SOA Research Institute
SOCIETAL PURPOSE

An Introduction to Climate Change

Catastrophe and Climate

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Executive Summary

It is becoming increasingly clear that climate change, whether caused by natural or man-made processes, impacts our health, our life expectancy, our property, and our quality of life. This results in increased risk to insurers, bankers, investors, and other financial institutions. For some institutions, like property and casualty insurers, the risk may be immediate and catastrophic in nature as evidenced by recent events such as Hurricane Helene and the Los Angeles wildfires. For others, like life insurers, the risk may seem to be minimal. After all, the number of deaths attributable to these catastrophic events is a relatively small percentage of the overall mortality rate. Of course, this type of analysis ignores the impact of indirect deaths caused by factors such as air quality. Similarly, the nature of climate change is unpredictable. Today's risk is unlikely to be the risk a year from now or the risk for ten years from now. For example, in the 1980s, there were only three or four catastrophic events a year. In 2024, there were 27.[1]

As with any type of risk, it is incumbent on actuaries and other risk analysts to evaluate and, potentially, mitigate that risk as it applies to their organization and to their specific responsibilities. This requires both a qualitative analysis to identify the key risk factors and a quantitative analysis to measure the impact of a specific risk. Actuaries and other risk analysts already have basic risk management skills, but we need to know more about how it impacts our practice areas. In some cases, actuaries may also have to enhance their skill sets.

This article is the first in a series of articles designed to provide a starting point for those who are starting to incorporate climate change into their day-to-day work. For those who are already incorporating climate change into their day-to-day work, these articles may be a useful way to expand your understanding beyond just your practice area. This article will cover topics that apply across all practice areas; the remaining articles will be practice specific.

About Climate Change

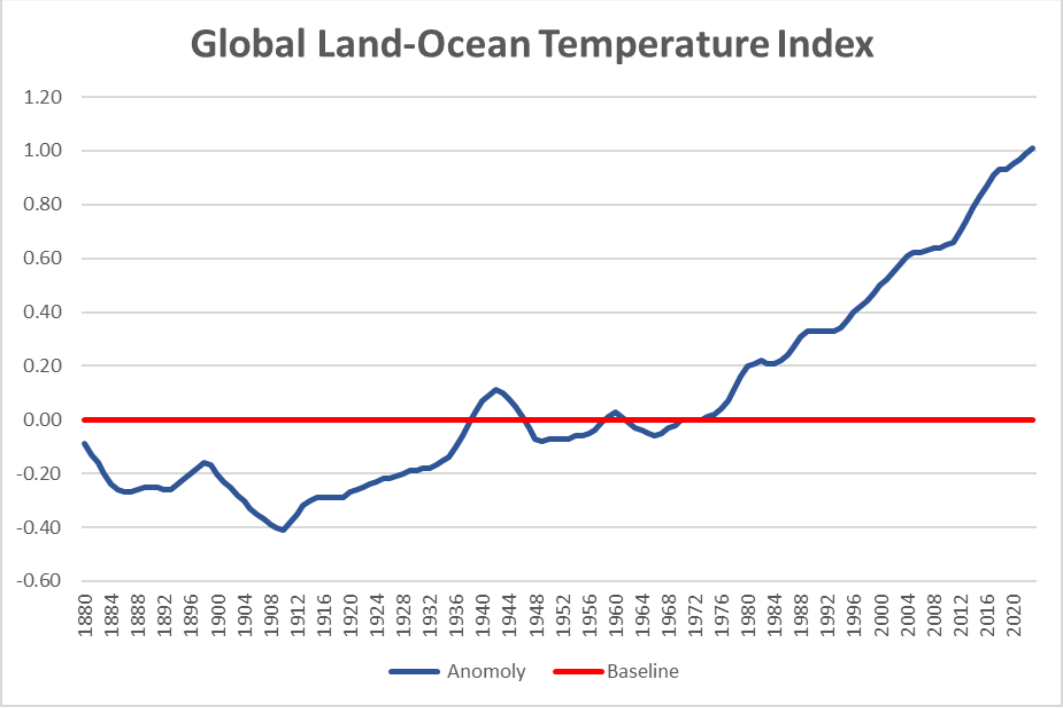
It is easy to confuse the concept of climate change with weather. Weather is basically what you see on the evening news: How hot will it be tomorrow? Will rain ruin your plans for the weekend? The weather is both short-term and location-specific in nature. Climate change, on the other hand, measures change, like average temperatures and rainfall, over decades or even centuries. It encompasses large regions and, since it involves the oceans and the atmosphere, it extends to the entire planet.

