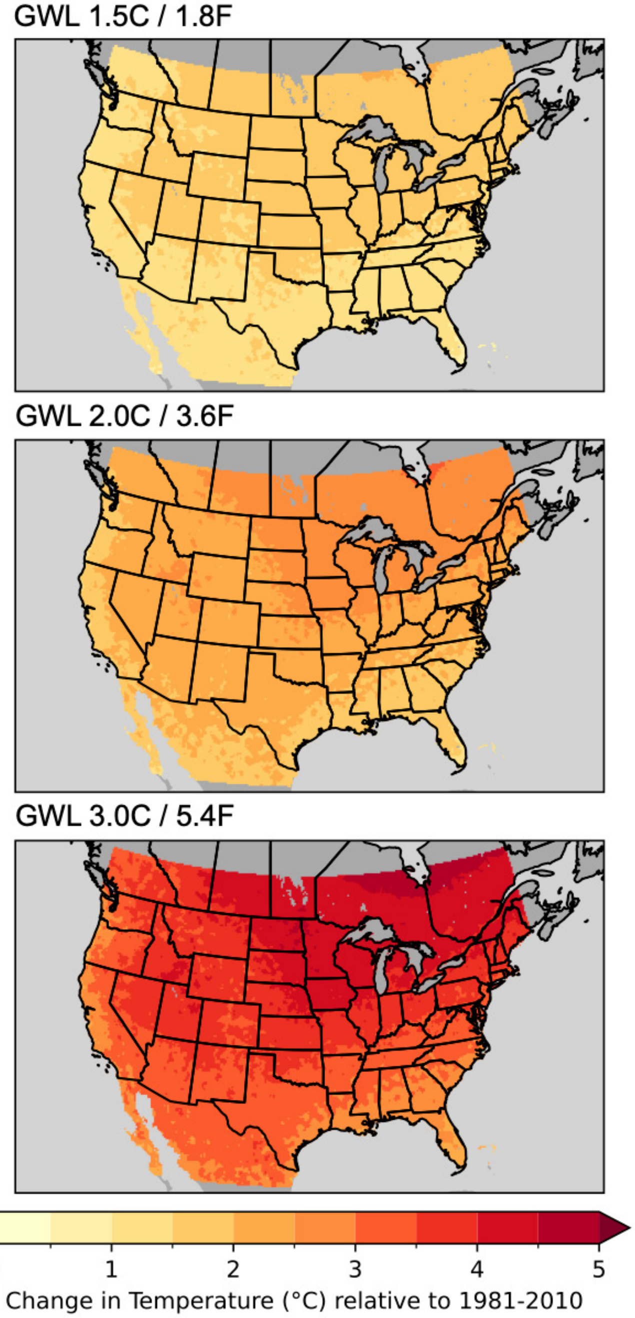


Figure 1. Ensemble average of all LOCA2 CMIP6 downscaled projections of change in annual average temperature for Global Warming Levels (GWLs) 1.5C, 2.0C, and 3.0C as compared to 1981-2010 average. GWLs represent scenarios of how future regional climate conditions emerge if the global average temperature were at specific levels.

(primarily the future trajectories of emissions of greenhouse gases and aerosols due to humans as well as due to other natural processes) as inputs into the climate models to perform the CMIP experiments (see Box 1: How CMIP experiments work). The scenario development process in each IPCC report cycle has resulted in a combination of some continuity in scenario storylines and emission trajectories and significant differences for each Assessment Report. Throughout this document, “scenarios” generally refers to IPCC-developed emissions scenarios.

2.3.3 Alternative Scenarios

Other types of scenarios have been created that can be more salient to a particular climate change analysis. Two examples used in the US context are US-specific sea level rise (SLR) projections (Sweet et al. 2022) and so-called ‘Global Warming Levels’. The SLR scenarios are meant to provide more specific information about plausible levels of SLR across the US coast that considers regional and local factors that can have large mediating influences on the global SLR signal. In addition, the rate and level of SLR is subject to a large amount of inertia in the climate system. This means that there can be a long delay between the human activities that cause a change in planetary temperature and the amount of SLR that will occur because of those activities. Thus, the SLR-specific scenarios tend to be less tightly coupled solely to emission trajectories and reflect broader uncertainty about both emissions trajectories and the rate of physical responses to a warming planet. See Sections 4.4 and 4.8 for application examples that use SLR scenarios.

Global Warming Levels (GWLs) represent a wholly different class of scenarios. In this case, outputs from climate models originating from the CMIP-IPCC scenario process are framed in terms of the projected conditions that accompany the time period when the model’s global mean surface temperature has reached some climatologically averaged threshold of change. Using this formulation, neither the time series of projected changes, nor the originating IPCC scenario are retained in the analysis. For example, an analyst who is interested in comparing how climate change affects local precipitation patterns if the planet warms by 1.5°C/1.8 °F versus 3°C/5.4 °F could use GWLs. Global mean surface temperatures are obtained from all available CMIP model runs and the first multi-decade period (typically 20 or 30 years) when the average projected temperature change reaches the desired GWL is retained. Using this time period, changes in other climate variables can be calculated and compared to the results from other GWLs (Figure 1). GWLs are most useful when the decision or analysis is not sensitive to temporal dynamics such as the particular timing of events or interannual variability. The most prominent example of the use of GWLs in a decision-making context is the United Nations Framework Convention on Climate Change (UNFCCC); the agreement between most nations that governs the process to take global action to avoid ‘dangerous anthropogenic climate change’, which historically referred to a 2°C (3.6°F) GWL compared to pre-industrial conditions.

Scenarios are used to “force” or “prescribe” the underlying drivers of change in climate models. The future conditions simulated by climate models for scenarios are referred to as “projections” and not “forecasts” because the models attempt to simulate how the future climate system would respond to scenarios of future emissions rather than precisely forecast the state of the climate system at a point in time. Since it is quite difficult to assign a likelihood to any underlying scenario, it is similarly difficult to assign a likelihood to any projections produced by climate models. See additional details on how projections are created in Box 1.

Box 1. How CMIP experiments work

The climate projection outputs from CMIP are often a core part of any analysis of the potential consequences of climate change on Department RoAs. Understanding the nuances of these projections and the experiments that produce them is important to be able to properly contextualize the results for decision making. Briefly, CMIP consists of a coordinated set of computer-based experiments whose protocols provide instructions for different climate modeling groups around the world to execute on an agreed-upon timeframe. Because the climate modeling groups are all performing the same set of experiments, with only the models themselves differing between groups, the results can be combined and analyzed as a multi-model ‘ensemble’ of results. Examining the results across the ensemble of models provides a better characterization of the true uncertainty about the future (which is difficult to quantify). Below is a condensed description of how CMIP experiments are structured. For a detailed explanation of CMIP experiments, see Taylor (2007) and Eyring et al. (2016).

The CMIP Experimental Design

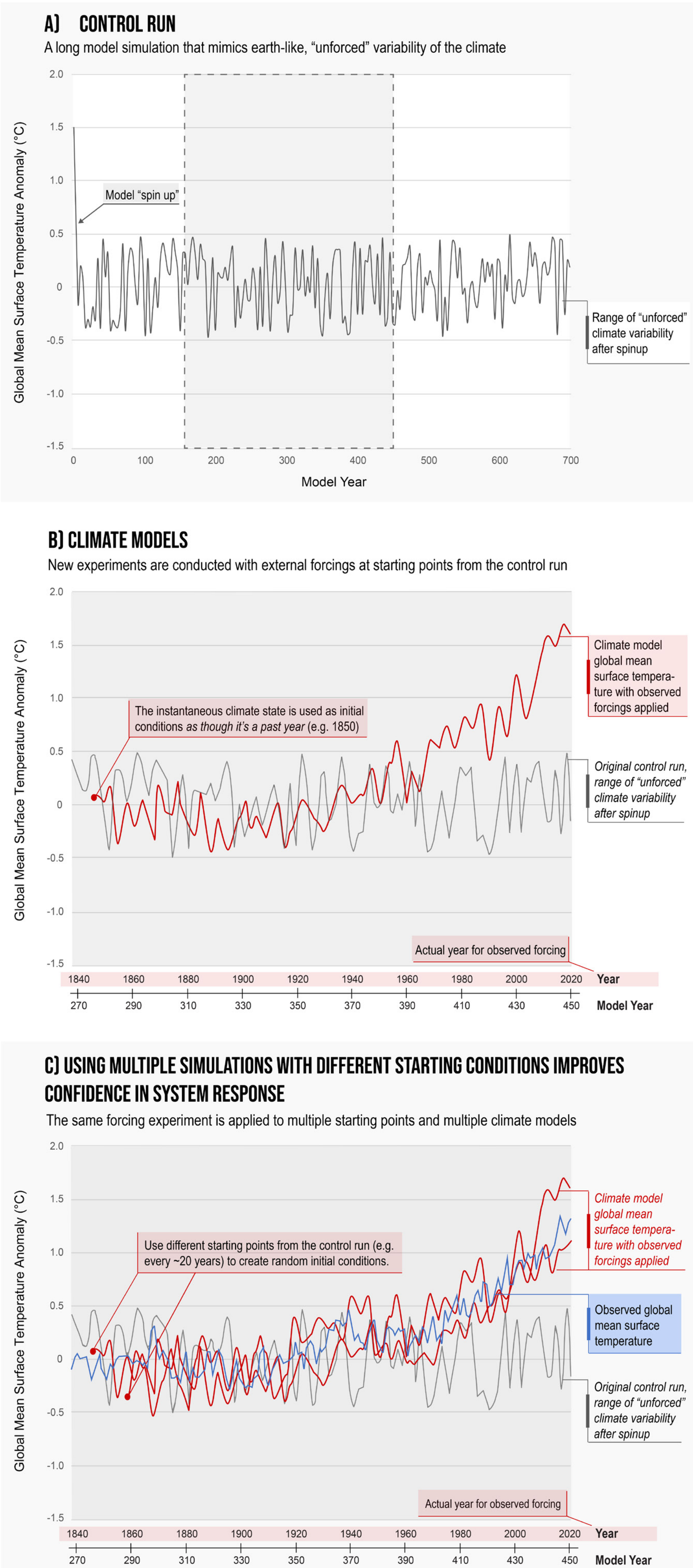
Control Run

First, climate scientists perform a ‘control run’, like a laboratory experiment where a control group is not exposed to stimuli (Figure 2a). During the control simulation, a numerical climate model simulates an ‘Earth-like’ climate over many model years. Importantly, no external changes or ‘forcings’ that would affect the overall climate system are prescribed. For example, greenhouse gases that would affect Earth’s energy balance are held constant at some pre-defined level, such as what was experienced immediately before the Industrial Revolution. To simulate the climate system, the model divides the Earth’s atmosphere and ocean into horizontal grid cells and vertical layers. Within each cell, it solves mathematical equations representing the physical processes governing the Earth’s climate. Results are carried forward to the next model time step, typically just a few minutes into the future, and the output is used to solve the equations again. The size of an individual grid cell is referred to as the model resolution and tends to decrease in size with successive generations of climate models as computational power increases. Repeating this process produces physically consistent simulations of the earth’s weather and climate systems and associated climate variables (e.g. temperature, humidity, winds, precipitation, etc.). Thus, this numerical climate model can be thought of as producing an ‘Earth-like’ climate. Importantly, while the simulation is Earth-like, it is not an exact replica of any actual sequential period in Earth’s history.

Selecting Starting Points

The next step is to choose starting points for the experiment (Figure 2b). New simulations are initiated using different model years of the control simulation (say, every 20 years) as starting points to create random initial conditions. Because no external forcing has yet been applied to the control simulation, each starting point is a physically consistent representation of an earth-like climate before humans began to strongly influence it, regardless of the actual model year from which the initial conditions were taken. Thus, if four experiments are to be conducted using a particular climate model, model years 360, 380, 400, and 420 of a 500-year control simulation might be the starting points for the new experiment. But each of those model years is consistent with earth’s actual climate state from say, 1850. So, although the model year’s simulated weather will not match the actual weather observed on earth for the target year, except by chance, the means and variances for different climate variables (calculated from decades of climate model output compared to decades of climate observations) should be consistent with each other. This is an important distinction between the output from CMIP experiments compared to the familiar short-term daily weather forecasts. Although the types of models used in both cases are similar, the numerical weather prediction models are operating from initial conditions that are based on the actual observed weather conditions. In that case, the simulated weather conditions are thus meant to be exact predictions of future weather conditions, rather than Earth-like simulations (like CMIP) that would only exactly match observations for a particular simulation point in time by chance.

ANATOMY OF A CMIP EXPERIMENT



Experiments

Finally, like scientists applying a set of treatments in a laboratory experiment, climate scientists use these initial conditions to run simulations with external forcings (Figure 2b and 2c). The nature of the experiments can take on any number of characteristics. But most commonly, two classes of CMIP experiments are conducted: 1) a historical climate simulation that mimics the observed ramp-up in greenhouse gas concentrations in the atmosphere from the 19th century to present, and 2) scenarios that reflect plausible policy choices or trajectories of future human emissions of greenhouse gases and other atmospheric pollutants that can influence the climate. When different modeling groups perform the same set of experiments using their own control simulations as the baseline, the result is an ensemble of Earth-like climate simulations whose outputs are comparable to each other.

Figure 2. Anatomy of a CMIP climate model run. After an initial "spin up" period, the model stabilizes to simulate climate condition as shown in (a). Once stable, new forcings (including greenhouse gas concentrations) are prescribed consistent with observations to model how the climate responds (b). This step is repeated for other starting model years to create random initial conditions and explore the resulting simulated climate (c). Adapted from [Held et al. 2019](#).

The Power of CMIP Experiments

The CMIP multi-model ensemble provides a powerful tool for decision makers seeking to understand the consequences of different policy choices or pathways of future greenhouse gas emissions. This is because it is now possible to more accurately represent the three primary types of uncertainty that are inherent in a multi-model ensemble with outputs spanning multiple scenarios of plausible emission trajectories (as shown in Figure 3):

1. natural or internal variability - variability in the day-to-day or year-to-year weather that is not due to any external forcing,
2. model uncertainty – differing choices in the structure of climate models that reflect unresolved scientific uncertainty about how to model the climate system, and
3. scenario uncertainty – uncertainty about the likelihood that humans will progress on one trajectory over another of differing greenhouse gas emissions.

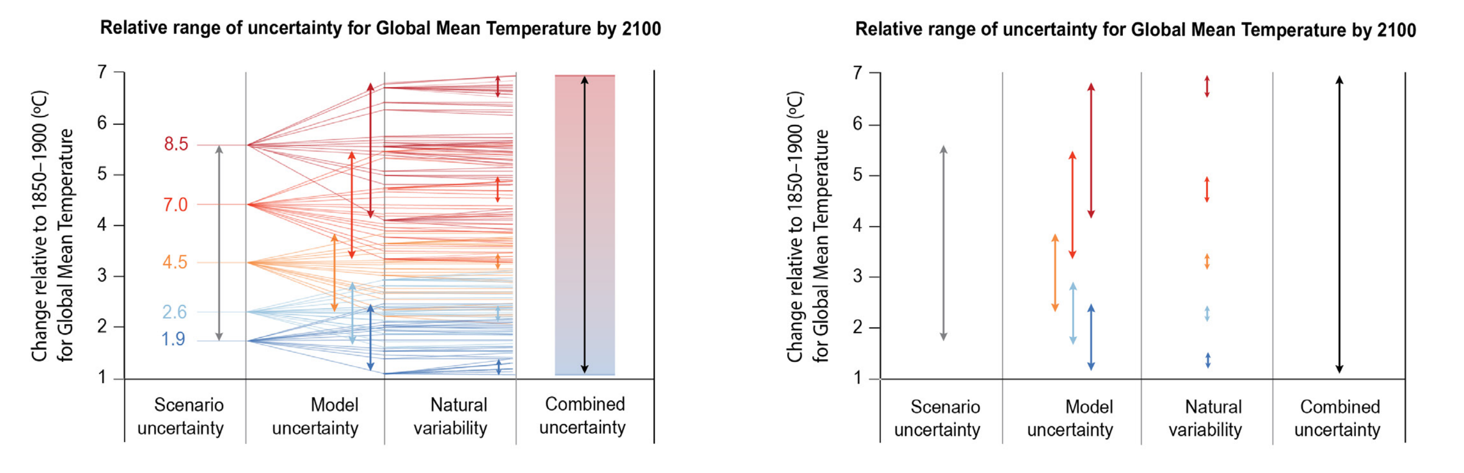


Figure 3. The cascade of uncertainty that reflects all three categories of climate projection uncertainty. Scenario uncertainty for projected global temperature change by the end of the 21st century is shown for five SSP scenarios. Model uncertainty is shown with the results for individual models or the average result from multiple simulations or 'runs' from the individual model. The relative contribution of natural or 'unforced' variability is shown for select models and reflects annual variations in the weather that are not due to external human or natural influences. The arrow lengths represent the relative contribution of each type of uncertainty (and their combined uncertainty) to global mean temperature by the end of the 21st century. The panel on the right depicts the same arrows without the individual scenarios and models. Adapted from: Figure 1.15 in [IPCC 2021.]

2.3.4 Dealing with Uncertainty

There could be hesitancy to use available climate change information because of a perceived large level of uncertainty. For example, a large spread across climate models for a given scenario, or large differences in projected outcomes under a higher emissions scenario versus a lower emissions scenario may result in a decision maker deciding there is not enough information or too much uncertainty to act. However, a large amount of uncertainty, in and of itself, is not a sufficient basis to determine that taking no action is the most appropriate decision when considering climate change information. For example, there can be 'large' differences among the climate model responses for a particular scenario (or even across scenarios), that still lead to similar anticipated effects on a RoA if an important threshold is crossed in many, or all projections. For example, Figure 4 shows the projected SLR for a historic structure with a base elevation of 1.5 feet above current sea level. In this case, there is a large range of projected outcomes, but the uncertainty about the exposure of the RoA is quite low. If there is true ambiguity about the future vulnerability of the RoA from either model or scenario uncertainty, the range of potential outcomes simulated by the climate model ensemble should be considered for each scenario. The risk orientation associated with the decision (informed by Departmental and Bureau legal, policy, or financial imperatives) can also help analysts and decision makers determine whether it is more important to focus on the average versus the extreme outcomes for a given scenario. See Section 2.4 below for a discussion of risk orientation. As with all aspects of the decision, thoroughly document how all sources of uncertainty were considered and characterized.

As stated in 526 DM 1, *"... uncertainty about the likelihood of future climate trajectories is expected. This adds complexity to the decision-making process but should not ordinarily result in no-action outcomes."* Although it might be tempting to delay action while waiting for more information, doing so could have

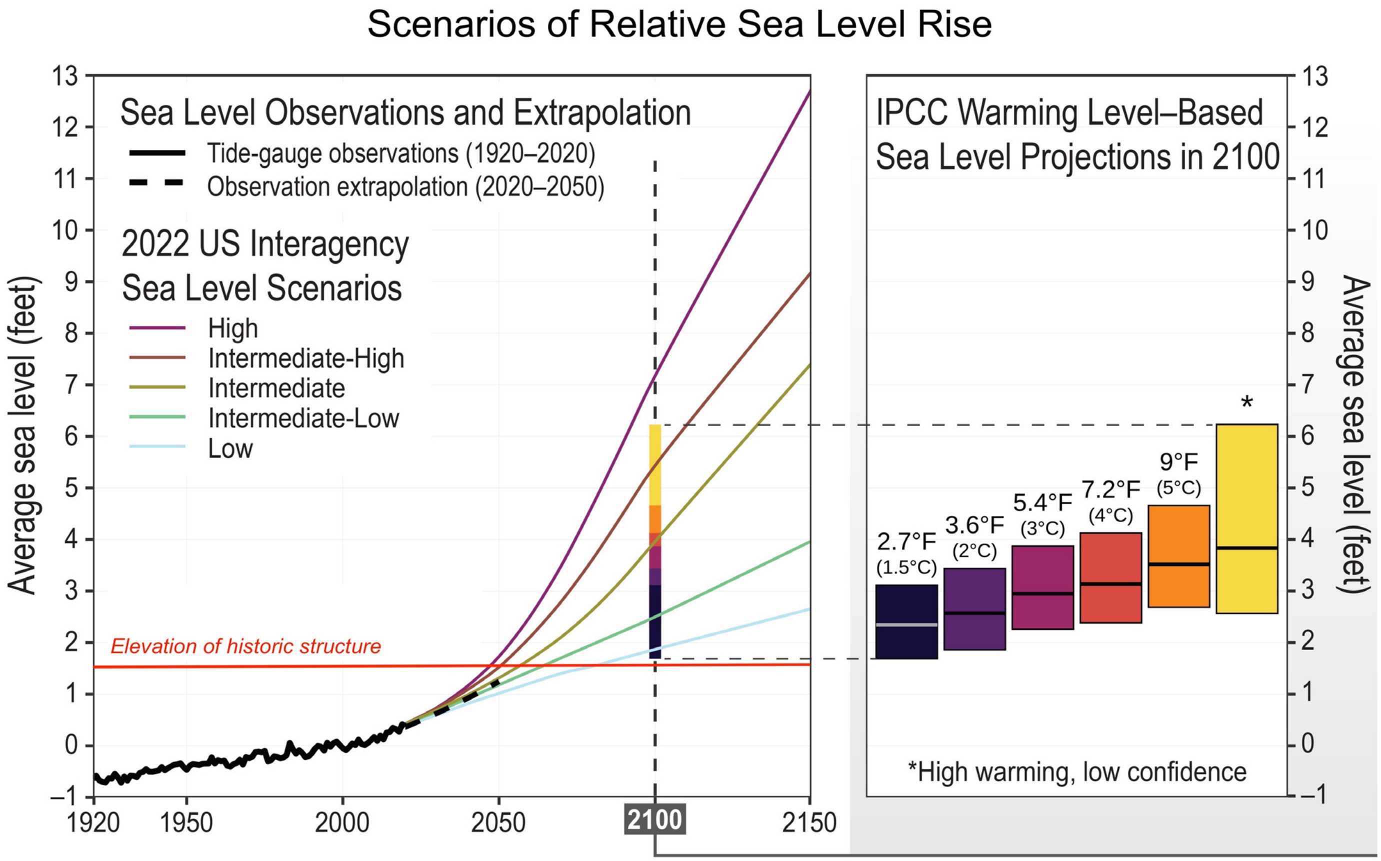


Figure 4. Projected SLR through 2150 for a coastal historic structure managed by National Park Service based on US Interagency Projections (Sweet et al. 2022) and the associated IPCC warming level SLR projections for the year 2100. While there is broad uncertainty across the SLR scenarios, the uncertainty of the expected exposure is low since all scenarios show water levels above the elevation of the historic structure even before 2100. Adapted from USGCRP 2023 and Sweet et al. 2022.

opportunity costs and potentially lead to worse outcomes (Grantham et al. 2009, Naujokaitis-Lewis et al. 2018). Additionally, in many cases decisions must be made on pre-determined schedules and delaying action is not an option. The myriad tools for decision making under uncertainty remain relevant when considering climate change.

2.4 Risk Orientation

Understanding risk orientation helps inform the application of climate change science. The risk orientation of Departmental decision makers will reflect the mandates, mission, and policies of the bureau they represent. It is important to avoid overconfident decision making when considering climate change risks to Departmental RoAs.

While this guidance emphasizes best practices for assessing the sensitivity and exposure of RoAs to climate change, this is only one part of the broader risk assessment often needed to support Departmental planning and decisions. The field of risk analysis provides many tools for making decisions in the face of uncertainty (Clemen 1996; Runge and Converse 2020). When there is uncertainty about the future and potential for losses or negative consequences, there is risk. And while uncertainty may be objectively quantified, how people value those potential losses depends on other aspects of the problem. As such, it is important to consider the risk orientation of decision maker(s). Risk orientation, a decision maker's general disposition toward risk in the context of a given decision, is influenced by the mission of the bureau, the magnitude of the investment under consideration, whether losses can only be reduced versus avoided all together, how far removed the consequences are expected to be (in time or space), whether the decision is reversible or irreversible, and existing laws and policies.

Risk orientations can be broadly categorized as risk-neutral, risk-averse, or risk-seeking (Clemen 1996; Tversky and Kahneman 1992). A risk-neutral decision maker chooses the action that will provide on average the best result, as defined by the management objectives. A risk-averse decision maker, on the other hand, prioritizes minimizing the chances of undesirable outcomes. Risk-seeking decision makers are more comfortable making decisions that involve the risk of a relatively poor outcome if the potential benefit is high. In many everyday situations risk-seeking behaviors can occur when people confront guaranteed losses. In this case, there is evidence that individuals may be more comfortable taking actions that could result in even greater losses if this risk is paired with an opportunity to reduce or eliminate the original guaranteed loss.

The risk orientations of Departmental decision makers likely fall somewhere on the spectrum between risk-neutral and risk-averse and will reflect the mandates, mission, and policies of the bureau they represent. They are, however, unlikely to be risk-seeking in most contexts. This is because when considering the effects of climate change in DOI decisions, a primary objective is often management and stewardship of public resources and assets, in which the long-term persistence of the RoA is highly valued. In this case, losses or negative outcomes are likely to be considered more impactful than an equivalent opportunistic gain. Note however that as damages or negative outcomes increase due to climate change, there may be more frequent consideration of risk-seeking orientations in cases where some losses to RoAs are already occurring.

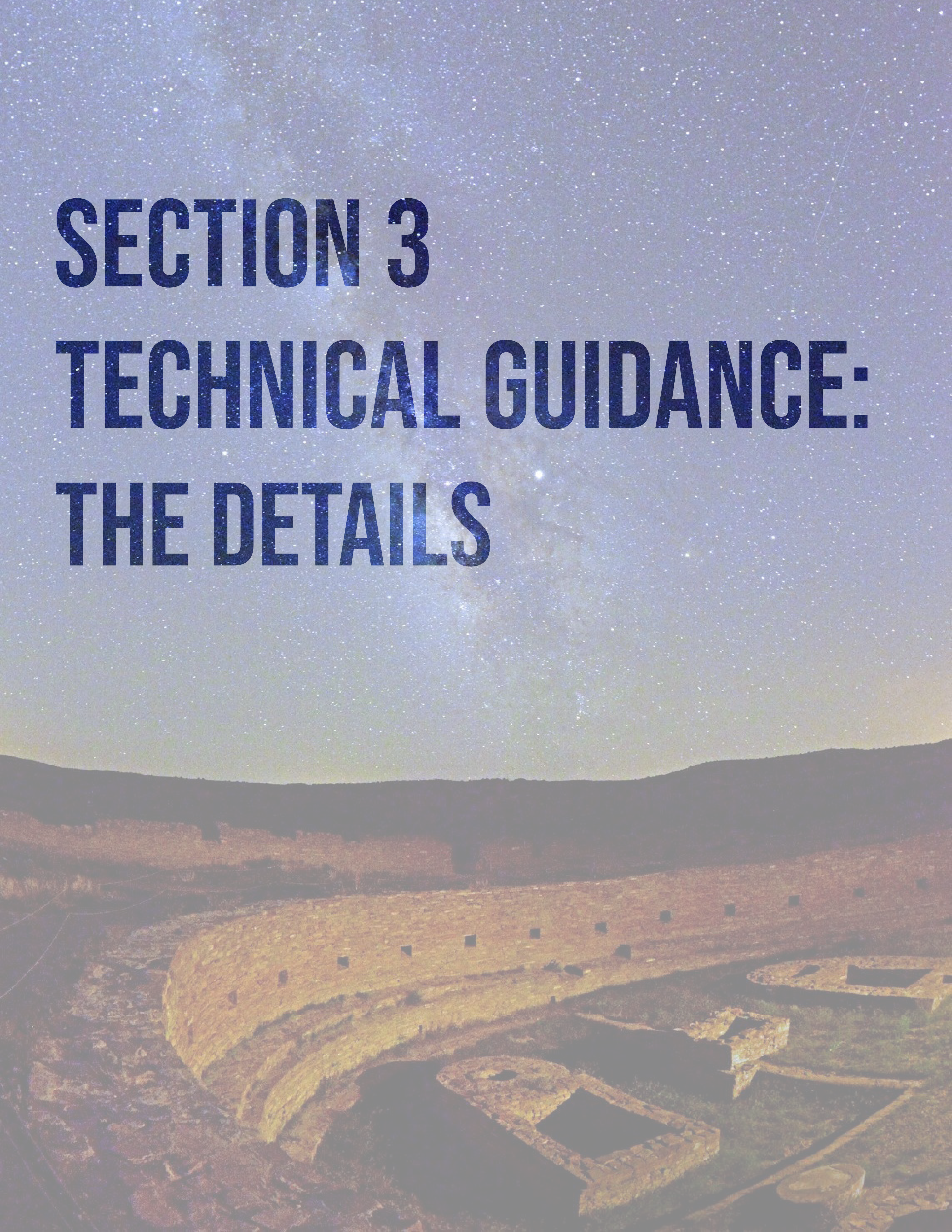
When multiple bureaus are involved in the same or linked decisions, a challenge often arises if the decision-making bureaus do not share the same risk orientation. Conflicting risk orientations can arise due to diversity in the types of decisions and legal or regulatory mandates faced by different bureaus. For decisions involving multiple bureaus, it is critical to communicate at the start of a decision process to ensure the approaches are consistent and appropriate to capture the risk orientation of all decision makers. In some cases, explicitly exploring and documenting risk orientations within individual bureaus and agencies is a necessary first step toward clear communication. See Sections 4.9 and 4.10 for examples involving multiple bureaus.

Risk orientation describes how a decision maker will act under a given probability of loss (or gain). But, in the case of climate change, the estimated probabilities needed to evaluate risk are often deeply uncertain, particularly when the decision context reaches decades into the future (See Sections 2.3.1 and 3.3.6). This is especially challenging when there are outcomes with estimated (but uncertain) low probabilities of occurrence, that are nevertheless

Bayside Picnic Area, Assateague Island National Seashore, after Hurricane Sandy. Photo by NPS.

associated with high impact losses, for example the possibility of a catastrophic flood event or many other outcomes associated with very high greenhouse gas emissions over the 21st century. Due to the uncertainty associated with these low-probability/high-impact outcomes, it may be tempting to not consider these possibilities when assessing risk. Underestimating the probability of poor outcomes may lead to actions that appear risk-seeking, which could increase the chances of regretful outcomes. In other words, the overconfident decision maker chooses an action that aligns with a more optimistic view of the future, which could result in poor outcomes if climate impacts turn out to be more severe than the set of outcomes that were originally considered. This is why 526 DM 1 1.5.A(5) states that the climate change scenario selection process should "enable consideration of higher risk outcomes." Following this policy reduces the chances of engaging in overconfident decision making and allows for a more accurate consideration of the risks associated with climate change.

SECTION 3
TECHNICAL GUIDANCE: THE DETAILS



3. TECHNICAL GUIDANCE: THE DETAILS

3.1 Overview of Principles

Principles for incorporating climate change science are common across applications: 1) consider the effects of future climate change on a resource, 2) characterize the risks, and 3) characterize the uncertainties.

This section discusses principles for incorporating high-quality climate change information into a decision or analysis process. The ultimate goal is for Department staff to use this information to produce rigorous assessments of the risks that climate change could pose to the RoA under consideration. Note that the steps described below (and in the Workflow in Section 3.5) may be revisited multiple times, starting with a quick assessment and progressing into a deeper analysis if needed. Before beginning the analysis, it is critical to assess whether coordination is necessary across multiple parties that have jurisdiction or an interest in the analysis and decision process. If coordination is necessary, consider the differences in approaches across organizations to determine if a unified approach to assessing climate-related risk is possible, or if multiple approaches are warranted.

Variation in approaches is to be expected because the context and circumstances that govern the analysis process can differ based on availability of data or models. Irrespective of those differences, the principles underlying the analysis process (based on Department policies 523 DM 1 and 526 DM 1) should remain the same, namely:

1. Climate change is happening now, and the effects of future changes should be considered in decision making;
2. Characterizing climate change risk is critical to achieving Departmental priorities; and,
3. Characterizing uncertainty in climate change risk assessments is important to reduce the chances of overconfidence in decision making that can lead to undesirable outcomes.

The first step is to gain a general understanding of the RoA sensitivity and exposure to climate change (Sections 3.2 and 3.3 below). Having some quantifiable information about these two variables allows an estimation of vulnerability of the RoA. Often, the simplest approach is to conceptually characterize vulnerability as a combination of sensitivity and exposure. This simple approach ignores other concepts that might also be useful for consideration of risk, including adaptive capacity, probability of occurrence, and hazard. This guidance focuses on the exposure assessment while recognizing other aspects important for consideration of risk (See Box 2. Sensitivity, exposure, vulnerability, and risk).

If there is reliable evidence that either the RoA is not sensitive to climate change, or the RoA will not be exposed to climate change, the appropriate references or data can be documented and further analysis is not required. If either the sensitivity or exposure has not been characterized, or there is evidence of sensitivity or exposure, more work may be required to understand the vulnerability of the RoA in the context of the decision (Section 3.3.2). The decision context should also be considered before beginning an analysis, as this can influence how scenarios and models are selected to characterize uncertainty and risk. In the sections below, we discuss the process and key considerations for each of these steps.

Box 2. Sensitivity, exposure, vulnerability, and risk

To understand potential risks due to climate change for a given decision, we first need to understand the climate change vulnerability of the RoA under consideration. In simplest terms, vulnerability can be considered a product of two factors: the sensitivity of the RoA to changing climate conditions, and the expected exposure of the RoA to those new conditions.

To illustrate these concepts, consider this problem: you are deciding whether to move to Austin, Texas, but are concerned about rising temperatures.

Assessing sensitivity

What is your sensitivity to air temperature? Take a minute and think about the temperature at which you feel the most comfortable. Next, think about the minimum and maximum temperature that you can tolerate. This is a first step to understanding your sensitivity to temperature. We can take it a step further by thinking about how your happiness varies across that range. Are you equally happy at any temperature within that range (less sensitive)? Or are you only completely happy with your ideal temperature, and your happiness drops off as you move towards the extremes (more sensitive)? Is your preference skewed toward warmer or cooler temperatures, or symmetrical? Consider the hypothetical sensitivity curves in Figure 5—which one of them best captures your temperature sensitivity?

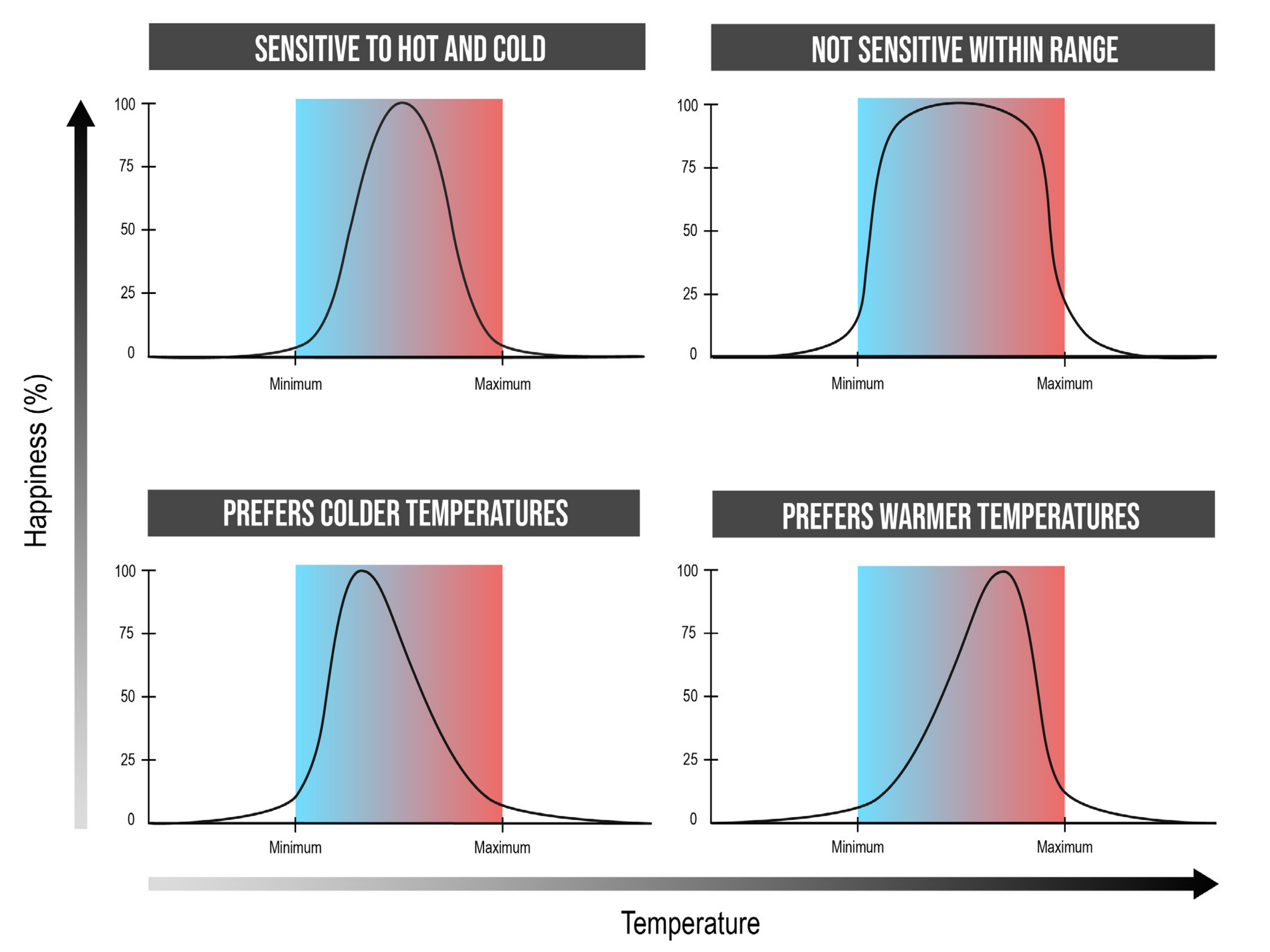


Figure 5. Conceptual diagram of happiness associated with air temperature as an example of identifying climate sensitivity.

Describing exposure

Now that you have described your sensitivity, the next step is to look at how likely you are to be exposed to temperatures outside of your comfort zone if you move to Austin. What type of climate metrics would you need to look at to understand exposure in this case? For example, you might look at average temperatures for each month to identify how many months of the year are expected to be outside of your preferred range. For Austin, the hottest month of the year on average is August, with mean daily maximum temperatures of 97°F and the coldest month is January with mean daily minimum temperatures of ~38°F. Depending on your sensitivity profile, you might be more concerned with the maximum temperatures or minimum temperatures. It's also important to consider the spatial and temporal scale of the problem. Are you concerned about temperatures within Austin city limits? Within Travis County, TX? Within the whole state? How long do you expect to live there? All of these choices will guide how exposure is quantified.

Understanding vulnerability

Your sensitivity to temperature combined with projected exposure to temperatures outside of your preferred range describe your climate vulnerability if you move to Austin. Not everyone in Austin will have the same vulnerability, because this depends in part on individual sensitivity. Someone who is highly sensitive to temperature (strong preference for a narrow range of temperatures) will be more vulnerable than someone who is less sensitive (wider range of preference), even under identical climate exposures. Likewise, a given person will have different climate vulnerability depending on where they live and, therefore, their exposure to temperatures outside of their preferred range.

Adaptive capacity, the ability to adapt to new conditions or mitigate negative impacts of climate change, may also be important to consider. You might view your overall vulnerability differently if you work indoors and are able to remain in a climate-controlled environment than if you primarily work outdoors. Within a decision context, it's important to keep in mind that mitigations like air conditioning could also affect other objectives, for example, the cost of living.

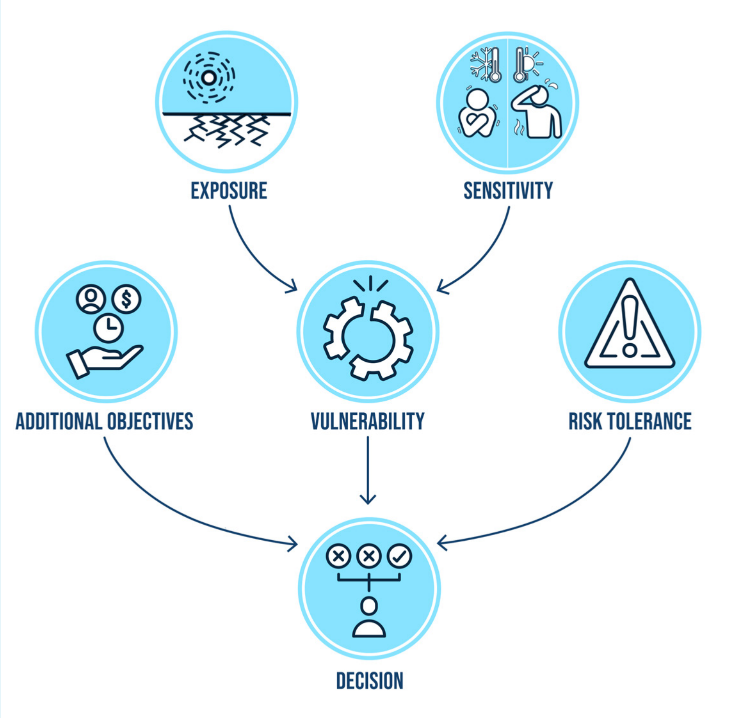


Figure 6. Conceptual diagram of how sensitivity, exposure, vulnerability, and risk tolerance feed into a decision.

Evaluating risk

The final step is putting the climate vulnerability you've assessed above in the context of the decision (Figure 6). Because there is uncertainty about future climate conditions and the possibility of being exposed to temperatures outside of your ideal range, there is risk.

Hazard is another concept that can be included as part of the assessment of risk. Hazard describes the potential for severe undesirable consequences; in this case, temperatures that might drastically impact your comfort or health. Hazard identification is sometimes considered part of assessing the sensitivities of a RoA (see *4.8 NPS Facility Rehabilitation* example for how hazards are used in an assessment).

Identifying Other Objectives

You likely have reasons that you want to move to Austin outside of temperature, i.e., other objectives. Maybe moving to Austin will put you closer to family, or you really appreciate the opportunities to see live music. Are you considering a permanent relocation, such as buying a house, or just a trial period where you will rent a house for a few years? How much are you willing to pay for housing and utilities? What is your personal risk orientation in this case: are you risk-neutral, risk-seeking, or risk-averse?

Making a Decision

All of these elements of the decision, in addition to climate vulnerability, will influence your final choice. If moving would make you highly vulnerable to climate change, it would be a permanent move, and you are risk-averse, you might choose not to move to Austin. However, if you are highly vulnerable but it is a temporary move, the other objectives are extremely important to you, and you are risk-neutral, you might decide to make the move. Climate vulnerability does not automatically dictate what the decision should be, but it should be considered in any thorough decision process.

3.2 Sensitivity

Assess current state of knowledge about the RoA sensitivity to climate change. Obtain additional information if needed through new analyses or consultation with relevant experts.

How might climate change affect the viability of a fish species, the health and function of an ecosystem, the facilities in a park, or a reservoir? Potential effects of climate change could include reduced survival of the fish due to heat stress, or risk of park facilities to flooding due to sea level rise. To understand a RoA's sensitivity to changing climate, the first step is to assess the current state of knowledge using existing information and expertise. Often, the expertise to assess sensitivity is present within the bureau or related Interior programs since it involves mission-critical subject matter expertise. Other potential sources of knowledge include the scientific literature and Indigenous Knowledges. Sometimes, there may be limited information about the sensitivity of a RoA to the changing climate, and thus new analysis or data collection may be needed. If there is evidence that the RoA is sensitive to climate change, the effect of climate on the RoA and associated uncertainty needs to be characterized. This could involve using existing models or data, eliciting expert judgment, developing new analyses, or moving forward with a high degree of uncertainty in the system response to climate change (Box 3).

Box 3. Combining system models

While the climate model outputs described in this guide can help managers explore potential climate change impacts, they are not alone sufficient to understand climate change-related risk. Additional information is often needed to understand the sensitivity of the RoA to climate change and to project the future status of the RoA under different climate change scenarios. The system models used will vary depending on the decision context and type of RoA, but could include process-based quantitative models (e.g., hydrologic models, process-based vegetation models, wildlife population dynamics models), conceptual models (e.g., influence diagrams), or qualitative models (e.g., categorical condition tables).

Consider a decision involving recovery of an imperiled freshwater mussel that is known to be highly sensitive to water temperature and stream flow rate, in which a management objective is to minimize the probability of extinction of the mussel (Figure 7). Climate models and downscaling algorithms are used to produce projections of temperature and precipitation on a spatial and temporal scale relevant to the decision. The decision relevance of the climate variables in this case may mean obtaining projections for a particular season (say, during particularly sensitive times of the year for juvenile recruitment) and at a spatial scale that can resolve changing conditions over an elevational gradient. Those projected climate conditions are then used as inputs to stream system models, which results in projected flow rate and stream temperature. Finally, the projected stream temperatures and flows are used in a population system model to determine the probability of extinction under each climate scenario. The climate models are not the endpoint of the analysis, but rather provide critical projections that are built upon in subsequent modeling steps and the ultimate analysis of extinction risk.

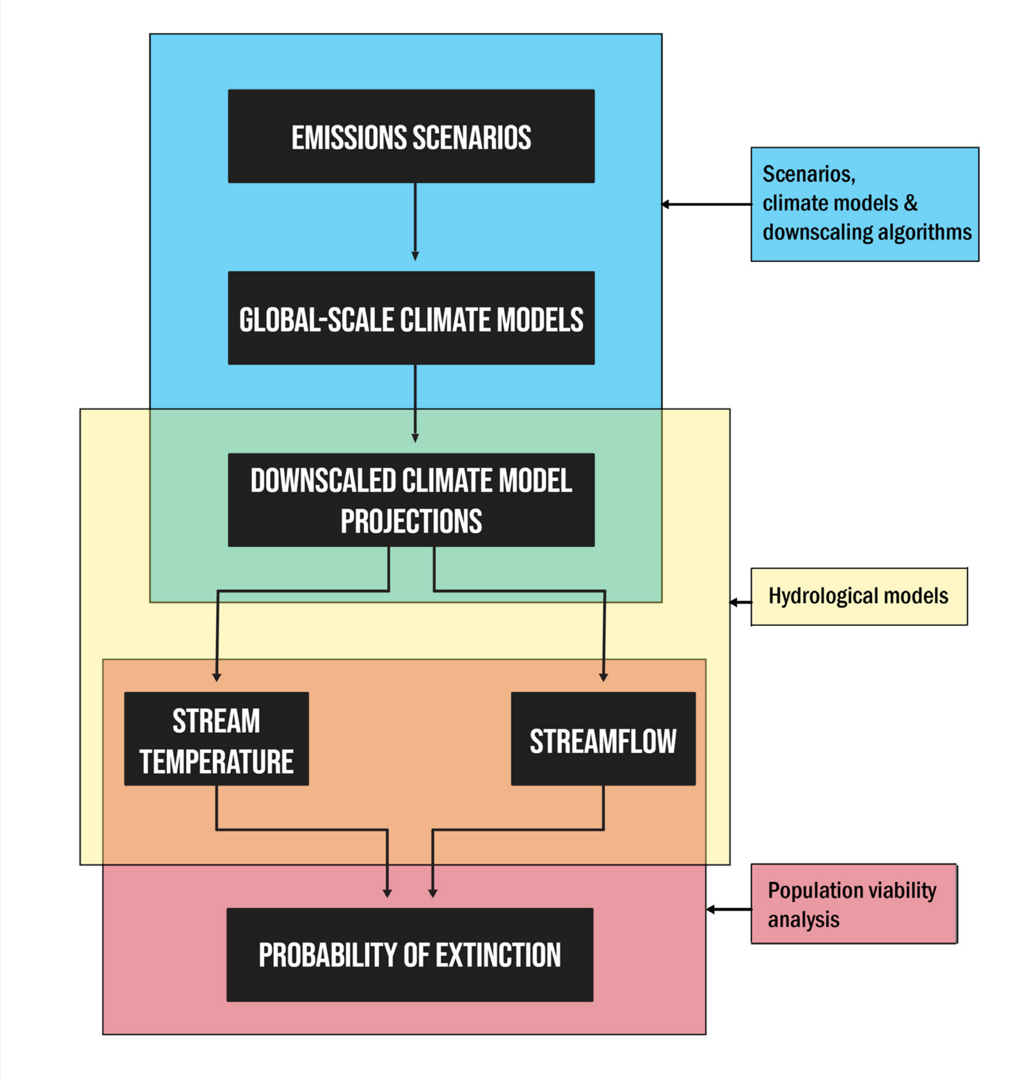


Figure 7. Diagram depicting how climate scenarios and models feed into other process models to assess risk. In this example, climate data feed into streamflow models, which are then used to assess the probability of extinction to a mussel species.

3.3 Exposure

3.3.1 Use of High-Quality Information

Use high-quality observations, IPCC scenarios, and projections from IPCC or USGCRP to assess exposure to current and future climate changes. Any downscaled climate projections should be derived from peer-reviewed methods in consultation with a climate modeling specialist.

526 DM 1 1.5.A(1) states Departmental policy to *"incorporate, as a routine practice, high-quality information from observations of current climate change and future climate change projections into planning and decision making, and when developing or revising management plans, setting priorities for scientific research and assessments, and making major investment decisions."*

High-quality information from observations includes:

- rigorously developed and peer reviewed 'reanalyses' (a technical term from atmospheric science referring to a statistically rigorous and physically consistent blending of observations and model outputs),
- peer-reviewed and vetted recent observations, including in-situ, blended, and statistically interpolated observations,
- Indigenous Knowledges, and
- peer reviewed and vetted paleoclimate datasets.

High-quality scenarios consist of (at a minimum) internally consistent depictions of plausible pathways for future emissions, greenhouse gas concentrations, and other atmospheric constituents (like microscopic aerosol particles that are a byproduct of many industrial processes). Scenarios developed for use by the IPCC or the U.S. Global Change Research Program (USGCRP) are high quality because of the extensive peer review process across multiple national governments (including the US Government) or multiple federal agencies.