GLOBAL WARMING

It is also easy to confuse the concepts of global warming and climate change. Global warming refers to the fact that the earth's surface and the oceans have been slowly getting hotter over time. So how does that work?

The sun has been warming the earth since it was formed from clouds of solar dust and gas nearly five billion years ago. The sun's rays stream to the earth then bounce back into the atmosphere, a steady process keeping the climate relatively stable over time. The industrial revolution introduced the "greenhouse effect." Greenhouse gases form a porous shield around the earth, which traps those rays from escaping back out into space. One greenhouse gas that gets a lot of attention is carbon dioxide, which is generated not only from natural processes, like volcanic eruptions, but also from man-made processes, like the extraction, refining, and burning of fossil fuels, like oil, coal, and natural gas. According to a study by the United Nations, fossil fuels contribute over 75% of all global greenhouse emissions.[2] Although this change started in the Industrial Revolution, there has been a clear rise in average temperatures over the last few decades as shown in Figure 1.

Figure 1
GLOBAL WARMING



Data Source: https://climate.nasa.gov/vital-signs/global-temperature/?intent=121

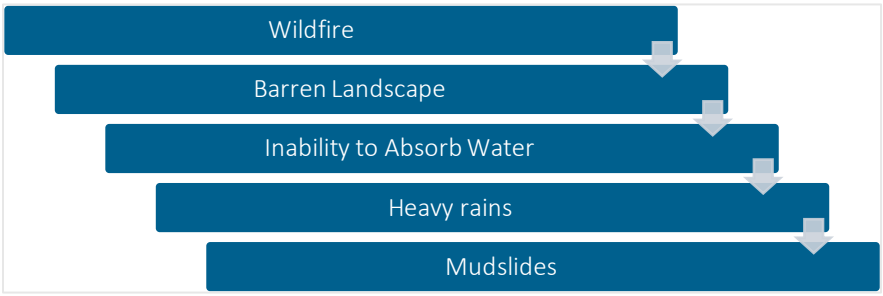
CLIMATE CHANGE IMPACT

One way to view the impact of climate change is in terms of individual perils. For example, global warming leads to more extreme temperature events, which impact mortality. One study[3] has shown that globally approximately 9% of all deaths can be attributed to temperature extremes, some of which can be attributed to climate change, whether caused by man-made or natural processes. Similarly, the steady risk in global temperatures is associated with an increase in the intensity of hurricanes and a rise in the number of wildfires, floods, and other catastrophic events. These events have a major impact not only on the finances of people and businesses, but they also may have significant health implications. For example, wildfires result in poor air quality which increases the prevalence of asthma cases and worsens many chronic diseases like chronic obstructive pulmonary disorder ("COPD") and heart disease.

These events, however, do not always occur in isolation. A compound event involves multiple hazards occurring simultaneously, or in close succession, and can lead to more damage than a single event. For example, in 2020 the combination of drought and extreme heat led to devastating wildfires across California, Oregon, and Washington. Similarly, a cascading event occurs when one hazard triggers subsequent hazards, resulting in an amplified overall impact. For example, a wildfire can lead to landslides and degraded water quality as illustrated in Figure 2.