High-quality information from projections include model outputs associated with CMIP, USGCRP or other federal government sources that ensure a rigorous peer-review process has been conducted at some point in both the model development and the model simulation phase for producing climate projections (526 DM 1 1.5.A(4)). Downscaled climate model projections (see Section 3.3.3) are similarly considered high quality if vetted using established review processes or produced (and similarly vetted) by federal agencies or international organizations that involve federal agencies. New downscaled climate model data produced specifically for a DOI-related analysis should be derived from peer-reviewed methods in consultation with a climate modeling specialist. Appendix A provides a list of web-based tools frequently used for initial assessments. **Caution should be used when incorporating the data and visuals from these tools (especially as the sole source of exposure information) as information about inherent assumptions and limitations of the underlying data are rarely communicated in the tools.**

3.3.2 Initial Screening

To understand exposure, consider the projected changes in relevant climate variables and relevant time horizon. NCA or IPCC reports may be useful for initial screening to assess magnitude and confidence of future exposure.

The next step is to understand the exposure, i.e., how do we expect the relevant climate variables to change in the area of interest over the decision time horizon? The key considerations to keep in mind when assessing exposure are:

1. the projected changes in the climate-related metrics that are relevant to the RoA, as identified in the sensitivity assessment (e.g., seasonal temperature, monthly precipitation, ocean pH, etc.), and
2. the time horizon relevant to the decision.

An initial high-level screening of these considerations may be useful to assess the depth of exposure analysis that will be required. At the most general level, the most recent National Climate Assessment (NCA), IPCC Assessment Report, or other assessments published in the scientific literature or by federal agencies can provide high-level summaries of projected changes to sensitive resources. These reports contain recent scientific assessment of climate change impacts by sector and region and enable exploration of future climate conditions with visualization tools such as those listed in Appendix

A. When performing this screening, the most critical information to assess is the direction of change in climate metrics that are expected to affect the RoA (i.e., positive change, negative change, or neutral) and the confidence or agreement in the projected changes.

Depending on the Bureau's policies and considerations, the exposure assessment could conclude after the initial screening when two conditions are met:

1. the expected climate changes cause no discernible change in exposure compared to the current conditions, and
2. there is high confidence or evidence agreement that this is the case.

Any other outcomes could require further analysis to assess the degree and likelihood of positive or negative effects due to changing exposure, as well as the uncertainty of those changes. This analysis is necessary to assess vulnerability (and ultimately the risks) posed to the RoA under different potential management outcomes.

For example, consider a historic structure managed by National Park Service along the steep slopes of Glacier Bay, Alaska. Park managers are concerned about the possible impacts of SLR on the structure, which sits 500 feet from the water's edge. Initial review of NCA suggests with high confidence that the rates of relative SLR are stable for this area for the next 100 years (due to land rise response from the last ice age), even under high-risk scenarios. With high confidence of neutral impacts, the exposure assessment could conclude. However, if NCA only reported low confidence in this exposure, or the impacts were likely to be positive or negative, then further exposure analysis would be needed. Any subsequent analysis should incorporate high-quality information from relevant observations, scenarios, and/or climate models.

Bartlett Cove at Glacier Bay National Park & Preserve. Photo by NPS.

3.3.3 Selecting data sources and models – Climate Models and Downscaling

Use CMIP model ensembles as the basis for climate change projections. Consult with a climate modeling expert when deciding whether to use downscaled versions of these models and to determine what kind of downscaling is most appropriate.

Many climate models exist, each generating their own outputs and datasets that can be used to project climate conditions into the future (see Appendices for Resource Lists and Box 1: How CMIP experiments work). When exploring potential climate change effects, it is best to use a collection (or ensemble) of multiple models. CMIP phases are the most widely used multi-model ensemble approaches, allowing users to compare multiple climate models, different simulation runs from a single climate model (e.g., same time period and scenarios but a different starting point for climate conditions), or both (see Box 1: How CMIP experiments work). The scientific community continues to develop and improve climate models that are incorporated into new CMIP phases and each IPCC Assessment Report cycle.

An important consideration is whether to use the original climate model output from CMIP versus a post-processed version at higher resolutions. Due to limitations in computing power, the current generation of global climate models usually simulate the climate system at relatively coarse spatial resolutions (~100 km / 62 mi). Downscaling is the process of using an additional model to project climate information at a finer spatial scale based on the original climate model output. Downscaling is often used in natural resource management because global-scale climate models usually do not operate at sufficiently fine spatial and/or temporal resolution to simulate smaller scale (1-10 km / 0.6-6 mi) features that can strongly influence local climate.

For example, Puerto Rico is a small mountainous tropical island with an area of approximately 3,400 mi^2 (~8,900 km^2), or roughly 100 miles east-west by 35 miles north-south. Annual average rainfall totals range from more than 130 inches in the eastern rainforests to less than 40 inches in the subtropical dry forests along the southern coast. Given the size of the island, there are likely to be only two or three grid boxes from the global-scale climate model that will span this area; meaning that there will also only be two or three projected values for the whole island for any given climate variable. Downscaling is thus particularly useful for Puerto Rico to be able to simulate localized climate change responses compared to the broader patterns simulated by the coarser global-scale climate models. Additional reading on selecting climate data for risk and impact assessment can also be found in OSTP (2023).

Within a given CMIP phase, many different datasets are available that differ in their downscaling approach. There are two broad approaches to downscaling: 1) empirical-statistical methods and 2) dynamic/physical modeling. Table 1 compares these approaches.

Ideally, one would have high-resolution dynamically downscaled projections for every scenario and global-scale climate model, as this would allow the best characterization of uncertainties for future possible conditions. The reality is that computing capacity is limited, and one usually must choose between using 1) a few mechanistic, complex dynamic

Table 1. Comparison of statistical and dynamic downscaling approaches.

	Statistical Downscaling	Dynamic Downscaling
General method	Creates statistical relationships between local historical data and climate model simulations of past conditions, then applies those relationships onto a climate model's future simulations.	Uses global-scale models as input to higher-resolution regional numerical climate models that resolve processes of the climate system at finer scales.
Use of historical data	Requires adequate historical data to establish meaningful relationships between the observations and the coarse resolution climate models.	Does not require any local historical observations.
Processes vs. patterns	Does not enable exploration of processes that cause changes in climate variables.	Enables analysis of processes and mechanisms that produce changes in climate variables.
Computing needs	Does not require substantial computing resources.	Requires substantial computing (often high-performance clusters).
IPCC scenarios	Projections usually available for multiple IPCC scenarios.	Projections rarely available for multiple IPCC scenarios.
Climate variables	Projections available for common variables such as temperature and precipitation.	Projections available for dozens of variables.
Geographic coverage	Projections available especially for location with dense networks of historical weather observations, especially the continental US.	More commonly used for locations that lack adequate historical data or when it's critical to maintain the physical relationship between climate variables.
Assumptions	Makes an important (but limiting) assumption that the relationship between observations and a climate model's historical simulation is stationary and holds true for the future.	Does not assume static (or stationary) climate relationships since projections are not dependent on historical observations.

projections or 2) statistically downscaled projections created for many scenarios and climate models. It is important to note that higher resolution datasets are not necessarily better quality than lower resolution options, depending on the downscaling approach and methodology used. See Appendix B for more information about commonly used data resources and references that critically evaluate different downscaling methods. Deciding which downscaled datasets to use can be difficult – users should consult with a bureau climate modeling expert or their local USGS Climate Adaptation Science Center.

3.3.4 Climate model uncertainty and accuracy

Use multiple models to account for the range of outcomes due to model uncertainty. Do not rely solely on an ensemble average and avoid attempts to select a 'best' climate model. Consult with a climate data and modeling expert to assess which data and model resources are most appropriate for any given application.

When summarizing projections from multiple models, it is tempting to focus on the mean climate conditions projected across all models. However, it is important to consider the range of outcomes in addition to the multi-model mean. Relying solely on the multi-model mean to represent future conditions can substantially underrepresent the model uncertainty. This can lead to overconfident decision making if more extreme climate outcomes that the RoA is sensitive to are not considered in the analysis (see Section 2.4). As a result, 526 DM 1 1.5.A(6) states it is Department policy to *"use multiple models to capture a range of potential future climate conditions."*

One potentially useful technique frequently used by NPS to characterize uncertainty is by examining the range of projected outcomes across two important climate axes, like temperature and precipitation. This produces a graphical display of future possible climates that can be intuitively categorized as different 'states' such as "warm-wet", "warm-dry", "hot-wet", "hot-dry". This approach can be used for projections of decision-relevant climate variables and help distill potential climate variables that are important across a wide variety of RoAs. See Section 4.7. NPS Resource Stewardship Strategy application and Figure 4.7.1 as an example.

A common, and reasonable, question to ask when selecting and aggregating climate model information is, "which models are the best?". This seemingly simple question is quite difficult to answer given Earth's complex climate system and the nature of climate model outputs derived from CMIP experiments (see Box 1: How CMIP experiments work).

In a typical error analysis or accuracy assessment, model simulations are compared to observed climate data. And in general, comparing past observations to model simulations of the recent past (i.e., hindcasting) can provide an assessment of how well the climate system is represented. However, care must be taken when comparing observations to climate model outputs derived from CMIP. CMIP experiments are designed to simulate an "Earth-like" climate system, but do not generate exact replicas of any actual sequential period in Earth's history. As a result, historical 'weather' simulated in CMIP protocols will not match the actual observed weather on Earth for a particular day, except by chance. Thus, model accuracy in this case must be judged by how closely the simulated climate matches large-scale or multi-year trends in the observed climate system, and not from predicting an actual sequence of weather events.

Furthermore, given the complex and interconnected nature of both the climate system and the models used to simulate it, it can be difficult to assess if a model is simulating a particular climate variable for a particular geography for the 'right' reasons (i.e., it is accurately simulating all the actual climate processes that lead to those climate variable values) or if some of the accuracy is due to a combination of model skill and model luck (i.e., counteracting model errors that cancel out).

For these reasons, model accuracy assessments should be done in consultation with relevant climate experts. Such careful assessments can improve the expected reliability of climate model projections. These typically focus on global-scale measures of accuracy, such as an assessment of whether a climate model's simulated sensitivity to increasing greenhouse gases aligns with independent lines of evidence (e.g., Massoud et al. 2023). If consultation with a climate scientist is not feasible, and other methods for assessment of model performance are not easily applied (e.g., Boyles et al. 2024), the best practice is to treat all available climate models equally and to summarize the results across the full range of outcomes.

3.3.5 Using historical observations to predict future trends

Historical observations are useful for understanding past conditions and recent climate trends may provide useful predictions for the next several years.

Historical observations are needed to establish the relationship between RoAs and climate. They can serve to build understanding of the sensitivity of the RoA to climate change, to establish baselines for comparison to changing conditions, and to predict future climate trends. Understanding the dynamics of recent trends may provide insight about the near-term trajectory of the climate system in response to the combined influences of natural variability and greenhouse gas emissions. These shorter-term insights from recent trends are important because while recent observations will be strongly influenced by natural variability such as the timing and strength of an El Niño event or recent volcanic eruptions, these phenomena are not likely to be captured by long-term CMIP experiments. And while important volcanic eruptions or variations in solar output are included in CMIP experiments, they only occur up to the point when the historical simulation ends. Similarly, the El Niño-Southern Oscillation (ENSO) phenomena are simulated in these experiments, but ENSO events will only have the same timing, phase, and amplitude as an observed event by chance (See Box 1: How CMIP experiments work).

Using historical observations to extrapolate different climate trends into the future is thus most appropriate for decisions with short time horizons, e.g., 1-10 years in the future. Beyond this time frame, the predictive skill of observed trends is likely to deteriorate because of multi-decadal variability and the uncertainty about future levels of greenhouse gases in the atmosphere. This is particularly true when considering fast-responding climate variables like air temperature (Hawkins and Sutton 2009). Employing statistical forecasting must be done carefully to minimize common model-fitting problems associated with climate data that can significantly affect the accuracy and reliability of the predictions (see Chapter 7 in Wilks 2020 for further discussion).

3.3.6 Selecting scenarios to consider risk

Because it is difficult to identify a most-likely scenario, use multiple scenarios to assess risks from a range of plausible societal pathways. When constraints prevent the use of multiple scenarios or if decision makers are risk averse, ensure that the chosen scenario will enable consideration of higher risk outcomes.

The degree of exposure (and associated vulnerability) depends on future human actions and thus, climate-influencing emissions. Therefore, selecting scenarios is a critical part of a vulnerability analysis and risk assessment. When feasible, use scenarios associated with the most recent IPCC Assessment and CMIP phase, since they represent the most up-to-date work by the scientific community (526 DM 1 1.5.A(3)).

Table 2. SSP related to RCPs as described in CMIP6. SSPs are numbered incrementally. RCPs are numbered according to the change in radiative forcing projected to occur by 2100 relative to the preindustrial era (circa 1750). Additional details are available in Riahi et al. (2017).

SSP	RCP(s) associated with SSP	Description
SSP1	RCP 1.9 RCP 2.6	Sustainability: The world shifts gradually, but pervasively, toward a more sustainable path, emphasizing more inclusive development that respects perceived environmental boundaries.
SSP2	RCP 4.5	Middle of the road: The world follows a path in which social, economic, and technological trends do not shift markedly from historical patterns.
SSP3	RCP 7.0	Regional rivalry: A resurgent nationalism, concerns about competitiveness and security, and regional conflicts push countries to increasingly focus on domestic or, at most, regional issues.
SSP4	RCP 3.4 RCP 6.0	Inequality: Highly unequal investments in human capital, combined with increasing disparities in economic opportunity and political power, lead to increasing inequalities and stratification both across and within countries.
SSP5	RCP 3.4 RCP 8.5	Fossil-fueled development: This world places increasing faith in competitive markets, innovation and participatory societies to produce rapid technological progress and development of human capital as the path to sustainable development. Global markets are increasingly integrated.

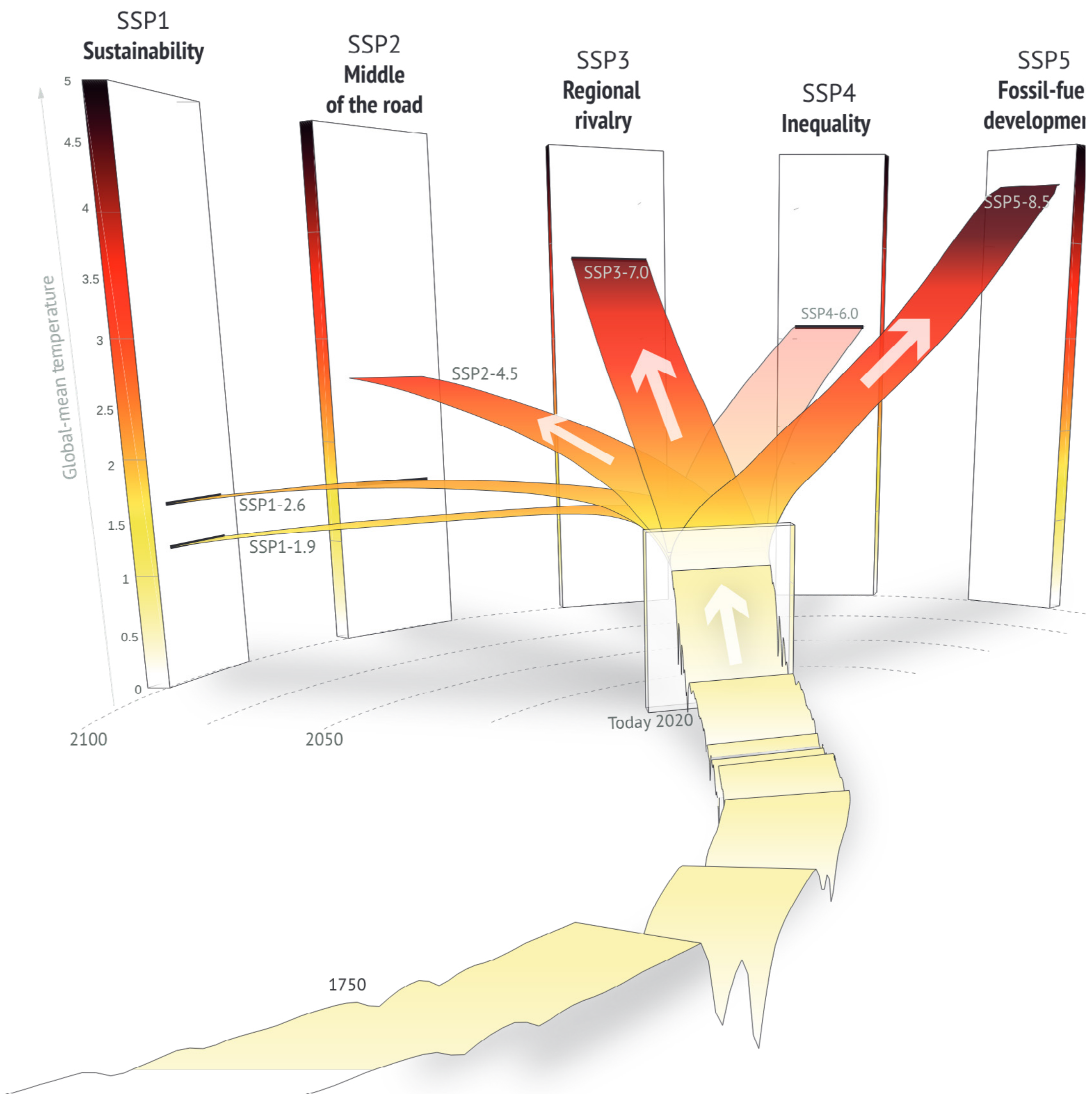


Figure 8. The SSP scenarios and their five socio-economic SSP families. Shown are illustrative global mean temperature levels relative to pre-industrial levels with historical temperatures (front band), current (2020) temperatures (small block in middle), and the branching of the respective scenarios over the 21st century along the five different socio-economic families with their associated warming. The bands over the 21st century indicate the five SSP scenarios SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5 that are used as priority scenarios in IPCC AR6. Adapted from Meinshausen et al. (2020).

As of 2024 this would include the Shared Socioeconomic Pathways (SSP) scenarios that are associated with the Sixth Assessment Report (AR6) of the IPCC and CMIP6 experimental results. While older, CMIP5-based projections using Representative Concentration Pathway (RCP) scenarios developed for the IPCC AR5 remain relevant and some decision-relevant projections may only be available for this prior generation of models and scenarios. See Table 2 for a comparison of RCP and SSP scenarios. Figure 8 describes the SSP scenarios developed for AR6.

Based on how emissions scenarios are developed by the IPCC, it is not possible at this time to confidently determine which pathway is most likely to occur. However, this does not mean that all scenarios are necessarily equally likely.

Consider the following scenarios:

- **Scenario SSP1-1.9:** The SSP scenarios representing the most aggressive emissions reductions (such as SSP1-1.9) may still be technically feasible, but current enacted policies and practices place global emissions (and therefore the amount of global warming) on a higher trajectory. This lowers the expected (but still uncertain) likelihood of this scenario coming to pass relative to scenarios depicting higher near-term trajectories of emissions. However, levels of warming and associated climate change at different points in time resulting from SSP1-1.9 could be plausible with aggressive carbon dioxide removal even if emissions overshoot the SSP target (Riahi et al. 2022).

- **Scenario SSP5-8.5:** Similarly, the highest emissions scenarios (RCP8.5 or SSP5-8.5) would represent a departure from current policies and energy production transitions (Hausfather et al. 2022), but the projected climate change under these scenarios remains plausible due to potential for strong feedback responses, tipping points, decreasing capacity of natural carbon sinks, uncertainties in socio-political factors, and the Earth's climate sensitivity (Lenton et al. 2019, Forster et al. 2021, Riahi et al. 2022).
- **SSP3-7.0:** SSP3-7.0 is unique among the SSPs in that it, by design, does not greatly reduce aerosol emissions and also substantially decreases forest area as compared to other SSPs. Higher aerosols will affect, among other climate system variables, projections of future evapotranspiration and precipitation (Shiogama et al. 2023).

The design and range of outcomes of IPCC scenarios illustrate the challenge in assigning likelihood to any given one. Because accurately identifying a single "most likely" scenario is difficult with currently available evidence, 526 DM 1 1.5.A(5) states that Department policy is that *"whenever feasible use multiple scenarios that span a wide range of potential outcomes."*

Deciding which scenarios to use depends on a number of factors. One consideration is risk orientation; when decision makers are risk averse, it is important to evaluate scenarios that reflect potential "worst case scenarios" (e.g., SSP5-8.5). Alternatively, scenario selection may be constrained because projections for specific climate or climate-influenced variables relevant to the decision are only available for a subset of the original CMIP/IPCC scenarios. For example, the downscaled climate model outputs used in the Fourth NCA were only available for the IPCC AR5 era RCP4.5 and RCP8.5 scenarios. When projections are not available for all scenarios, good practice is to use the scenarios that represent future climates spanning upper and lower bounds of planetary warming. Assuming that relevant climate variables are available, a choice may have to be made between using global climate model projections for many scenarios or downscaled projections for fewer scenarios. Consideration should be given in this case to how sensitive the results of the analysis are likely to be to the spatial resolution of the models compared to the range of possible outcomes. Section 3.4 provides additional discussion on trade-offs when selecting climate projections. When time, resource, or informational constraints prevent the use of more than one scenario, use a scenario that will enable consideration of higher risk outcomes (526 DM 1 1.5.A(5)). Decision makers should include a justification for their scenario choices in their analysis to ensure transparency and reproducibility.

3.3.7 How far into the future should the analysis consider?

Use a time-period for model projections consistent with relevant timeframes of the policy, action, or decision being considered.

The time period to use for a climate change analysis should be driven by the decision context but may also be subject to data availability. Some decisions may be sensitive to climate change effects many decades or more into the future. Similarly, some issues may warrant consideration of time intervals and not only endpoints in the future. When assessing the impacts to a long-lived RoA (e.g., a species or a dam) that may be sensitive to climate change and are exposed to projected climate changes for the rest of the 21st century, one should include consideration of long-term climate change projections across multiple scenarios to evaluate the risk profile for the RoA in the near- and long-term. 526 DM 1 states it is Departmental policy to *"use the time-period for model projections of the future climate change consistent with the relevant timeframe of the policy, action, or decision being considered. For climate change models used by the Department, the full time-period of available model outputs is considered to be high-quality information."*

Data constraints also factor into choosing a time period for analysis. Most (but not all) climate projections available through CMIP or NCA tend to cover the 21st century, but not beyond. Importantly, the full time period of these projections is considered to be high-quality information as the underlying scientific uncertainty is not expected to change with time even while scenario uncertainty does (see reducible and unreducible uncertainty in Section 2.3). While the end-date for these climate model projections is likely to extend beyond 2100 in future iterations of CMIP and the NCA, as of 2024, this remains a common limitation in current analyses. In these cases, if the decision is sensitive to changes beyond the time period of the projections, it is best to still summarize the potential exposure over the available data because this will provide useful information about the risks associated with different actions. In addition, consulting with a climate science expert could be helpful to understand potential conditions beyond the period of the available projections.

3.4 Dealing with tradeoffs when characterizing uncertainty and risk

Consider principles for applying climate science when limitations prevent complete implementation of best practices.

The process described in this guide to incorporate climate change information into analyses and decision making represents a set of best practices that can be applied in many contexts. Sometimes though, data, time, capacity, or financial limitations will not permit a complete implementation of best practices. In these cases, when tradeoffs are inevitable, it is best to consider the principles underlying the recommended actions. This will help develop rigorous solutions that can still accomplish Departmental objectives of using high-quality science to incorporate climate change information in decision making. The basic principles laid out in this technical guidance (consistent with526 DM 1 and 523 DM 1) are to recognize that:

1. Climate change is already or will be affecting almost all RoAs in which the Department has an interest. Decisions will have to be made in response to these effects using the best information available.
2. Characterizing climate change risk is critical to achieving Departmental priorities but is only partly an objective process. The process involves the objective quantification of uncertainty using high-quality information AND an assessment of risk orientation that depends on the decision maker operating under legal, policy, mission, or other bureau or Departmental constraints.
3. Characterizing uncertainty (to the extent feasible) in a climate change risk assessment is important because it reduces the chances of overconfidence in decision making (i.e., regretful losses from making a choice one would not have chosen with a more accurate uncertainty characterization). This requires the use of high-quality information to assess sensitivity and exposure of RoAs to climate change.

We can illustrate how these principles can still be followed, even if data limitations require a deviation from the process outlined in this guidance.

Consider a common dilemma many analysts find themselves in: Should the analyst prioritize maximizing the number of climate change scenarios that are considered? Or is it acceptable to use a pre-existing dataset that only has model outputs for a subset of scenarios (often only two) but is considered a more reliable source of information about future climate change? The preferred pre-existing dataset could be a downscaled version of the CMIP projections, and therefore contains finer resolution detail about future climate change that is important to be able to accurately characterize the exposure of the RoA.

In this case, all three principles could still be adhered to as long as there is some way to understand, either explicitly or implicitly, the plausible range of potential outcomes on the time scales being considered. If the preferred dataset does not have low- or zero-emissions climate scenarios, one strategy to implicitly consider the full range of outcomes is to use observations from the recent past when greenhouse gas emissions were at or below current levels (e.g. the prior 20-30 years) as a proxy for the missing scenario. But, in contrast, an analysis that relies solely on a high-quality dataset that does not contain information from a plausible higher emissions scenario would not be consistent with the three principles. This is because the potential future climatic changes under that scenario would be unprecedented in the recent past, and therefore past observations could not serve as a reliable analog for the future.

3.5 Workflow for Application of Climate Change Science

This workflow serves as a high-level reference for consistent steps to guide readers through a process for applying concepts in this technical guidance. While this represents a general process for meaningful application of climate change science in Department analyses, individual applications may require some deviation from this approach.

Workflow Step 1: Frame the decision context. A purpose of this guidance is to help with decision making. As such, before climate change information can be used in an analysis, the decision context must first be considered. Thus, as part of framing the decision context we must first identify the RoAs that will be analyzed as part of the decision-making process. Additionally, it is important to clearly understand other aspects of the decision including the identities of the decision maker and interested parties, the relevant spatial and temporal scales, the management objectives, any sideboards (law, regulation, policy) and the possible alternative actions that could be taken. Go to step 2.

Workflow Step 2: Determine coordination needs. There could be multiple decision makers either within the same bureau or including other entities (State, Federal, Tribal agencies; private landowners; etc.). There may also be interested parties that will not be involved in the actual decision making but whose views are important to the decision. If there are multiple decision makers, develop an agreed coordination approach to ensure consistency and alignment of subsequent analysis steps. There could be one analysis, or each entity may proceed independently with climate risk assessments, but comparable analytical outputs are necessary to facilitate the decision-making process (See Section 3.1). Go to step 3.

Workflow Step 3: Assess sensitivity. Has the sensitivity of the RoA to climate change been characterized? (see Section 3.2)

a. Yes - there is evidence that the resource or asset is sensitive to climate change. Go to step 4.

b. Yes - evidence indicates little or no sensitivity of the RoA to climate change. No further analysis is required. Document with appropriate references or data.

c. No- further analysis will be needed. Go to step 4.

Workflow Step 4: Describe relationship with climate. Can the relationship(s) between the RoA and the climate system be represented in resource models or from existing knowledge? (see Section 3.2)

a. Yes – using either existing knowledge (e.g., data from models, and observations), or by developing new knowledge, characterize the sensitivity of the RoA. Go to step 5.

b. No – if a relationship cannot be characterized due to lack of observational data, models, or knowledge within the required timeframe, then document the current high level of uncertainty about that relationship between the RoA and a given climate variable. No further steps are possible.

Workflow Step 5: Assess exposure. Can the exposure of the RoA to the relevant climatic changes be quantified? (see Section 3.3)

a. Yes – model outputs are available to project the plausible range of climate change exposure or impacts for the RoA. These output datasets:
(1) consist of relevant variables, timescales, and spatial and temporal resolutions,
(2) are sufficiently reliable to confidently assess the consequences of climate change, and
(3) are from a sufficiently large number of models so that projections are consistent with known scientific uncertainties. Go to step 6.

b. No – If the necessary climate or climate-impact model outputs are not available to conduct the exposure analysis (or cannot be made available in a timely manner), then document the current high level of uncertainty about the exposure of the RoA to future climate change. Consult DOI climate science experts about appropriate steps forward to obtain information necessary to conduct the analysis.

c. Unknown - Consult climate science experts (with your bureau or USGS) about relevant climate model projections and methods for assessing exposure to the RoA.

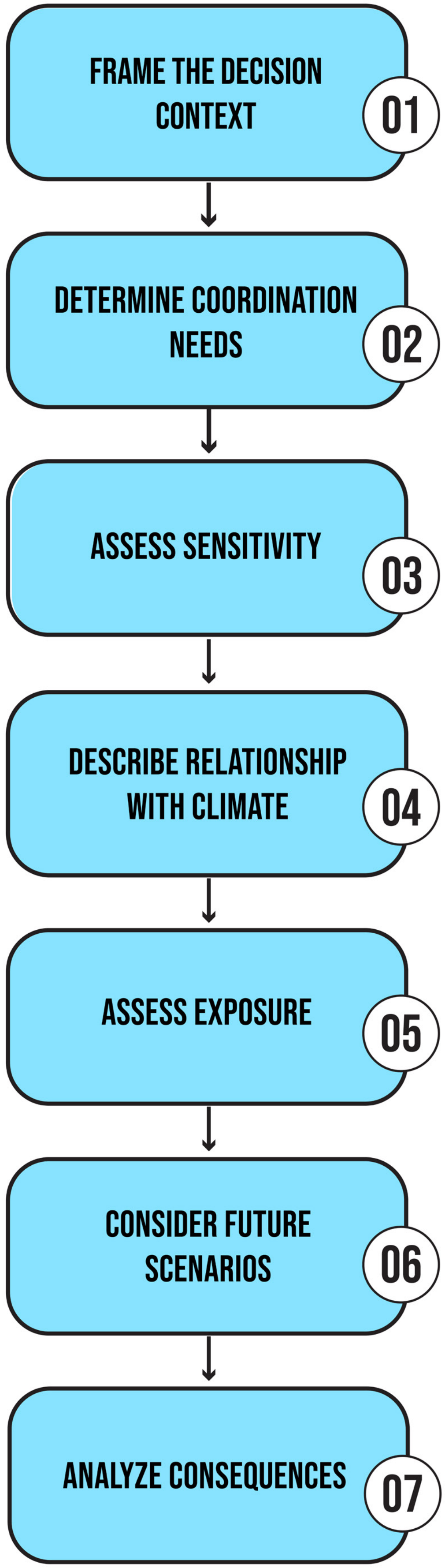
Workflow Step 6: Consider future scenarios. Is it important in the current decision context to consider undesirable, unacceptable, or catastrophic outcomes OR do timescales of decades or longer into the future need to be considered to assess the risk of these outcomes? (see Sections 3.3.5 - 3.3.7, 2.4, and Box 2)

a. Yes -use model outputs from multiple scenarios that reflect the range of plausible future net greenhouse gas emissions trajectories or the bounds of plausible future levels of global warming. Use the full time period of climate model projections when consideration of longer time scales is necessary to assess risk to the RoA. Use at least two scenarios depicting the upper and lower levels of future global warming including one that enables consideration of higher risk outcomes. Go to step 7.

b. Yes – but consideration of multiple scenarios is not feasible. To reduce the risk of overconfident decision making, use a scenario that enables consideration of higher risk outcomes (such as RCP 8.5). Go to step 7.

c. No - timescales beyond the next decade do not need to be considered. Use trends from recent high-quality observations to extrapolate conditions for the next 1-10 years. Alternatively, use climate model outputs from IPCC scenarios that reflect recent trends in greenhouse gas emissions. Go to step 7.

Workflow Step 7: Analyze consequences. For each scenario and set of model outputs: analyze, synthesize, and summarize the consequences of climate change for the RoA under consideration. Consider the full range of model projections available (as opposed to a single model, single multi-model average, or arbitrary subset of the full model ensemble). Summarize the range of possible impacts. See Box 4 for detailed example of a climate impacts assessment process. At this point, the analysis may be ready to move to the decision stage, or goals may need to be reconsidered, or more detailed scoping may be needed to contextualize the climate change information in a way that clarifies the options. Subsequent steps beyond this document may benefit from consulting additional DOI policies or guidance, such as the DOI Adaptive Management Technical Applications Guide.



Box 4. An example process for climate change impacts assessment.

Don't know where to start? Here is one (but not the only) "recipe" for an impacts assessment with questions to consider in each step. Each step references the relevant workflow step in Section 3.5.

1. **Frame the decision problem and identify partners** [Workflow *Step 1: Frame the Decision Context & Step 2: Determine Coordination Needs*]. While this step may seem obvious, it's often important to explicitly document the specific RoA of interest and the goals for any assessment of impacts from climate change. This helps to focus effort for later steps, especially if multiple partners are involved or have an interest in the analysis and outcomes.

2. **Identify climate sensitivities** [Section 3.2 and Workflow *Step 3: Assess Sensitivity*]. Be specific when possible – climate model projections are more useful when the specific relationship to the resource or asset is well understood. What are the precise climate variables or thresholds related to change in the RoA? Does it respond to average annual temperature changes, or can you identify precise thresholds (such as when temperature drops below freezing)? If you have a response model (conceptual, statistical, mechanistic, etc.) that describes how the RoA will change, then the specific climate variables in that model should be identified - this will help with the subsequent steps in an analysis.

   2.1. Assess response model performance [Workflow *Step 4: Describe Relationship with Climate*]. Compare your RoA response model with observed historical conditions to assess model error. Response model performance can be assessed by analyzing the model's ability to replicate past conditions of the RoA, often by inputting observed historical climate variables into the model and comparing output with independent observations. This is an important step towards understanding the accuracy and reliability of your model and the associated uncertainties.

3. **Identify the climate projection data** [Section 3.3 and Workflow *Step 5: Assess Exposure*]. There are many aspects to consider when selecting appropriate climate projection data. Making the selection often requires detailed knowledge of climate projection models and downscaling methods and can be challenging. Appendix B provides a summary of commonly used climate projection datasets. Sometimes, the ideal dataset doesn't already exist and so compromises must be made, or a new dataset created with customized downscaling. If this seems like too much at any step, you should consult with a climate specialist in your bureau, in your local USGS Climate Adaptation Science Center, or with a partner who has this expertise.

   3.1. Consider the relevant spatial scales and extents. How much spatial detail (or resolution) is needed to understand the vulnerability of your resource or asset? Does the RoA include both terrestrial and marine extents? Keep in mind that global climate models provide data every ~100 km (~60 mi) and there are many downscaled climate projection datasets with 4km (2.5 mi) resolution (or finer), but higher resolution does not always mean the data are more meaningful or "better." Similarly, while global-scale climate models cover the entire globe, many downscaled projections are only available for the contiguous US or specific regions. Selecting the appropriate dataset is easier if the relevant spatial scales and extents are clearly identified.

   3.2. Consider the relevant time horizon. You should consider the relevant time resolution and period into the future that is important for your impact assessment. Is your RoA sensitive to short-term or short duration events like flash floods or extreme daily temperatures? Or is the concern more for larger time scale factors such as sea level rise or annual precipitation changes? Similarly, consider how far into the future you need to explore to consider the vulnerabilities. Is the concern for your resource or asset mostly over the next 10-20 years, or is it a long-lived RoA (like a dam, tortoise, or historic structure) where you want to understand risks over the next 75+ years? While many downscaled datasets provide projections through the year 2100, some only provide projections for individual periods into the future. Explicit identification of the relevant time scale and period fosters easier selection of appropriate data.

   3.3. Consider the available downscaled datasets. If climate model spatial resolutions don't meet your needs to explore your resource's vulnerability, you'll likely want to use downscaled climate projections (see Section 3.3.3). Based on the climate variables that you identify above when you consider sensitivity, some datasets may be more appropriate than others. If your resource or asset is sensitive to the number of consecutive days with temperature above 90F, then you will need to consider datasets that have daily projections from which that threshold can be counted. If your RoA is sensitive to a climate variable that isn't readily available (e.g., soil temperature, inundation frequency, fire frequency, drought frequency) then you may need to use an intermediate model to generate projections for your subsequent analysis (see *Box 3*). It's also important to ensure the downscaling method used is appropriate for your identified climate sensitivity – while many methods are adequate for accurately replicating observed seasonal or annual temperature, they may inadequately replicate daily temperature and precipitation extremes. It's helpful to know the advantages and limits of the downscaling methodology when deciding which datasets are most appropriate – this is often where you might want to consult with a climate expert in your bureau or your local USGS Climate Adaptation Science Center.

3.4. Consider the emissions scenarios [*Workflow Step 6: Consider Future Scenarios*]. The CMIP archive contains projections for dozens of climate models, most with multiple common scenarios, but downscaled projections often use only a subset of these. Many dynamically downscaled datasets only provide projections for one scenario and a few global-scale climate models. Statistically downscaled projections are more likely to downscale many climate models and two or more scenarios. If your impact assessment goals warrant consideration of high-risk or high-impact outcomes, then make sure you select a plausible upper-bound scenario and a dataset that provides projections for this scenario (see *Section 3.3.6*).

4. **Perform the analysis** [*Workflow Step 7: Analyze Consequences*]. Goals are clearly defined. The sensitivity of the focal RoA is identified. Appropriate climate projections have been selected. Now, assess the range of impacts to the RoA from projected changes in climate.

4.1. Create response model hindcast and compare with observed sensitivity. Climate model datasets provide simulated (modeled) conditions over a historical period. This hindcast period does not provide historical observations, rather the climate model's simulation of that period. By using the climate model hindcast as input to the resource response model, one can compare the sensitivities of the response model to both observed climate (from 2.1 above) and modeled hindcast climate. For example, consider a habitat model developed using observations of past climate and past changes in habitat structure and quality for 1985-2010. The climate model simulation for this same historical period (1985-2010) should be used as a climate input to the habitat response model and compared with the observed changes in habitat structure and quality. This comparison provides important insight into how the response model simulates the climate model hindcast on which projections are derived.

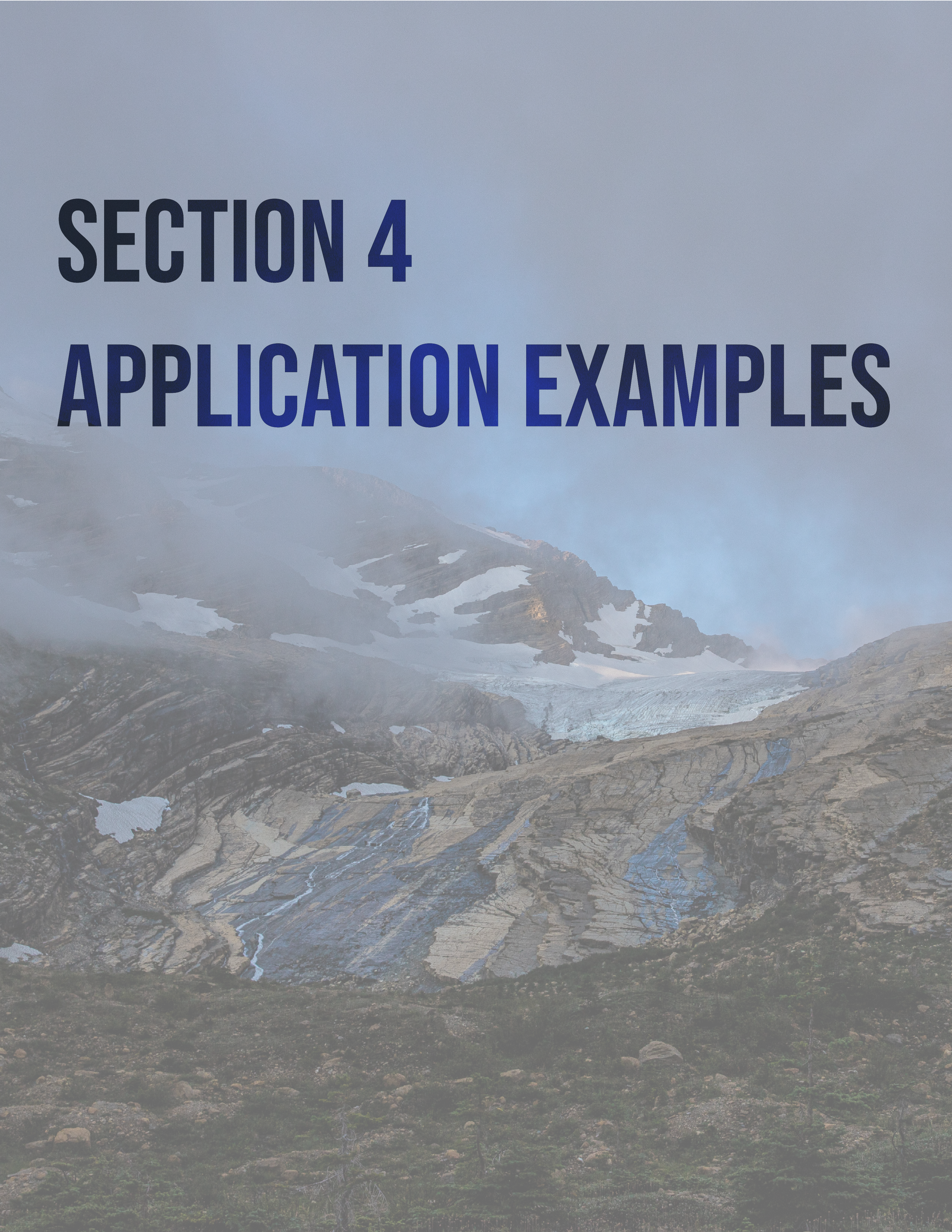
4.2. Generate response model output for future conditions. For each climate model and scenario, analyze future projections of climate and consequences for the asset. This is often performed by inputting the climate variables from each climate projection into the asset response model and then analyzing the response output to understand the range of outputs and impacts. Avoid using only the multi-model mean as an input as this prevents assessment of the full range of outputs (and the associated impacts) and can lead to overconfidence in the results.

4.3. Summarize response model output. For each scenario, compare the response model output with the response model baseline and summarize output (consequences) across the full range of model projections. Avoid using only a single model, a single multi-model average, or arbitrary subset of the full model ensemble. A summary might include the minimum, maximum, and mean (average) of the response model output. Often, the most interesting aspect is the relative change of future conditions compared to the past. With quantitative response models, the response model hindcast can be subtracted from the response model projections to understand the relative change. This difference from the hindcast has the added benefit of providing simple bias correction and removing (at least some) of the response model error. Often, it is appropriate to summarize consequences across models associated with each scenario to understand the range of outcomes for each scenario. This also enables the characterization of structural uncertainty across climate models. Use caution when summarizing outputs across multiple scenarios (e.g., combining output from RCP4.5 and RCP8.5) as this can mis-characterize the scenario uncertainty.

5. **Summarize the consequences.** Summarizing outputs from the resource model in response to climate projections for each scenario is often the final step in characterizing potential climate change impacts on a RoA. However, additional context or summarization may be needed to achieve your assessment goals. It is important to document the relevant considerations, uncertainties, and basis for choices as part of the summarized impacts assessment.

SECTION 4

APPLICATION EXAMPLES



4. APPLICATION EXAMPLES

4.1 Introduction

This section provides a series of hypothetical examples that apply the principles described in Sections 2 and 3 to analysis and planning processes typical of Department of the Interior bureaus and offices. These examples are **fictional** – the places, resources, and assets **are not real** and **should not be interpreted or cited as truth.** Figures, charts, and tables provided do not reflect any real data or analysis. However, the examples are derived from real situations reflective of typical Departmental challenges. When appropriate, these hypothetical examples do refer to actual datasets and tools that might be used in real applications. Tables of these tool and data resources are provided in Appendices.

The purpose of these is to provide contextual examples, grounded in real world issues, that illustrate typical challenges faced in applying the principles in 526 DM 1. Each example provides general context on the nature of the issue or decision, then describes the process used to apply climate change science to the challenge. While each example follows the principles and technical elements described in Sections 2 and 3, they purposefully do not all follow a precise recipe since each application has its own specific context and challenges. Examples may draw from individual bureaus but are designed to be useful for readers across all Interior bureaus and offices.

It is important to note that these examples focus solely on the use of climate change datasets and tools for insights into climate change effects and not the myriad of potential biological, ecological, infrastructure, and social responses to climate change projections. These other biological and social responses to climate change are critically important for the Department of the Interior's mission but are beyond the scope of this guidance.

Plants and Habitat	Hydrology	Landscapes	Facilities / Infrastructure	Coastal / Marine	Wildlife Species

Example	Categories
4.2 BoR Basin Study	Hydrology
4.3 FWS Species Status Assessment	Wildlife Species, Landscapes
4.4 FWS Coastal Refuge Planning	Coastal / Marine, Plants and Habitat
4.5 BLM NEPA EIS for Land Restoration	Landscapes, Plants and Habitat
4.6 BOEM Offshore Energy Study	Coastal / Marine
4.7 NPS Resource Stewardship Strategy	Landscapes, Wildlife Species
4.8 NPS Facilities Rehabilitation	Facilities / Infrastructure, Coastal / Marine
4.9 Multi-Bureau: Dam Raise Threatens Critical Habitat	Wildlife Species, Plants and Habitat, Hydrology, Facilities / Infrastructure
4.10 Multi-Bureau: DoD expansion Affects BLM & NPS lands	Facilities / Infrastructure, Plants and Habitat, Wildlife Species

4.2 BoR Basin Study

Water managers in the fictional Clear River Basin are experiencing a growing imbalance between water supplies and water demands due to a variety of factors. Factors include observed and projected climate change affecting the quantity and timing of available water supply, population growth, increasing regulatory requirements and constraints, changes in Reclamation Project (Project) operations, and inadequate water resources infrastructure (**Workflow Step 1: Frame the Decision Context**).

The Clear River Basin Consortium is a group of multiple organizations with jurisdiction, consultation, or other direct involvement in the decision process of balancing water operations in the Clear River Basin. Seeing the growing imbalance between water supply and demand, the Consortium submitted a basin study proposal through the Bureau of Reclamation's Basin Study Program (program) to develop a project management plan. In alignment with program requirements, the Consortium and Bureau of Reclamation entered into a Memorandum of Agreement to provide 50/50 federal/non-federal cost-share to perform the basin study (**Workflow Step 2: Determine Coordination Needs**).

Water managers struggle to address emerging climate change conditions, including increases in the frequency and intensity of extreme events (such as droughts and floods) and their impact on water operations. Numerous studies show that global and regional climate conditions are changing, changes will continue (and likely accelerate) over the 21st century, and that climate change will significantly affect regional water supplies, demands, and management (IPCC 2021, USGCRP 2023) (**Workflow Step 3: Assess Sensitivity**).

To facilitate describing the quantitative relationship between the climate system and the resource in the Clear River Basin, the study team develops multiple future climate and hydrology scenarios to represent the projected range of future climate conditions over the study area through the end of the 21st century (**Workflow Step 4: Describe Relationship with Climate**). The team accesses a readily available, peer-reviewed set of climate projections for multiple emissions scenarios from the Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections archive (Reclamation et al. 2018). They use a total of 64 bias-corrected and downscaled CMIP5 climate projections from 32 different global climate models under two future emissions scenarios (RCP4.5 and RCP8.5) to develop the climate scenarios (**Workflow Step 5: Assess Exposure**). Water availability is identified as a critical resource, and the team selects both lower and higher emissions scenarios to provide range of climate futures to assess the uncertainty in potential future water supply and demands.

The study team then develops hydrology results using the Variable Infiltration Capacity (VIC) hydrology model to simulate hydrologic conditions under each projection and climate scenario (**Workflow Step 6: Consider Future Scenarios**). The team selects the VIC model because it can be calibrated with historical datasets, the model performs well in simulating historical flows, and the errors and uncertainties are well understood. These climate and hydrology results are subsequently used as the basis for evaluating future water supplies and demands in the Clear River Basin Operations Model. The Clear River Basin Consortium identifies water supply availability as the main impact for further evaluation. Based on this decision, the study team further explores three variables to understand future changes in water supply and demands: potential evapotranspiration (PET), snow water equivalent (SWE), and total

Lake Powell, Glen Canyon National Recreation Area. Photo by NPS.

runoff. PET is a key indicator of landscape water demands, including consumptive use by evaporation and transpiration from bare soil, water surfaces, native vegetation, and crops. SWE is a key indicator of water supplies in the region, where runoff from many watersheds is dominated by snowmelt. Lastly, total runoff is a direct indicator of the water supply available to the Clear River Project system.

Projected future runoff, similar to the range of future projections of precipitation, suggests large uncertainty by year 2099 in the study area. The sources of uncertainty are mostly due to the combination of different scenarios and model differences. For example, the Clear River Basin had an annual average of 2 million acre-feet per year of runoff in the last 30 years. The projected changes in runoff range from an increase of approximately 500,000 acre-feet (+25%) for warmer and wetter RCP4.5 projections to a decrease of approximately 250,000 acre-feet (-12.5%) for warmer and dryer RCP8.5 projections. While current infrastructure would be pressed to store a 25% increase in runoff for the benefit to water users, a reduction of 250,000 acre-feet of runoff would have significant impacts, further stressing the already limited water supply in the Clear River Basin and causing shortages that highly impact all uses (Workflow **Step 7: Analyze Consequences**). Peer review is performed on the above analyses according to agency policy. The study team also documents their characterization of uncertainty to basin hydrology is limited due to the use of only a single hydrological response model (VIC).