Figure 2

CASCADING EVENT EXAMPLE



TOP CLIMATE RISKS

Of course, each organization will prioritize climate change risks based on their business needs and circumstances. That said, it may be useful to look at the priorities set by other organizations before finalizing those priorities. The World Economic Forum has identified the primary types of risk associated with climate change.[4] These priorities also serve as a useful typology. These priorities are:

- *Extreme Weather Events*. Over the last 40 years, there has been a dramatic increase in the number of extreme weather events. In the 1980's the average number of CPI-adjusted $1 billion events was 3.3. In 2024 the number was 27.[5] Each event causes damage to the landscape, property, life, and health.

- *Changes to Earth Systems*. Many significant eco-systems have been dramatically altered by global warming and climate change. In some cases, these changes may reach a tipping point. For example, scientists predict that 99% of all coral reefs will not survive if global warming reaches 1.5° C. Since 25% of all marine life feed off coral reefs during their lifetime, this may have significant impact on the global food supply.

- *Biodiversity Loss*. We rely on biodiversity for essential services, like pollination and water purification, and to build resilience in nature. Extreme temperatures and poor air quality disrupt habitats, which leads to biodiversity loss. Biodiversity loss leads to more vector-borne diseases, like Lyme Disease.

WHAT CAN WE DO ABOUT IT?

Efforts to deal with climate change fall into two major categories: mitigation and adaptation. Mitigation refers both to efforts to slow or stop the increase in global warming and to reduce damage. At the international level, the Paris Agreement is a legally binding treaty among 196 nations with the goal of keeping the increase in average global temperature to well below 2° Celsius above pre-industrial levels. Under the treaty, wealthier nations have agreed to support less wealthy nations financially and technically.[6] The degree of compliance varies by country, but some countries are making progress.[7] Most of the efforts focus on reaching "net zero" or changing energy mix in favor of increasing the use of renewables over fossil fuels. Mitigation efforts also include removing carbon dioxide from the atmosphere through direct capture, conservation, and reforestation. Forests function as "carbon sinks" since they can absorb carbon dioxide from the atmosphere and store it for many years. Adaptation refers to efforts to build resilience by minimizing the damage from climate change such as building flood defenses and modernizing building codes.

Although numerous solutions have been proposed, there are three key questions that should be addressed at the macro level and/or the micro level. These questions are:

- *How Can We Identify Risks and Evaluate Solutions?* This is an actuarial question and one that we have been addressing in general terms for a long time. That said, climate change introduces new challenges that we as a profession must and will address at a more detailed level going forward.

- *Who Is Going to Pay for It?* This is a philosophical, economic, political, and actuarial question. From a philosophical viewpoint the primary question is, "Should the cost of addressing climate change be borne by society as a whole or just those who contribute to the problem?" From the economic viewpoint the primary question is, "How will effort to adapt and mitigate the impact of climate change impact other aspects of the economy?" From a political perspective, the key question is, of course, "What will voters and donors support?" Finally, from an actuarial perspective the primary question is, "How can I evaluate the risk and impact in keeping with professional standards?"

- *Who Are the Winners and Losers?* This is a policy and planning question. Whether it is a governmental mandate or a company initiative, in estimating the impact of a potential solution to a climate change problem, it is easy to think about the impact in aggregate terms: What is the net cost or savings? How will this change one's carbon footprint? What is the impact on overall employment numbers? Another aspect of this type of analysis will be the impact on individual people. Sometimes this is about jobs. If a job in the fossil fuel industry is eliminated, will those people be able to get a job in the green energy industry? If not, what happens to them? It is also about meeting basic needs. About 80% of the world's energy comes from fossil fuels. Some people can afford climate-friendly alternatives, like solar energy panels for their homes and electric cars. Others cannot afford these things. How does the transition work for those people?

REGULATION

From wildfires scorching California to hurricanes battering the Gulf Coast, extreme weather events have exacerbated risks precipitously, prompting a sudden recalibration of coverage and premiums and in insurer insolvency/exits. The National Association of Insurance Commissioners (NAIC) Climate and Resiliency Task Force[8] was launched in 2020 and laid the groundwork for the National Climate Resilience Strategy (2024) which unifies state efforts around five pillars: closing protection gaps, flood insurance reform, data modernization, risk mitigation, and scenario testing. One note: this article focuses on state regulation since the focus is on insurance implications.