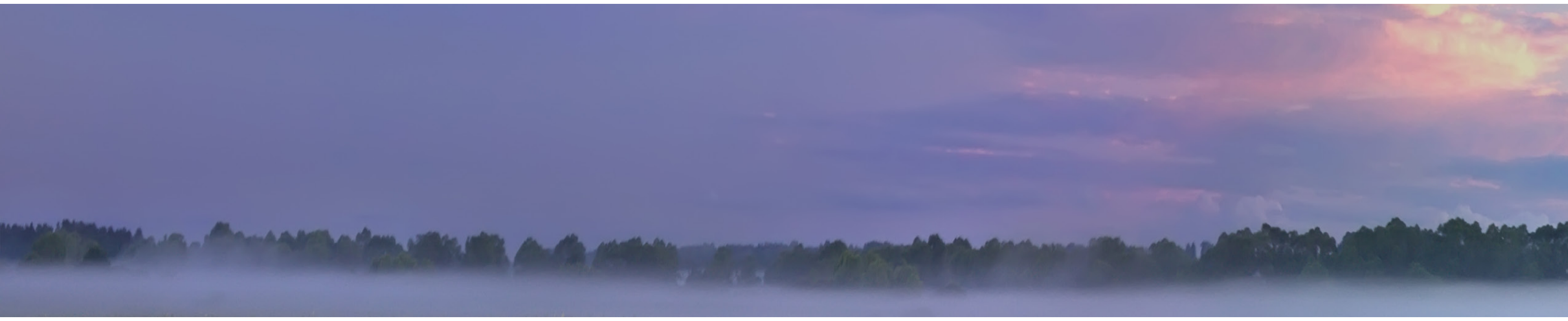
The study team and partners develop and evaluate adaptation strategies to address the projected gap in water supply and demand. They identify study area vulnerabilities, including limited storage, sensitive species, surface water and groundwater reliance, and land use changes. They then formulate adaptation strategies, including but not limited to demand management, diversifying water supplies, improving operational flexibility, improving resource stewardship, and increasing flexibility in resource sharing and agreements. To help prioritize adaptation strategies, the team then performs a trade-off analysis of the adaptation strategies. Following program requirements, evaluation criteria for ranking the strategies include 1) Effectiveness, 2) Efficiency, 3) Acceptability, and 4) Completeness. The Consortium uses this information to develop a water management plan for the Clear River Basin.

Baby box turtle, Russell Cave National Monument. Photo by NPS.

4.3 FWS Species Status Assessment

The Species Status Assessment (SSA) is an analytical approach the U.S. Fish and Wildlife Service (FWS) uses to inform decisions pertaining to the Endangered Species Act (ESA), including classification decisions (i.e., listing, down-, or delisting), and recovery planning. In the SSA process, FWS considers the effects of climate change on the species' needs and the anticipated species' response (e.g., physiological, behavioral, demographic response of a species due to a change to one of their needs, etc.) as well as other influences such as habitat loss or predation (Workflow **Step 1: Frame the Decision Context**).

FWS conducted an SSA for a fictional turtle species. An early step of the SSA is assessing the species habitat and demographics needs. FWS identified that the turtle's habitat needs included aquatic habitat, upland habitat, and basking sites. In addition, important demographic factors to consider include abundance, reproduction/recruitment, survival, and connectivity. FWS then determined what may be influencing (positively or negatively) the availability and condition of the turtle's needs (Workflow **Step 3: Assess Sensitivity**). They identified habitat loss and fragmentation, altered hydrology, predation, nonnative species competition, disease, road impacts, collection, contaminants, and climate change as potential threats to the species. For climate change specifically, FWS identified that increasing temperatures, drought, extreme flood events, and high severity fire may have



an influence on the viability of this species.

When FWS is deciding how to analyze the potential impacts of these threats on current and future viability, they are required by the ESA to consider “the best scientific and commercial data available.” As such, FWS includes a discussion on the climate information considered and justification on what was or was not included in the SSA. FWS uses scenario analysis to project future conditions including projections from both climate and non-climate influences. FWS projects a range of plausible future influences and species responses, bounded by an upper plausible-limit scenario and a lower plausible-limit scenario (USFWS 2023a). If climate change is identified as a threat to the species’ viability, FWS routinely uses the reports and tools from IPCC and USGCRP to inform their description of plausible changes in climate and also uses localized and downscaled models as available. To ensure the plausible range of uncertainty in future climate change is captured, the current FWS best practice is to bound those projections using RCP4.5/SSP2-4.5 and RCP8.5/SSP5-8.5 scenarios (USFWS 2023b). When considering timeframe for those scenarios, FWS selects timeframes for the analysis that are relevant to and useful within the decision context. For all ESA classification decisions, the timeframes for projections of climate variables are based on the best scientific and commercial data, while the subsequent timeframe of species-response to projected environmental conditions is based on species’ life-history. The FWS considers IPCC and USGCRP data over their full timeframes to be reliable.

After conducting an extensive literature review and working with local FWS biologists and species experts, the team identified three past, current, and future threats that have the greatest influence on the species viability: anthropogenic impacts (human modification/land conversion), predation (by a large invasive frog species), and drought (**Workflow Step 4: Describe Relationship with Climate**). For this fictional turtle, FWS assessed future condition of the species using a population viability analysis (PVA) and used two scenarios to evaluate the effects of land conversion, predation, and drought out to 2100 (**Workflow Step 5: Assess Exposure**). FWS assessed land conversion in the PVA which used Integrated Climate and Land-Use Scenarios (ICLUS) projections. ICLUS produced spatially explicit projections of human population and land-use, incorporating RCPs. For drought, FWS used the Standardized Precipitation Evapotranspiration Index (SPEI) with 1986–2005 as the baseline for comparison, consistent with IPCC climate scenarios that use this same baseline period and 2006 as a starting point for CMIP5 RCP scenarios (**Workflow Step 6: Consider Future Scenarios**). SPEI was used because it combines the relative frequency and intensity of drought into a normalized metric that was found in a prior study to effectively describe past changes in pond turtle habitat suitability. Predation was incorporated into the model using a past rate of spread of the local bullfrogs to project future rate of spread. The results of the PVA were used to assess extinction risk under two scenarios (RCP8.5 and RCP4.5) by considering changes to the species’ resiliency, redundancy, and representation - three species viability principles that every SSA assesses when evaluating a species’ potential risk of extinction (USFWS 2016, Smith et al. 2018) (**Workflow Step 7: Analyze Consequences**). The results indicated that species resiliency, redundancy, and representation decreased under both scenarios. These results are included as part of the comprehensive SSA used to inform the decisions for listing under ESA.

In this example, using a range of scenarios provided FWS critical information on the species’ risk of extinction through time. Extending the time frame to 2100 ensured that the FWS considered best scientific data available when assessing risk of extinction. The use of two scenarios provided decision makers with an estimate of risk across a range of plausible futures

Stork gliding over misty meadows. Photo by USFWS.

to capture the extinction risk over time under different scenarios. The use of future scenario analysis provided the FWS with quality science to help strengthen their ability to make sound decisions in the face of uncertainty.

4.4 FWS Coastal Refuge Planning

The mission of the FWS's National Wildlife Refuge System is to:

> *"[A]dminister a national network of lands and waters for the conservation, management and, where appropriate, restoration of the fish, wildlife and plant resources and their habitats within the United States for the benefit of present and future generations of Americans."*

With over 570 Refuges, FWS manages 95 million terrestrial and nearly 850 million water acres. Many of these Refuges are in coastal zones experiencing impacts of sea level rise (SLR). SLR planning is crucial to conserving the ecological and cultural features of Refuges as well as protecting important infrastructure that supports public access (**Workflow Step 1: Frame the Decision Context**).

In this case study, a fictional coastal Refuge encompassing over 30,000 acres has lost 5,000 acres of freshwater wetlands and salt marshes since 1938 due to SLR and associated threats (**Workflow** Step 3: Assess Sensitivity). This Refuge is an internationally important migratory bird sanctuary that also provides important habitat for at-risk and endangered mammals and birds. To inform refuge planning and potential future acquisitions, the Refuge partnered with state and federal agencies and non-governmental organizations (NGOs) to develop a report and adaptation plan identifying high value marshes most resilient to SLR, potential marsh migration corridors, and areas where terrestrial habitats could convert to salt marshes (**Workflow** **Step 2: Determine Coordination Needs** and **Workflow** **Step 4: Describe Relationship with Climate**).

Specifically, the partnership evaluated several SLR scenarios using a marsh migration model that has been previously shown to adequately simulate historical changes on the Refuge (**Workflow** **Step 5: Assess Exposure**). The model simulates the dominant SLR-driven wetland conversion processes including inundation, erosion, accretion, and soil saturation and allows users to account for uncertainty in input variables. The partnership reviewed the latest SLR scenarios from the 2022 Interagency Report (Sweet et al. 2022) and decided to evaluate the possible impacts from all five scenarios through 2100 (**Workflow** **Step 6: Consider Future Scenarios**). The team reviewed other sources of uncertainty in the model including elevation, accretion rates, tide ranges, erosion rates, and uplift/subsistence rates. Based on a literature review and discussions with the agency model developer, the team decided they had the greatest uncertainty in erosion and uplift/subsistence rates. They ran the model several times adjusting for confidence values in these two parameters. They explored model outputs through the end of 21st century because the partnership was interested in both habitat and long-lived infrastructure.

Using the marsh migration model outputs, the team identified Refuge wetlands most resilient to SLR, marsh migration corridors, and terrestrial lands that could convert to new marshes across all five SLR scenarios. The model also produced an overlay map depicting marsh migration/inundation results based on uncertainty in the erosion and uplift/subsistence parameters. From these predictions, the team used the results from the intermediate and high SLR scenarios to compare potential impacts to endangered species habitat and critical Refuge road infrastructure (**Workflow** **Step 7: Analyze Consequences**).

Next, the partnership used geospatial tools to determine which resilient current and future marshes under both SLR scenarios are predicted to provide the highest quality habitat for seven proxy at-risk and endangered bird species. High value marshes were defined by the area of transitional and high marsh, ratio of interior to edge habitat, and distance from upland habitats.

The team then compared the predicted area of remaining and converted high value marsh habitat at year 2100 under the two SLR scenarios. Under the high SLR scenario, nearly all existing salt marsh habitat was inundated and nearly 500 acres of new habitat was created. Under the intermediate SLR scenario, 90% of existing wetlands were inundated and approximately 700 acres of new habitat created. Given the extensive loss of almost all existing wetlands under both scenarios, the partnership focused their adaptation strategies (see below) on the 10% of remaining wetlands predicted by the intermediate model and migration corridors and areas of new marsh predicted by both models. To further identify potential adaptation opportunities at current and future resilient marshes, the team also overlaid several additional spatial datasets. These include modeled land use change to 2050 and current aquatic barrier information (e.g., undersized culverts and bridges). These datasets were developed by state and federal partners and are considered the most robust site-specific land use information available. The land use change model helped the team identify which upland areas are most at risk of development and would therefore be unavailable without conservation as migration corridors or conversion areas. The barrier information was used to inform potential blockages in future migration corridors.

The partnership identified three adaptation strategies consistent with the Resist-Accept-Direct (RAD) framework: 1) build resilience of existing marsh areas (Resist); 2) facilitate migration of marshes inland (Accept/Direct); and 3) support the transition of upland areas into marsh (Direct).

> Adaptation Strategy 1 – Build Resistance of Existing Marsh Areas: To inform this strategy, the partnership used spatial modeling tools to identify marshes with underlying geology conducive to maintaining salt marsh features and habitat values for salt marsh bird species. Resilience-building strategies in these marshes include adding sediment to raise elevation and creating living shorelines to slow the loss of priority marshes.

> Adaptation Strategy 2 - Facilitate Inland Marsh Migration: marsh migration models were used to identify potential marsh migration corridors linking existing marshes to surrounding wetlands and uplands under different SLR scenarios. The Refuge is working with state and local partners to acquire land and easements along two of these priority marsh migration corridors to ensure land is undeveloped as salt marshes move inland.

> Adaptation Strategy 3 - Support the Transition of Upland Areas into Marsh. The Refuge and partners are actively managing areas, such as forests and old agricultural fields, as they transition into salt marsh. Management activities include controlling invasive species to facilitate native salt marsh vegetation colonization, removing standing snags, and planting transitional vegetation. In some instances, agricultural areas that have become too low and wet to farm have been converted to moist-soil impoundments to maintain high-value migratory bird habitats.

While these adaptation strategies apply primarily to the Refuge and adjacent lands, the partnership continues to engage the broader community through a technical committee, informal and formal public meetings, support for marsh migration projects on non-Refuge lands, and ongoing discussions around the cultural and economic benefits of the Refuge. The partnership is also working to establish an ongoing monitoring plan at 5-year and 10-year intervals.

This successful Refuge SLR planning effort highlights several crucial process elements. First, the plan relies on the best available SLR, spatial, and habitat information to inform where adaptation is needed. Second, the plan recognizes that multiple approaches are needed, based on site characteristics, available funding, and conservation opportunities. Finally, because the plan was written collaboratively with a broad group of partners, it serves as a cohesive conservation vision for the greater Refuge area and informs several components of the Refuge's Comprehensive Conservation Plan.

4.5 BLM Restoration of Land Resource Area

The Bureau of Land Management's fictional Juniper Field Office (BLM-JFO) is developing a Resource Management Plan (RMP) Environmental Impact Statement for the imaginary Apple Mountains Resource Area (AMRA) on the Colorado Plateau. The AMRA contains large stands of two needle Pinyon Pine (Pinus edulis) and assorted desert shrubs. The BLM-JFO has determined that much of the AMRA is in a degraded state and in need of restoration (**Workflow Step 1: Frame the Decision Context**).

Drought, combined with the invasion of non-native annual grasses, has contributed to a trend of larger and more frequent fires in the area's valuable pinyon–juniper woodlands over the past 30 years. About half of the total pinyon–juniper woodland within the AMRA has been lost due to fire and drought die-off. This has had negative impacts on the Pinyon Jay (*Gymnorhinus cyanocephalus*) as it requires pinyon–juniper habitat for nesting and foraging. Pinon Jays helps pinon and juniper trees to proliferate by dispersing their seeds. Cheatgrass (*Bromus tectorum*) is now widespread throughout much of the AMRA and represents a significant fire hazard because of its flammability. It can change the fire recurrence interval from the natural 200 to 400 years for pinyon–juniper woodlands to three to five years for cheatgrass-dominated sites (Ypsilantis 2003). Climate change is expected to bring warmer and drier conditions to the region, leading to more intense droughts and increased fire risk requiring a revised management plan (USGCRP 2023). In the AMRA, wildfire risk is a primary concern given the large proportion of degraded woodlands and widespread cheatgrass establishment (**Workflow Step 3: Assess Sensitivity**).

The BLM-JFO is analyzing possible climate change impacts on drought-induced mortality in pinyon–juniper woodlands to evaluate a range of AMRA vegetation management strategies for the RMP. Because the pinyon–juniper woodlands serve as important wildlife habitat, have local cultural significance, and help sequester carbon, the BLM-JFO would like to protect the remaining pinyon–juniper woodland in the AMRA, but changing climate conditions could make conservation efforts difficult to impossible.

The BLM-JFO identified prior research relating vapor pressure deficit to drought-induced two needle Pinyon mortality (**Workflow Step 4: Describe Relationship with Climate**). Vapor pressure deficit (VPD) measures how much water is in the air versus the maximum amount of water vapor that can exist in that air and can be used as an indicator of potential moisture stress for plants. The prior research indicated that, since 1900, three drought-induced mortality episodes have each occurred following consecutive summers (June-August) with a mean VPD greater than 2.5 kPa. The AMRA is located within the larger region analyzed by this prior research, thus the BLM-JFO is confident its findings are a suitable foundation for assessing future climate change impacts for the area.

The BLM-JFO used ClimateToolbox.org to access 20 climate model projections from CMIP5 (**Workflow Step 5: Assess Exposure**). ClimateToolbox.org is useful because it includes a large set of variables at

a higher spatial resolution (~4 km / 2.5 mi), making it ideal for different kinds of future climate modeling (i.e., hydrology, ecology, vegetation, fire). Moreover, ClimateToolbox.org has a unique feature that allows users to input custom polygon shapes to obtain information specific to their area, such as a BLM field office boundary. ClimateToolbox.org provides CMIP5 model outputs that are statistically downscaled using the Multivariate Adaptive Constructed Analogs (MACA) method version 2 with the gridMET training dataset. This method removes some biases and increases the resolution of the model outputs (Abatzoglou and Brown 2012). ClimateToolbox.org allows users to obtain data for a single grid cell, an entire county or state, or a custom polygon. The BLM-JFO used the AMRA shapefile as the geographic area for the analysis. While CMIP6 climate projections are newer, ClimateToolbox.org does not yet include these projections nor the relevant land management variables.

The BLM-JFO obtained monthly climate change projection data from all twenty CMIP5 models on ClimateToolbox.org and both available RCP scenarios to capture a broad range of potential futures for the mid-century (2040–2069) period (Table 4.5.1). They selected this timeframe because it most closely corresponds to the timeframes associated with BLM-JFO management plans and strategies. Two Representative Concentration Pathways (RCPs), RCP 4.5 and RCP 8.5, are used to project future greenhouse gas concentrations and their potential impacts on the climate system (**Workflow Step 6: Consider Future Scenarios**).

As indicated in Figure 4.5.1 and Table 4.5.1, all the CMIP5 models show an increase in mean summer temperature and VPD by mid-century under either the RCP 4.5 or RCP 8.5 scenario (**Workflow Step 7: Analyze Consequences**). In the RCP 4.5 scenario, the model mean summer temperature increase is 4.5°F above 1971-2000 mean conditions with an increase of 0.37 kPa in VPD. For the RCP 8.5 scenario, these increase to 6.0°F and 0.48 kPa, respectively. Notably, there is a strong linear correlation between summer mean VPD and temperature (Figure 4.5.1) with mean VPD increasing by roughly 0.1 kPa per degree (°F). The GFDL-ESM2M model stands out for projecting the least amount of warming and smallest increase in VPD in either RCP scenario (Table 4.5.1). The inmcm4 also projects considerably less warming than the other CMIP5 models. Conversely, the MIROC-ESM-CHEM projects the hottest conditions for mid-century with an increase of 7.2°F and 8.6°F above mean historical summer temperatures under RCP 4.5 and RCP 8.5, respectively.

In the historical (1971-2000) period, summer VPD in the CMIP5 models averaged about 1.8 kPa with all models within 0.1 kPa of the mean. During the thirty-year historical period, summers with a mean seasonal VPD greater than 2.5 kPa were extremely rare in the CMIP5 models. During the historical period, fifteen of the models had zero summers above the 2.5 kPa threshold, four models had one summer, and one model indicated three summers exceeded this threshold. None of the CMIP5 models simulated any historical instances of consecutive summers with mean VPD greater than 2.5 kPa.

Table 4.5.1. CMIP5-MACAv2 Projections of Mean Summer Temperature Change and Mean Summer Vapor Pressure Deficit (VPD). Changes in mean temperature over the 1970-2000 averages are provided for RCP 4.5 and RCP 8.5 for 2040-2069. Historical summer average VPD for 1971-2000 is shown along with projected summer values for RCP 4.5 and RCP8.5 for 2040-2069.

Model	RCP 4.5 (2040-2069) **Δ Mean Summer Temperature (°F)**	RCP 8.5 (2040-2069) **Δ Mean Summer Temperature (°F)**	Historic (1971-2000) Mean Summer VPD (kPa)	RCP 4.5 (2040-2069) Mean Summer VPD (kPa)	RCP 8.5 (2040-2069) Mean Summer VPD (kPa)
bcc-csm1-1	+4.5	+6.0	1.84	2.28	2.42
bcc-csm1-1-m	+4.0	+5.7	1.85	2.24	2.37
BNU-ESM	+3.7	+5.3	1.86	2.05	2.11
CanESM2	+6.0	+7.3	1.82	2.20	2.31
CCSM4	+4.2	+6.0	1.84	2.17	2.31
CNRM-CM5	+3.6	+4.6	1.81	2.06	2.08
CSIRO-Mk3-6-0	+6.2	+7.1	1.82	2.30	2.38
GFDL-ESM2G	+4.0	+5.0	1.79	2.16	2.21
GFDL-ESM2M	+0.8	+1.7	1.88	1.90	1.86
HadGEM2-CC365	+4.9	+6.6	1.78	2.21	2.31
HadGEM2-ES365	+5.7	+8.2	1.81	2.30	2.62
inmcm4	+2.2	+4.8	1.85	1.99	2.23
IPSL-CM5A-LR	+6.0	+7.7	1.86	2.36	2.49
IPSL-CM5A-MR	+6.3	+8.3	1.80	2.36	2.55
IPSL-CM5B-LR	+3.1	+4.4	1.84	2.06	2.13
MIROC5	+3.7	+5.1	1.89	2.16	2.29
MIROC-ESM	+6.7	+7.6	1.82	2.38	2.45
MIROC-ESM-CHEM	+7.2	+8.6	1.85	2.48	2.63
MRI-CGCM3	+3.0	+4.4	1.83	2.09	2.18
NorESM1-M	+4.9	+6.3	1.84	2.23	2.33
20 Model Mean	+4.5	+6.0	1.83	2.20	2.31
20 Model Max	+7.2	+8.6	1.89	2.48	2.63
20 Model Min	+0.8	+1.7	1.78	1.90	1.86

Table 4.5.2. CMIP5-MACAv2 Projections of the occurrences of Summer Vapor Pressure Deficit (VPD) greater than 2.5 kPa. The total count and the count of consecutive days with VPD>2.5 kPa are shown for each model for the historical simulations (1971-2000), and RCP 4.5 & RCP 8.5 for the period 2040-2060. Projections for RCP4.5 & RCP 8.5 also include the average duration of years with consecutively high summer VPD occurrences.

Model	Historic (1971-2000)		RCP 4.5 (2040-2069)			RCP 8.5 (2040-2069)		
	Total	Consecutive Events	Total	Consecutive Events	Avg. Duration (years)	Total	Consecutive Events	Avg. Duration (years)
bcc-csm1-1	0	0	13	3	3.7	20	5	3.2
bcc-csm1-1-m	0	0	12	2	4	17	5	2.6
BNU-ESM	0	0	6	0	-	7	1	2
CanESM2	0	0	7	1	3	17	6	2.5
CCSM4	0	0	10	2	2.5	20	4	4
CNRM-CM5	0	0	6	1	2	6	0	-
CSIRO-Mk3-6-0	0	0	12	4	2	19	4	3.8
GFDL-ESM2G	3	0	5	1	2	3	0	-
GFDL-ESM2M	0	0	10	3	2	10	2	2.5
HadGEM2-CC365	0	0	8	1	2	15	3	3.7
HadGEM2-ES365	0	0	14	2	2.5	29	2	14.5
inmcm4	0	0	4	1	2	8	3	2.3
IPSL-CM5A-LR	0	0	17	4	3.8	21	4	4.8
IPSL-CM5A-MR	0	0	15	3	3.7	24	4	5.5
IPSL-CM5B-LR	1	0	4	0	-	5	0	-
MIROC5	0	0	8	2	2.5	13	4	2.8
MIROC-ESM	0	0	18	5	3.4	20	3	6
MIROC-ESM-CHEM	1	0	23	4	4.8	25	3	7.7
MRI-CGCM3	1	0	5	0	-	8	2	3
NorESM1-M	1	0	17	4	3	20	4	4.5
20 Model Mean	0.4	0	10.7	2.2	3.1	15.4	3.0	4.2
20 Model Max	3	0	23	5	4.8	29	6	14.5
20 Model Min	0	0	4	0	-	3	0	-

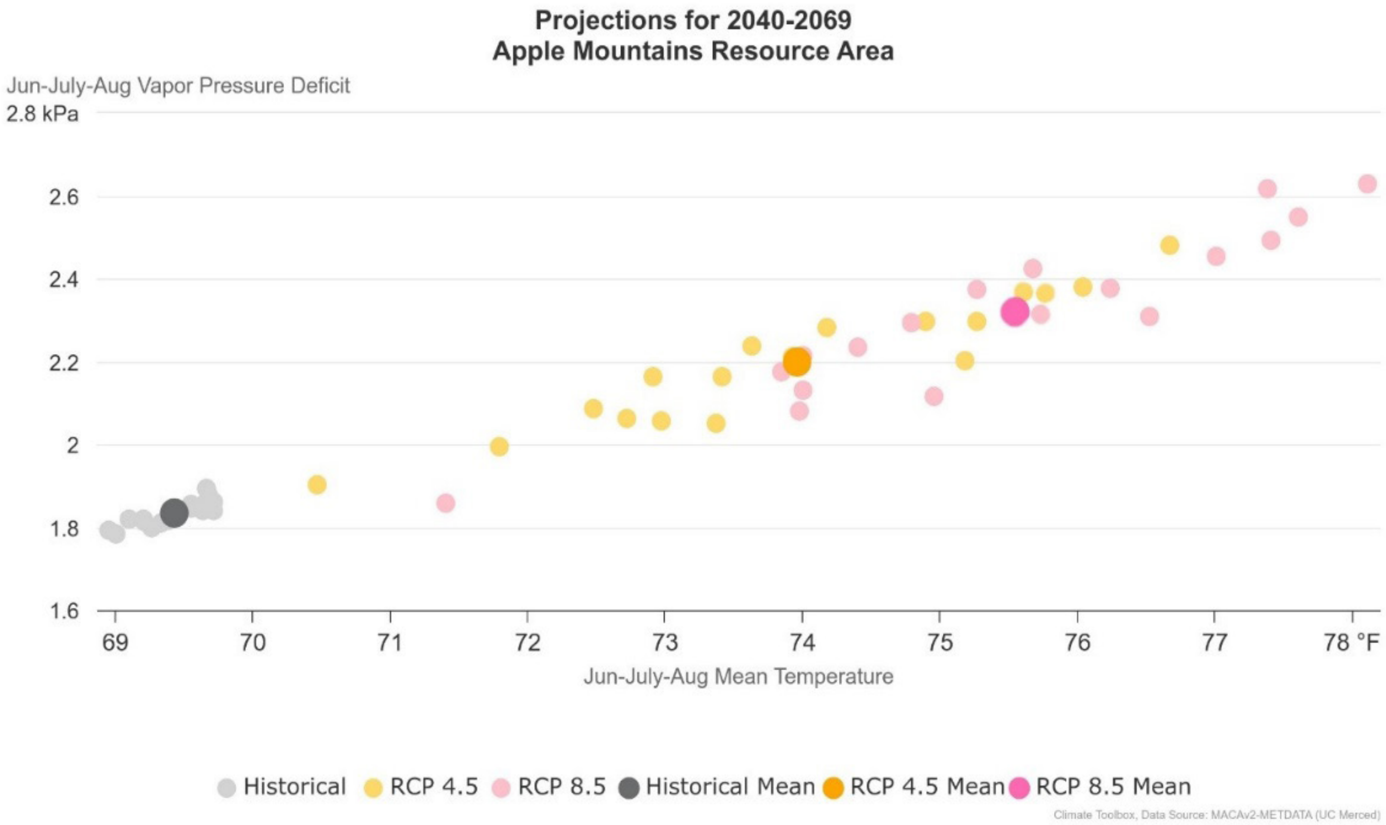


Figure 4.5.1. Summer Vapor Pressure Deficit (VPD) vs Summer Temperature in CMIP5 Projections of Historical and Future (2040-2069) Climate. Source: The Climate Toolbox.