Getting Started

Some actuaries, especially property/casualty actuaries, already include climate change in their day-to-day work. That is not surprising given the impact that climate change disasters have on their bottom line. Others may not see this as a priority because at first glance the impact appears to be immaterial. For example, in 2023 the number of deaths directly attributable to $1 billion dollar events discussed above was less than 500[9] or less than 0.02% of all deaths in 2023.[10] This number may be misleading for two reasons. First, these numbers only reflect direct deaths at the time of the event. It is not unusual to see a material increase in excess deaths over time. For example, in Puerto Rico the original estimate for Hurricane Maria in 2017 was only 64 deaths. Later estimates revised that number to 4,645.[11] This is the number for just one hurricane for one year. What about the compound impact over time?

So, how does an actuary start the process of incorporating climate change into their day-to-day work? Of course, that answer depends on the current status, resources available, and priorities. Regardless of those parameters, there are three elements necessary to begin: a qualitative analysis, a plan, and a quantitative analysis.

QUALITATIVE ANALYSIS

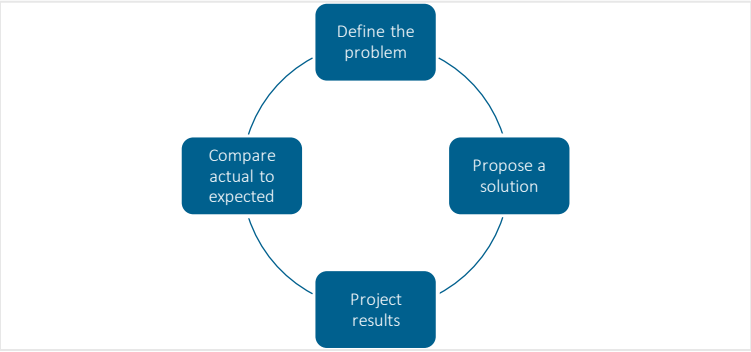
The purpose of a qualitative analysis is to identify and understand the risks and opportunities underlying climate change and the impact that it has on the problem at hand. For example, a life actuary will likely want to know which perils impact mortality and how those perils are likely to change over time. This article series is a good place to start a qualitative analysis, but in many instances the qualitative analysis will require a deeper analysis, like a comprehensive literature review. A qualitative analysis may also require data mining internal sources.

Once the risks and opportunities have been identified, then the next step is to develop a framework for understanding how climate change impacts the business problem at hand. This may be a simple diagram or a more complete picture like the EPA Risk Framework.[12] For the most part, this framework can be used to describe any risk associated with a business. There are two elements, however, that are particularly important in analyzing the risk associated with climate change: the physical risk and the transition risk. Physical risks reflect direct impacts as the result of climate change. Examples include damage to an asset caused by flooding, heat-related illnesses, and crop damage due to drought. The transition risk reflects the magnitude and timing of mitigation and adaptation efforts, such as regulatory change, technology improvements, and market shifts. In addition to the transition and physical risks, there is a liability risk which includes regulatory enforcement, shareholder litigation, human rights violation, and contract breaches.

PLAN DEVELOPMENT

Once the qualitative analysis is complete, the next step is developing a plan, which includes the objectives and specific action steps needed to implement the plan. These efforts may include incorporating climate change in day-to-day analytics or evaluating efforts to mitigate and adapt to climate change. Of course, the plan should include some version of the actuarial control cycle like the one shown in Figure 3.

Figure 3
SAMPLE ACTUARIAL CONTROL CYCLE



QUANTITATIVE ANALYSIS

Back in the days when computers were slow and data was scarce, the best practice was to set premiums conservatively to avoid losing money. That has changed over time. Today clients and managers want answers, they want them quickly, and they will demand accountability. Over the years, actuaries and other analysts have had to adapt to the new normal by enhancing their methodologies and data sources. Today we are at another inflection point. This inflection point is driven not only by the expected impact of climate change over the next few years, but also by an ever-increasing need to better evaluate risk and produce accurate, meaningful projections. To some extent actuaries and other analysts have already begun addressing the new normal in several ways:

- *Catastrophic Modeling*. As the name implies, catastrophic modeling refers to projecting the costs and/or evaluating the risk relating to catastrophic events like hurricanes, wildfires, and floods. Catastrophic modeling has always been a part of an actuary's skill set, but as the frequency and intensity of catastrophic events increases, so does the need for more complete and accurate catastrophic modeling.

- *Machine Learning*. The term "Artificial Intelligence" (AI) is certainly a hot buzzword these days. AI, however, is only one type of a broader category of analytical techniques that are often referred to as machine learning. Some machine learning techniques are "unsupervised" in the sense that data is grouped into categories based on their commonalities, not based on a prescribed algorithm. One advantage of machine learning is that it can quickly process great quantities of data in a short time and produce results that may be missed when relying on human intervention alone. The disadvantages include potential biases in the process and the relative inability to attribute the groupings to specific variables.

- *Regression Analysis*. The purpose of regression analysis is to determine a specific value, which may be a dollar amount, a temperature, or similar number. To that end, the underlying algorithm establishes a formula, which represents the pattern underlying a set of data. In its simplest form, regression analysis is basically "dots around a line." The dots represent data points, and the line represents the best estimate of the pattern underlying the data points. The distance between the dots and lines represents the variance between the data and the pattern. The variance can be explained either by inadequacies in the underlying data and methods or by random variation. More sophisticated regression techniques provide correlations between the variables used to determine the underlying pattern, a relative advantage over machine learning at this point.

- *Stress Testing*. Financial institutions use stress testing to evaluate risks and opportunities under various scenarios. This analysis may be done using a scenario generator. A scenario generator is software that predicts future results, like future mortality rates, investment returns, etc. The value of a scenario

generator is that it allows the user to test results using multiple sets of variables. Currently economic scenario generators are used widely for projections of interest rates, return on investments, etc. One technique, Bayesian Networks, can be used to incorporate climate change into a projection.

- *Data Sources.* Historically, actuaries and other analysts have relied heavily on experience data available through proprietary or published sources. There is a good reason for this. The data is usually credible and relevant to the situation at hand. That said, to meet upcoming challenges additional data sources may be needed. Sources for data about climate change include the SOA, NOAA, NASA, and published papers. In the U.S., the federal government publishes papers on a wide variety of topics, including race and income. These sources must be carefully reviewed for relevance and determining techniques for including them into actuarial workstreams.

- *Impact of Mitigation and Adaptation Efforts*. In most cases some type of financial analysis is done before a mitigation or adaptation initiative to determine if the effort is worthwhile. After the effort has been launched, another financial analysis is done to see if the effort worked as planned. These types of analyses can be done using a top down or a bottom up approach. Top down analytics usually rely on some combination of machine learning, regression analysis, and scenario/stress testing. Examples of a bottom up approach include comparing key metrics before and after the effort and comparing the results to similar situations.

- *Social Discounting*. Financial analysts commonly reflect the time value of money into long-term projections by applying an interest rate discount. In analyzing the impact of adaptation and mitigation impacts, other factors, including the trade-off between consumption today and possible catastrophic events in the future.

- *Indirect Costs*. The value of any activity, whether it is a manufacturer buying a new machine or an organization sponsoring a climate change mitigation and adaptation effort, is usually measured in terms of direct costs and savings to the principal. In almost every situation, however, there are several indirect costs which need to be included. For example, if a manufacturer buys a piece of equipment, then the primary question is, "How did that equipment impact the bottom line?" If, however, that equipment also improved air quality in the plant, then savings associated with fewer asthma attacks should be considered in the evaluation. Today, indirect costs are measured by big studies which may or may not apply to the principal. A relatively new concept called a "value stack" is one way to meet this challenge.