The models indicate that episodes of extreme summer drought will become common by mid-century (2040-2069) under either RCP scenario. Each model projects a large increase in the number of years with mean summer VPD greater than 2.5 kPa (Table 4.5.2). In RCP 4.5, the model mean increases to 10.7 years with summer VPD greater than 2.5 kPa and increases to 15.4 years in RCP 8.5. With such a large increase in the number of summer seasons above this threshold, the frequency of consecutive summers with a mean VPD above 2.5 kPa is also expected to increase. In the RCP 4.5 scenario, twelve of the twenty CMIP5 models have four or more occurrences of consecutive summers above the VPD threshold and many of these persist for longer than back-to-back summers. For RCP 8.5, thirteen of the CMIP5 models have three or more events, and nine of the models project four or more events during the 2040-2069 period. In several of the models, such as the HadGEM2-ES365 and MIROC-ESM-CHEM, extreme summer drought conditions would be the average mid-century climate. Overall, the models suggest that the mid-century climate will be unsustainable for persistence of the two-needle Pinyon within the AMRA.

The BLM-JFO analysis of future summer drought in the AMRA suggests that preserving the remaining two-needle Pinyon stands may be unrealistic. Accordingly, resource specialists suggest that adaptative management towards directed change to habitat of more suitable species as an appropriate management strategy.

4.6 BOEM Offshore Energy Study

The Bureau of Ocean Energy Management (BOEM) is responsible for stewarding U.S. Outer Continental Shelf (OCS) energy, mineral, and geological resources, as well as protecting the environment that the development of those resources may impact. Interest in wind energy and oil exploration and production in the shallow waters offshore Alaska has created a need to advance BOEM's understanding of the past, current, and future atmospheric and oceanographic conditions. For decades, Alaska has been experiencing substantial shifts in the intensity and frequency of extreme climate events related to temperature, sea ice, and coastal erosion, with high confidence for future continued change also in precipitation and marine and terrestrial ecosystems (Rantanen et al. 2022) (**Workflow Step 1: Frame the**

Sea Lions, Glacier Bay National Park & Preserve. Photo by NPS.

Decision Context).

Misty Rock Bay, a fictional location along coastal Alaska, has been identified as a potential site for future development. BOEM needs to understand how longer periods of open water, decreased sea ice, and changes in ocean and atmospheric conditions due to climate change in the vicinity of Misty Rock Bay might affect wave and storm surge conditions, sediment transport patterns, and coastal erosion rates which can affect offshore infrastructure (Workflow **Step 3: Assess Sensitivity**). In addition, offshore infrastructure can likewise impact its surrounding environment (e.g., sediment transport patterns).

BOEM develops a study with colleagues at the University of Alaska Fairbanks (UAF) to explore how longer periods of open water, decreased sea ice, and changes in ocean and atmospheric conditions due to climate change might affect wave and storm surge conditions, sediment transport patterns, and coastal erosion rates along Alaska's northern coast and nearshore marine environment. BOEM is interested in understanding how conditions may change during the lifespan of typical offshore wind farm and oil production projects (30 years) between 2030 and 2060. Results from this study will help inform monitoring activities associated with planned projects and to support National Environmental Policy Act analyses for future lease sales, Exploration Plans, and Development and Production Plans (DPPs).

To better understand past and current conditions, BOEM scientists use satellite observations of sea ice from 1979 to present and confirm the timing of sea ice break-up and freeze-up are occurring earlier and later in the year, respectively. They find that in the 1980s, partial sea ice cover was intermittently present in the study area during the summer and early fall months (July–September). However, by 2019, little to no sea ice was common between August to mid–October (Workflow **Step 4: Describe Relationship with Climate**). Since Alaska's rapidly changing climate can potentially alter the impact that BOEM's leasing in the region has on the surrounding marine, coastal, and human environments, BOEM must also account for the impact of climate change during the lifetime of the Exploration and Development Scenario in its Environmental Impact Assessment (EIA) analyses.

To this end, a modeling system, including downscaling from the global to local scale as well as calibrations and validations of individual models, is developed to generate projected spatial statistics of waves and sediment transport pathways over the study area for the period 2030–2060 (the estimated timeframe of proposed wind energy and oil production projects) (Workflow **Step 5: Assess Exposure**). While global climate models are routinely used for assessing climatological parameters, including changes in storm patterns, atmospheric variability, temperatures, and precipitation, these models generally do not provide parameterizations of ocean wind waves required for this study, necessitating the need to run large-scale (global to regional) wave models to generate time-series wave parameter metrics.

The spatial resolutions for available global climate models (~100 km) are too coarse to capture the small-scale coastal processes across the continental shelf and the nearshore environment. Furthermore, the wave and hydrodynamic models require projections of wind speed, wind direction, atmospheric pressure and sea ice, which are not available from existing downscaled products. Thus, the project team commissions a modeling study to consider which global models should be used and to dynamically downscale them to produce the needed atmospheric and oceanic inputs for the wave and hydrodynamic models at a spatial resolution of ~20-25 km. After balancing the need to characterize the range of future climate risks under different scenarios against the high computing costs for such dynamically downscaled studies, the BOEM team decides to select a subset of models to downscale. These models are selected based on how well they simulate historical wind, pressure, and sea ice observations.

They find, for example, that one model's historical simulations have larger errors in sea ice fields than what are found in observations, while another climate model's simulations produce wind speeds that are often higher than observed. While no single climate model performs best with all of these criteria, the BOEM research team is able to select 5 global-scale climate models to downscale for future projections. They make note in their study report that these same models may not best simulate future conditions – past performance does not guarantee future accuracy. The calibrated models are developed using historical observations, then applied for the future period (2030-2060) to develop time series of wave and hydrodynamic conditions and their effect on shoreline change rates and sediment transport patterns over the study region.

Ideally, the impacts of climate change under a range of projected emissions scenarios would be considered in this study. However, dynamical downscaling (even with only 5 climate models) has high computational cost, and thus only a higher emissions scenario (SSP5-8.5) is explored (Workflow **Step 6: Consider Future Scenarios**). This is noted in the study report with the associated limits on interpreting the potential risks and a suggestion that future studies should consider other scenarios as resources are available.

The downscaling study produces large amounts of data (several Terabytes) that are used to drive the wave and hydrodynamic models BOEM uses to assess future impacts to the proposed wind and oil projects. Historical and projected future wave heights are calculated using the wave model. The projected period (2030-2060) was calculated for a model ensemble consisting of CMIP6 output from five selected climate models under a single higher emissions scenario (SSP5-8.5). The time series were reconstructed for each ensemble member and wave statistics were calculated separately for each model ensemble member

Future wave heights are projected to be slightly greater in Misty Rock Bay compared to the past (1979 – 2019) (Workflow **Step 7: Analyze Consequences**). While differences for the mean wave heights appear to be small, the difference for the 95th percentile reaches roughly 15 cm, primarily in areas inshore of the barrier islands (Figure 4.6.1). The differences for the 99.5th percentile reach ~25 cm and are more evenly distributed across Misty Rock Bay than for the 95th percentiles. The difference can partially be attributed to differences in the wind pattern between hindcast and projections, specifically more wind coming from a southerly direction for the projections. However, the continued reduction in sea ice cover is found to be the primary cause for the differences. The longer ice-free season allows for more frequent and stronger autumn storms that generate higher extreme wave heights.

Sediment transport patterns within Misty Rock Bay were modeled with the coupled wave hydrodynamic-sediment transport model. The model was run with representative sea states to assess the sediment transport potentials for the entirety of the 40-yr hindcast and 30-yr projection time periods. Under the single higher emissions scenario (SSP5-8.5), BOEM finds that sediment mobility increases to 30% for the 30-year future period (2030-2060) compared to 15% of the time during the 40-year historical period

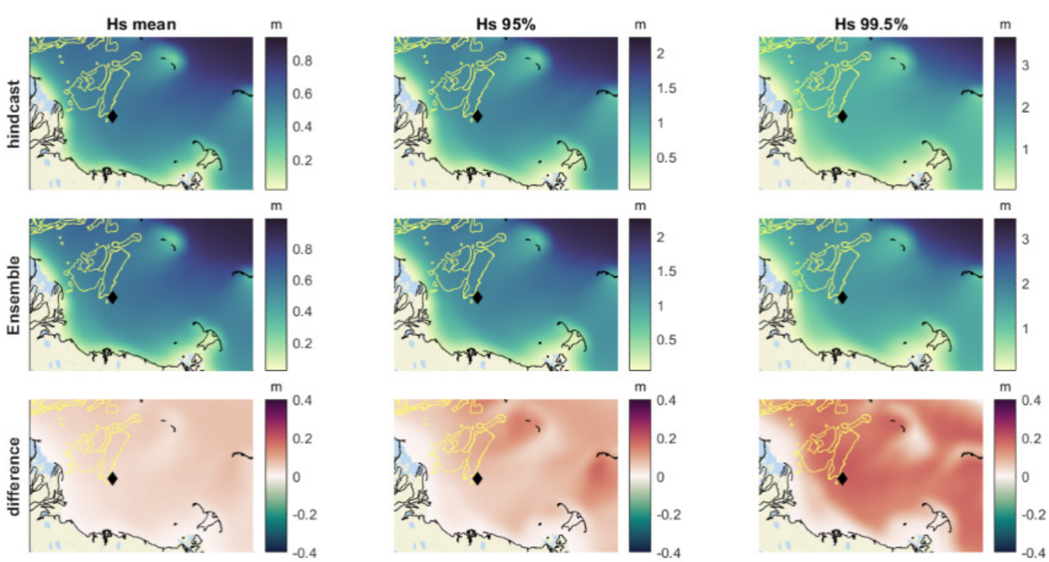


Figure 4.6.1: Mapped wave heights for mean, 95th, and 99.5th percentile for hindcast (1979-2019 historical) simulation, model ensemble projected (2030-2060) simulations, and the differences within the fictional Misty Rock Bay.

(1979-2019). An analysis among the climate models shows significant inter-model variability, but that three of the five climate models consistently indicate large changes in sediment transport magnitudes compared to the hindcast.

Results from this study provide BOEM with information regarding the projected changes in oceanographic conditions within the nearshore region of Misty Rock Bay under a single higher emissions scenario (SSP5-8.5). These results are used to refine requirements for both the pending permits and design of future environmental impact studies for the region.

4.7 NPS Resource Stewardship Strategy

The fictional Roaming Bison National Park (RBNP) was established to preserve a landscape central to North America's history. This park supports mixed-grass prairie, ponderosa pine, and riparian plant communities and contains one of the most intact prairie wildlife communities in North America, including genetically diverse, brucellosis-free American bison. It is considered a sacred site for many Indigenous communities and continues to be the center of cultural and spiritual activity of affiliated Tribal Nations.

RBNP is completing a Resource Stewardship Strategy (RSS), an integrated planning process to set short- and long-term goals and objectives for natural and cultural resource stewardship, and to identify activities (i.e., management strategies) to achieve and maintain desired conditions. Priority resources that the RSS will focus on include (**Workflow** **Step 1: Frame the Decision Context**):

- aquatic resources,
- vegetation (including the forest/prairie complex, riparian vegetation, and plants of Tribal collection interest),
- archaeological resources, and
- wildlife (including bison and black-footed ferret).

To support developing climate-informed resource objectives and management strategies, the park is conducting a scenario-based impact assessment grounded in climate projections, application of expert opinion, and synthesis of existing science (Miller et al. 2022) to inform the RSS development. All decisions involve RoAs that are within park boundaries; however, coordination with other partners and organizations when developing and conducting the climate analysis is still necessary to understand other potential resource responses and adaptation options to climate change. In particular, and in accordance with 301 DM 7, coordination with affected Tribal Nations is particularly important in recognizing the goals of the 2014-2015 Buffalo Treaty and the immense importance of the American Buffalo to Indigenous peoples (**Workflow** **Step 2: Determine Coordination Needs**).

The project team believes all priority resources are impacted by climate change, but their individual climate sensitivities need to be quantified (**Workflow** **Step 3: Assess Sensitivity**). The team meets with park staff, resource subject-matter experts (SMEs), and tribal representatives, where together they describe: 1) How climate extremes affected resources in the past, and 2) Future concerns about resources. From this meeting, they derive a long list of metrics that characterize climate sensitivity in the park. For example, erosion from extreme precipitation negatively impacts archaeological resources, soil stability around historic structures, and development of ephemeral springs (**Workflow** **Step 4: Describe Relationship with Climate**).

Additionally, the team assesses climate sensitivity of prairie and ponderosa pine forests by comparing historical normalized difference vegetation index (NDVI) to a water balance model that accounts for the interactive effects of climate, soils, and topography on water availablity for plants and ecosystems. The project leads assess annual gross primary production with NDVI derived from a time-series of 16-day maximum value composite, 250-m resolution MODIS images from 2000-2014 for areas in the park that had not burned recently and have minimal presence of invasive exotic species. They run a water balance model (Thoma et al. 2020, Tercek et al. 2021) for the same time period, using historical climate data as inputs, and fit a linear regression between soil moisture and climatic water deficit. Results show that park grasslands are sensitive to spring soil moisture, while ponderosa pine forests are responsive to climatic water deficit. From the list of climate sensitivities to all priority resources, the project leads work with participants to narrow the list to a subset that "poses the greatest risk for achieving conservation objectives" (Stein et al. 2014). They then identify corresponding climate metrics or key resource sensitivities: spring (March-June) soil moisture, maximum annual climatic water deficit , and extreme precipitation (days/year with >1 inch precipitation) – all climate changes that can be quantified (**Workflow Step 5: Assess Exposure**).

The project leads next explore which climate scenarios and models to use (**Workflow Step 6: Consider Future Scenarios**). An RSS is a medium-time length plan, to be updated every 10-20 years, so mid-century (2050) projections are used to inform the future analysis. Given the importance of characterizing extreme precipitation, daily projections are needed. MACAv2 CMIP5 projections are older data but still useful for exploring a range of climate futures and are available for 20 global climate models using medium- and high-emissions scenarios (RCP 4.5 and 8.5, totaling 40 projections). MACA uses a multi-variate, constructed analogs approach that incorporates larger regional patterns and dependence of climate metrics. This makes it a suitable dataset choice for use in areas with complex topography (like RBNP), for simulating extreme events, and for simulating realistic hydrological events. The latter consideration is important because all of the key resource sensitivities are related to hydrological processes.

The goal of this scenario-based impact assessment is not to predict the future, but to explore the variation in emissions and model uncertainty by selecting a small but representative subset of future climate states and developing their implications. Thus, project leads identify and develop three climate futures that together encompass wide divergence across the key resource sensitivities (as discussed in Section 2.3). Bracketing the range of plausible futures and related uncertainties allows managers to decrease risk of surprise (Figure 4.7.1; see Lawrence et al. 2021 for detailed description of model selection methods).

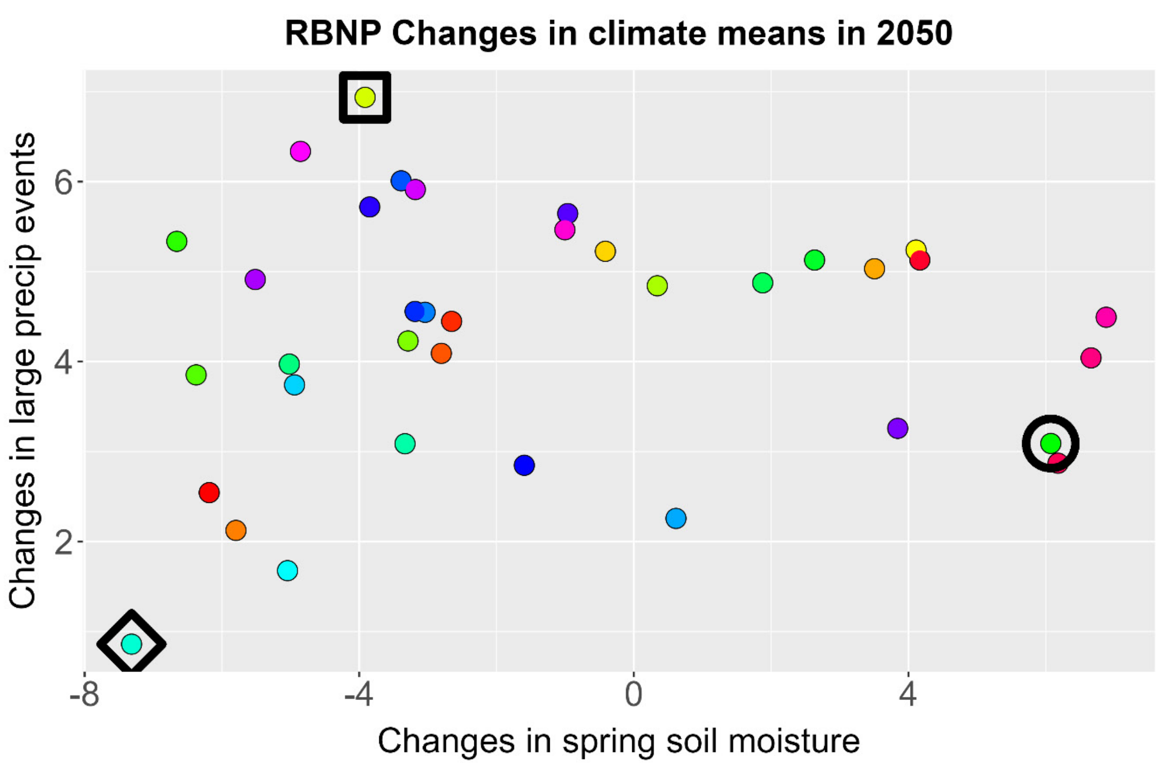


Figure 4.7.1. Projected changes for 40 CMIP5 MACAv2 models in spring soil moisture and large precipitation events across RCP4.5 and RCP 8.5 for the fictional RBNP. Climate future 1 (circle) is GFDL-ESM2G.rcp45; Climate future 2 (square) is CanESM2.rcp85; and Climate future 3 (diamond) is HadGEM2-CC365.rcp85. These are selected to cover the range of projected conditions to inform the RSS scenario planning process.

For each climate future, the project leads then characterize change in the climate-sensitive metrics identified in the first step for all priority resources (**Workflow** **Step 7: Analyze Consequences**). They synthesize the results and present them to the project team, where they identify how each priority resource would be affected by each climate future. The resulting resource implications (Table 4.7.1) are then used by park staff (with input from partners) to stress test desired resource goals and activities to determine their feasibility, given the future scenario. In this example, the goal of maintaining the historical forest-prairie boundary is not feasible in climate futures 2 or 3. From this information, park managers set new climate-informed resource stewardship goals that are robust to the future scenarios: to adaptively manage ponderosa forests and maintain examples of the culturally significant landscape. Designated adaptation activities to achieve this goal are to engage in targeted monitoring to understand change in ponderosa regeneration, update fire management plans, and prepare for mechanical thinning, if needed.

Table 4.7.1: Impacts to key ecosystem processes under selected climate futures for the fictional Roaming Bison National Park. Impacts are elicited from a fictional team of experts and community partners.

Resource: Ponderosa pine forest	Climate future 1 implications	Climate future 2 implications	Climate future 3 implications
Forest regeneration	Potential increase in forest regeneration	Lower regeneration rates of ponderosa pine due to decline in spring moisture availability	Significantly reduced regeneration of ponderosa pine due to decline in spring moisture availability
Forest/prairie boundary	Forest expansion into prairie (if prescribed fires becomes more difficult to implement)	Prairie expansion into forest; potential erosion issues around pine bluffs, affecting archaeological resources.	Prairie expansion into forest
Forest extent and density	If potential increase in regeneration balances increased mortality, **forest will persist largely as is or could even increase** in extent if prescribed fire does not keep up with expansion into grasslands.	Increased fire risk and greater mortality from other causes, combined with lower regeneration, cause slow (or very fast, if catastrophic fire) **decline** in forest extent and density.	Increased fire risk and greater mortality from other causes, combined with lower regeneration, cause slow (or very fast, if catastrophic fire) **decline** in forest extent and density.

4.8 NPS Facility Rehabilitation

The National Park Service (NPS) is rehabilitating employee housing at the fictional Beautiful Coastal National Park (BCNP) on the Gulf of Mexico to address deferred maintenance (**Workflow Step 1: Frame the Decision Context**). The park is located on a strip of beach (an area with known climate risks) and the existing employee housing has had flooding issues and wind damage from hurricanes in the past (**Workflow Step 3: Assess Sensitivity**). To ensure that facility investments are financially, operationally, and environmentally sustainable, NPS Facility Investment Strategy requires park staff to identify climate hazard-related deficiencies and impacts for all proposed capital projects from initial phases of the capital investment process (CIP).

To inform the first phase of the CIP (the Investment Concept phase), park staff engage with subject-matter experts to complete the NPS Climate Change and Natural Hazards Level 3 handbook, in accordance with NPS policy memo 15-01. This handbook is a screening tool to be used prior to approval of project scoping funding to help teams determine potential climate change effects and natural hazards to a proposed facility investment.

The first step in the handbook is to complete a checklist of 27 hazards (e.g., sea-level rise, flash flood, drought, pest infestation, etc.) where park staff or other subject-matter experts consider whether it is a "known", "potential", or "not applicable" hazard (**Workflow Step 3: Assess Sensitivity** and **Step 4: Describe Relationship with Climate; Figure 4.8.1**). If the area has been impacted by the hazard in the past or it is determined that the area or asset could be impacted by the potential hazard in the future (considering the full lifespan of the proposed investment) it is considered to be a "known hazard." If the hazard has not occurred but is known to occur in this geologic setting or other assessments consider it to be probable, "potential hazard" should be selected. If none of these apply, "not applicable" should be selected.

Park staff use the historical climate to identify that the portion of the beach where the facility is located has already experienced impacts due to extreme precipitation, hurricanes, coastal storm surge, tornadoes, and coastal erosion - these hazards are marked as 'known hazards'. Review of NCA5 and NOAA State Climate Summaries indicated that sea level change, changing humidity patterns, and

Hazard	Examples of Risk or Secondary Hazard	Best Professional Judgment	Information Source(s) Used
Sea Level Change	• Inundation. • Shoreline erosion. • Destruction of infrastructure, e.g., through saturation. • Water quality effects. • Water supply diminished.	☐ Known hazard ☐ Potential hazard ☐ Not applicable	*Projections:* ☐ NOAA: Sea Level Rise Viewer ☐ NASA: Interagency Sea Level Rise Scenario Tool ☐ Other: ________
Coastal Storm Surge	• Wind driven rising water, e.g., hurricane, nor'easter.	☐ Known hazard ☐ Potential hazard ☐ Not applicable	*Projections:* ☐ NPS: Sea level rise and storm surge projection ☐ NOAA: SLOSH *Historical data:* ☐ FEMA: National Flood Hazard Layer ☐ Other: ________
Coastal Erosion	• Destruction of infrastructure. • Unstable shoreline.	☐ Known hazard ☐ Potential hazard ☐ Not applicable	*Historical data:* ☐ USGS: Coastal Change Hazards Portal ☐ NOAA Digital Coast Tools Other: ________
Flash Flood	• Sudden rising water, e.g., in a dry wash or canyon. • Loss of life due to unexpected flooding. • Destruction of infrastructure, e.g., through impact or saturation. • Reduced or precluded visitation. • Power failure due to areawide power outages.	☐ Known hazard ☐ Potential hazard ☐ Not applicable	*Projections:* ☐ May require a site flood study ☐ Climate Toolbox: Climate Mapper (for Western US) *Historical data:* ☐ FEMA: National Flood Hazard Layer ☐ Other: ________

Figure 4.8.1. Example of Climate Change and Natural Hazards Checklist

increasing very hot days were "potential hazards" for this region (Workflow **Step 4: Describe Relationship with Climate** and **Step 5: Assess Exposure).**

The next step in the handbook is to complete a risk assessment for "known" or "potential" hazards or implications identified previously that can be used to identify appropriate project adaptations to minimize or mitigate the risks (and ultimately determine whether the investments are sustainable and whether the cost to mitigate risk is financially feasible). Because the rehabilitation will be a large capital investment with an anticipated 40-year lifespan, park staff consider both intermediate- and upper-bound projections for hazards to understand the potential for high-impact outcomes (Workflow **Step 6: Consider Future Scenarios**).

Park staff use the NOAA sea level rise viewer (see Section 2.3.3) to map local scenarios and visualize areas of the beach at risk to coastal flooding in 2060 to account for the anticipated 40-year lifespan of the housing facility (with construction expected to begin in 2026) (Workflow **Step 7: Analyze Consequences**). They determine that in 2060, a 1.4 feet increase in ocean levels is projected under an the Interagency SLR Intermediate Scenario and 2.2 feet is projected in the High Scenario, both falling under the minimum three foot elevation that serves as the Federal Flood Risk Management Standard for critical assets. With this information, park managers work with contractors to amend the design to mitigate coastal flooding risks.

The team assessed extreme precipitation and changing humidity patterns using ClimateToolbox.org by looking at change in humidity, seasonal precipitation, and runoff anomalies for late-century (2070-2099) for both intermediate and high emissions scenarios (RCP 4.5 and RCP 8.5) (Workflow **Step 6: Consider Future Scenarios**). They selected ClimateToolbox.org for its ability to show relatively fine spatial (4km/25mi) resolution data useful for local-scale assessments and daily data to assess extreme events. They used the future boxplots tool for both scenarios to get a sense of the range of uncertainty among the projections. While precipitation is highly uncertain, runoff and maximum relative humidity are projected to decrease under both scenarios. The project leads use the same tools to assess increasing very hot days by looking at both change in summer maximum temperatures and days with heat index > 100°F. Heat index is a measure of human heat stress from current conditions and, while not appropriate for all ecological applications, in this application it usefully informs sizing HVAC systems. All projections show increasing very hot days (Workflow **Step 7: Analyze Consequences**). This information is passed to the project design team. While future risks from hurricanes and tornadoes are almost impossible to assess from global climate projections, other scientific assessments suggest these will increase in frequency and/or severity (USGCRP 2023). Thus, it is assumed the risk will continue, so the building design should manage risk appropriately.

With this information, park managers can work with the project team to modify the existing proposal to mitigate potential climate impacts or hazards.

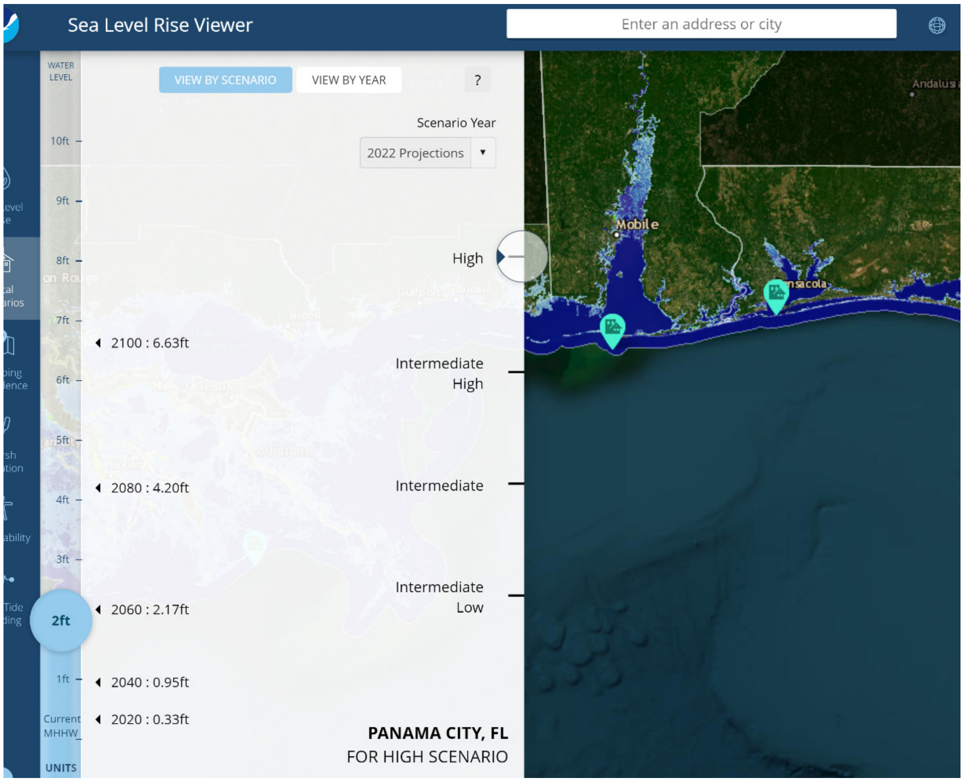


Figure 4.8.2. NOAA Sea Level Rise Viewer Scenarios Tool.

4.9 Multiple Bureau Example: Raising the height of a dam in the western US

The BoR is considering whether to raise a fictional dam in the western US. A higher dam would provide for additional water storage and provide additional capacity for flood risk management. However, that additional storage would also periodically inundate upstream federal land interests (e.g., public access and recreation sites) managed by the BLM and NPS, as well as critical habitat for an iconic endangered species monitored by the FWS, the fictional Sage-Crested Jumping Lizard.

Increased inundation would affect land interests managed by BLM and NPS, and reproductive success of the fictional Sage-Crested Jumping Lizard, possibly leading to extinction. The Secretary of the Interior must decide whether to raise the dam, and how high given the costs and both positive and negative impacts (Workflow **Step 1: Frame the Decision Context**).

Understanding the possible impacts of future climate will help BoR, BLM, NPS, and FWS provide the needed information to inform the Secretary's decision. Management of the existing dam is highly sensitive to weather and seasonal climate variations. With a taller dam, the reservoir will be able to store additional water produced during heavier precipitation events and provide increased water supply during dry periods. Seasons with higher flow input will also inundate critical habitat more frequently. The reservoir is a long-lived asset expected to operate for more than 100 years with this taller dam. The species affected has a shorter life span of 10-12 years, but its reproductive success is highly dependent on the vegetation and forage found only in the upper reaches just above the current reservoir's maximum water level.

This decision involves four bureaus: BoR, BLM, NPS, and FWS. BoR is responsible for managing the water supply for this basin, BLM and NPS are responsible for the land interests, and FWS is responsible for administering the Endangered Species Act. Thus, it is critical for the bureaus to coordinate their analyses to ensure the results are comparable. For this decision, the BoR study lead, BLM and NPS land management leads, and the FWS at-risk species lead meet to understand which specific climate metrics are going to be used to explore impacts to this reservoir and the lands affected (Workflow **Step 2: Determine Coordination Needs**).

They decide that frequency and depth of inundation in the areas that could be affected are the most important metrics, but FWS is also interested in understanding how future temperature and precipitation extremes may affect forage conditions in the critical habitat (Workflow **Step 3: Assess Sensitivity**). To explore the impacts of climate, they will use two models: a coupled hydrology-reservoir operations model that BoR has used previously and a vegetation model that FWS has used for forage health in a different location (Workflow **Step 4: Describe Relationship with Climate**). These models have the following qualities and needs:

- The reservoir operations model has been shown to perform well in simulating water level changes in the past and the errors are well understood. It is important to understand the reservoir operations model's strengths and limitations to interpret uncertainties from simulations of future conditions as only changes that exceed the model error are meaningful for considerations for how the dam might operate under future climates.
- The combined hydrological and reservoir operations model (hydrology model) requires extensive environmental data to properly simulate local conditions, including daily inputs of air temperature, precipitation (liquid and frozen), incoming solar radiation, humidity, plus annual inputs for elevation (for slope, aspect), land cover, and soils (for infiltration and groundwater).
- The forage health model is simpler and only requires information on soils, monthly precipitation, monthly average air temperature, and the temperature of the hottest and coldest months.
- The forage model has not been tested in this location. The study leads decide that existing elevation and soils are assumed to not change into the future. While none of the watershed area above the reservoir has any urban development (and no urbanization is anticipated), the study leads question whether land use can be assumed to remain constant since climate change has been shown to affect vegetation structure. In this case, they decide that they can also allow for unchanging land cover in the hydrology model since there was a previous study for this reservoir that simulated land cover variations and showed these variations don't have much effect on the water levels in the reservoir. However, FWS is

interested in how vegetation consumed by the endangered species will be affected. They decide land cover can be held constant in the hydrology model and specifically note that assumption in their report and the basis for the decision. For the FWS forage health model, FWS scientists will need to compile data from the critical habitat zone on the food source for this species and confirm that the model can adequately simulate past variations in forage supply and health.

The study leads next look to explore which climate scenarios and models to use (Workflow **Step 5: Assess Exposure**). As they look at the model requirements for climate data inputs, it becomes clear that there isn't an ideal dataset. Given the life span of the dam, they want to explore potential climate impacts through 2100. The watershed is in a region with spatially variable temperatures, complex topography, snowpack as an important water input along with warm season rainfall, and complex cloud and incoming radiation patterns depend on seasonal winds. Study leads must decide which of the following data best meets all the study needs:

1. A new set of downscaled daily high-resolution projections based on 33 CMIP6 global models was published using three emissions scenarios (SSP1-2.6, SSP2-4.5, SSP5-8.5), but that study only includes average temperature and does not include any downscaled estimates of incoming solar radiation or humidity.
2. Another study using 31 CMIP6 global models provides estimates of these climate metrics plus snowpack for five emissions scenarios (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5), but only on a monthly timestep.
3. An older study using 20 CMIP5 projections provides daily estimates of total precipitation (liquid and frozen), temperature, incoming solar radiation, and humidity but only for two scenarios: RCP 4.5 and RCP 8.5.

All three downscaling studies have data for a common baseline period of 1981-2010 and provide projections to the year 2100.

The study leads also considered contracting for a new downscaling study but found those costs to exceed the available budget. Based on guidance from the modeling experts, the study leads decide that its more important for the hydrology model to have daily climate inputs than to have monthly inputs with snow or the most recent CMIP models. They are most interested in sub-monthly precipitation extremes and accurate measures of potential evapotranspiration that might impact reservoir operations and the inundation of critical habitat, and only the older CMIP5 study provides the critical model inputs to adequately simulate inflow and evapotranspiration (Option 3). They recognize that while the CMIP5 projections are older, they are still useful to explore a range of potential future climates. They decide they want to understand how the impacts may vary both in the next 30 years and for the 30 years at the end of the century so that they can more clearly distinguish the role that emissions scenarios play in the projected impacts. These choices, and the basis for them are included in the study report (Workflow **Step 6: Consider Future Scenarios**).

Now that the BoR, BLM, NPS, and FWS study leads have agreed on the data, they go back to work on individual modeling simulations using the following steps (Workflow **Step 7: Analyze Consequences**):

1. BoR uses the 20 downscaled CMIP5 climate models as input for the reservoir model and simulates conditions over the baseline period (1981-2010) with the current dam height.
2. BoR then summarizes the statistics of *simulated* daily water levels and inflow across all the models for each calendar month. These are then compared with the historical water levels and inflows that were observed from 1981-2010. This provides BoR with a sense of how accurate the simulation is for these conditions.
3. BoR modifies the model to raise the height of the dam to the new proposed level, and then inputs the 20 downscaled climate projections from 2031-2060 and 2071-2100 into the reservoir simulation with current reservoir management rules included (but adjusted for the new dam height). All 20 downscaled projections are used because the reservoir model is very complex and has many non-linear equations, which make it difficult to a priori decide which of the climate models would produce the widest envelope of simulated reservoir conditions.
4. Model outputs for daily water levels and inflow are then summarized for both 30-year periods by calendar month and compared with the simulated baseline summaries. By comparing model projections with the baseline, the bias associated with any structural model errors is reduced, and BoR can more easily assess the impacts of climate change on the reservoir.
5. The projected changes in reservoir water levels, inflow, and frequency of inundation to critical habitat are summarized, along with the study

design, assumptions, and uncertainties.

Meanwhile, FWS is working to understand how climate change may affect forage health (**Workflow Step 7: Analyze Consequences**). The forage model FWS is using has only been applied to a location >1,000 miles from this study and so FWS is unsure if it will also work for the critical habitat for this species. Because this species has been endangered for 35 years, there is extensive data about its critical habitat. Data from 20 years of observations of weather, soils, and forage are used to calibrate the forage model, which FWS uses to simulate forage health over the most recent 15 years. FWS confirms the model is adequate, and then follows the steps similar to BoR: 1) use the simulated baseline climate projections for all 20 downscaled CMIP5 models for 1981-2010; 2) compared baseline output with historical observations to characterize errors; 3) use projected future climate for 20 downscaled CMIP5 models for 2031-2060 and 2071-2100 to estimate impacts to forage for the nearer and more-distant future; 4) compare projections to baseline to estimate the impacts of changing climate with any systemic bias removed. The projected changes to forage abundance and health, and the expected impacts to species viability, are summarized along with the study design, assumptions, and uncertainties.

With each bureau-specific study completed, the BoR and FWS study leads gather to compare results. The FWS study on future forage conditions suggests extreme heat and drier soils will negatively affect forage abundance and quality, but under the current recovery rate of the species it should be adequate to prevent extinction as the forage appears to persist but moves further upslope. However, FWS notes that during a few extreme events simulated with 40% of the models under RCP 8.5, forage may disappear for an entire summer, which may reduce population to more critical levels. FWS concludes that due to projected changes in forage condition alone, extinction is possible but not likely under these simulated conditions.

BoR reservoir studies show that with the proposed taller dam, available water storage supply based on setting a new target water level will be increased by 19%-24% under RCP 4.5 and 15%-20% under RCP 8.5 as precipitation intensity is projected to increase overall, but increased temperatures (and the associated evapotranspiration) increase water loss especially under RCP 8.5. With the new target water level for water storage, 14% of the current critical habitat would be permanently inundated.

The variability of reservoir water levels also increases due to projected increasing hydrologic variability. The projections show periods with more intense precipitation and runoff stored for both water supply and flood control pools, but also more periods with lower precipitation and runoff. Critical habitat may be inundated more frequently during years with large snowpack and snowmelt. With the taller dam the current zone of critical habitat for the species will be entirely inundated during spring runoff in 30% of the years (model average) by 2100 under RCP 4.5 and in 5% of the years by 2100 under RCP 8.5. Warmer conditions under RCP 8.5 produce precipitation that more often falls as liquid rain and less snow, thus producing less snowpack in this basin and less frequent spring runoff that flood the critical habitat.

FWS concludes that under RCP4.5 there is substantial risk of adverse effects to this population of the species as repeated annual inundation of the critical habitat would prevent the species from recovering without additional aggressive management (such as relocation). FWS finds that inundation projected under RCP 8.5 would only minimally affect this population of the species.

Table 4.9.1: Summary of projected climate change by scenario.

Impact	RCP4.5	RCP8.5
Water supply	+19% (min) +22% (avg) +24% (max)	+15% (min) +18% (avg) +20%(max)
Forage	Loss but no adverse impacts to species	Loss in 30% of model summers will adversely impact species
Inundation of Habitat during spring flood storage periods by 2100	25% of years (min) 30% of years (avg) 33% of years (max) - Substantial adverse effects to population	0% of years (min) 5% of years (avg) 7% of year (max) - Minimal adverse effect to population

With common scenarios and data used for both sets of models, the Secretary of the Interior has comparable information to consider whether to raise the dam or consider other options such as relocation of species, modification of reservoir operations, or a reduced new height for the dam (these alternative options require additional studies using a similar coordinated approach). Ultimately, the final decision will be based on the perceived benefits, costs, legal requirements, and risk orientation of the Secretary of the Interior.

4.10 Multiple Bureau Example: DoD expansion affects BLM & NPS managed areas

The Department of Defense (DOD) plans to expand its training infrastructure at a fictional Air Force installation in a US desert. The best locations for expansion would affect adjacent land managed by BLM and NPS (Workflow **Step 1: Frame the Decision Context**). The topography of the area is generally flat, surrounded by high mountains 100 miles away. BLM is most concerned with how installation expansion will impact recreation at a very popular adjacent off-highway vehicle (OHV) open use area, famous for a nationally recognized, annual OHV race event. NPS is most concerned with how the proposed new infrastructure will affect noise pollution and air quality for park visitors. Importantly, this land is also habitat for a fictional tortoise that is listed as Endangered under the Endangered Species Act and has a recovery plan in place. The tortoise species typically lives 60+ years and is endangered due mostly to habitat loss and roadway death from moving vehicles. As part of the consultation between Interior and Defense, agencies want to understand how a changing climate may also affect the future of this habitat and the viability of this tortoise (Workflow **Step 3: Assess Sensitivity**).

BLM is concerned about how future climate will contribute to conditions that reduce OHV recreation opportunities, as climate change is associated with increasing storm event severities resulting in severe flash flooding that severely damages recreational access roads and sites. Specifically, BLM has identified a threshold where severe damage occurs to sites of interest with daily rainfall of 2 inches. NPS, concerned about how future climate may worsen air quality associated with pollution from increased aircraft and training traffic, uses an air quality model to predict changes in visibility and air quality based on particulates, air chemistry, and atmospheric conditions – specifically changes in humidity, wind, and turbulence in the lowest 10 km (6.2 mi) of the atmosphere. FWS (responsible for management of Threatened and Endangered species) has determined that this tortoise's survival is dependent on healthy habitat and uses a species population model to describe how changes in annual temperature and precipitation patterns affects habitat – changes closely related to variations in annual total precipitation and extreme maximum temperatures (temperature on the hottest day of the year) (For each bureau, these are part of Workflow **Step 4: Describe Relationship with Climate**).

Because of the complexity of the individual bureau responsibilities, a joint study team is established with experts from DoD, BLM, NPS, and FWS (Workflow **Step 2: Determine Coordination Needs**). Since the Interior bureaus each have design requirements and reliable models (based on past studies), they decide that they have sufficient existing data and understanding of their systems to reasonably explore the risks from future climate conditions. The bureaus, with DoD agreement, decide they should explore at least two future emissions scenarios, including one that captures the upper bounds of plausible warming (Workflow **Step 6: Consider Future Scenarios**). Each Interior bureau has different needs from climate model projections. For its air quality model, NPS needs data on future turbulence and wind conditions not just at the surface but through the lowest 3 km (1.7 mi) of the atmosphere. BLM needs projections of extreme rainfall conditions, while FWS needs annual precipitation and maximum temperature on the hottest days of the year. For stormwater designs and the habitat model, BLM and FWS would like high spatial resolution projections to see how local precipitation patterns may shift, especially under a changing summer monsoon. Because the tortoise is long-lived, FWS wants projections as far into the future as possible but will settle for projections through the end of the 21st century.

The joint study team considers several data requirements as summarized in the table below:

- NPS's requirements mean they must use dynamically downscaled climate model projections as none of the statistically downscaled projections include estimates of humidity, turbulence, and winds above ground level. They decide they can use the most recent set of projections produced by the US Environmental Protection Agency (EPA) for air quality simulations. These projections include all of the hourly atmospheric dynamics needed to run the NPS air quality model based on CMIP6 global models, but only for SSP5-8.5 using 10 global climate models through 2100. These projections are only available with spatial resolution of 50km.
- For BLM and FWS, 50 km (31mi) spatial resolution is too coarse to capture the possible climate impacts to local soils and habitat. BLM and FWS want to use the newest LOCA2 statistically downscaled CMIP6 projections which provide 6 km spatial resolution for SSP2-4.5, SSP3-7.0, and SSP5-8.5. LOCA2 provides statistically downscaled daily minimum temperature, maximum temperature, and precipitation for 27 global climate models out to year 2100.
- After much discussion, the BLM, NPS, and FWS decide that their individual ideal analyses will not be comparable, and so must compromise. They decide that since NPS's data requirements are the least flexible, and that CMIP5 projections are still useful for exploring climate impacts to these resources, they will collectively use the CMIP5 projections from the 10 global models available for NPS. However, BLM and FWS will use the newest LOCA2 statistically downscaled projections for these 10 global models so they can take advantage of higher spatial resolution and explore SSP5-8.5.

While all three bureaus will not be using identical data, they are using common global climate models and emissions scenarios. While this compromise to use different datasets is not ideal, each bureau is still able to proceed with mission-relevant analysis and meaningfully compare results. Furthermore, NPS's climate variables of interest do not overlap with BLM and FWS. NPS, BLM and FWS consider contracting for further dynamical downscaling using the EPA dataset to scale down to 6 km spatial resolution, but quickly determine the costs in time and money to develop such a dataset would be prohibitive. In particular, the Interior bureaus are under a time pressure to determine impacts to its resources within a few months.

Given the time pressure, the Interior bureaus decide to further simplify their analysis process. Instead of doing model simulations with 10 models, they begin by using the wettest, driest, warmest, and coldest climate models. The basis for this choice is that, for BLM and FWS, this will adequately characterize the risks to the tortoise and future stormwater. NPS is reluctant, as their air quality model is much more complex with many non-linear responses in atmospheric chemistry – it would be very difficult to determine in advance which four models would adequately capture the range of future climate

Table 4.10.1. Attributes of climate projection data selected for analysis.

Bureau / Data	Variables	Spatial Resolution	Climate Scenarios	Number of Climate Models
NPS / EPA dynamic downscaling	Hourly atmospheric humidity at 10 levels between surface and 500 mb pressure level Hourly air temperature at 10 levels between surface and 500 mb pressure level Hourly winds at 10 levels between surface and 500 millibar pressure Hourly turbulent kinetic energy	50 km	SSP5-8.5	10
BLM, FWS / LOCA2 statistical downscaling	Daily temperatures Daily precipitation	6 km	SSP2-4.5, SSP3-7.0, SSP5-8.5	27 (10 common with above)

impacts to visibility and air quality. However, NPS agrees this is a reasonable way to prioritize their simulations, and they plan to perform simulations with additional global model inputs as time allows.

The DOI bureaus borrow from the NPS scenario planning approach (see NPS RSS example or Lawrence et al. 2021 for details) and analyze critical climate metrics from each LOCA2 downscaled climate model over the periods 2031-2060, 2051-2080, and 2071-2100. For each period and each of the 10 models, they plot:

1. wettest annual precipitation,
2. driest annual precipitation,
3. wettest 1 day precipitation,
4. coldest minimum daily temperature.

From these plots, they select the models that capture the broadest range for all of these conditions. Four of the models selected capture the annual warmest, annual wettest, annual driest, and coldest conditions across all three time periods. By adding a 5th climate model, they can also capture the wettest single day model.

As a compromise, all Interior bureaus decide to use these 5 climate models for their individual impacts modeling. This provides five climate futures for a single climate emissions scenario, but a higher risk one. NPS uses the dynamically downscaled projections from these models from US EPA, while BLM and FWS use the LOCA2 statistically downscaled projections. The joint study team compares the selected dataset to ensure consistency of the projections. All three bureaus document the rationale for their choices and the assumptions and caveats associated with concurrence from their DoD partner.

Each bureau follows a similar analysis process (**Workflow Step 7: Analyze Consequences**):

1. Climate variables from each of the five downscaled models' baseline periods are used as inputs to each bureau's resource impact model with simulations over a historical baseline period of 1981-2010. These results are compared with observations for this period to assess the model's error.
2. Those same climate variables for the future projections are input into the impact models for the period 2030-2100.
3. Results from the impact models are then summarized over the three overlapping 30-year time periods (2031-2060, 2051-2080, and 2071-2100) and compared with the baseline period simulations to understand the relative changes from future climate conditions.
4. Summaries of the data include the mean changes and the ranges for each climate variables and impact metrics (habitat suitability area, visibility, air quality index, 25-year storm event, etc.).

Once each bureau has completed its individual analysis to their resources of interest, they reconvene with their DoD partners to share results:

- BLM finds that under this climate emissions scenario (RCP8.5), there are 1-day rainfall events that exceed the current stormwater design in 40% of total model years by 2060 and 60% of total model years by 2100, suggesting that any new roads would need larger culverts and a stormwater retention pond to prevent damaging erosion to other infrastructure.
- NPS's analysis took the longest, as the computing time for the air quality simulations is extensive and NPS had to bring in extra resources to complete simulations using all five climate models. NPS finds that visibility will almost certainly decrease during the monsoon season when humidity is higher as compared to current conditions; days with poor visibility increase by 10% across all models by 2060 and 37% by 2100.
- FWS finds that summer rains may increase across the region, supporting increased plant growth which may improve some habitat. As a result, FWS thinks that existing tortoises can be moved to other locations within the expanding habitat without risks from the proposed DoD installation expansion. However, there is extensive model spread in annual precipitation projections with some models showing small changes and others showing much larger changes. There is also the potential for increased fire risk due to rising temperatures and increased fuel-loading from increased plant growth that may include negative invasive species. Therefore, FWS would like to adjust the monitoring program to more closely measure how vegetation responds to local precipitation.