- *Total Risk Analysis*. There are two types of risk in any financial projection: the projection risk and the random variation risk. As the name implies, the projection risk is the risk associated with over-stating or under-stating key parameters. For life insurance, this is the risk associated with mortality rates. If you have a big enough population, it is easy to be over-confident that the mortality rates being used are accurate. The problem is, they may accurately reflect past experience, but what about future experience? A few years ago, almost no one expected life expectancy to decrease, but it certainly has. Also, what will the mortality rates be in 10 years if we do not meet the global warming targets? The projection risk is the risk associated with missing the underlying value. In life insurance, the projection risk is the risk associated with missing the mortality rate. The random variation risk is the risk that happens even if the parameters are 100% correct. In life insurance, this risk can be determined by using the binomial distribution assuming the mortality rate is correct. Total Risk Analysis is a framework for consistently measuring both the projection risk and the random variation risk to determine the total risk.

- *Winners-Losers.* Most value analytics focus on the decision-maker or principal. In insurance, the principal is the insurer and the analysis centers around determining the cost and savings associated with any action.

There are always down-stream effects. For example, if an insurer raises rates across the board, does that accurately reflect the risk for all the policyholders impacted?

- *Black Swan Risks.* Black swan risks, which are also referred to as pop-up events, are unexpected events, like Hurricane Helene in Asheville. From a risk perspective, the question is, should the impact of that storm impact property insurance rates next year or is that just a risk the insurer should bear?

Key Observations

The purpose of each of the remaining articles in this series is to provide a starting point for actuaries who want to incorporate climate change in their day-to-day work. There are six practice-related articles. Each of those articles includes an overview of the key risks and quantitative methods currently in use. The key observations from these articles are summarized below.

CLIMATE CHANGE AND THE GENERAL INSURANCE INDUSTRY

By William R. Wilkins, ASA, CERA, FCAS, MAAA

Although catastrophe modeling has always been part of the actuarial toolbox, the need for more scientifically based models became apparent after the devastating effects of Hurricane Andrew in 1992. This need for better models goes beyond just property coverage, like home and auto insurance. For example, traditionally liability products, like errors and omissions coverages and professional liability, were not related to climate change. Recently, however, there have been several lawsuits for failure to prepare adequately for catastrophic events. Similarly, surety bonds, which often cover construction projects completion to specification, are often impacted by business interruptions caused by weather related events.

CLIMATE RISK AND INVESTMENTS

By The Society of Actuaries Research Institute Catastrophe & Climate Strategic Research Program Steering Committee

With emerging regulations and evolving investor requirements, insurers and other financial institutions are increasingly expected to identify, measure, assess, and manage climate risks. These expectations apply to both liabilities and assets.

Climate risks can be broadly categorized into two main types: physical risks and transition risks. Physical risks arise from direct environmental changes, such as extreme weather events, rising sea levels, and shifts in precipitation patterns. These risks can lead to asset damage, supply chain disruptions, and increased operational costs for businesses. For instance, hurricanes and floods can devastate infrastructure, while prolonged droughts threaten agricultural productivity. Transition risks, on the other hand, stem from the economic and policy shifts associated with efforts to mitigate risk or build resilience. This includes not only the changing environment but also technological advancements, policy regulations, market dynamics and consumer demand. There is also a liability risk which is discussed above.

CLIMATE CHANGE AND THE LIFE INSURANCE INDUSTRY

By Sam Gutterman, FSA, CERA, FCAS, MAAA, FCA

Climate change can impact one's health, which in turn impacts mortality rates. For example, warmer temperatures lead to increased drought, which leads to reduced agricultural output, which leads to food insecurity, which leads to

under nutrition, which leads to increased chronic diseases. Chronic diseases, like diabetes and heart disease, are leading causes of deaths. Of course, for any individual the impact of climate change will depend on the person's exposure and sensitivity to climate-related hazards and their sensitivity to those impacts. At a population level, exposure to climate-related hazards includes the risk characteristics of the group, the location, the extent of adaptation, and the severity and timing of the hazard.