With these analyses, Interior and DoD can incorporate the impacts of climate change into discussions for ameliorating the impacts of possible expansion of the Air Force installation infrastructure.

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APPENDIX A: WEB-BASED CLIMATE TOOLS.

These are web resources that enable users to view future climate projections and associated information. The resources list is not comprehensive but is intended as a starting point for Departmental applications. Many tools exist beyond this list that may also be useful. Users should understand the strengths and limitations of how the tools present information **AND** the underlying datasets used. Additional information on climate data and tools for risk and impacts assessments can be found in OSTP (2023).

Tool	Geographies	Scenarios	Metrics	Ensemble or specific model	Temporal Resolution	Time Periods	Notes
AGCI User Guide to Climate Change Portals							Provides an overview of many climate change portals and uses of their products.
Climate Toolbox	CONUS ONLY Point locations, polygons, states, counties, or watersheds (HUC8)	RCP4.5, RCP8.5	Air temperature w/ thresholds, precipitation, evapotranspiration, soil moisture, total moisture, runoff, snow-water equivalent, drought indices, fire risk indices, heat and chill accumulation	Ensemble mean or one of 20 individual models	Annual, Seasonal, Monthly	2010-2039, 2040-2069, 2070-2099	Numerous tools relevant to many sectors with many derived metrics. Allows for point, area, custom area averages. Data available for download in netCDF, geoTIFF, ASCII, WMS, and csv. Figure download also available. Projections based on CMIP5-MACA2. CONUS only; Some tools only available for western US; Documentation on methods for derived metrics is limited Citation varies by tool: Hegewisch, K.C., Abatzoglou, J.T., Chegwidden,O., and Nijssen, B., ‘ Climate Mapper’ web tool. Climate Toolbox (https://climatetoolbox.org/)
USGS National Climate Change Viewer	CONUS ONLY National, States, Counties, Watersheds	RCP4.5, RCP8.5, SSP2-4.5, SSP3-7.0, SSP5-8.5 Global Warming Levels of 1.5°C, 2°C, 3°C	Air temperature, precipitation, evapotranspiration, runoff, soil storage	Ensemble mean, or one of 20 individual models, or all models for each GWL	Annual, Seasonal, Monthly	2025-2049, 2050-2074, 2075-2099	CMIP5 MACA plus Monthly Water Balance Model for hydrology; CMIP6 LOCA2 plus Monthly Water Balance Model for hydrology; Variety of geographic units (counties, states, watersheds). Downloadable reports for each unit (csv and PDF formats) CONUS only; No point estimates Provides information on model agreement (% of models) and statistical significance for projected changes. CMIP6 version provides individual models, weighted model means, and GWLs. Alder, J. R. and S. W. Hostetler, 2013. USGS National Climate Change Viewer. US Geological Survey https://doi.org/10.5066/F7W9575T
LLNL Green Data Oasis (GDO) Web Portal	CONUS plus portions of northern Mexico and southern Canada	RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5	Air temperature, precipitation, and hydrology variables (VIC)	Varies with Downscale method; general several dozen	Daily and Monthly	Varies, depends on downscaling method	Download tool that provides data access to several downscaled CMIP3 and CMIP5 climate AND hydrological projections, including BCSD, BCCA, and LOCA with VIC hydrology model. The training datasets for the downscaling methods can be accessed alongside simulations. Users can extract data from any of the dataset for the area and time period they are interested in. The tool will also calculate spatial and temporal statistics (mean and standard deviation) for the data in the selection. No graphical output – resource for accessing climate projection data across spatial scales.
Climate Mapping for Resilience and Adaptation	Counties, some data/thresholds at specific points	SSP2-4.5, SSP5-8.5	Air temperature w/ thresholds, precipitation w/ thresholds, heat and chill accumulation, coastal inundation	Weighted means of 32 model ensemble (CMIP 6 LOCA2 downscaled data)	Annual, seasonal, monthly	2015-2044, 2035-2064, 2070-2099	Maps and Charts based on LOCA2 Shows only ensemble mean but incudes graphics & tables with model spread. Map and chart figures available.
NCA5 Atlas	Counties	GWL 1.5C GWL 2.0C GWL 3.0C GWL 4.0C	Air temperature w/ thresholds, precipitation w/ thresholds	Global Warming Levels	Annual, seasonal, monthly	N/A	GWLs based on LOCA2 and STAR downscaled projections from CMIP6 Available for CONUS and AK, HI, PR

Tool	Geographies	Scenarios	Metrics	Ensemble or specific model	Temporal Resolution	Time Periods	Notes
NOAA Sea Level Rise Viewer	Relative SLR at points of interest (tide gauge sites); areas affected by sea level rise are displayed over a base map	Total sea level rise for 5 US Inter-agency Scenarios	Sea level rise (SLR; relative to Mean Higher High Water), marsh migration, SLR/flooding vulnerability, and high tide flooding.	Projections based on Interagency SLR scenarios	Based on user-selected amount of SLR or 5 time points (local scenarios)	2020, 2040, 2060, 2080, 2100 (for local scenarios)	Regional SLR rates from coordinated multi-agency report as input data, but only pre-defined SLR levels based on 1ft increments (connects to projections from 2017 and 2022 interagency reports.) Data download available as CSV for tide gauge sites and 1-degree grid AND as raster files. Based on simple bathtub model (doesn't include local sediment, vegetation dynamics), may not be locally useful. Simple marsh migration estimates, may not be locally useful. Projections are relative to 2000. Adjustable projections (user selects amount of SLR), some local scenarios but for relatively few locations. Legends are hidden but display when clicking an icon in the top right corner. National Oceanic and Atmospheric Administration, National Ocean Service, Office for Coastal Management, 2023. Sea Level Rise Viewer v3.0.0 [Online] https://coast.noaa.gov/slr/
NASA Flooding Analysis	US States and territories	5 US Inter-agency Scenarios	Sea level Rise, Flooding (inundation) days	Projections based on Interagency SLR scenarios	Annual, Decadal	1970-2100	Provides visual projections of SLR and tidal flooding with charts and tables. Uses newest interagency report for data input. Available for >90 sites, but not every coastal point NASA and University of Hawaii Sea Level Center, 2023. Flooding Days Projection Tool. [Online] https://sealevel.nasa.gov/flooding-days-projection
USACE Climate Hydrology Assessment Tool	CONUS HUC watersheds (4- or 8 digit) and stream segments	RCP4.5, RCP8.5	Streamflow, including some extremes based on VIC/mizuRoute, precipitation and temperatures	Mean of 32-model ensemble	Annual, monthly	1951-2099	CMIP5 LOCA1 climate projections with VIC hydrology. Based on LOCA1 – has known limitations in representing 1-day precipitation amounts. Includes a few extremes (1-day, 3-day flows and precip). Naturalized flows (ignores projects/reservoirs/impoundments/levees) Provides visuals with mouse-over numbers, trends, and metrics of statistical significance. Presents data for Water Years, not calendar years. U.S. Army Corps of Engineers. (28 January 2023). Climate Hydrology Assessment Tool (CHAT). Version 2.3. https://climate.sec.usace.army.mil/chat
Scenario Network for Alaska and Artic Planning's Climate Tools	Communities in Alaska and northwest and central Canada	RCP4.5, RCP6.0, RCP8.5 (depends on tool)	SNAP has a suite of tools that are hazard or feature-specific. Community climate charts (temperature and precip), precip projections for infrastructure, Northern Climate Reports	5-model ensemble	Monthly	2030-2039, 2060-2069, 2090-2099	Northern Climate Reports for Changing Arctic Ecosystems is especially useful for Departmental applications. Many different tools, including hydrology. Uses a simple Delta approach for projections. Some indicators use BCSD approach. University of Alaska Fairbanks, International Arctic Research Center, 2023: Scenarios Network for Alaska and Arctic Planning. [Available online at http://www.snap.uaf.edu/.]
Hawai'i Climate Data Portal	State of Hawaii	N/A Historical only	Rainfall, Evapotranspiration, Solar radiation, Temperature				Maps of historical trends by months and some ability to download timeseries data for limited historical period. See How to Cite – Hawai'i Climate Data Portal (hawaii.edu) for detailed recommended citation formats.
Integreated Climate and Land Use Scenarios (ICLUS)	CONUS	RCP4.5 - SSP2, RCP8.5 - SSP5	Various land use and population projections	GISS-E2-R or HadGEM2-ES	Decadal	2010-2100	Projects future population to drive land use change, considering average precipitation and temperature for summer and winter. The GIS tool enables users to run SERGoM with the population projections developed for the ICLUS project and allows users to modify the spatial allocation housing density across the landscape.

APPENDIX B: DATA RESOURCES FOR HISTORICAL AND FUTURE CLIMATE PROJECTIONS

The data resources provided are not intended as a comprehensive list but as a starting point for Departmental applications. CMIP5-based projections are included as relevant while CMIP6 products continue to be developed. Users should understand the strengths and limitations of any data as part of its use in Departmental applications.

Data	Description	Notes
UCAR Climate Data Guide	Curated expert insight on over 200 observational datasets and climate indices, searchable by variable & browsable.	Key strengths and limitations are included for each dataset. Historical only – projections are not included.

Data	Geographies	Scenarios	Metrics	Ensemble Size	Temporal Resolution	Time Periods	Spatial Resolution	Notes
CMIP6 LOCA2 Daily	CONUS	SSP2-4.5, SSP3-7.0, SSP5-8.5	Air temperature, Precipitation	27 models	Daily	1950-2100	~6 km	LOCA2 addresses limitation from LOCA1 by using different training data and time of observation adjustment. Used in NCA5. Pierce, D. W., D. R. Cayan, D. R. Feldman, and M. D. Risser, 2023: Future Increases in North American Extreme Precipitation in CMIP6 Downscaled with LOCA. J. Hydrometeor., 24, 951–975, https://doi.org/10.1175/JHM-D-22-0194.1
CMIP6 LOCA2 Thresholds & Extremes	CONUS	SSP2-4.5, SSP3-7.0, SSP5-8.5	40 metrics on air temperature, precipitation	27 models	Monthly, Annual metrics	1950-2100	~6km grid, counties, watershed	40 metrics of threshold counts and extremes for air temperature and precipitation derived from CMIP6 LOCA2. https://www.sciencebase.gov/catalog/item/65cd1ff2d34ef4b119cb3d07
CMIP5 MACAv2	CONUS	RCP4.5, RCP8.5	Air temperature, Precipitation	20 models	Daily	1979-2100	~6 km	Core dataset in ClimateToolbox.org. Large-scale analogs may not capture more local extremes. Abatzoglou J.T. and Brown T.J. A comparison of statistical downscaling methods suited for wildfire applications, International Journal of Climatology (2012), 32, 772-780
CMIP5 LOCA	CONUS	RCP4.5, RCP8.5	Air temperature, Precipitation, Specific humidity	32 models	Daily	1950-2100	~6 km	Used in NCA4, but LOCAv1 found to underestimate heavy precipitation and overestimate days with precipitation due to training dataset used. Pierce, D. W., D. R. Cayan, and B. L. Thrasher, 2014: Statistical Downscaling Using Localized Constructed Analogs (LOCA). J. Hydrometeor., 15, 2558–2585, https://doi.org/10.1175/JHM-D-14-0082.1
CMIP5 BCCA	CONUS	RCP2.6, RCP4.5, RCP6.0, RCP8.5	Air temperature, Precipitation	33 models	Daily	1950-2100	~6 km	This data is basis for LaFontaine et al 2023 Hydrological projections using PRMS. Large-scale analogs may not capture more local extremes. Reclamation, 2013. 'Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections: Release of Downscaled CMIP5 Climate Projections, Comparison with preceding Information, and Summary of User Needs', prepared by the U.S. Department of the Interior, Bureau of Reclamation, Technical Services Center, Denver, Colorado. 47pp
CMIP5 BCCA PRMS	CONUS	RCP2.6, RCP4.5, RCP6.0, RCP8.5	52 Hydrological metrics	13 models	Metrics for period averages, Daily flow data available	1950-2100	Stream reach, hydrological response unit (~ HUC12)	Simulates natural flows only without water control impoundments/reservoirs. Only CONUS-wide daily hydrological projections. LaFontaine, J.H., and Riley, J.W., 2023, Model Input and Output for Hydrologic Simulations for the Conterminous United States for Historical and Future Conditions Using the National Hydrologic Model Infrastructure (NHMI) and the Coupled Model Intercomparison Project Phase 5 (CMIP5), 1950 - 2100: U.S. Geological Survey data release, https://doi.org/10.5066/P9EBKREQ.
CMIP6 BCSD Daily	Global	SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5	Air temperature, Precipitation, Humidity, Incoming radiation, Winds	21 models	Daily	1950-2100	25 km	BCSD captures central tendencies but quantile mapping does not capture extremes. Referenced as NASA NEX-GDDP-CMIP6. Thrasher, B., Wang, W., Michaelis, A. et al. NASA Global Daily Downscaled Projections, CMIP6. Sci Data 9, 262 (2022). https://doi.org/10.1038/s41597-022-01393-4 Thrasher, B., Wang, W., Michaelis, A. Nemani, R. (2021). NEX-GDDP-CMIP6. NASA Center for Climate Simulation. https://doi.org/10.7917/OFSG3345

Data	Geographies	Scenarios	Metrics	Ensemble Size	Temporal Resolution	Time Periods	Spatial Resolution	Notes
CMIP5 BCSD Monthly	CONUS	RCP2.6, RCP4.5, RCP6.0, RCP8.5	Air temperature, Precipitation	33 models	Monthly	1950-2100	~1 km	BCSD captures central tendencies but not extremes. Referenced as NASA NEX-DCP30, LLNL/BoR. Thrasher, B., J. Xiong, W. Wang, F. Melton, A. Michaelis and R. Nemani (2013), Downscaled Climate Projections Suitable for Resource Management, Eos Trans. AGU, 94(37), 321.
CMIP5 BCSD Daily	Global	RCP4.5, RCP8.5	Air temperature, Precipitation	21 models	Daily	1950-2100	25 km	BCSD captures central tendencies but quantile mapping does not capture extremes. Referenced as NASA NEX-GDDP. Thrasher, B., Maurer, E. P., McKellar, C., & Duffy, P. B., 2012: Technical Note: Bias correcting climate model simulated daily temperature extremes with quantile mapping. Hydrology and Earth System Sciences, 16(9), 3309-3314
CMIP5 BCSD	Alaska, Hawaii	RCP4.5, RCP8.5	Air temperature, Precipitation	10 models	Monthly	1950-2099	AK: 12km, HI: 1 km	Statistical downscaling PLUS hydrological projections (VIC). BCSD captures central tendencies but quantile mapping does not capture extremes. Mizukami, N., A. J. Newman, A. W. Wood, E. D. Gutmann, and J. J. Hamman, 2022: 21st century hydrologic projections for Alaska and Hawai'i. Boulder, CO: UCAR/NCAR/RAL. doi: https://doi.org/10.5065/c3kn-2y77
SNAP (AK)	Alaska	RCP4.5, RCP6.0, RCP8.5	Air temperature, Precipitation	5 models	Monthly	2006-2100	2 km spatial	Uses a simple Delta downscaling method with limited ability to capture future climate variability. Walsh J.E., Bhatt U.S., Littell J. S., Leonawicz M., Lindgren M., Kurkowski T. A., Bieniek P. A., Gray S., & Rupp T. S. (2018). Downscaling of climate model output for Alaskan stakeholders, Environmental Modelling & Software, 110, 38–51. DOI 10.1016/j.envsoft.2018.03.021
ClimateNA	North America	SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5	Air temperature, Precipitation	Up to 13 models	Monthly	1961-2100	1 km	Uses a simple (delta) downscaling method with bias correction based with limited ability to capture future climate variability. Website provides ensemble averages and raw data for 8 models. Offline software has more functionality. Includes projections for US, Canada, Mexico. High spatial resolution due to interpolation, not more locally accurate data. Mahony, CR, Wang, T; Hamann, A and Cannon, AJ, 2022. A CMIP6 ensemble for downscaled monthly climate normals over North America. International Journal of Climatology 42 (11), 5871-5891 DOI: https://doi.org/10.1002/joc.7566
WorldClim	Global	SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5	Air temperature, Precipitation	23 models	Monthly	2021-2100	1 km	Uses a simple (delta) downscaling method - bias correction based only on ensemble mean with limited ability to capture future climate variability. Spatial resolution derived from interpolation, not more locally accurate data.
NA-CORDEX	Most of North America	RCP2.6, RCP4.5, RCP8.5	Air temperature, Precipitation, Air Pressure, Humidity, Winds, Radiation, Cloud cover, Snow, Runoff, Soil moisture, Evaporation	Up to 10 global models, up to 7 regional climate models	Daily (precipitation is sub-daily for some models)	2006-2100	50 km	Dynamically downscaled, many simulations include bias correction. Domain excludes northern AK, HI Mearns, L.O., et al., 2017: The NA-CORDEX dataset, version 1.0. NCAR Climate Data Gateway, Boulder CO, accessed [date], https://doi.org/10.5065/D6SJ1JCH
Inter-Agency SLR projection	Global, >90 tide gauge sites	Change in Global MSL by 2100: 1 ft, 1.6 ft, 3.3 ft, 4.9 ft, 6.6 ft	Regional sea level rise, extreme water levels	N/A	Decadal	2020-2150	>90 Tide gauge sites 100 km for extreme water levels	Latest coordinated effort by USG on sea level rise projections. Scenarios are related to CMIP6 but focus on changes to total GMSL by 2100. Sweet et al., 2022: Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines. NOAA Technical Report NOS 01. National Oceanic and Atmospheric Administration, National Ocean Service, Silver Spring, MD, 111 pp. https://oceanservice.noaa.gov/hazards/sealevelrise/noaa-nos-techrpt01-global-regional-SLR-scenarios-US.pdf
Pseudo Warming Projections for Hawaii	Hawaii	RCP 4.5, RCP8.5	Air temperature, precipitation	Ensemble means	Monthly	Obs 1990-2009 Future 2080-2100	250 m dynamical downscaling	Raw data available at: https://waihona.its.hawaii.edu/index.php/s/W6dDzXSe9rxKaA9 Zhang, C., Y. Wang, K. Hamilton, and A. Lauer, 2016: Dynamical Downscaling of the Climate for the Hawaiian Islands. Part II: Projection for the Late Twenty-First Century. J. Climate, 29, 8333–8354, https://doi.org/10.1175/JCLI-D-16-0038.1.

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APPENDIX C: TRAINING FOR DEVELOPING RELEVANT CLIMATE-RELATED SKILLS

The available trainings (as of 2024) provided are accessible to all Department personnel and are most relevant for developing the climate-related skills needed for applying of the technical guidance. They are not meant to equip someone with all the climate-related skills needed, but they can be used as a starting point for building competency or developing further proficiency. Additional trainings and learning resources can be found in the DOI Climate Change Training Inventory SharePoint.

Bureau	Title	Relevant topics covered	Target audience	Delivery Mode
DOI	Climate Change 101	Basic climate change science Impacts on DOI resources DOI responses to climate change	All DOI employees	Online, Self-paced
USFWS	Climate Academy	Basic climate change science Vulnerability assessments Decision support tools Adaptation planning tools	Natural resource and conservation professionals tasked with understanding climate change impacts and using this knowledge while making decisions	Online, Instructor-led
USGS	Managing for a Changing Climate	Basic climate change science Climate modeling Climate impacts and vulnerability	Natural and cultural resource managers	Online, Self-paced
NPS	Scenario Planning: An Introduction	Scenario planning	Park managers, planners, and others involved in long-term planning efforts	Online, Self-paced
USFWS	Fundamentals of Structured Decision Making	Decision analysis	Natural resource managers who need a high-level overview of structured decision making	Blended
USFWS	Introduction to Structured Decision Making	Decision analysis	Natural resource practitioners with experience in conservation, who need to apply these skills	In-person, Instructor-led
USFWS	Decision Analysis: Tools	Decision analysis	Decision support staff who want to improve their quantitative skills in decision analysis	In-person, Instructor-led
USFWS	Decision Analysis: Tools - Online	Decision analysis	Conservation professionals or those who want to improve their quantitative skills in decision analysis	Online, Instructor-led

GLOSSARY OF TERMS

The following terms and definitions are consistent with the U.S. Global Change Research Program (USGCRP) National Climate Assessment terminology.

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.

Adaptive management. Decision making that accounts for what is uncertain as well as what is known about the processes that influence natural resource behavior through time and the influence of management on resource changes. Adaptive management seeks to reduce this uncertainty and thereby improve management through enhanced understanding of management effects. Additional information about Interior's policies for adaptive management can be found in DOI 522 DM 1 (2023).

Downscaling. The process of using either empirical or numerical models to project climate information at a finer spatial scale based on the coarser spatial scale of the original climate model. Downscaling is often used in natural resource management applications because global-scale climate models are designed to capture global-scale or broad regional processes and usually do not operate at a fine enough spatial and temporal resolutions to simulate smaller scale features that drive local climate.

Climate Change. Changes in averages and variability of weather conditions that persist over multiple decades or longer. Climate change encompasses both increases and decreases in temperature, as well as shifts in precipitation, changing risk of certain types of severe weather events, and changes to other features of the climate system.

Climate Change 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. Departmental policy on climate change adaptation is provided in DOI 523 DM 1 (2023).

Climate Models. Mathematical models that simulate, either numerically or empirically, the physics, chemistry, and biology that influence the climate system.

Climate Projections. Results from global climate models characterizing future climate conditions under climate change scenarios.

Exposure. Change in climate conditions in the area of interest over the relevant time horizon.

Hazard. An act or phenomenon that has the potential to produce harm or other undesirable consequences to a person or thing.

High-Quality Information. For the purposes of this document, high-quality information is information that promotes reasoned, fact-based agency decisions. Information that meets the standards for objectivity, utility, and integrity as set forth in the Department's Information Quality Guidelines would qualify as high-quality information.

Indigenous Knowledge (IK). A body of observations, oral and written knowledge, innovations, practices, and beliefs developed by Indigenous Peoples through interaction and experience with the environment. It is applied to phenomena across biological, physical, social, cultural, and spiritual systems. IK can be developed over millennia, continues to develop, and includes understanding based on evidence acquired through direct contact with the environment and long-term experiences, as well as extensive observations, lessons, and skills passed from generation to generation. IK is owned by Indigenous Peoples and is often intrinsic within customary or traditional governance structures and decision-making processes. Other terms such as Traditional Knowledge(s), Traditional Ecological Knowledge, Tribal Ecological Knowledge, Native Science, Indigenous Science, and others, are sometimes used to describe this knowledge system. Department of the Interior has formal policy for consideration and inclusion of Indigenous Knowledge DOI 301 DM 7 (2023).

IPCC. Intergovernmental Panel on Climate Change was created in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP)to provide governments with scientific information that they can use to develop climate policies.

Linked decisions. Recurrent decisions that can be connected over space, time, or both. The decision at one location or in one time period influences the RoA in other locations or time periods, and therefore influences future decisions as well. These decisions can be formally solved as Markov decision processes.

Model Structure. The underlying components that are used to build a model. For climate models, this includes mathematical methods for simulating physical processes (the movement of energy and mass), methods for simulating chemical and biological processes, numerical methods for simulating these processes in sufficiently small spatial units (such a grids), and methods for estimating processes that occur at scales that are too small to explicitly resolve. These underlying components vary across different climate models and contribute to model uncertainty.

NEPA. National Environmental Policy Act (1970) requires federal agencies to assess the environmental effects of their proposed actions prior to making decisions.

Radiative forcing. The change in the net (downward minus upward) radiative flux (expressed in watts per square meter) at the tropopause or at the top of atmosphere due to a change in an external driver of climate change, such as a change in the concentration of carbon dioxide or in the output of the sun.

Risk. Uncertainty that includes the possibility of an adverse outcome with regards to management objectives, e.g., threats to life, health and safety, the environment, economic well-being, and other things of value. Risks are often evaluated in terms of how likely they are to occur (probability) and the damages that would result if they did happen (consequences).

Scenarios. Storylines based on assumptions used to help understand potential, plausible future conditions. For climate change scenarios, factors such as technological capabilities, societal choices, population growth, and land use are considered which can influence future climate conditions. Scenarios are neither predictions nor forecasts. Scenarios are commonly used for planning purposes.

Sensitivity. The extent to which something changes in response to external stimulations.

Simulations. Discrete attempts using climate models to replicate physical processes of the Earth system. Simulations of the future are called projections; simulations of the past are called hindcasts.

Uncertainty. An expression of the degree to which the future is unknown. Uncertainty about the future climate arises from the complexity of the climate system, the ability of models to represent it, and the inability to predict the decisions that society will make. There is also uncertainty about how climate change, in combination with other stressors, will affect people and natural systems.

USGCRP. U.S. Global Change Research Program was established by Congress in 1990 to coordinate federal research and investments in understanding and responding to the forces shaping the global environment, both human and natural, and their impacts on society

Vulnerability. In the climate context, the degree to which physical, biological, and socioeconomic systems are susceptible to and unable to cope with adverse impacts of climate change.