AN INTRODUCTION TO CLIMATE CHANGE FOR HEALTH ACTUARIES

By Joan C. Barrett, FSA, MAAA and Rebecca Owen, FSA, MAAA

Although it may seem counterintuitive, initial health care spend tends to decrease somewhat whenever there is a major event like a hurricane.[13] Of course, there tends to be a slight increase in emergency care at that time, but those costs are usually offset by people forgoing needed care for both chronic diseases and preventive services during the event and immediately after. Although the net event-driven impact may be small in any one year, actuaries performing pricing and/or reserving projections need to consider the possibility that costs will return to more normal levels in the next year. In the long term, climate change impacts not only the health of an individual, but also the infrastructure needed to deliver care. Health plan sponsors may want to respond to both the short-term and long-term impact of climate change through more effective networks and care management programs.

CLIMATE AND RETIREMENT PLANNING

By Ruth E. Schau, FSA, EA, FCA, MAAA

Climate change may impact quality of life in a specific area. For example, after Hurricane Helene in 2024 residents of Asheville North Carolina and surrounding areas found themselves without cars to drive, no electricity, and little or no drinking water. Although this impacted all residents, it was often more acute for retirees with limited mobility and financial resources. Although this may suggest that it may be prudent to consider the impact of climate change on retirement planning, only 37% of pre-retirees say they think that climate change is likely or somewhat likely to affect their retirement security.

ENTERPRISE RISK MANAGEMENT'S ROLE IN CLIMATE CHANGE AND THE INSURANCE INDUSTRY

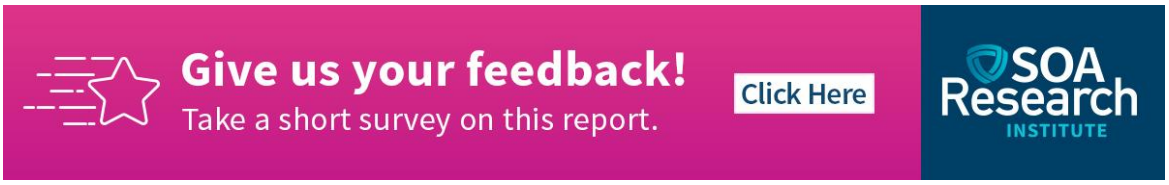
By William R. Wilkins, ASA, CERA, FCAS, MAAA

Enterprise risk management (ERM) is a firm-wide strategy to identify and prepare for hazards potentially impacting the firm's finances, operations, and objectives. According to the most recent Emerging Risk Survey, climate change is the top emerging risk. Techniques for evaluating this risk include scenario analysis and stress testing. Several organizations have provided scenarios for this purpose, including the Intergovernmental Panel on Climate Change and the Network for the Greening of the Financial System. Once the evaluation is complete, the firm must decide how to address the risk given their risk appetite. Strategies include risk mitigation, risk transference, risk acceptance/management, and risk avoidance.

The SOA Catastrophe & Climate Strategic Research Program

Research published by the Society of Actuaries Research Institute Catastrophe & Climate Strategic Research Program can be found at Catastrophe and Climate | SOA . Launched in 2021, the Catastrophe & Climate research program has published a variety of research reports, essays, and other write-ups covering a wide variety of impacts from climate risks and catastrophes. The SOA Catastrophe & Climate Research Linked-In group can be found here SOA Catastrophe and Climate Research | Groups | LinkedIn, and readers are encouraged to join and participate in the discussions. The Society of Actuaries also offers a Climate Risk Certificate Program which can serve as either an

introduction to all courses covering the fundamentals of climate change or a full Climate Risk Certificate Program; recommended for actuaries and others who want practical instruction and training about climate risk. Information can be found here Program Registration | SOA.



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About The Society of Actuaries Research Institute

Serving as the research arm of the Society of Actuaries (SOA), the SOA Research Institute provides objective, data-driven research bringing together tried and true practices and future-focused approaches to address societal challenges and your business needs. The Institute provides trusted knowledge, extensive experience and new technologies to help effectively identify, predict, and manage risks.

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